

WOLLONGONG COASTAL MANAGEMENT PROGRAM - STAGE 2 COASTAL AND ESTUARY PROCESSES STUDY 2025

Prepared by Salients for Wollongong City Council
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WOLLONGONG COASTAL MANAGEMENT PROGRAM - STAGE 2 COASTAL AND ESTUARY PROCESSES STUDY 2025

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Executive Summary

E.1 Overview

This report presents a review of the physical environmental and human factors which influence coastal hazards along the Wollongong coastline. It has been prepared to support the development of Wollongong City Council's Coastal Management Program (CMP) as part of an overall hazard and risk assessment being led by Salients. The study area covers the open coast and estuarine creeks/lagoons within Wollongong's Local Government Area (Figure E.1). Lake Illawarra is being managed under a separate CMP.

Coastal hazards are a combination of physical processes which have the potential to threaten built and/or environmental assets and/or public safety. Under the NSW *Coastal Management Act 2016*, there are seven listed coastal hazards:

- “(a) beach erosion,*
- (b) shoreline recession,*
- (c) coastal lake or watercourse entrance instability,*
- (d) coastal inundation,*
- (e) coastal cliff or slope instability,*
- (f) tidal inundation,*
- (g) erosion and inundation of foreshores caused by tidal waters and the action of waves, including the interaction of those waters with catchment floodwaters”*

The focus of this report is on the underpinning processes which give rise to these hazards. Accordingly, it relates mostly to those aspects of the environment that can cause erosion and/or inundation of land. The subject matter primarily relates to the physical nature of the coast, and not biological or ecological processes. Biological and ecological processes are being addressed separately in the development of Council's CMP.

The report contains two main sections:

- An introductory level description of relevant coastal processes (Section 2)
- An overview of the character of the Wollongong Coast, considering its formation and current character (Section 3).

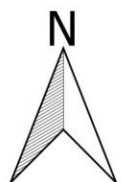
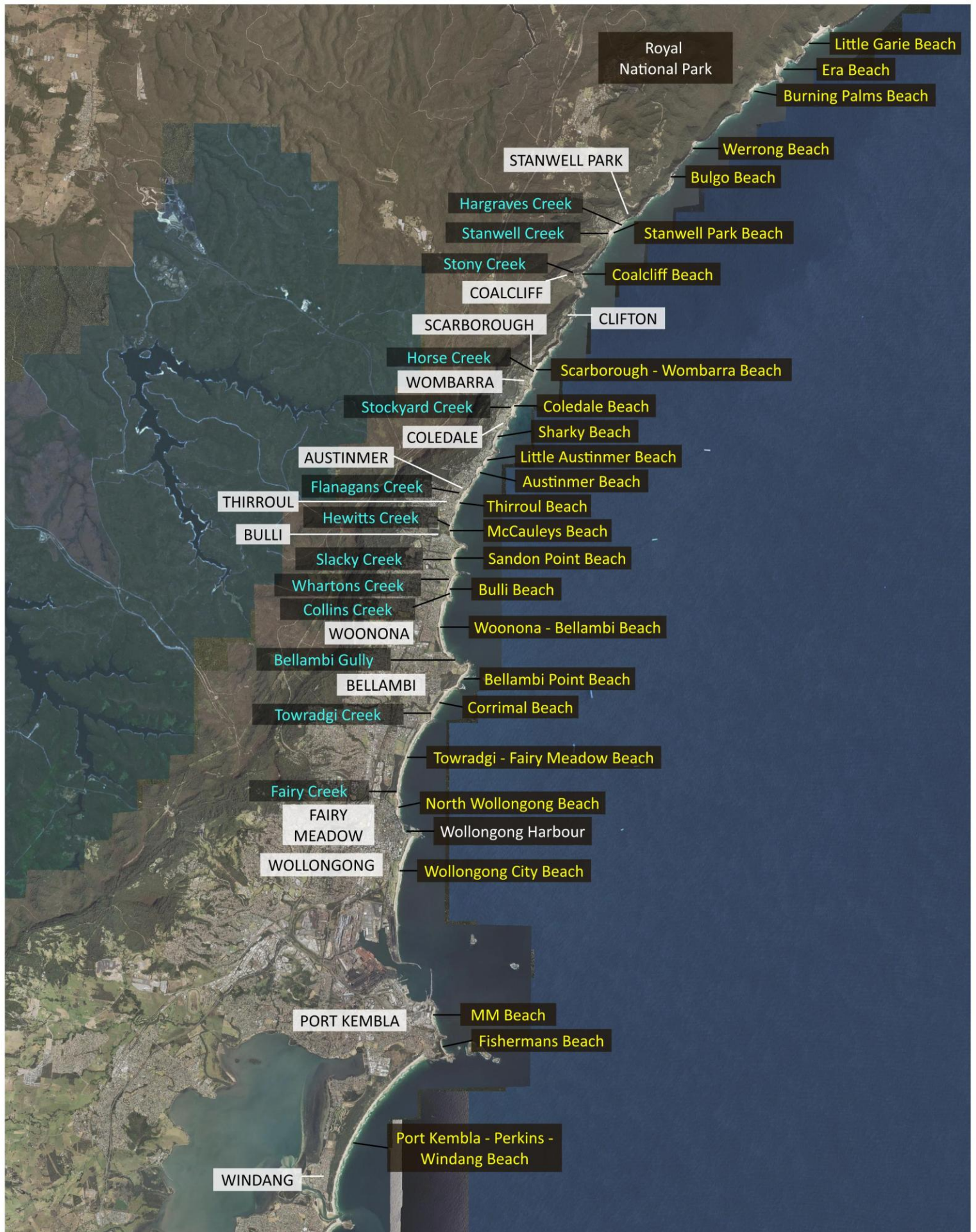


Figure E.1 Features of the Study Area Coastline



Wollongong Coast and Estuary Processes Study

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Summaries of these two sections are provided below. The report is presented as an overview, and does not focus on individual beaches and headlands, except where these provide examples or comparisons that are useful to understand the whole of the coastline in context. More localised consideration of beaches, headlands and estuaries will be provided in the hazard and risk studies which build on the information provided herein.

E.2 Key Coastal Processes

E.2.1 Tides and Water Levels

The tides along the NSW coastline rise and fall around twice a day, predominantly in response to the gravitational forces of the moon and sun. Tides cause water and sediment to move in and out of estuaries and coastal creeks although the influence of tides diminishes with distance upstream. Tide ranges also fluctuate on a fortnightly cycle, between larger (spring) and smaller (neap).

In addition to tides, water levels along the coast are influenced by factors such as atmospheric pressure, wind, and waves. The low atmospheric pressure associated with storms contributes to storm surge, raising water levels with the surge being exacerbated by strong onshore winds. The 1% annual exceedance probability (AEP) still water level (tides plus storm surge) calculated from historical records, is around 1.45 meters (AHD).

All water levels, including normal tides and extreme water levels, are becoming higher due to climate change related sea level rise offshore of the NSW coast.

E.2.2 Waves and Storm Events

Waves, predominantly generated by wind, are a key process causing the coastline to cyclically erode and accrete. During storms, large waves can erode beaches by transporting sand offshore. Subsequently smaller waves act to rebuild beaches. The average offshore wave height along Wollongong's coast is around 1.6 meters, with larger storm waves (>3.0 meters) more frequent in autumn and winter. Waves typically approach from the south and southeast throughout the year. Waves from the north east are relatively common during spring and summer.

Storms significantly impact the coastline, bringing strong winds, large waves, and sometimes severe coastal erosion. Elevated water levels can combine with catchment flooding from heavy rainfall to exacerbate hazards related to inundation. Storms can redistribute sediment and change the shape of shorelines and estuarine entrances. Storms are important events contributing to the risk from coastal hazards, particularly within settled areas.

E.2.3 Sediment Transport and Coastal Morphology

Sediment movement is driven by waves and currents and can be classified as either alongshore or cross-shore. The dominant movement of sand is driven by wave action, with cross-shore transport during storms leading to erosion from the sandy beach and the formation of sandbars offshore. Alongshore sediment transport generally follows a northward direction along the Wollongong coastline due to the predominant south-southeast wave direction. Breaking waves both suspend sediment from the bed and drive a (typically) northward alongshore current within the surf zone. However, this movement is often constrained by headlands and rocky geological features, which limit sediment movement between beach sections.

Beach rotation—alternating periods of erosion and accretion at opposite ends of a beach occur at some beaches, with El Nino/La Nina phases influencing the direction and size of waves approaching the coast. La Niña phases often result in increased sand deposition at the southern end of beaches. Windborne sand transport is also a notable factor, particularly at locations like Port Kembla, where wind driven sand has formed large dunes. When that sand is not stabilised, it has the potential to ‘drift’ across adjacent land and interfere with use of built infrastructure.

E.2.4 Geological and Bathymetric Features

The geological composition of the Wollongong coastline plays a significant role in shaping coastal features. The Illawarra Escarpment, which runs approximately parallel to the coast but trends inland with distance south, influences the shape and nature of beaches, cliffs, and headlands. The northern coastline, where the escarpment is close to the coast, features prominent cliffs and rocky bluffs, while the southern coastline has broader coastal plains between the coast and the base of the escarpment.

The continental shelf offshore of Wollongong is narrow, allowing large swell waves to approach the coast with minimal attenuation, meaning that damage from waves at the coast can be significant during storm events. The nearshore zone (0-30m depth) is dominated by rocky reefs and outcrops, particularly in the northern regions. These also play a role in the dissipation of wave energy, with the rough surface helping to slow waves and the irregular depths also sheltering some beaches.

E.2.5 Human Activities and Coastal Modifications

Human activities have significantly altered Wollongong’s coastal environment over the past 200 years, especially in urbanised areas. Modifications such as seawall and breakwater construction, sand mining, dune vegetation removal and reshaping, and estuary entrance modifications have altered natural processes. Urban development along the coast has led to the construction of roads, buildings, and other infrastructure, sometimes in areas where they are threatened by coastal hazards.

Further disturbances, such as informal pedestrian access and the removal of vegetation, contributed to the spread of weeds and pests, affecting the natural dune systems and the health of coastal ecosystems. Despite these challenges, restoration efforts, including beach improvement programs and local conservation initiatives, have helped stabilise dunes and mitigate against coastal erosion.

E.2.6 Climate Change and Long-Term Sea level Rise

Climate change is expected to exacerbate coastal hazards, predominantly due to ongoing sea level rise. Sea levels have fluctuated over long, geological time frames, sea levels rising around 130m following the last glacial period, over a period stretching from 20,000 to around 6000 years before present.

Today, anthropogenic climate change is accelerating the rate of sea level rise, with projections suggesting a rise of at least 2 meters (globally averaged) over the coming centuries. This will lead to a landward retreat of shorelines, particularly in areas with limited sediment supply, such as Sandon Point. Other areas, like Port Kembla, may be less affected due to differences in the presence of available sand.

E.2.7 Summary

The coastal and estuarine environments of Wollongong are shaped by a complex interplay of natural processes and human activities. While storm events, tidal dynamics, and waves continuously modify the coastline, climate change and human modifications have the potential to exacerbate the challenges faced by coastal managers over coming decades. A fundamental understanding of coastal processes is important to help inform decision making as part of the development of a Coastal Management Program.

E.3 Overview of the Wollongong Coast

E.3.1 Formation of the Wollongong Coast

The coastline of Wollongong has been shaped over millions of years by geological processes and large fluctuations in sea levels. Around 80–85 million years ago, the Tasman Sea began forming as Australia and New Zealand drifted apart, with the final rift completed approximately 55–60 million years ago. Today, Wollongong's coastal geology is largely stable, with the Illawarra Escarpment playing a significant influence on the region's coastal features.

The escarpment, which runs parallel to the coast in the north before shifting inland further south, has influenced the development of cliffs, headlands, and beaches. North of Scarborough, steep cliffs and small, pocket beaches dominate, while the southern coastline has broader coastal plains, larger estuaries, and longer sandy beaches. The

presence of the escarpment also contributes to landslide risks in the northern coastal areas.

Over the past 6,000–7,000 years, following a period of around 130m of sea level rise spanning over 10,000 years, sand deposits have built up along the coastline, with many beaches forming as thin layers of marine sand overlying older sediments. The movement of sand along the coast is influenced by headlands and breakwaters, which influence how sand is retained or transported between different sections of beach. Broader “sediment compartments” which cover multiple beaches, are mapped under the NSW Coastal Management Act 2016 and three of these cover the Wollongong Coast, namely (from north to south) (i) Illawarra Coast North Sediment Compartment, (ii) Wollongong Sediment Compartment, and (iii) Illawarra Coast South Sediment Compartment.

Geological factors and historical sea level changes continue to shape the Wollongong coastline. During glacial periods, when sea levels are much lower, coastal sediments were deposited further offshore on the exposed continental shelf. As sea levels rose following the last glacial period, the coastline moved inland, reworking these sediments into the present-day beaches and dunes. Today, ongoing climate change and rising sea levels present challenges, particularly where there is limited sand.

E.3.2 Offshore of Wollongong

The continental shelf offshore of Wollongong is relatively narrow and steep, meaning swells generated out in the ocean can reach the shore with minimal loss of energy. This results in stronger wave action along the coast, which influences erosion, sediment transport, and beach dynamics. The depth of the seafloor increases quickly beyond the shoreface (the most active part of the beach including underwater to a depth of tens of metres), with around 80% of the continental shelf lying deeper than 50 metres.

The ocean bed offshore of Wollongong, to depths of 30m and more are occupied by extensive rocky reefs and outcrops, especially in the northern sections of the coastline. These reefs play a role in breaking wave energy and shaping coastal processes. However, the limited presence of offshore sand deposits means that many of Wollongong’s beaches rely on sand which is already present and ongoing replenishment of sand from offshore is not expected to play a significant role as the beaches adjust to sea level rise by receding.

E.3.3 Coastline and Onshore Characteristics

Wollongong's beaches are shaped by the interplay of waves, sand supply, and coastal topography. The sandy barriers along the coast vary in type, with many classified as "receding barriers", meaning they have lost sand over time due to natural erosion and limited replenishment. These beaches are especially vulnerable to storm events, which can strip sand away, sometimes exposing older estuarine muds beneath.

Beach compartments are influenced by headlands and nearshore rock formations, which limit the movement of sand between different sections of the coast. The largest continuous sand deposit is found south of Port Kembla, stretching along Perkins and Windang beaches, while northern beaches tend to have thinner sand layers and are more prone to extensive erosion of sand during storms.

Dune systems have been significantly altered by human activity over the past two centuries. Early colonial land use, including cattle grazing, contributed to the loss of natural vegetation, while sand mining in the mid-20th century further degraded many dunes. Since the 1970s, restoration efforts have helped stabilise dunes in some areas, but challenges remain, particularly in locations where sand movement still threatens infrastructure.

Beyond the beaches, Wollongong's coastline features a mix of rocky cliffs and headlands, with the northern section dominated by steep cliffs formed from more resistant rock layers. These cliffs are shaped by both marine erosion and landslides, which are more prevalent in areas where weaker rock formations are exposed. South of Thirroul, the coastline transitions into a broader coastal plain, with larger estuaries and floodplains. These estuaries, such as Fairy Creek and Towradgi Creek, play an important role in coastal drainage and sediment transport.

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1 Background

1.1 Introduction

This report has been prepared as part of Stage 2 of development of the *Wollongong Coastal Management Program* (CMP). The CMP is being prepared by Wollongong City Council under the requirements of the *Coastal Management Act 2016* (CM Act) and its associated Coastal Management Manual (NSW Government, 2018).

The study area considered by this report comprises the Coastal Zone of the Wollongong Local Government Area, excluding Lake Illawarra, but including the estuarine creeks and open coast. The aim of this report is to research, characterise, and summarise local coastal and estuary processes within the study area. The information in this report is foundational for subsequent studies being undertaken by a team led by Salients, with the assistance of Tetra Tech Coffey and Jeremy Benn Pacific.

This report is part of the hazard assessment being completed as part of “Stage 2” of the CMP development process. The subject matter focusses on those processes which influence the coastal hazards defined within the CM Act, which are:

- (a) beach erosion,*
- (b) shoreline recession,*
- (c) coastal lake or watercourse entrance instability,*
- (d) coastal inundation,*
- (e) coastal cliff or slope instability,*
- (f) tidal inundation,*
- (g) erosion and inundation of foreshores caused by tidal waters and the action of waves, including the interaction of those waters with catchment floodwaters.*

This report is structured as follows:

- Section 2 provides a description of coastal processes relevant to hazards on the Wollongong coast.
- Section 3 gives an overview of the nature and form of the Wollongong coast.

An overview of the location of the beaches within the study area is provided in Figure 1.

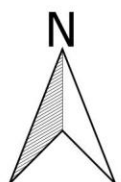
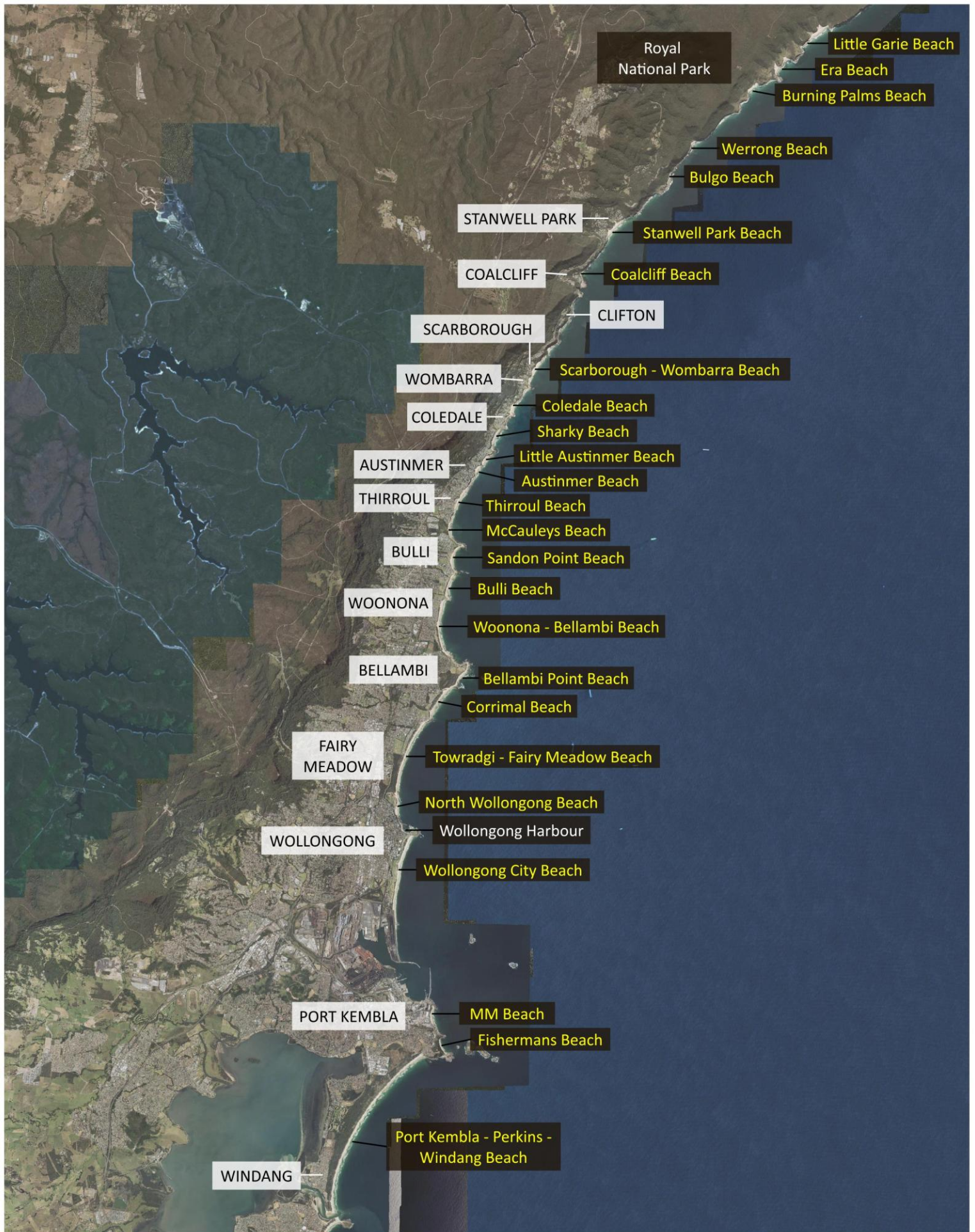


Figure 1 Beaches of the Wollongong Coast

Wollongong Coast and Estuary Processes Study

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While Section 3 discusses the underpinning geology along the Wollongong Coast, rocky cliff and bluff areas are not discussed in detail. For more site-specific descriptions of the rocky sections of coastline, reference should be made to the Coastal Cliff and Slope Instability Hazard Study (Tetra Tech Coffey, 2025). Similarly, more detailed physical descriptions of the small creek and lagoon estuaries included in the overall hazard assessment are provided in the Coastal Entrances and Foreshore Erosion Study (Salients, 2025).

2 Coastal Processes

2.1 Key Points

- Wollongong's coast is shaped by tides, waves, and storms, along with changes made by people. Understanding these processes is important for future management.
- Tides and Water Levels
 - Tides are largely caused by the gravitational pull of the moon and sun, making water levels rise and fall twice a day along the Wollongong Coast.
 - Tides help move water and sand in and out of estuaries and small coastal creeks.
 - The size of the tides varies over a two-week cycle, with higher (spring) tides transitioning to lower (neap) tides and back.
 - Other factors like wind, air pressure, and storms also affect water levels.
 - Water levels are rising due to climate change (i.e. sea level rise).
- Waves and Storm Events
 - Wind creates waves that continuously change the beach by eroding and then rebuilding the sand berm.
 - Large waves during storms (> ~3 meters wave height) can quickly erode the beach, carrying sand offshore.
 - After storms, smaller waves help restore the beach by moving sand back onshore.
 - Storms at the same time as heavy rain increase the risk of flooding and damage along the coast.
- Sediment Transport and Coastal Shape
 - Sand moves along the beach and offshore/onshore, mainly transported by waves and the currents created by waves.
 - During storms, waves can pull sand off the beach and form sandbars offshore in the surf zone.
 - Beaches sometimes experience cycles of erosion at one end and buildup at the other, influenced by dominant weather patterns. This is called 'beach rotation'.
 - Wind can also carry sand onshore, such as at places like Port Kembla, where drifting sand can interfere with the use of land, roads and other infrastructure affecting nearby land if the sand is not held in place.
- Climate Change and Human Activities
 - People have built walls, roads, and other structures along the coast over the last 200 years.
 - Activities like sand mining and removing vegetation have changed the natural movement of sand and water.
 - These changes can make the coast more vulnerable to damage from storms and erosion.
 - Local efforts, such as beach restoration and conservation projects, work to protect and rebuild the coastline.
 - Over geological time scales, sea levels have varied greatly (e.g. 130m in the past 20 000yrs)
 - Climate change is causing sea levels rise now, and this seems to be accelerating.
 - Higher sea levels are expected to move the shoreline inland over time.

2.2 Introduction

Under the previous coastal management framework (superseded in 2018), it was common to undertake a combined *Coastal Processes and Hazards Study* for the open coast, alongside an *Estuary Processes Study* inside and around estuaries. These were historically undertaken under relevant manuals published by the NSW State Government (NSW Government, 1992, 1990).

In the context of assessing the seven hazards listed under the present *Coastal Management Act 2016*, it is still useful to understand the actual physical processes which give rise to these hazards. This chapter aims to provide a brief, high-level introduction, presenting widely accepted principles related to those processes. Coastal processes are all subject to active research and there is a wealth of available information which can be readily accessed. Key documents which have been used in developing the material in this chapter are:

- **NSW Government, 1990.** *NSW Coastline Management Manual* (Contains a summary of coastal processes and hazards relevant to that previous management framework)
- **NSW Department of Land and Water Conservation, 2001.** *Coastal Dune Management: A Manual of Coastal Dune Management and Rehabilitation Techniques*. Coastal Unit, DLWC, Newcastle. (Relates to dune vegetation).
- **NSW Government, 2018.** *Our Future on the Coast. NSW Coastal Management Manual Part B*. (Discusses the current coastal management framework in NSW).
- **van Rijn, L.C., 1993.** *Principles of Sediment Transport in Rivers, Estuaries and Coastal Seas*. Aqua Publications. (Deals extensively with sediment transport processes, erosion, and accretion)
- **The CoastAdapt web page:** <https://coastadapt.com.au/> (Useful resource for when considering sea level rise and its management)

Reports with more specific consideration of conditions in Wollongong are also available:

- **Salients, 2023.** *Wollongong Scoping Study*.
- **Cardno Lawson Treloar, 2010.** *Wollongong City Council Coastal Zone Study Volume 1 - Main Report*.

The processes described below do not act in isolation but interact in many ways. For example: the effects of tides and waves interact to elevate water levels; water levels and waves are important components determining the impact of coastal storms; and

waves and tides both generate currents in different parts of the coast. Those interactions are considered in more detail in the hazard assessments being completed as part of the overall project. Unsurprisingly, some repetition of concepts does occur in the following sections, but this has been limited where possible.

2.3 Tides

Astronomical tides are the regular rise and fall of water levels in the ocean and estuaries, predominantly driven by the gravitational forces of the moon and sun, and the rotation of the Earth. Tidal dynamics are important for the movement of water and sediments in coastal areas, and inside estuaries. Tidal currents most notably cause water to flow in and out of coastal creeks and lagoons along the Wollongong coast. That regular flow of water carries sediments in and out of estuaries as well.

Along the NSW coast, astronomical tides are semi-diurnal, meaning that the ocean water level goes up and down approximately twice a day. There is a further fortnightly cycle from smaller tide ranges (neap tides) through to larger tide ranges (spring tides, see Figure 2).

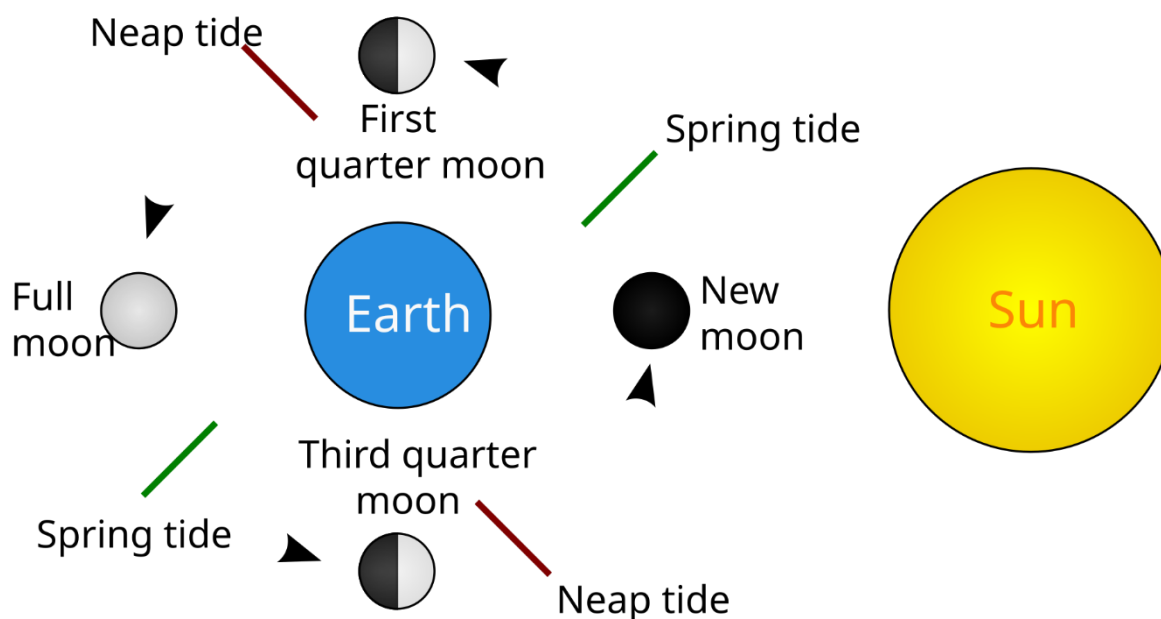


Figure 2 Schematic Representation of the Different Tide Stages with Reference to different stages of the Lunar Cycle¹

¹ By User:KVDP, SVG conversion by Surachit - Public domain image: File:Tides schematic.JPG which was based on an image in "Leidraad voor het Stuurbrevet" by Richard Vooren, Paul Van den Keybus, Public Domain, <https://commons.wikimedia.org/w/index.php?curid=8752107>

The maximum astronomical tide range offshore of NSW is around 1.9m. Tides propagate quickly along the NSW coast, resulting in minimal shore-parallel tidal currents.

Tidal currents are most pronounced in the vicinity of the entrances to estuaries, with the tides flowing in and out around twice a day. The entrances to estuaries are some of the most dynamic parts of the coast. As tides propagate through the entrance to an estuary, they are modified in several ways, typically being attenuated (reduction in range inside an estuary) and lagged (high and low tides occur later inside estuaries).

2.4 Waves

Waves are mostly generated by wind and have an important role in coastal erosion, beach formation, and the stability of coastal landscapes. The large, energetic waves which occur during storms can erode beaches by carrying sand offshore, altering the shape and profile of the coastline. The eroded sand is commonly deposited in the nearshore zone, within a storm bar not far offshore of the beach. That storm bar causes waves, which are more powerful during storm activity to dissipate their energy over the offshore bar instead of breaking on the beach. In this way, there is dynamic feedback where protection of the beach increases, tending to limit the amount of sand that can ultimately be eroded during a storm.

Conversely, waves can also be constructive during calmer conditions, when swell waves are smaller and typically not as steep and erosive. These waves act to carry sand shoreward and deposit it back onto the beach, contributing to beach accretion and the formation of new coastal features. The action of waves influences the distribution of sediments along the coast, affecting the location, steepness, and stability of beaches, dunes, and other coastal features.

Waves along the Wollongong coastline are generated by various weather systems, with a mean significant offshore wave height (Average height of highest 1/3 of waves in deep water, or $H_{s,0}$) of approximately 1.5m. Larger storm waves, with $H_{s,0}$ exceeding 3.0m, are more common in autumn and winter, though storms can happen at any time of the year. Waves can approach from directions ranging from south to northeast, though the dominant wave direction is from south to southeast.

2.5 Water Levels

Variations in water level along the NSW coast are influenced by several processes in addition to the astronomical tides, including barometric pressure, wind and wave setup, wave runoff, and climate change.

Still water levels are raised above normal astronomical tide levels during storms due to a lowering of barometric pressure and onshore winds. When combined, these

components are referred to as “storm surge”. Water levels are increased further by the dynamic action of waves which add components of wave setup (caused by the shoreward transfer of energy where waves are breaking) and wave runup (where waves finally collapse and run up the beach face).

There are a range of other continental and ocean scale processes which can also modify water levels by several centimetres. For example, when storms coincide with high spring tides, severe coastal hazards such as erosion and coastal inundation are exacerbated. These infrequent but severe events can pose a major risk to coastal infrastructure Figure 3.

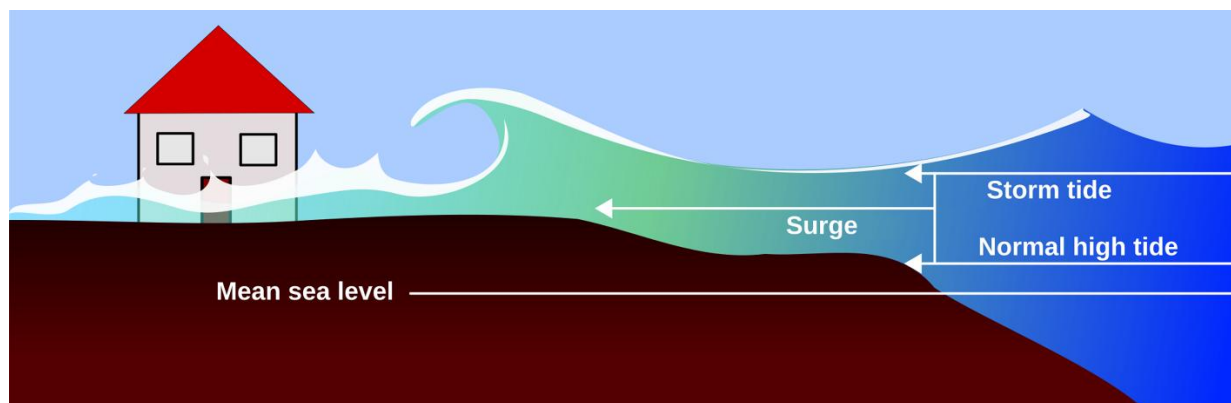


Figure 3 Impact of Combined Storm Surge, Tides and Waves²

Historically, a commonly adopted still water level (excluding wave setup and runup) for the 1% annual exceedance probability (AEP) event has been around 1.45m measured in Australian Height Datum (AHD) for the NSW coast. This must now be adjusted due to an ongoing, climate change related rise in mean sea level. With mean sea level rising, baseline astronomical tide levels will rise by the around the same amount, and the additional storm surge, wave related, and other ocean scale water level processes will continue to act. This means that, with 0.5m of sea level rise, the 1% AEP event still water level will also rise by around 0.5m, to around 1.95m AHD along the NSW coast.

2.6 Storms

Storms, including tropical cyclones and East Coast Lows (ECLs), have a significant impact on the NSW coast. These weather events can bring powerful winds, heavy rainfall, and large waves, having substantial impacts on the coastline and associated assets. Storms are accompanied by strong winds and low atmospheric pressure and are therefore accompanied by “storm surge”. Storm surge not only acts on the open

² Adapted from SuperManu - Image:Surge big.jpg by Robert Simmon, NASA GSFC, via NOAA. Uploaded by Pierre cb, Public Domain, <https://commons.wikimedia.org/w/index.php?curid=2264485>

coast but also propagates into estuaries. This raises water levels, potentially flooding inland areas which fringe those estuaries.

Along the Wollongong coastline, storms can occur throughout the year and can approach from directions ranging from south to north east. ECLs typically form along the coast from Fraser Island in Queensland, south to East Gippsland in Victoria. These systems can rapidly intensify overnight, generating powerful offshore waves, intense rainfall, and strong winds. ECLs tend to cluster together in time, such as during the notable event in May-June 1974 when three separate events were experienced along the Wollongong Coast (E. Bryant and Kidd, 1975).



Figure 4 Erosion following Storms in the mid 1970's, Northern End of MM Beach³

Extreme storms can cause severe coastal erosion. Heavy rainfall associated with stormy weather can exacerbate flooding in coastal and estuarine areas. Additionally, storms can mobilise and redistribute sediments, reshaping shorelines and estuary mouths, and altering coastal environments long after the storm has passed.

Storm events are a major agent of change along the coast.

2.7 Currents

Currents are influenced by tides, waves, wind, and discharge from estuaries. Currents play a key role in transporting sediments along the coast and within estuaries,

³ From the collections of Wollongong City Libraries and the Illawarra Historical Society - P19/P19194

influencing the stability of beaches and foreshores. Waves generate currents in and around the beach. These are complex and continually changing, affected by the water level, configuration of bars and the angle at which the waves approach the beach.

Nearshore circulations caused by breaking waves result in the generation of rip currents. While rips are well known due to the dangers they present to the public, large rips during storms can also act to drag sand offshore, beyond the breaking waves, exacerbating any erosion of the beach in the near vicinity of the rip Figure 5.

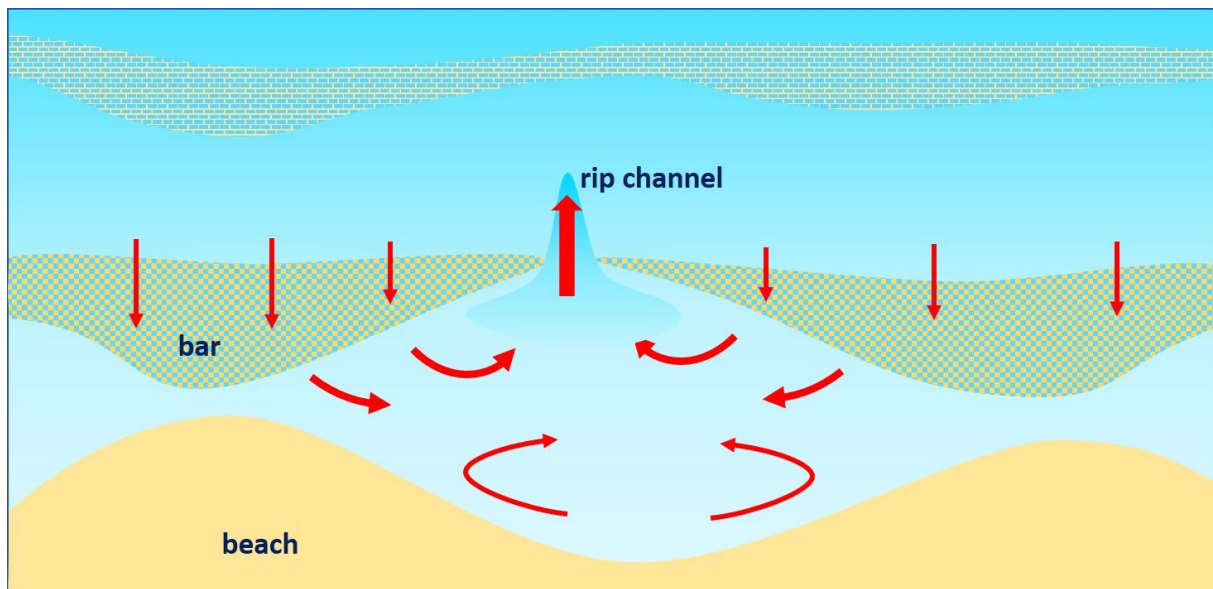


Figure 5 Generation of Rip Currents⁴

Currents within estuaries, including those resulting from storm surge (combined with tides) and those resulting from catchment floods can act to erode the foreshores inside estuaries. This erosion can threaten assets located close to those foreshores.

2.8 ENSO and other climate drivers

The El Niño Southern Oscillation (ENSO) and Interdecadal Pacific Oscillation (IPO), while not the only climatic indices that affect weather on the East Coast of Australia, are two drivers of storminess and coastal responses in NSW. Both ENSO and IPO are driven by variations in sea surface temperatures and atmospheric pressure over the Pacific Ocean, with the frequency and intensity of ENSO moderated by the IPO .

Other key indices for overall storminess in NSW are:

- The Indian Ocean Dipole (IOD): Negative phase associated with warmer waters in the eastern Indian Ocean enhances storminess in NSW.

⁴ Accessed from CoastalWiki: <https://www.coastalwiki.org/w/images/2/28/MorphoRip.jpg>, 25/02/2025

- Southern Annular Mode (SAM): Negative phase can lead to more frequent storms across southern Australia.

2.8.1 El Niño Southern Oscillation (ENSO)

ENSO has two main phases: El Niño and La Niña, and an intermediate, “neutral” phase. Each phase has distinct impacts on global weather patterns. ENSO tends to vary irregularly, changing between phases over periods (typically) of 2-7 years. These phases have a notable impact on the overall climate of Australia, including storminess and erosion patterns along the NSW coast.

During La Niña periods, wetter conditions and more frequent and intense storms occur along the NSW coastline. Furthermore, storm waves tend to arrive from a slightly more northerly direction. Along the NSW coast, La Niña periods are associated with more frequent tropical cyclones and east coast lows are typically observed, with severe beach erosion and increased flooding.

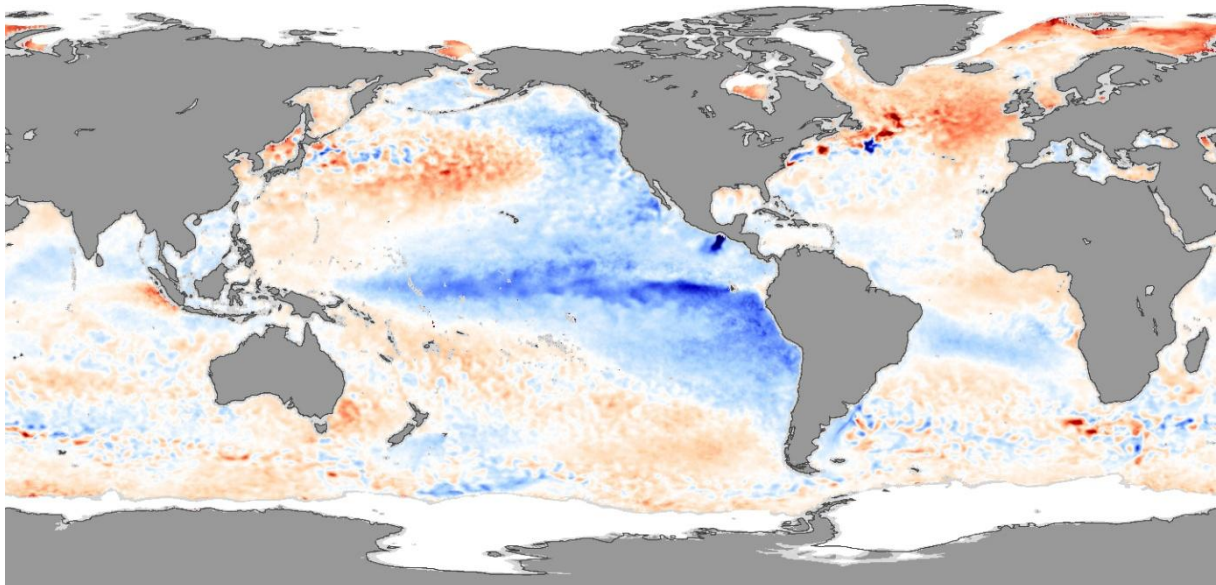


Figure 6 Temperature anomalies (Blue = cooler, red = warmer) for a La Niña event during November 2007.

El Niño events bring drier and calmer conditions to the NSW coast with fewer storms and decreased wave energy. Additionally, mean sea levels along the NSW coast tend to be slightly lowered during El Niño periods due to changes in wind patterns and ocean currents.

ENSO has been strongly correlated with beach rotation described on the NSW coastline (Ranasinghe et al., 2004; Short et al., 2000; Short and Trembanis, 2004). This is discussed further in Section 2.10.3.

2.8.2 Interdecadal Pacific Oscillation (IPO)

The IPO influences climate patterns over periods of 15-30 years. The IPO has three phases: positive, neutral, and negative. During a positive IPO phase, the intensity and frequency of El Niño events is increased, while La Niña events tend to be weaker and less frequent. The opposite occurs during a negative IPO phase, with weaker and less frequent El Niño events and more frequent and intense La Niña events.

During the negative IPO phase, the Pacific jet stream tends to shift southward, bringing more moisture and storminess to eastern Australia.

2.9 Rainfall and Runoff

Rainfall provides freshwater input to estuaries, providing the mix of salinity conditions that characterise an estuary. In terms of coastal hazards, freshwater inflows during floods can exacerbate foreshore erosion inside estuaries, and can scour shoals present at the entrance, flushing sediments from the estuary into the ocean. The influence of freshwater inflows tends to be more pronounced within the upstream reaches of estuaries, but this varies significantly from system to system.

Many of the coastal catchments in the study area are small and steep, particularly along the northern parts of the coast. This means that low lying coastal areas are prone to flash flooding which may well occur around the same time that coastal inundation is having an impact, causing overall flooding to be exacerbated.

Stormwater outlets are located on several Wollongong beaches. Following heavy rainfall events, these outlets can cause localised scouring of the beach. However, these impacts are generally confined to the vicinity of each outlet and do not significantly affect the overall beach morphology.

2.10 Sediment Movement

Sediment transport involves the movement of sand and other materials by wind (aeolian processes) and water (fluvial and marine processes). This process shapes coastal and estuarine landscapes. Sediment can be moved onshore and offshore (cross-shore sediment transport) and along the shore (alongshore drift), resulting in cycles of erosion and accretion that vary in duration from weeks to decades. In some cases these processes cause changes to the shape of the coastline or an estuarine entrance which may persist.

2.10.1 Alongshore sediment transport

Alongshore (or 'longshore') sediment transport is the movement of sediments along the coast due to wave action and currents. Waves approaching the shore at an angle create a current that moves sand parallel to the coastline. This current is most

pronounced within the surf zone, where waves are breaking. The dominant direction for sand movement along the NSW coast is from south to north due to the prevalence of waves approaching from the SSE to ESE direction. Waves generate an alongshore current which, when combined with the stirring action of waves as they are breaking, drive a south to north alongshore sediment transport. Considering the Wollongong Coast, however, alongshore sediment transport is significantly constrained by the presence of headlands and rocky geology, which act to “compartmentalise” beaches. This means that in many locations, the sand remains contained within a single beach embayment with waves unable to move beach sand around headlands.

2.10.2 Cross shore sediment transport

Cross-shore sediment transport involves the movement of sand and sediments perpendicular to the shoreline, driven by wave action and wave driven currents. This process influences the shape and profile of beaches, with a beach tending to oscillate between an eroded and accreted condition, dependent on the occurrence of destructive waves (during storms), followed by periods of calmer (constructive) waves (Figure 7).

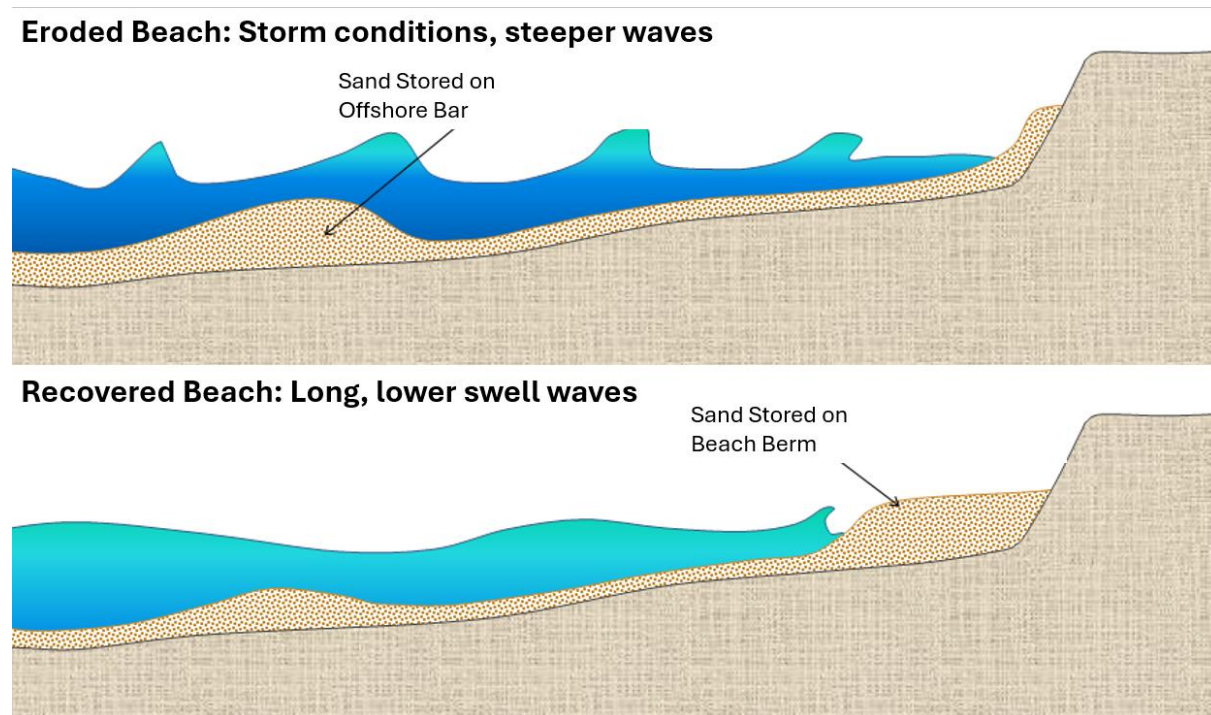


Figure 7 Post Storm (top) and Recovered (bottom) Beach Profiles

During storms, waves can erode sand from the beach face and deposit it in deeper water further offshore and depositing it on the sandbars. In calmer conditions, waves transport sand back onto the beach, restoring its shape. This process of rebuilding the beach profile following a storm typically occurs naturally over a period of months but can take years. Due to the complexity of sand and water movement along the coast, beach recovery cannot necessarily be guaranteed.

Circulations associated with rip cells can cause sand to move both ways along the beach and offshore.

2.10.3 Beach rotation

Beach rotation is a process where different ends of the beach experience alternating periods of erosion and accretion due to shifts in the dominant wave direction and intensity over time. At a particular beach, the dominant wave direction can change over longer periods (seasonally to interannually), causing sand to accumulate at opposite ends of the beach. One end of a beach will narrow, while the other end will accrete sand, causing the beach to “rotate”. La Niña periods are associated with more sand at the southern end of beaches in NSW. During La Nina periods, waves tend to approach from a more easterly direction (Ranasinghe et al., 2004) and less sand tends to be present at the northern end.

2.10.4 Windborne (aeolian) sediment transport

Wind-blown (or aeolian) sediment transport is important for the formation and stabilisation of sand dunes, with dune vegetation playing a crucial role in stabilising these formations by trapping sand with their roots and rhizomes.

However, wind-blown sediment transport can also lead to the burial of assets such as roadways and vegetation, as well as the blocking of stormwater drains. Wind-blown sand can impact coastal pool infrastructure, accessways, car parks, and buildings located near the beach and along adjacent roads. Additionally, wind-blown sand can smother new plantings and hinder dune revegetation efforts.

Along the Wollongong coast, the stand out location for windblown sand transport and associated issues is at the northern end of Port Kembla – Perkins - Windang Beach, in Port Kembla.

Issues associated with windborne sediment, and the behaviour of foredunes and dune vegetation along the Wollongong Coast are discussed in more detail in Appendix B.

2.11 Coastal Entrances

The scope of the CMP includes numerous estuaries, primarily small coastal creeks and lagoons classified as Intermittently Closed and Open Lakes and Lagoons (ICOLLs). ICOLLs are commonly separated from the ocean (or closed) by a sand barrier (or berm) which forms across the entrance preventing tidal exchange. The barrier is built primarily by the action of waves.

When ICOLLs are closed, water levels and water quality are strongly influenced by catchment inflows. When significant rainfall occurs, catchment inflow fills the waterway. If the water level rises enough to overtop the barrier (Figure 8), the entrance

can scour and create a channel that enables tidal exchange to occur. This opening process typically happens over several hours.

After a flood event, the barrier is gradually rebuilt until the entrance is again closed. The typical period which an ICOLL will remain open varies significantly between each estuary. Water levels inside an ICOLL can also be increased by waves overtopping the barrier. Conversely, an open barrier can exacerbate flooding inside an ICOLL if there are high tides combined with storm surge.

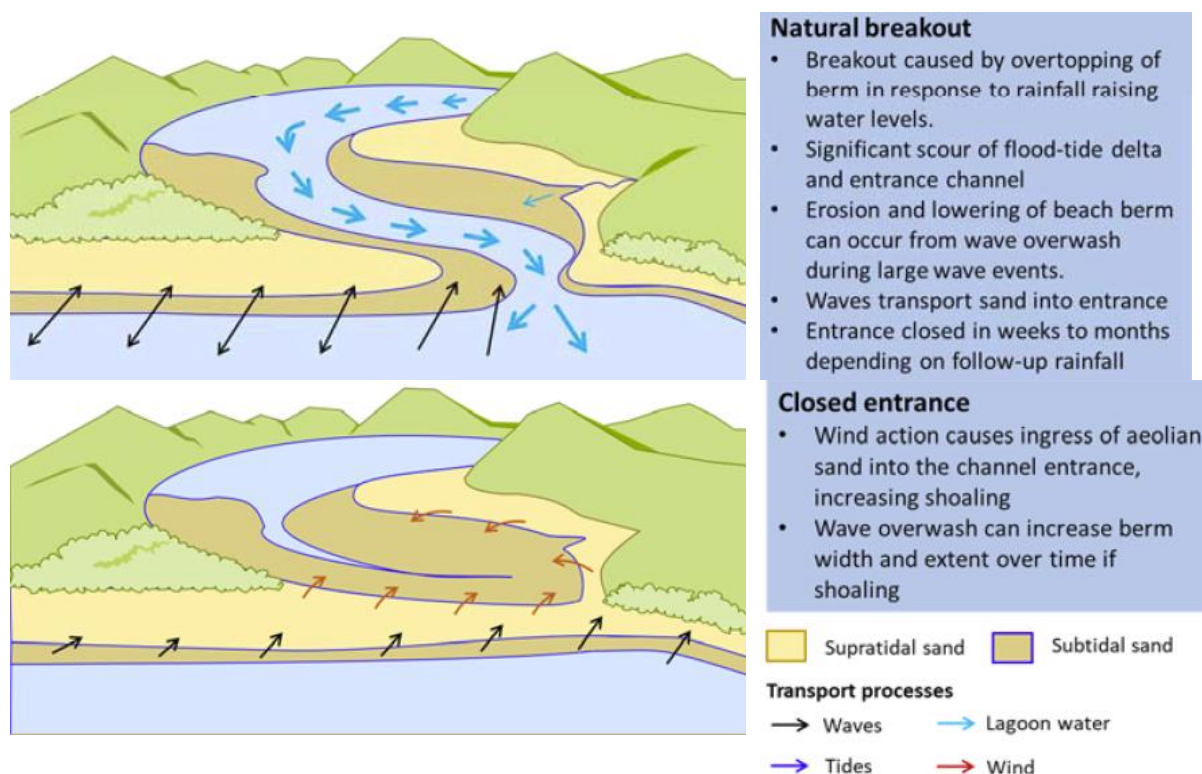


Figure 8 ICOLL Opening and Closure⁵

In some instances, mechanical intervention is used to breach the berm intentionally, in an attempt to ease flooding of low-lying areas adjacent to the waterway. At some locations in NSW this is particularly necessary where development surrounding ICOLLs is low lying and active management is needed to protect infrastructure and property.

⁵ Modified from Ferguson et al.(2020)

2.12 Climate Change

Climate change will impact coastal processes through sea level rise and changes to temperatures and rainfall patterns, with decreased rainfall in winter and increased rainfall in autumn and summer expected in the Illawarra region⁶.

Sea level rise is occurring along the coast of NSW, and will continue to occur for hundreds of years, regardless of global efforts to curb greenhouse gas emissions. However, the rate of change and eventual total amount of sea level rise that will occur depends on those global efforts. At least 2m of sea level rise offshore of NSW is now expected, but the timing remains uncertain. The adoption of a sea level rise projection is an important part of several of the hazard studies to be completed by this project. Wollongong City Council has formally adopted a high emissions scenario (SSP5-8.5) for use in the hazard studies. Issues surrounding sea level rise, climate models and the selection of a projection are discussed in Appendix A.

2.13 Human Activities

The Wollongong coastal zone has been substantially modified by human activity over the last 200 years, and there are few areas remaining that have not been subject to modification. Recent examples include dune re-shaping and profiling, removal of dune vegetation, breakwater construction (at Port Kembla and Lake Illawarra) and estuary entrance modification. These activities and others are discussed in more detail in Appendix B.

Development exists behind several of Wollongong's beaches such as walkways, roads, surf clubs, seawalls, and residential development. While seawalls and similar structures can protect shorelines from storm damage, they can also have other impacts such as disrupting the natural movement of sand and sediment, leading to erosion in adjacent areas.

Riparian and dune environments are subject to human disturbance through informal pedestrian access and modifications such as dune reshaping and removal of vegetation. Disturbance and removal of vegetation can lead to weed infestation and increased prevalence of pest species.

By the 1980s, it was noted that foredunes in the Wollongong district had been largely removed or levelled as part of urban development (Sherwin and Holmes, 1986). However, the presence of well-preserved foredunes at the southern end of Towradgi Beach was noted, indicating that those dunes had been stable for several decades. Several of the main embayments along the Wollongong Coast (Thirroul, Bulli and Woonona-Bellambi) were noted by more recent research (Doyle, 2019), as being highly

⁶ AdaptNSW Illawarra Climate Change Snapshot <https://www.climatechange.environment.nsw.gov.au/illawarra>

modified. Dune management is important along the Wollongong Coast and its history is discussed in more detail in Appendix B.

Within the estuaries of the Wollongong coastal zone, there have been obvious changes with development in the catchment and, in some instances, straightening, realignment and/or concrete lining of creek channels.

3 Overview of the Wollongong Coast

3.1 Key Points

Formation of the Wollongong Coast

- The Wollongong coastline was shaped over millions of years by geological processes and changing sea levels, as the Tasman Sea has formed, from around 80–85 million years ago.
- The location of the Illawarra Escarpment influences cliffs, beaches, and headlands, with steep coastal areas in the north and broader plains in the south.
- Over the past 6,000–7,000 years, sand deposits have formed thin layers over older sediments, with the process controlled by headlands and, more recently human-made structures.
- Three key sediment compartments, identified under the *NSW Coastal Management Act 2016*, cover the open coast of the Wollongong Local Government Area.
- Rising sea levels due to climate change pose challenges, and erosion issues may be exacerbated along beaches where sand is already limited.

Offshore of Wollongong

- The continental shelf near Wollongong is narrow and steep, allowing ocean swell to reach the shore with minimal energy loss.
- The resulting energetic wave climate influences coastal erosion, sand movement, and beach stability.
- The seabed offshore of Wollongong's beaches contains extensive rocky reefs, especially in the north. These can help break waves but also mean that offshore sand extents are limited.
- Most beaches in Wollongong do not receive new sand from offshore, meaning they are vulnerable to erosion as sea levels rise.

Coastline and Onshore Characteristics

- Wollongong's beaches vary in their classifications, with many considered to be "receding barriers". These barriers are prone to ongoing recession over time.
- Sand movement along the coast is largely controlled by headlands and rock formations. The largest sand deposit stretches south from Port Kembla to the entrance of Lake Illawarra.
- Human activities, including land clearing, cattle grazing, and sand mining, have significantly altered dune systems, though some restoration efforts have helped stabilise certain areas in more recent decades.
- The coastline features steep cliffs in the north, shaped by long term erosion and landslides, while the southern coastline transitions into a broader coastal plain with larger estuaries.
- Estuaries such as Fairy Creek and Towradgi Creek play a key role in draining the coastal plain. Estuaries become progressively smaller and steeper towards the north of the Wollongong coastline.

3.2 Formation of the Wollongong Coast

3.2.1 Overview

Formation of the New South Wales coast began around 80 to 85 million years ago with the initial rifting of the Tasman Sea. Over time, the rift caused the seafloor to spread, separating New Zealand and Australia, with the final formation of the Tasman Sea completed by approximately 55 to 60 million years ago. The original western edge of the rift is now located at the edge of the NSW continental shelf, which is around 40 kilometres offshore from Wollongong. As the area is entirely on the Australian Plate, it is considered geologically stable.

The continental shelf offshore of Wollongong is relatively steep. The shoreface, which for management purposes is broadly considered to be the “active” part of the coast (typically up to 30m depth), only extends a few kilometres from the coast (Kinsela et al., 2022). Due to this steepness, around 80% of the continental shelf lies at depths greater than 50 metres (Abuodha and Woodroffe, 2010). Overall, the inner continental shelf is primarily bedrock with some areas having a thin cover of sediment (Sherwin and Holmes, 1986). A notable exception in the near vicinity of Wollongong is a shelf sand body which is present offshore of the Royal National Park but does not extend south into areas offshore of the Wollongong LGA.

The Wollongong coastline is heavily influenced by the Illawarra Escarpment, which runs adjacent to the northern Wollongong coast before trending inland to the south of Scarborough-Wombarra. This inland trend results in a coastal plain that widens to approximately 14 kilometres near Lake Illawarra, with the width of the plain influencing coastal topography, beach formation, and the region's vulnerability to coastal hazards (GHD, 2010).

Over millions of years, the Illawarra Escarpment has developed under the influence of coastal processes, substantial variations in sea level and variable climatic conditions (Abuodha, 2009). North of Scarborough, beaches such as Stanwell Park and Coalcliff are contained within small valleys carved deeply into bedrock and separated by significant coastal cliffs. The steep terrain and adjacent geology also make this northern coastline prone to landslide hazards. In contrast, the southern coastline is characterised by flatter landward slopes, estuaries, and floodplains. Here, sandy beaches dominate, with fewer prominent headlands, and cliffs generally less than 10 metres in height, except for notable features such as Hill 60 at Red Point (Carvalho et al., 2017b). The coastal plain, extending past Wollongong and south to Port Kembla, is highly urbanised.

“*Sediment Compartments*” are discrete lengths of coastline useful for management purposes which have been defined for the entire NSW coast (Short and Thom, 2018)

and have significance under the NSW *Coastal Management Act 2016* (CM Act). These compartments, delineated by prominent features such as headlands and waterways, function as units for analysing sand movement over engineering timescales (i.e. 25 to 50 years: Short, 2020). Along the Wollongong Coast there are three secondary sediment compartments identified in the CM Act:

- **Illawarra Coast North Compartment:** Extending 38 kilometres from Port Hacking Point in the Sutherland LGA, to Bellambi Point.
- **Wollongong Compartment:** Stretching 15 kilometres from Bellambi Point to Red Point, near Port Kembla.
- **Illawarra Coast South Compartment:** Spanning 13 kilometres from Red Point to Bass Point, in the Shellharbour LGA.

Carvalho et al. (2017b) discussed sand deposits within the Wollongong sediment compartment, noting the different deposits separated by headlands and Port Kembla's breakwaters. The northernmost beaches of the Wollongong Compartment include Corrimal, Towradgi, Fairy Meadow, and North Wollongong. To the south of those beaches, Wollongong Harbour and Flagstaff Hill are present adjacent to the Wollongong CBD, with Wollongong City Beach then stretching south to Coniston. north of Port Kembla. Further south, smaller embayments containing Fishermans and MM (North Port Kembla) beaches are present between the southern breakwaters of Port Kembla and Red Point.

Bedrock features, including reefs and elevated platforms, dominate around 50% of the shoreface within the Wollongong Sediment Compartment, making this compartment relatively deficient in sand (Short, 2020).

To the south of Port Kembla (within the northern part of the Illawarra -South sediment compartment) the largest natural beach barrier within the Wollongong LGA encloses Lake Illawarra on its landward edge, with Port Kembla, Perkins, and Windang Beaches on its ocean edge. A recent study of the Illawarra South Compartment found that about one-third of the nearshore area comprises low-profile rocky reefs (Kinsela et al., 2022). The more extensive offshore sand along Port Kembla – Perkins – Windang Beach makes this beach unique when compared to all other beaches along Wollongong's Coast.

Sherwin and Holmes (1986) noted that beach sediments along the Wollongong coast have been deposited by the ocean over the last 6,000 to 7,000 years. These marine deposits are thin and interbedded with alluvial sediments derived from the erosion of the Illawarra Escarpment. The marine sands typically comprise well-sorted, rounded quartz grains with some shell grit, and are particularly thin to the north of Thirroul, where beaches are small and, bordered by cliffs and rock platforms (Bryant, 1981).

The wider coastal plain along the southern coast of the study area accommodates increasingly larger estuaries and floodplains which function as sediment sinks for alluvial deposits eroded from the Illawarra Escarpment. These alluvial sediments are often found just below the ground surface behind the beaches (Abuodha and Woodroffe, 2010). The widening coastal plain south of Thirroul corresponds with the exposure of rocks associated with the Illawarra Coal Measures at the base of the escarpment.

While there are many factors which affect the landforms present along the Wollongong Coast and, by extension, the way it will be affected by coastal hazards in future, two dominant, long-term influences on the coast are (i) the underpinning geology, and (ii) variations in sea level over millions of years. These matters and their implications are discussed in more detail in the following sections.

3.2.2 Geology

As noted in the preceding section, the geology of the Illawarra Escarpment plays a significant role in controlling the shape of beaches along the Wollongong coastline. The escarpment exposes outcrops of the rock layers from the Sydney Basin, comprising interlayered sandstones, mudstones, and coal from the Illawarra Coal Measures, overlain by the mudstones and claystones of the Narrabeen Group. These layers, in turn, are topped by cliffs of Hawkesbury Sandstone. The sediments that form the rock layers of the Sydney Basin were deposited during the Late Permian and Triassic periods, roughly 200 to 300 million years ago (Flentje, 2012).

The escarpment is situated on the southeastern edge of the Sydney Basin. Due to subsidence of the basin's centre as sediments accumulated, the escarpment rocks dip towards the northwest at a typical angle of 3 to 5 degrees (Flentje, 2012; GHD, 2010). This dip explains the greater exposure of the Illawarra Coal Measures at present sea levels as one moves southward along the coast. In contrast, these more erodible rocks are “submerged” in the northern suburbs of Wollongong and the Royal National Park. The stratigraphy of rock units exposed along the Wollongong Coast is shown in Figure 9. Along the Wollongong Coast, we are primarily concerned with the rocks of the Narrabeen Group, the Illawarra Coal Measures, and the Shoalhaven Group which outcrops at Port Kembla.

Since the rifting of the Tasman Basin, the escarpment has evolved through slope processes, coastal erosion, and marine abrasion. Over time, the escarpment has retreated around 40 kilometres from the continental shelf. Various researchers estimate the long-term recession rates to range from 0.4 to 2 mm per year ((Flentje, 2012; Thom et al., 2010). This long-term averaged rate is not representative of the present-day retreat rate of coastal cliffs as the long-term rate incorporates a broad range of climatic and sea level conditions, which don't represent today's conditions.

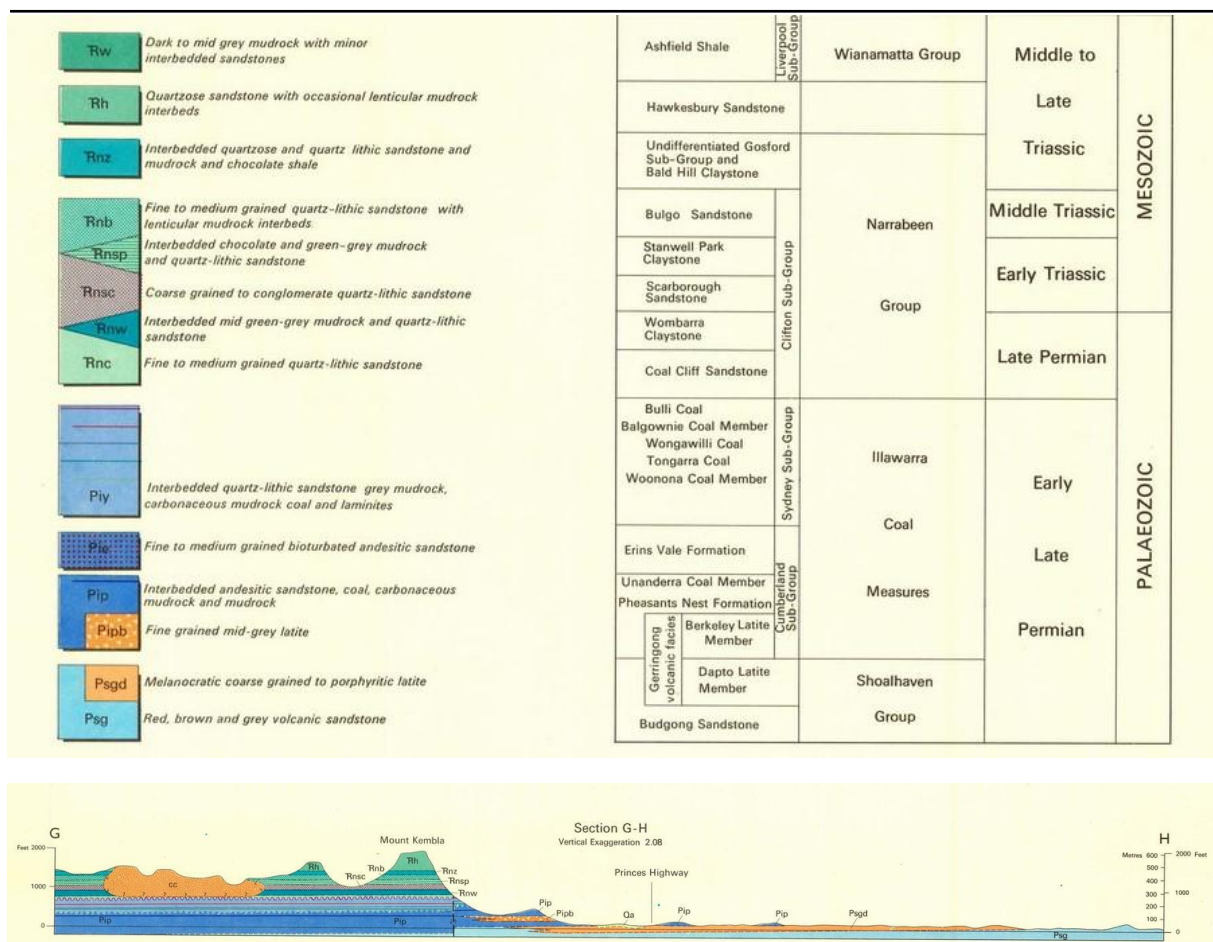


Figure 9 Representative Geological Cross Section extracted from Bowman 1974⁷, (extending from landward of Mount Kembla to Red Point, Port Kembla, illustrating the stratigraphic sequence of the Wollongong Coast)

The present-day geology of Wollongong's open coastline has been usefully subdivided into four geological domains by GHD (2010), who described different sections of the coast based on the dominant rock formations. The extent of each domain is illustrated in Figure 10, and described in turn below.

Narrabeen Group (Domain 1): From the northern edge of the LGA to the Clifton Fault (south of Coalcliff Beach), this domain is dominated by the Narrabeen Group, which forms steep cliffs close to the coast. Notable beach embayments include Stanwell Park and Coalcliff. The Stanwell Park and Wombarra Claystones in this area are weak and subject to landslides, while the overlying Scarborough Sandstone is more stable but prone to rockfalls. GHD characterised this domain as "oversteepened," with frequent hazards like landslides, rockfalls, and debris flows.

⁷ © State of NSW, Extracts from, Bowman H.N., 1974, Wollongong 1:50 000 Geological Map, 9029-II, Geological Survey of New South Wales, Sydney. Sourced from <https://digs.geoscience.nsw.gov.au/>, <https://digs.geoscience.nsw.gov.au/product/333>, 15/10/1024.

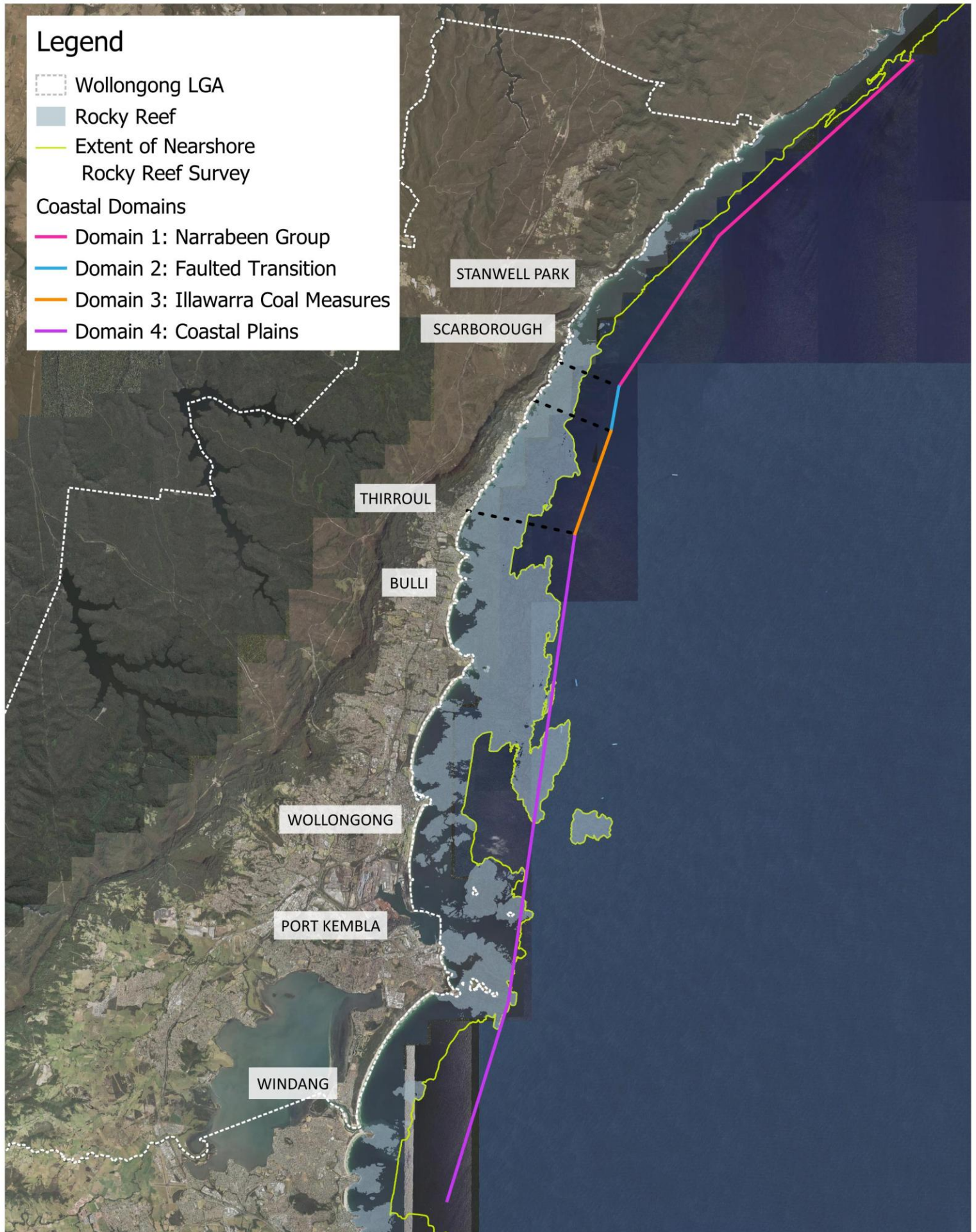


**Figure 10 Extent of Coastal Geological “Domains”
(after GHD, 2010) and Rocky Reefs**

Wollongong Coast and Estuary Processes Study

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Faulted Transition (Domain 2): From the Clifton Fault to the North Scarborough Fault (northern end of Scarborough Beach), this domain exposes both the Narrabeen Group and the Illawarra Coal Measures at sea level. The steep coastal cliffs primarily comprise the Eckersley Formation (from interbedded sandstone, claystone and coal between the Bulli and Wongawilli Coal seams). The Bulli Coal Seam is typically exposed near the top of the cliffs. This domain also features significant rock platforms at sea level.

Illawarra Coal Measures (Domain 3): South of Scarborough, the Illawarra Coal Measures outcrop at sea level. This domain has moderate cliffs and more frequent beaches, typically associated with creeks and flatter landward topography. Landslide activity occurs mostly inland, and rockfalls are the predominant hazard at the coastline. The Illawarra Coal Measures, especially the Sydney Subgroup, are considered unstable and subject to rapid deterioration when exposed (Sherwin and Holmes, 1986).

Coastal Plains (Domain 4): From Thirroul Beach to the entrance of Lake Illawarra, beaches backed by coastal plains dominate this domain. Headlands in this region are generally less than 25 metres high, with one notable exception being Hill 60 (Red Point) at Port Kembla. Headlands and rock platforms are typically from the lower layers of the Illawarra Coal Measures, including:

- Erins Vale Formation: Bulli Point, Waniora Point, Bulli Beach (elevated section of Bulli Beach Tourist Park) and Collins Rock.
- Pheasants Nest formations: Bellambi Harbour and Point, Sandspit Point and Towradgi Point

The southern cliffs and headlands around the Wollongong CBD and at Port Kembla are underlain by Budgong Sandstone, while the offshore Five Islands are composed of the more resilient Dapto Latite (Sherwin and Holmes, 1986). Both rock units are from the Shoalhaven Group, which underlies the Illawarra Coal Measures.

The steep cliffs, headlands and rocky coastlines of Wollongong are subject to both coastal processes (tides and waves) and sub-aerial processes, such as rainfall-induced weathering and landslides. The instability in and around coastal cliffs is often influenced by saturation and the liquefaction of soils, rather than just coastal processes GHD (2010). Hence instability is more often triggered by saturation of the overlying rock and soil mass, rather than weathering and erosion around sea level. Even so, rock falls can be triggered by the undermining of cliffs due to the erosion of weak rocks at or around sea level.

Geology significantly influences the morphology of beaches along the entirety of Wollongong's coastline. Wollongong's beaches are semi-compartmentalised, exposed to waves, and dominated by bedrock reefs and headland boundaries (Bryant, 1981).

Along the northern sections of the coast, streams have carved small valleys into the sandstone cliffs, creating small beaches with variable characteristics. Beach alignment is controlled by the spacing and location of flanking headlands and the dominant south-easterly wave approach (Hesp, 1993). Doyle (2019) noted that the geology of the coast limits the alongshore exchange of sediment between beaches, though sand may move offshore under high-energy conditions, such as during storms.

3.2.3 Long-Term Sea level Changes

Globally, sea levels have fluctuated regularly over the past 700,000 years, and possibly longer, in response to temperature oscillations that occur approximately every 100,000 years. These cycles typically involve a gradual drop in temperature, with corresponding sea level falls as water is frozen in polar ice caps and glaciers. In turn, this is typically followed by rapid warming and a rise in global sea levels. This cyclic pattern of cooling and warming has remained relatively consistent over the past few 100,000-year cycles with similar maximum and minimum global temperatures reached during each cycle (Flentje, 2012).

Flentje noted several factors may explain these cyclic temperature changes, including:

- Variations in Earth's orbit, which oscillates between elliptical and near-circular shapes on a 100,000-year cycle.
- A wobble of Earth's axis that occurs over a 19,000- to 23,000-year period.
- Changes in the tilt of Earth's axis by a few degrees every 41,000 years.

Periods of low sea levels are referred to as *glacial periods*, while periods of high sea levels, such as the present, are known as *interglacial periods*. During glacial periods, Wollongong's coastline is located tens of kilometres further east on the continental shelf. Erosion of the Illawarra Escarpment continues during glacial periods, with streams delivering sediment to the coastal plains currently submerged on the continental shelf. As sea levels rise at the end of glacial periods, the coastline shifts westward, with wave action reworking sand and transporting it across the continental shelf. This reworked marine sand, composed primarily of rounded quartz grains, forms the sandy beach barriers at the coastline. The most recent, cyclic sea level rise period and the associated movement of the coastline are termed the *Postglacial Marine Transgression*. The peak of the last glacial period occurred around 21,000 years ago, with sea levels approximately 130 metres lower than today, after which sea levels began to rise as temperatures rose once more.

Sea levels rose until about 7,000 years ago. There has been some academic debate about sea level changes since this time. However, based on research from Wollongong (Bulli, Thirroul, and McCauleys Beach), it is generally agreed that a "highstand" where mean

sea level was around 1.2 metres above its present level, was reached around 6,900 years ago (Bryant et al., 1992; Dougherty et al., 2019; Flentje, 2012; Jones et al., 1979). Mean sea levels then remained elevated until about 2,000 to 1,500 years ago, when they slowly fell to present levels. Since industrialisation in the 1800s and the resulting enhanced generation of greenhouse gases, this falling trend has markedly reversed. The impact of anthropogenic climate change on sea level rise has become most notable over recent decades.

The last 2.6 million years is known as the *Quaternary Period* and is divided into the *Pleistocene Epoch* (until 11,700 years ago) and the more recent *Holocene Epoch*. Sediments along the coastline are often categorised along these lines, with Holocene-aged sediments continuously reworked along the immediate shoreline, while some of the more landward sediments are Pleistocene in age, deposited during a previous interglacial period more than 100,000 years ago.

A classification of Quaternary coastal sediments along the New South Wales coast was completed by Troedson et al. (2016). Along the northern Wollongong coastline, beaches such as Bulgo, Coalcliff, Wombarra, and Scarborough are directly backed by rocky cliffs and bluffs. In some areas, where space allows, constrained dune systems may be present (e.g., South Era, Burning Palms, Coledale, Austinmer). As the coastal plain widens southward, a mix of Pleistocene clays, silts, fluvial, and marine sands can be found immediately behind the dunes. Sandon Point Beach is particularly unique in this regard, as Pleistocene sediments are found directly behind the beach with minimal dune development.

Detailed studies, including radiocarbon dating (Jones et al., 1979), present a more complex picture of the sediments behind these barriers. At Sandon Point Beach, for example, Jones et al. (1979) identified four sedimentary units overlying bedrock, including an *upper sand unit*, *grey sandy mud*, *mottled mud unit*, and *basal mud unit*. Of these, the mottled mud unit which is also exposed at higher elevations around Bulli Point, is of Pleistocene age. However, the Grey Sandy Mud is believed to have been deposited during the Holocene behind a sandy beach barrier that no longer exists, having been subsequently eroded. This classification aligns with Hesp's (1993) classification of the beach as a *receded barrier*, where present-day beach sands are retreating over older estuarine deposits.

According to standard coastal geomorphological understanding, as sea levels continue to rise due to climate change, shorelines are expected to retreat landwards (Kinsela et al., 2022). Along some coastlines, this retreat could be offset by an ongoing supply of sediment from offshore. However, the rocky, sand-starved nature of Wollongong's coastline suggests that there will be little to no sediment supply, and erosion risks, particularly at receded barriers such as Sandon Point, may be exacerbated. The impact will likely be less pronounced along the Port Kembla – Perkins – Windang Embayment.

3.3 Offshore of Wollongong

3.3.1 Bathymetry

Bathymetric contours offshore of Wollongong are shown in Figure 11 which also shows the boundaries of the sediment compartments introduced in Section 3.2.1. The figure shows that the 30m bathymetric contour is typically 2 -3 km offshore of the coast. Beyond that, the bathymetry typically flattens between 30 and 60m depth, before steepening again further offshore.

Overall, the continental shelf is narrow, and steep compared to others around the world. This narrowness means that swell waves can approach the coast without being affected as much by bottom friction, meaning that relatively large waves are present near the coastline.

Figure 11 also illustrates the general topography inland from the coast, showing the proximity of the Illawarra Escarpment in the near vicinity of the coast, and widening of the coastal plain with distance south along the coastline.

3.3.2 Rocky Reefs

Unsurprisingly, the nearshore zone is notably characterised by the presence of extensive rocky reefs and outcrops with nearshore rock becoming even more prevalent with distance north along the coastline. The extent of rock in the nearshore zone is also illustrated in Figure 11.

3.4 Coastline and Onshore Characteristics

3.4.1 Beach Barriers

The beach barriers (the sandy beach and dune system) along the Wollongong coastline are mostly exposed to and dominated by waves, shaped by moderate southeast swells commonly exceeding 2 metres but with a tidal range of less than 2 metres (Andrew D Short and Woodroffe, 2009). These beaches are often compartmentalised by nearshore bedrock reefs and headlands, with the northern ends generally experiencing higher energy environments while southern ends are more sheltered (Bryant, 1981; Clarke and Eliot, 1988).

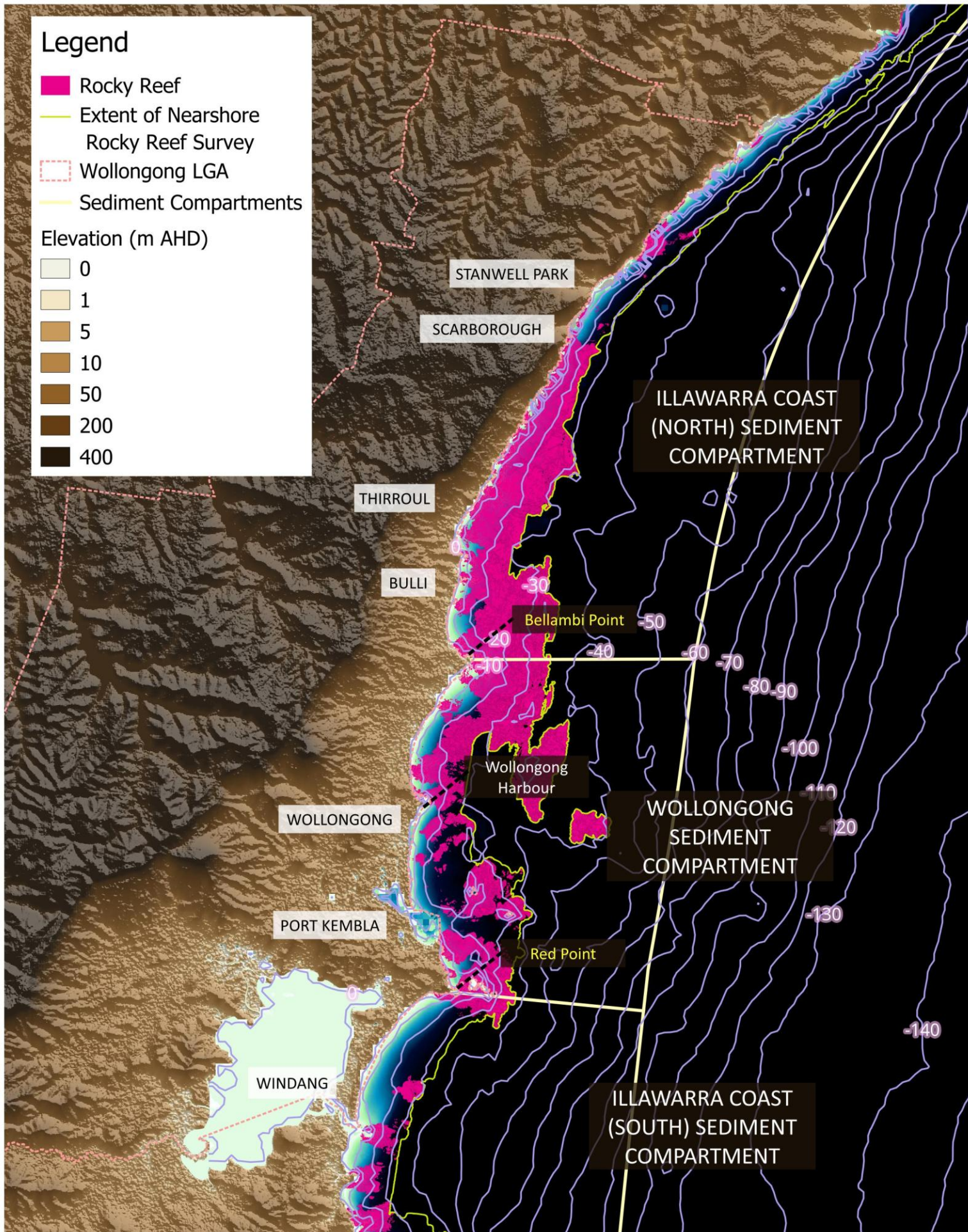


Figure 11 Bathymetry and Topography of the Wollongong Coast

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Salients

The sands comprising these beaches have largely been placed by the rising seas in the mid to late part of the Holocene, with mean sea level remaining at or near its present level (+/- ~ 1.0m) from around 6000 years ago.

During lower sea levels, sediment was deposited on the continental shelf by coastal rivers. This sand was gradually, reworked and sorted by wave action as seas rose and the ocean encroached westward across the coastal plain (Bryant, 1981; Young and Reffell, 1981). It is likely that the beaches of Wollongong now receive little, if any new sand from offshore (Young and Reffell, 1981).

There are several types of beaches present along the Wollongong Coast, and most researchers have adopted the classification of Thom et al. (1978). Thom et al. presented eight types of beach “barriers” grouped into four primary types as follows:

Prograded Barrier: Which typically have multiple beach ridges built seaward on top of a base sand sheet, with the ridges most commonly being added rapidly during the 2000 or so years following the sea reaching (approximately) its present level around 6000 years ago. Present day growth may be slow or non-existent.

Stationary Barrier: Which typically comprises a single ridge with limited evidence of seaward growth. This type of barrier, commonly abuts a gently sloping sand flat on its landward side, partly enclosing a shallow lagoon.

Receded Barrier: In this instance, these beaches are distinguished by lagoon or tidal flat deposits at the back of the beach (typically muddy, silty, finer soils). This type suggests an overall period of recession (over 3000 to 4000 years), where a pre-existing sandy barrier, which may have been large initially and may have enclosed a lagoon, has gradually receded, exposing the earlier, fine-grained deposits on the seaward side, as the existing beach relocates landward. The presence of this type of beach strongly suggests minimal supply of sand from offshore over the past 6000 years. Abuodha and Woodroffe (2010) highlighted this type of barrier as being particularly sensitive to sea level rise driven recession. Receded barriers are common along the Wollongong Coast.

Episodic Transgressive Barrier: These typically comprise stabilised and mobile transgressive dunes which can be expansive and reach up to 100m in height. In NSW, these typically form best when the beach faces south or south east and where bedrock headlands trap sand at lower sea levels. The classic example of this on the Wollongong Coast is immediately south of Port Kembla. These barriers will be activated from time to time where vegetation is lost and the sand is able to mobilise, being carried upwards and landwards. This manifests as ‘sand drift’ or ‘blow outs’, a known issue at Port Kembla.

In addition to these barrier types, there is a further type of beach, the “**Mainland Beach**”. Along the Wollongong Coast, these typically occur to the north of

Scarborough, or around prominent headlands, such as at Hill 60 (Red Point). These beaches most commonly occur as sand deposits abutting a bedrock coastline (or gravel/cobble, as at Coalcliff). These are commonly found in the vicinity of gullies discharging across rocky cliffs where an indentation in the coastal planform occurs, or to the rear of rock platforms. Mainland beaches typically comprise a thin veneer of sand over bedrock and may be ephemeral.

Hesp (1993) classified the barriers along the entire Illawarra coastline and his classification for beaches within the Wollongong LGA is presented in Figure 12.

The largest proportion of Wollongong's beaches are classified as receding barriers. As a result, they are susceptible to significant sand loss during large storm events (i.e. most of the sand can be stripped from the beach at some locations). Young and Reffell (1981) report that evidence from both Thirroul and Bulli beaches indicate that "*modern sands are only one to two metres thick*" above older estuarine muds and stream deposits. These receding barriers are highly vulnerable to further erosion due to this thin cover (Doyle, 2019; Abuodha and Woodroffe, 2010). The sediment at these beaches commonly overlies estuarine muds and alluvial clays (Young and Reffell, 1981). These beaches typically have only small foredunes.

Episodic Transgressive barriers are present at the northern ends of Corrimal and Towradgi Beach, Stanwell Park, Port Kembla, and South Era. These dunes become transgressive when a vegetated dune is eroded by wind, creating inland-moving sand sheets (Hesp, 1993). These types of barriers, composed of mixed sediments, reflect a history of erosion and landward migration, influenced by both wave and wind action.

Mainland Beaches are more common along the northern parts of Wollongong's coast, between Scarborough and Burning Palms. In these places, the escarpment is very close to the coast and/or the coastline is backed immediately by cliffs with the beach comprising a thin layer of sand to the rear of a rock platform (such as at Bulgo). Hesp's classification included stationary barriers at Fisherman's Beach and Little Garie. However, Fisherman's Beach is largely backed by the steep slopes of Hill 60 and its shape is dominated by the sheltering effects of its headlands and offshore islands.



Figure 12 Barrier Classifications and Beach Types

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Many northern beaches, such as Coledale and Sandon Point, lack active sediment sources and can be considered sand-starved (Bryant, 1981).

Beach state, in terms of whether a beach tends to be dissipative (broad shallow sloping bed with wide surf zone) or reflective (narrow surf zone with shore break) has been classified by Short (2007). This classification is shown in Figure 12.

Alongshore sediment transport is limited by the compartmentalised nature of Wollongong's beaches and with no significant influx from the catchment, alongshore transport, or from offshore, the primary source of sand since sea levels stabilised is the biological creation of carbonate (shell) material. Accordingly sand transport is largely restricted to local circulation within embayments, and beaches generally exhibit stable yet sand-starved conditions (Young and Reffell, 1981). Even so, Carvalho (2017b) did consider that the Wollongong Sediment Compartment (Hill 60 ("Red Point") to Bellambi Point) could be "leaky" although this remains somewhat unclear. This may well be the case for beaches stretching from North Wollongong through to Bellambi Point (e.g., ongoing sand accumulation in the Towradgi Ocean Baths is a known issue), although considering the prominence of Flagstaff Point and its associated reefs it is difficult to imagine the movement of sediment between City Beach and those beaches to the north of the Wollongong CBD.

The sediment on Wollongong's beaches is primarily fine- to medium-grained quartz sand, with occasional local variations such as jasperoid pebbles at Coalcliff Beach. The carbonate concentration in the northern parts of the LGA's coastline is up to 60%, with that proportion decreasing with distance south, coinciding with an increase in the presence of sandy plains in the nearshore instead of rocky reefs.

Recent assessments using aerial photography and shoreline mapping indicate that while Wollongong's beaches are subject to periodic storm erosion, they also demonstrate a degree of natural recovery and, in some cases, accretion (Abuodha and Woodroffe, 2010; BMT WBM, 2017)). Studies show that embayed beaches within the Wollongong LGA have maintained or increased dune volumes, based on the available aerial photography record, despite the limited sediment supply. This indicates some inconsistency with the above classifications of different barriers, which are largely based on geomorphological indicators of the way the beach has evolved over the past 6000 years.

Interestingly, these analyses overlap a period of known sea level rise (around 10cm or so since the earliest dates of photography). Yet, there seems to be no signal of beach recession that is yet discernible because of that sea level rise. There are a few points to consider here:

- Photogrammetric analyses are based on aerial photographs that are spaced some distance apart and interpretation can be difficult.

- While it is acknowledged that the shoreline will respond to sea level rise by receding, issues of any lag, or the key mechanisms effecting that recession (significant storms or storm clusters may be required for the beach to “catch up” to sea level) are presently not well understood and it is possible that we have not yet had conditions which would cause the necessary recession over recent decades.

These issues are not unique to beaches along the Wollongong coastline although analysis with newer sets of data and multiple lines of evidence are likely to assist greatly in future.

Cardno Lawson Treloar (2010) found no historical recession along the Wollongong Coast and indeed assessed that almost all photogrammetric profiles had steadily accreted since 1974. However, subsequent analysis by Salients found that multiple lines of evidence showed ongoing, chronic recession at McCauleys Beach. In recent years, the development of a continent-wide mapping of the coastline from satellite imagery has become available (Bishop-Taylor et al., 2021). This data set spans the period of available Landsat imagery, from approximately the late 1980's onwards, so therefore misses much of the period in the 1970's and 1980's where the NSW coast was recovering from significant storms in the 1970's. This data set is proving to be invaluable in assessing long term patterns of beach recession and accretion.

The satellite derived data set shows areas of erosion along McCauleys Beach, Thirroul Beach, at Coalcliff Beach, at Werrong Beach (in the National Park), and midway along Port Kembla - Perkins - Windang Beach. It is true that other notable changes have mostly shown accretion (north and south end of Port Kembla - Perkins - Windang Beach, north of Fairy Creek Entrance, around the Entrance to Bellambi Lagoon, south of Bellambi Point and in the middle of Sharky Beach). The data set is presently being considered in more detail as part of the coastline recession and erosion hazard study being completed to inform the CMP.

Care is required in considering how beach barriers will respond to sea level. The applicability of the Bruun Rule, commonly applied to predict shoreline retreat under sea level rise, needs to be considered carefully within embayed or reef-influenced areas such as the Wollongong coastline. Large reef structures can impede shoreface adjustments to rising sea levels, limiting sediment accommodation volume and potentially reducing the degree of predicted recession (Kinsela et al., 2022).

3.4.2 Dunes and Dune Vegetation

Detailed consideration of dunes along the Wollongong Coast, and history of their modification and management is provided in Appendix B. A concise overview is provided here. Reports by James Cook and Joseph Banks of their unsuccessful

attempts to reach land in April 1770, near the present-day site of the Woonona Ocean Baths, indicated that vegetation was present to the rear of the beach (presumably on the foredunes). In contrast, by the mid 1980's it was stated that:

"With the exception of parts of Bellambi, Towradgi, and Wollongong Beaches and the reconstructed dunes at Wanda [north of the study area, near Cronulla], Stanwell Park and Port Kembla Beaches, Foredunes are now absent from the Beaches of the Illawarra area."

Sherwin & Holmes (1986).

Initial colonisation began in the 1810s, primarily as an area for cattle grazing, initially in the Wollongong area and then further south towards Dapto. This was followed by colonisation of areas further north along the narrowing coastal plain, towards Bulli in the subsequent decades. The town of Wollongong initially developed over this period.

Doyle (2019) noted that several foredune plant species, including *Spinifex* were a popular food source for livestock and that, prior to the 1940's, coastal dune areas were used for grazing cattle. Grazing of dunes by livestock following early colonisation likely goes some way towards explaining the observations of Sherwin and Holmes.

In addition to any initial impact from settlement and grazing of dune vegetation from the 1800's onwards, some beaches along Wollongong's coastline have also been heavily impacted by sand mining. Sand mining has been a common cause of the degradation of indigenous plants on foredunes in NSW, with Brewer and Whelan (2003) noting that 'authentic' foredune plant communities were uncommon in much of NSW. Areas impacted by larger scale sand mining in Wollongong include Stanwell Park, Austinmer, Sandon Point, Woonona-Bellambi, Corrimal, Towradgi and Port Kembla - Perkins Beaches (Abuodha, 2009). More notable sand mining operations apparently occurred at the northern ends of the longer embayments between Bellambi Point and the entrance to Lake Illawarra (e.g. the "Episodic Transgressive" barriers at Perkins, Towradgi, and Corrimal Beaches).

Beach sand mining was effectively banned in NSW in the 1980's. Since the peak of sand mining in the 1950s through 1970s, there have been efforts to rebuild and revegetate dunes as part of the NSW Government's Beach Improvement Program, which ran from 1975 through to 1989 (Watson and Lord, 2005) and through the activities of Coastcare/Landcare groups which undertake dune regeneration, weeding, and beach access projects.

These more recent activities which were, in part, prompted by erosion during the 1970's, has meant that many dunes are now more likely to retain sand, providing a more significant buffer against the effects of major storms. There is a matter which needs to be considered carefully here. Beach behaviour since the stormy period in the

1970's characterised by the beach recovering naturally from those storms, and the additional effect of dune revegetation which further addressed some of the earlier effects of sand mining and livestock grazing can be considered anomalous. As noted above, recent analyses have reported that the data available at the time indicated beaches are typically "accreting" over time.

In deriving previous hazard lines, Cardno stated:

"since [1974] almost all the profiles have shown a steady accretion of beach width and beach volume. To this end no long-term shoreline recession could be identified and was therefore adopted to be zero (for present MSL) for the determination of erosion hazard lines."

The approach by Cardno is reasonable. Even though there was an apparent steady accretion evident from the historical aerial photograph record, the period analysed is likely anomalous over a longer record.

At some locations along the Wollongong Coast, urban and residential development has been built on dunes either immediately at, or close to the present-day coastline, with the removal of vegetation (if still present) and ground levelling likely to have occurred.

3.4.3 Rocky Cliffs and Headlands

An overview of the geomorphology of the Wollongong Coastline is shown in Figures 6 through 8, for the North, Central and Southern extents of Wollongong's coastline, respectively. These figures are relevant to both this section and Section 3.4.4.

As expected from prior sections, rocky coasts dominate the coastline from the northern LGA boundary to, approximately Thirroul. Jones et al. (1979) noted that prominent headlands along the Wollongong coast typically represent the extension of east-west trending onshore ridges, which terminate at the coast as sea cliff, rock platform and offshore rock reef complexes. The spacing between headlands increases with distance southwards, as the coastal plain widens, ridges less frequently reach the coastline and estuarine catchment sizes increase.

The formation of platforms and cliffs is influenced by marine, subaerial, and biological processes, often operating together in complex interactions (Stephenson, 2008). Ultimately, cliff recession typically occurs due to wave undercutting, slumping, landslides, and rockfalls, with debris at the cliff base gradually removed by wave action. This cyclic process is exacerbated during storms, heavy rainfall, or other extreme events, which accelerate retreat (Bird, 2016).

Legend

 Rock Platforms

 RockyCoastline

CoastalPlainSurfacePolygons

 Holocene Barrier (Dunes and Beaches)

 Holocene Estuarine (Swamps, Deltas, Channels and Lagoons)

 Holocene Freshwater Swamps

 Pleistocene - Bedrock Mantling Dunes

 Pleistocene Undifferentiated (Clays, Silts and Sands)

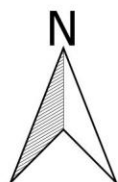
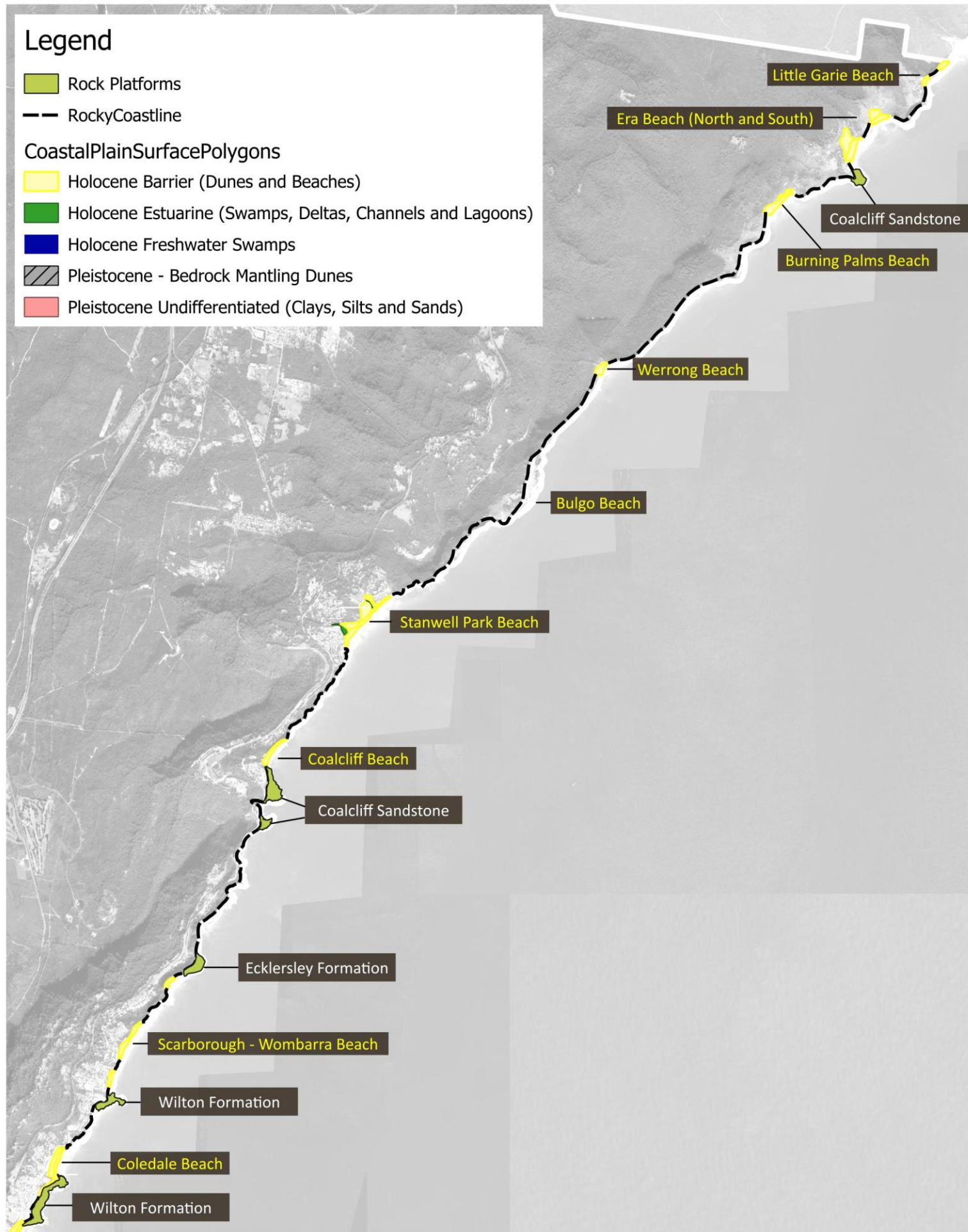


Figure 13 Coastal Geomorphology (Northern Coastline)

0 0.5 1 1.5 2 km

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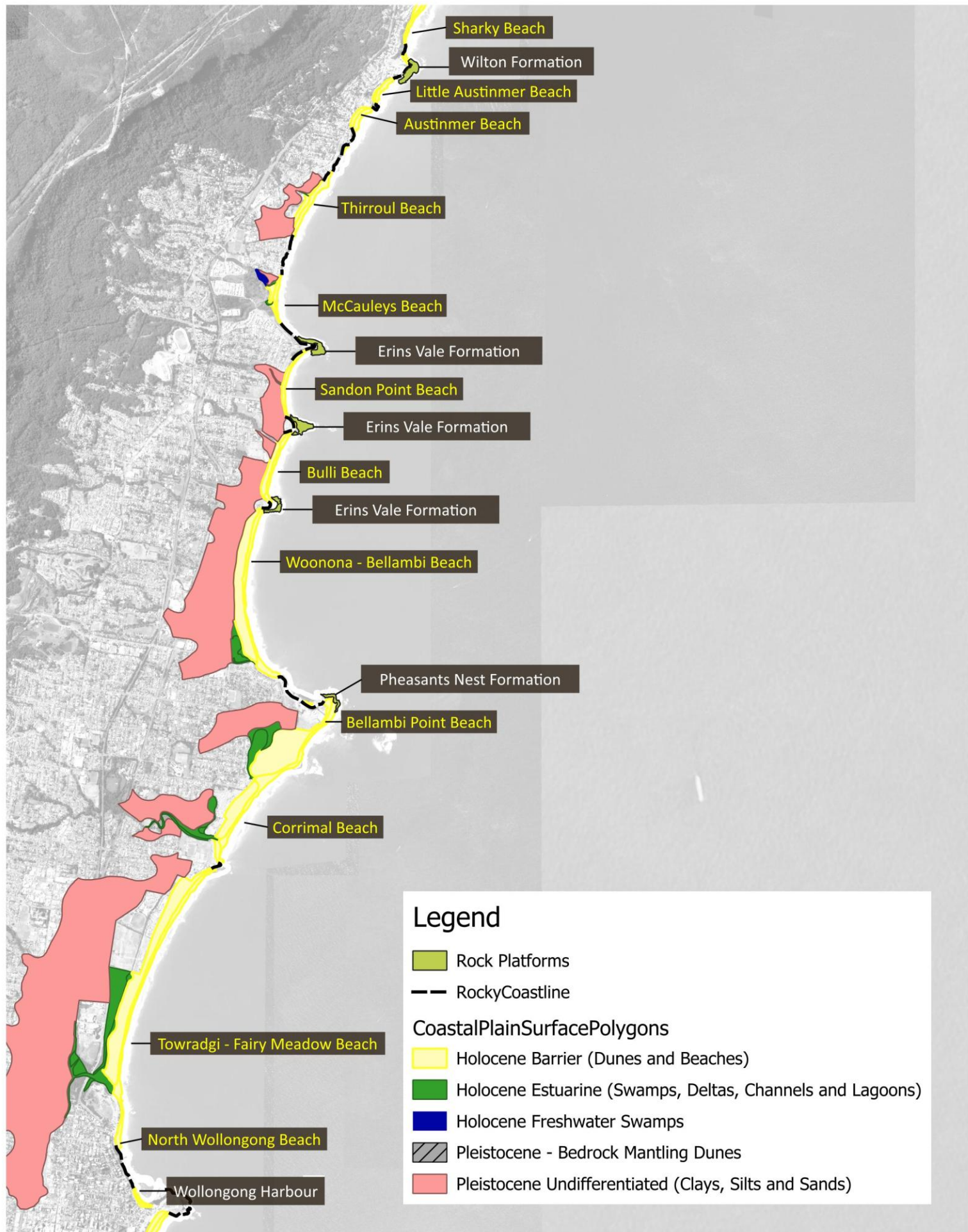


Figure 14 Coastal Geomorphology (Central Coastline)

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Salients

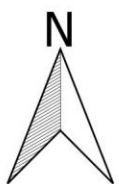
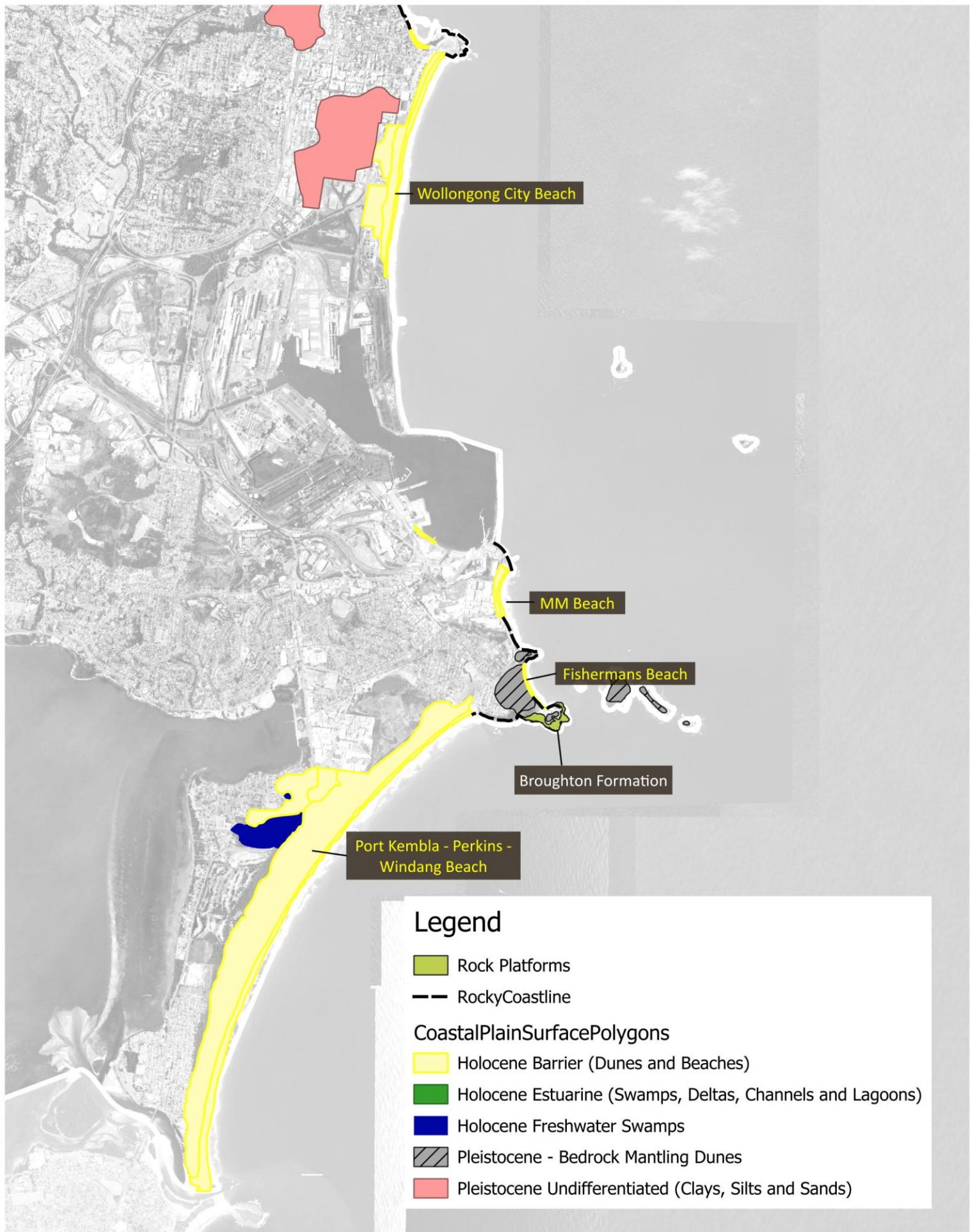


Figure 15 Coastal Geomorphology (Southern Coastline)

0 0.5 1 1.5 2 km

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Salients

Shore platforms are significant geomorphological features that mark previous positions of the shoreline. These platforms develop where softer rock types occur in the maximum weathering zone above sea level (Hesp, 1993). Rates of cliff retreat vary by rock type, ranging from millimetres per year in hard granites to centimetres per year in softer sedimentary rocks like shale (Bird, 2016).

There is ongoing debate among geomorphologists regarding the processes responsible for shore platform development and cliff retreat. Inherited features from previous high sea levels particularly from the Pleistocene epoch and even the Tertiary periods, play a role in determining modern rocky coast morphology (Stephenson, 2008). This is suspected to be the case for the Wollongong Coast, meaning it can't be assumed that the full width of a rock platform has evolved during the high sea level conditions experienced over the past 6 millennia. Bryant et al. (1990) clearly identified the role of inheritance from previous high mean sea levels during the Pleistocene, through analysis of data collected from elevated platforms at Red Point.

Shore platforms on the Wollongong coast are well-developed where (relatively) softer rocks, such as those in the Narrabeen Group and Illawarra Coal measures, outcrop near sea level. North of Thirroul, coastal cliffs are steep due to direct marine abrasion of an escarpment which has been oversteepened by ongoing erosion (Flentje, 2012).

While narrow platforms (<100m) front the relatively high cliffs to the north of the LGA, there are several more prominent headland platforms (Rock unit name is provided in brackets)⁸:

- At Semi-Detached point, south of South Era Beach where a platform extends some 120m from the base of the cliff (Stanwell Park Claystone).
- To the south of Coalcliff Beach, a platform which widens to the south of the Coalcliff tidal pool, to around 180m (Coalcliff Sandstone).
- A 150m platform further south of Coalcliff, to the north of the main Sea Cliff Bridge (Coalcliff Sandstone).
- Cape Horn, a 120m platform offshore of Scarborough Public School (Eckersley Formation).
- A 110m wide platform at Wombarra Rock Pool, offshore of the Scarborough Wombarra Cemetery (Wilton Formation).
- A 160m platform at the southern end of Coledale Beach which extends around to the northern end of Sharky Beach (Wilton Formation).

⁸ As reported by Minview (<https://minview.geoscience.nsw.gov.au/>) 26 November 2024.

-
- A 110m wide platform which extends between Austinmer Boat Harbour and Little Austinmer Beach (Wilton Formation).
 - A 150m platform at Sandon Point to the north of Sandon Point SLSC (Erins Vale Formation).
 - A 120m platform at Waniora Point (Erins Vale Formation).
 - A 120m platform at Collins Point, Woonona (Erins Vale Formation).
 - A 110m platform at Bellambi Point. (Pheasants Nest Formation).
 - The platform which extends around Hill 60 (Red Point) out to widths of around 120m (Broughton Formation).

The cliffs and platforms along the Wollongong coast are highly dynamic and affected by many destabilising processes. Subaerial processes such as heavy rainfall, groundwater percolation, and salt crystallisation contribute to weathering, erosion and slumping (Bird, 2016). The northern suburbs, in particular, are prone to landslides caused by the combination of steep slopes and weak rock layers, forces from waves and prolonged rainfall (Flentje et al., 2022).

Landslides and debris flows from the soils which overlie the cliff frequently affect rock platforms, as observed at Wombarra and similar locations (Flentje et al., 2022). In this instance, the toe of the cliff line may advance temporarily, with the crest retreating. Subsequently waves act to remove debris from the toe and may act further to erode a notch at the cliff base, with periodic collapse of the rock mass and recession of the cliff line.

Narrabeen Group strata, when exposed on the escarpment, are commonly associated with significant landslide activity. Thick, poorly drained talus soils at the base of escarpment exacerbate instability (Sherwin and Holmes, 1986). Efforts to mitigate these hazards include engineering solutions like the Sea Cliff Bridge, which was built in 2004 to replace a section of Lawrence Hargrave Drive, which hugged the unstable cliff line (a 'Corniche' road) between Coalcliff and Clifton.

3.4.4 The Coastal Plain and Estuaries

Commensurate with a decreasing dominance of the Illawarra escarpment at the coastline with distance southwards, other patterns also emerge:

- With distance south, the presence of increasingly broad, alluvial deposits (mostly dating from the Pleistocene according to maps provided by Troedson et al., 2016), becomes apparent (see Figures 10 through 12). The most northerly occurrence of a coastal plain of any significance occurs at Thirroul. To the north of Thirroul, the coastal barriers primarily comprise a sandy beach backed by a narrow dune which

is itself backed by steep topography. A notable departure from these characteristics is present at Stanwell Park Beach, where both Stanwell and Hargraves Creeks discharge to the Ocean. At one other notable location, around Sandon Point and the along the entirety of Sandon Point Beach, the back of the alluvial deposits are present immediately behind the sandy beach, with minimal dune present to help absorb the impacts of coastal erosion.

- With the widening coastal plain, and less ridgelines reaching the coast, several drainage pathways across the face of the escarpment meet to form larger estuaries, with the most notable of these being Fairy Creek. Fairy Creek conveys combined flow from the Towradgi Arm and Cabbage Tree Creek to the Ocean.

To the south of the Wollongong CBD, Allans Creek and the Gurungaty Waterway drain to Tom Thumbs Lagoon, which in turn flows to Port Kembla Harbour and into the Ocean. As the estuarine extents of this waterway are mostly managed by NSW Ports, it is of lesser concern to the CMP. Similarly, the largest estuary within Wollongong's LGA, Lake Illawarra, has its own CMP and is not being considered as part of this study.

A more detailed consideration of the different estuaries, their catchments and entrances, and any erosion issues associated with the estuaries is provided in Salients (2025).

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Appendix A Sea level Rise

A.1 Introduction

Sea level rise is a complex issue requiring careful consideration by planners when assessing development or identifying areas suitable for future development. In New South Wales, current state government policy places the responsibility for selecting relevant sea level rise projections, upon local councils. Within New South Wales' current coastal management framework, these projections are an important input to coastal hazard studies.

Sea level rise has already been occurring for at least the last century, both globally and offshore of NSW. This ongoing process, and natural variability in coastal water levels, means that mean sea level at any given time cannot be accurately determined. When the Australian Height Datum (AHD) was established, based on records from coastal tide gauges between 1966 and 1968, its zero value was set to correspond to mean sea level around Australia. Due to sea level rise since that time and noting that it is difficult to determine mean sea level at any given point in time, we expect that mean sea level offshore of Wollongong is (at 2025) somewhere between 10 and 12 cm above zero AHD. The implications of this are discussed in more detail within this Appendix.

The important thing to recognise is that mean sea level is no longer the same as 0.0m AHD; mean sea level has risen over recent decades and will continue to rise over coming decades and centuries.

A.2 Background to Sea level Rise

The amount of sea level rise that will happen in future depends on the interaction between several global systems, including the atmosphere, oceans, ice sheets and glaciers. Perhaps one of the most complex and unpredictable systems influencing future sea level rise is the global economy. Decisions made now regarding efforts to mitigate the generation of greenhouse gases, for example by reducing the burning of fossil fuels, will have long lasting impacts on how quickly, and how much sea levels rise in future.

While the expected rate and amount of sea level rise remains uncertain, there is broad consensus on the range within which sea level rise could possibly occur. Noting how complicated the interactions are that cause sea level rise, simple approaches to estimating future sea levels, such as assuming what has happened in the past will continue, fall short of what is required for planning on a warming planet. Simple approaches typically fail to account for complex 'non-linear' relationships between the atmosphere, ocean and ice, and the dynamic feedback loops that are expected to amplify changes over time.

Sea level rise is accelerated by several key mechanisms linked to global warming. As the Earth's atmosphere warms due to increased greenhouse gases, ice sheets and glaciers melt at accelerated rates, contributing additional water to the oceans. Simultaneously, warmer ocean temperatures cause thermal expansion, where water molecules spread out and occupy more space, further pushing water levels up.

Human activities, primarily through the burning of fossil fuels and deforestation, have significantly increased greenhouse gas concentrations in the atmosphere. Greenhouse gas emissions have increased steadily every decade since the 1900's. Carbon dioxide (CO₂) is the most prominent greenhouse gas, but methane (CH₄), nitrous oxide (N₂O), and water vapor also contribute to the greenhouse 'effect'. These gases more efficiently retain heat in the atmosphere disrupting Earth's energy balance and leading to subsequent warming of the oceans and land masses.

Extra greenhouse gases act in a way similar to adding more, or thicker blankets to a bed. They make it harder for heat to escape from the surface of the earth. This phenomenon is known as 'radiative forcing' and is fundamental to understanding the underlying cause of climate change. The resulting warming triggers various feedback mechanisms, some of which amplify the initial warming (positive feedback), while others dampen it (negative feedback).

Oceans play a pivotal role in the climate system by absorbing and redistributing heat around Earth. They have a vast capacity to absorb heat. Some estimates suggest that about 91% of the excess heat from global warming is stored in the oceans (Johnson, G. C. and Lumpkin, R, 2023). While the amount of resulting thermal expansion is proportionally small, the great depths and volumes stored in the oceans mean that it is noticeable as a change in the average height of the water level at the surface.

Thermal expansion has been the main major contributor to the 20cm or so of sea level rise (globally averaged) that has already occurred since the late 1800's. The other main key contributor is the melting of land-based ice, including glaciers, ice caps, and the massive ice sheets of Greenland and Antarctica. As temperatures rise, land-based ice will begin to melt more rapidly. Meltwater from these ice sources flows into the oceans, directly contributing to sea level rise. Various mechanisms that could speed up this delivery of melted ice to the ocean have been a source of great uncertainty over the past 20 years, and efforts to better understand these mechanisms are continuing.

The sea level rise which has occurred since 1900 differs notably from behaviour assessed from data covering the past several thousand years (for example, from ice cores, sediment cores, and studies of coral reefs). There is strong evidence that this impact is due to human-induced warming, particularly since the onset of the industrial revolution.

The 20cm or so of global sea level rise has not been constant and varies from place to place. This is partly due to the operation of large ocean circulation currents, which distribute heat around Earth, but move very slowly. Some of the better known of these currents are the Gulf Stream in the Atlantic Ocean, and the Antarctic Circumpolar Current, which flows from west to east around Antarctica.

Along the coast of New South Wales, the East Australia Current is important. It flows southwards from the tropics along the east coast, extending south to Tasmania, is strengthening due to climate change, and is expected to strengthen further as the Earth continues to warm. For this reason, sea level rise along the NSW coast is expected to be a bit larger than the global average.

One of the reasons it is hard to estimate sea level rise accurately is that there are natural variations due to normal interactions between ocean currents and the atmosphere. For example, during La Nina periods, the East Australia Current is stronger, and we get warmer water along the south coast of NSW. During El Nino periods, the East Australia current is weaker, and the water is cooler. These types of ocean-atmospheric interactions are complicated and not perfectly understood.

Local variations in sea level rise also differ significantly from the global average due to local geological processes. Some regions may experience amplified sea level rise due to land subsidence, or falls in sea level rise due to decreased gravitational attraction (because of the loss of ice around Greenland, for example). Others might see relative sea level fall due to an ongoing process known as post-glacial rebound. Around 20,000 years ago, during the last 'glacial period' (often referred to as the 'Ice Age', although this is not strictly correct), sea levels were much lower (by about 130m) and there was significantly more water frozen in polar ice caps and glaciers around the world compared to today. As these ice caps melted during the past 20,000 years, the weight of ice on top of land masses reduced and the effect is that some land masses have been 'rebounding' (rising relative to the ocean) since that time. This process is relatively insignificant in Australia because our continent was not extensively covered in ice.

In terms of the NSW coast, there has been minimal variation in historical sea level rise along the coast. Our most useful, long-term tide record is from Fort Denison, in Sydney Harbour. Annual average sea level records were obtained from the Permanent Service for Mean Sea Level (PSMSL⁹). The data were adjusted to approximate millimetres relative to Australian Height Datum (AHD¹⁰), plotted and analysed as shown in Figure A.1. Also shown (in Figure A.2) is a similar analysis for the shorter record (1992 to 2022) available from Port Kembla.

⁹ <https://psmsl.org/>

¹⁰ AHD is based on mean sea level as measured around Australia at tide gauges during the late 1960's.

Figure A.1 shows that mean sea level varies greatly from year to year, and it is difficult to discern a trend from the annual data. Furthermore, a “linear fit” to the average annual values does not pick up much of the detail or natural variation and provides an incomplete and overly simplistic representation of the nature of mean sea level over time. By applying a filter (A Hodrick Prescott filter is shown in Figure A.1) to the annual values to remove the “noise”, there is now a strong indication of an increase in the rate of sea level rise since around 2000. The rate of sea level rise between 2005 and 2023 has been between 4.0 and 4.5mm/year.

Close comparison between Figure A.1 and Figure A.2 demonstrates that annual mean sea levels at Fort Denison and Port Kembla, and the year-to-year variations have been very similar since 1992. Similarly to Fort Denison, the rate of rise post 2005 has been around 4.0 to 4.5mm/yr and the trend is a strong one.

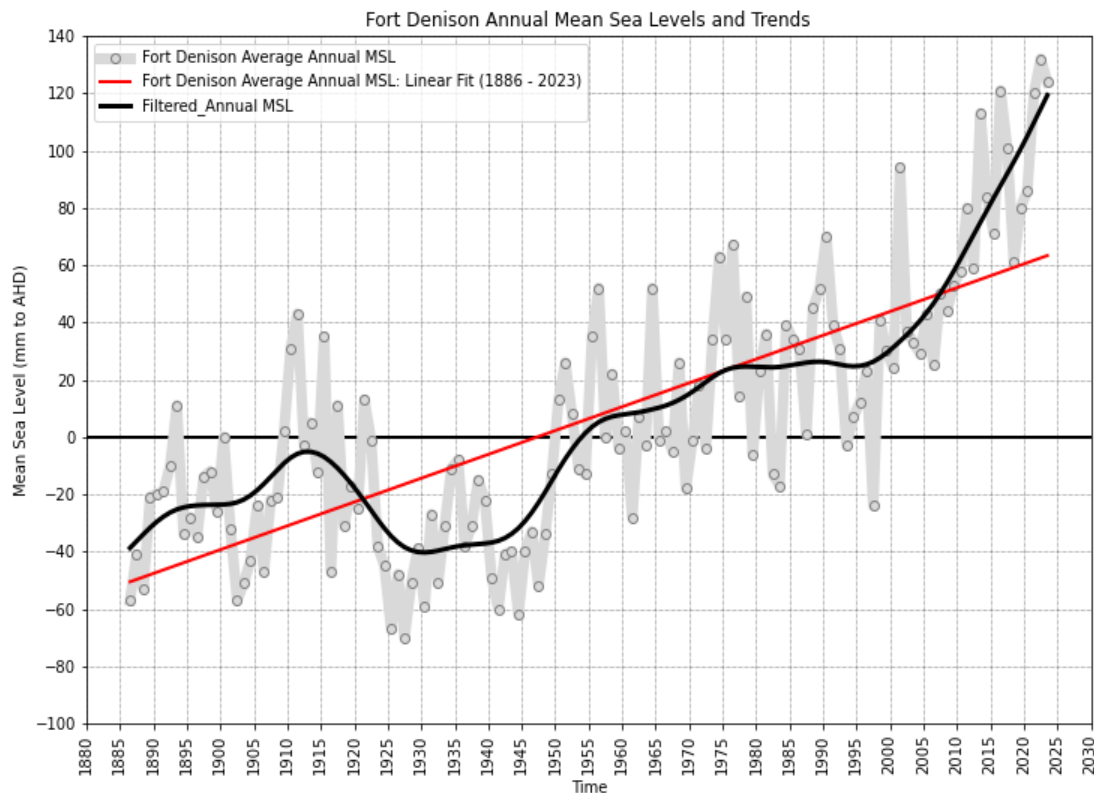


Figure A.1 Analysis of Annual Average Sea Levels at Fort Denison: 1886-2023

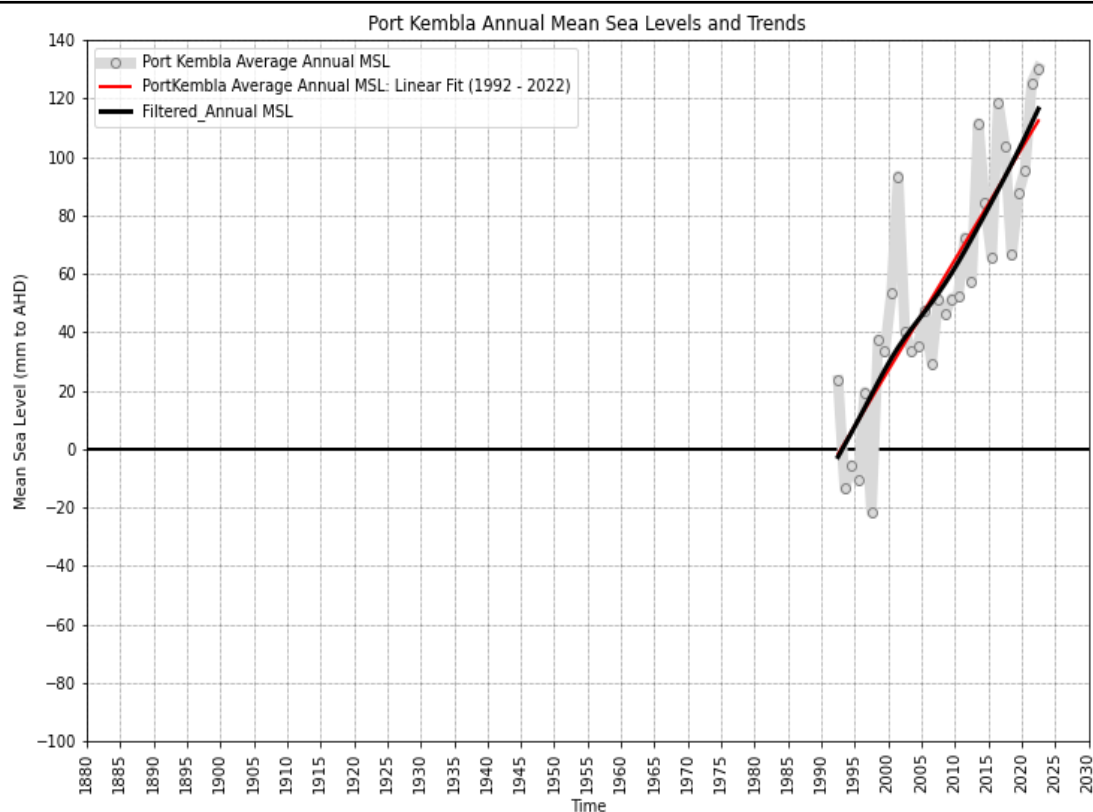


Figure A.2 Analysis of Annual Average Sea Levels at Port Kembla: 1992-2022

Divergence of the assessed trend at Port Kembla from that at Fort Denison during the 1990's illustrates some of the shortcomings of relatively short annual time series of annual mean sea levels. It is generally desirable to have records at least 60 years long to get a robust assessment. However, in this case, the close correlation between historical values at the two sites indicates that:

- The assessed trend at Port Kembla over the past 20 years is robust.
- There is minimal variation in historical behaviour of mean sea level along the coast between Wollongong and Sydney.

A.3 Role of the IPCC and Climate Change Scenarios

The most widely accepted and comprehensive assessments of how sea level might vary in future have been published by the Intergovernmental Panel on Climate Change (IPCC), every 6-7 years for the past few decades.

Established in 1988 by the United Nations Environment Programme (UNEP) and the World Meteorological Organisation (WMO), the IPCC's work consolidates extensive global research and observations. The resulting, comprehensive reports, synthesise the findings of thousands of peer-reviewed studies, and offer a consensus view on the state of climate science and projections of future climate scenarios. The reports are

authoritative scientific assessments used internationally in planning for climate change and sea level rise.

To project future climate conditions, the IPCC's latest Assessment Report (AR6) uses future scenarios called "Shared Socioeconomic Pathways" (SSPs). These scenarios represent different possible futures based on development of the global economy, resulting in varying greenhouse gas emissions and their associated radiative forcing effects. They are intrinsically linked to assumption regarding how successful the international community is in reducing the quantity of greenhouse gases emitted into the atmosphere in future.

There are five SSP's analysed in AR6 as outlined in Table A.1. It's impossible to be certain about which of these scenarios will manifest in the future. Arguments for and against the adoption of a particular SSP for planning commonly revolve around trends, policy positions and international agreements relating to greenhouse gas emissions and energy sources. None of these deterministic factors are guaranteed to continue in the future. Generally, the arguments as to which SSP most closely reflect the direction the global economy is headed vary between SSP2-4.5 and SSP5-8.5.

Table A.1 Description of Shared Socioeconomic Pathways in AR6

Name	Descriptor	Characteristics
SSP5-8.5	Fossil Fuelled Development (Taking the Highway)	Very high warming scenario, consistent with 4.4 degrees of warming by the end of the century. GHG emissions triple by 2075
SSP3-7.0	Regional Rivalry (A Rocky Road)	High warming scenario, consistent with 3.6 degrees of warming by the end of the century. CO ₂ emissions double by 2100. Major impacts of food security and increasing inequality with a divide between wealthy and poorer countries.
SSP2-4.5	Middle of the Road	Intermediate warming scenario. Estimated warming of 2.7° C by end of century. CO ₂ emissions around present levels till 2050, then falling but not reaching zero by 2100.
SSP1-2.6	Sustainability (Taking the Green Road)	Aims to limit global warming to below 2.0° above pre-industrial levels. Emphasis on sustainable development and conservation. Net zero achieved later in century compared to SSP1-1.9.
SSP1-1.9	Sustainability (Taking the Green Road)	Aims to limit global warming to below 1.5° above pre-industrial levels. GHG emissions cut to zero by 2050. Focus of wellbeing over economic growth. Warming returns to 1.4 degrees by the end of the century.

We don't know how quickly the international community will transition away from fossil fuels towards alternative energy sources. The Mauna Loa observatory in Hawaii provides the world's longest continuous record of atmospheric CO₂ concentrations, beginning in 1958. This data clearly shows that CO₂ levels are not only increasing but doing so at an accelerating rate. In recent years, annual increases have been about 2.5 parts per million (ppm) per year, compared to about 1 ppm per year in the early 1960s. While there are international agreements in place, the amount of CO₂ in the atmosphere is not only increasing, but the rate of increase is also increasing, despite agreements to curb emissions.

Importantly, it should be remembered that sea levels respond in a slower fashion to greenhouse gases than air temperatures. We are, however, certain that sea level rise due to emissions that have already occurred is 'locked in' for the next few hundred to one thousand years, regardless of the emissions scenarios and atmospheric warming that occurs. It has been stated in recent research that a global sea level rise of 2m will be exceeded sometime within the next 100 to 2000 years (Cozannet et al., 2023).

An increase in coastal erosion, flooding and inundation will occur within low lying areas. This will affect low lying infrastructure that already exists but also poses questions relating to intergenerational equity with new development. Is it fair to develop an area when it may only be viable for one, potentially two generations? At the end of this period, future generations will be forced to adapt. Or should we be planning for longer life coastal developments now?

Based on assessment completed following the release of the IPCCs Assessment Report 5 in 2013, Wainwright et al. (2014) found from a detailed review of scientific research at the time, various legal opinions, planning guidance, and dominant practice around Australia that:

- There has been a tendency in Australia to adopt more fossil fuel intensive scenarios for sea level rise planning.
- That planning guidance, legislation, and legal advice available at the time encouraged a cautious approach and promoted the selection of a higher sea level rise projection.
- From a workshop of practitioners, the future consequences of adopting a scenario that was too low were considered more severe than choosing one that was too high, a factor which is important from the viewpoint of promoting intergenerational equity.

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- That RCP 2.6 (from AR5, somewhat equivalent to SSP1-2.6 from AR6) was less plausible than the more intensive scenarios.

Due to these factors, it was recommended that RCP 8.5 (equivalent to SSP5-8.5) be adopted for planning purposes as a suitable and defensible sea level rise projection.

Based on recent developments, the state of the science, the findings of AR6, and subsequent summaries and research, we consider that the higher emissions scenario (SSP5-8.5 in AR6) is the most appropriate projection for Wollongong Council to adopt as its basis for assessing coastal hazards.

A.4 Models and Sea level Rise Projections

The effect of the warming atmosphere on the overall climate system, assuming an underpinning SSP, are investigated with computer simulations using models known as Atmosphere-Ocean General Circulation Models (AOGCMs), also known as General Circulation Models (GCMs) or Earth System Models (ESMs). These models simulate the interactions between the atmosphere, oceans, land surfaces, and ice sheets under different scenarios of greenhouse gas concentrations.

Numerous scientific organisations worldwide run these types of models to provide a range of possible outcomes based on different underpinning assumptions. It's the different results of those models that the IPCC uses to assess the uncertainty in the way the earth will respond to a selected SSP. Therefore, for a given SSP, there are a range of different values that are plausible for the different simulated outputs, such as the amount of sea level rise. The simulated ranges of sea level rise vary over time, and in locations round the world's coastlines.

It's important to note that these are not 'predictions' and are instead referred to as projections. They need to be treated as "what-if" scenarios to aid in understanding the possible future trajectory of sea level rise. As the future unfolds, the expected range of sea level rise will narrow and SSPs will be updated accordingly.

AOGCMs integrate the current scientific understanding of physical processes, from very small processes, such as the formation of clouds to much larger dynamics like ocean circulation patterns. Despite advances in modelling, the results of those models carry inherent uncertainties.

For example potential tipping points, where some threshold is crossed and a rapid 'step' change occurs, are challenging to accurately model, particularly when we don't have measured data (because we haven't previously crossed the threshold). One example of a potential threshold is related to the recession of beaches. Geomorphologists and coastal scientists generally expect that beaches will recede with

rising sea levels, but this is not expected to be a smooth process that mirrors the amount of sea level rise as it occurs. Instead, it may be necessary for a storm, series of storms, or semi persistent change to wave climate which provides the trigger for recession. As these are random processes, we can't be precise about when they might occur.

When considering sea level rise, the uncertainties associated with ice sheet dynamics in places like Antarctica, and the various tipping points that might occur, are of particular concern.

As outlined above, we have adopted SSP5-8.5 as the appropriate scenario for sea level rise planning for Wollongong's coastline. The projection of sea level rise determined for Port Kembla arising from AR6¹¹ is presented in Figure A.3. One factor often missed in sea level rise assessments, is to adjust the projection to a suitable datum. Noting that the baseline timeframe for AR6 sea level projections was 1995-2014 and, taking a midpoint of that period as 2005, we estimate that the mean sea level in 2005 was already 4cm above AHD (refer Figure A.1). Accordingly, to adjust the AR6 projections to AHD, addition of 40mm is appropriate for Port Kembla and the values illustrated in Figure A.3 include that adjustment. The term '% chance of non-exceedance' refers to the likelihood of an event occurring worse than has been predicted i.e. a 17% chance of non-exceedance has an 83% chance of being worse than has been predicted.

¹¹ The global variation of AR6 sea level rise projections are available from NASA at: <https://sealevel.nasa.gov/ipcc-ar6-sea-level-projection-tool>, accessed 5/07/2024.

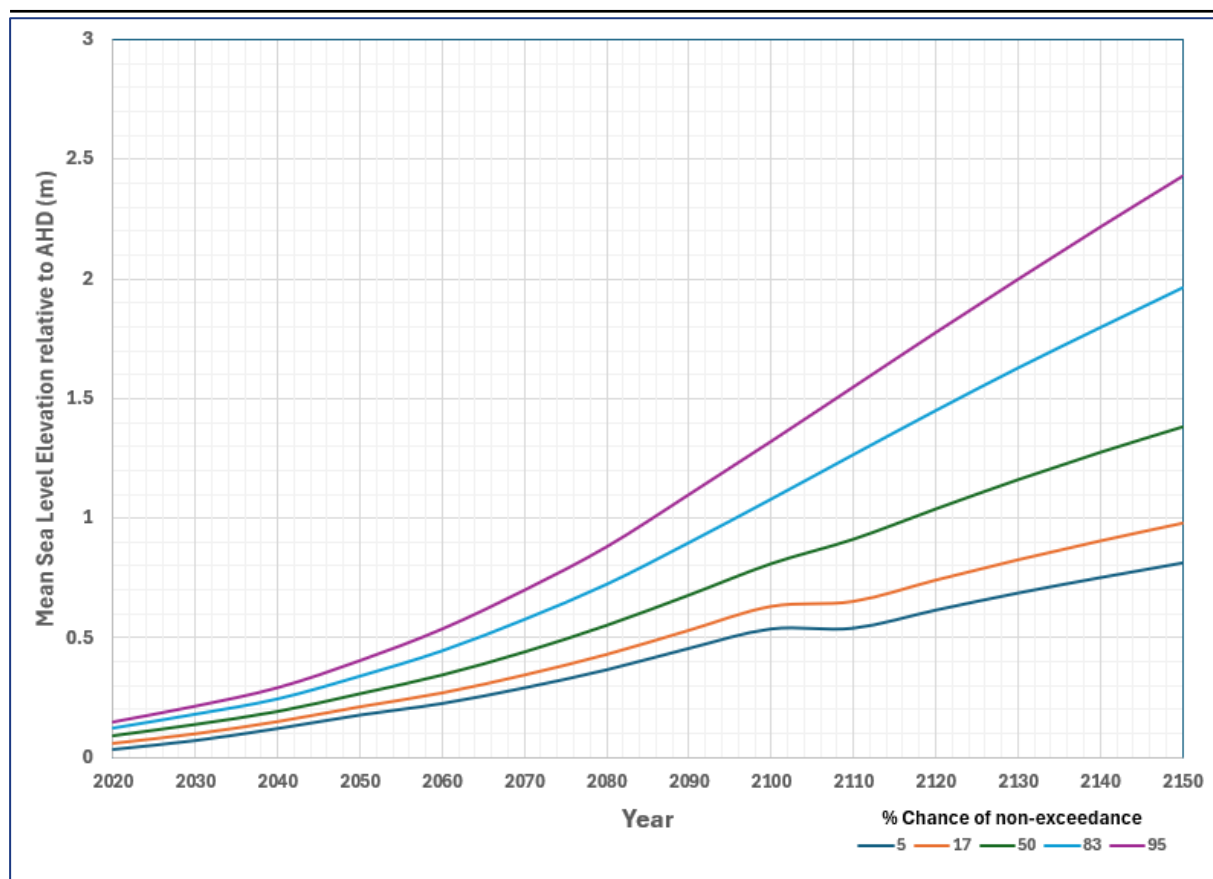


Figure A.3 SSP5-8.5 Sea level rise Projection for Port Kembla, from AR6, Assuming SSP5-8.5

One feature of Figure A.3 is the notable ‘flattening’ of the 5% and 17% lines between 2100 and 2110. To understand why this might be, it is important to note that there are naturally occurring interannual variations in “astronomical” tides. These relate to the relative distances between the earth, sun, and moon over timescales of greater than a year. Two key cycles are:

- The lunar declination cycle, relating to changes in the Moon’s orbital plane which changes over an 18.6-year period.
- A “quasi” 4.4-year cycle related to changes in the closeness of the Moon to the Earth.

Because of these effects, the annualised mean sea level due to astronomical forces can vary from year to year by a small amount (less than ~5cm offshore of New South Wales). These variations are mostly smoothed out in the chart shown as Figure A.3, where the lines are based on interpolation between tabulated 10 yearly values published by NASA. While we haven’t quantified these processes as the cause underpinning this apparent “flattening” in NASA’s data, variations of a few

centimetres in mean sea level are to be expected over multi-year cycles. We note that this is only a temporary flattening, which does not affect the time frames being considered by the CMP (2075 and 2125). Furthermore, it is only present for the lower quantiles (5 and 17%), which have less sea level rise to “mask” the process. For the higher quantiles, this effect is indistinguishable, as for those cases the projected sea level rise is much greater than any temporary flattening effects. A small effect can be determined from close examination of the 50% quantile. The flattening effect is insignificant in terms of the hazard assessment and the risk assessment which is to follow.

It is worthwhile noting that all the SSPs share similar levels of sea level rise prior to 2050 but diverge drastically by 2100.

We know that 2m of sea level rise will happen, the only question is when. Based on some postulated theories of climate change dynamics, there is also a possibility that 5m or more of sea level rise could happen by 2150. For example, the behaviour of ice sheets, and uncertainty associated with several postulated processes that may cause accelerated melting, and uncertainties associated with regional differences led the IPCC to publish an SSP5-8.5 (low confidence) projection. This projection includes a range of factors that push the upper (low probability of exceedance) estimates of sea level rise even higher than in the base scenario (SSP5-8.5 “moderate” confidence). The resulting low-confidence projection is presented in Figure A.4.

While not recommended as a projection for use by Wollongong Council at present, the residual uncertainty and potential increase in risks over the longer time frame need to be kept in mind.

Using high-end projections like SSP5-8.5 provides a buffer which acts as a proxy for some of the uncertainties associated with the future behaviour of the coupled ocean-atmosphere-cryosphere system.

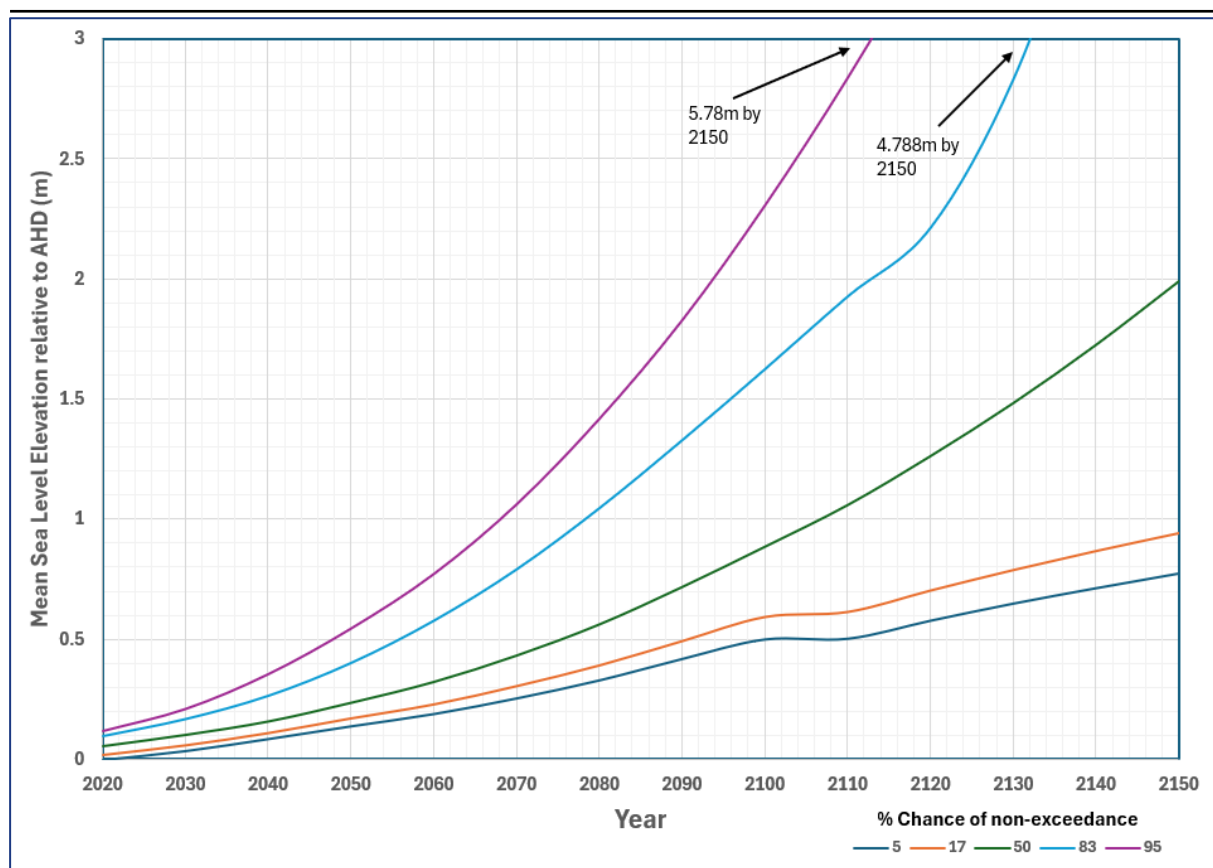


Figure A.4 SSP5-8.5 (low confidence) Sea level rise Projection for Port Kembla, from AR6, Assuming SSP5-8.5

The Wollongong LGA starts at Little Garie Beach in the north and extends south to Windang Beach, to the north of the entrance to Lake Illawarra. The possibility that sea level rise will differ along the Wollongong Coast has been investigated. The projection for tide gauges at Fort Denison in Sydney Harbour and Port Kembla in Wollongong, and from a location offshore of Wollongong (gridded model results) were extracted from the NASA sea level change portal¹². Selected results are plotted in Figure A.5.

There is only a slight (~1cm) greater sea level rise projected at Sydney than at Port Kembla at the lowest probability level (95) in 2150. Sea level rise at Sydney is slightly higher than Port Kembla. It seems likely this is due to expected strengthening of the East Australia Current.

The minimal difference shows that it is reasonable to adopt the projection from Port Kembla for the entire Wollongong Coastline.

¹² <https://sealevel.nasa.gov/>

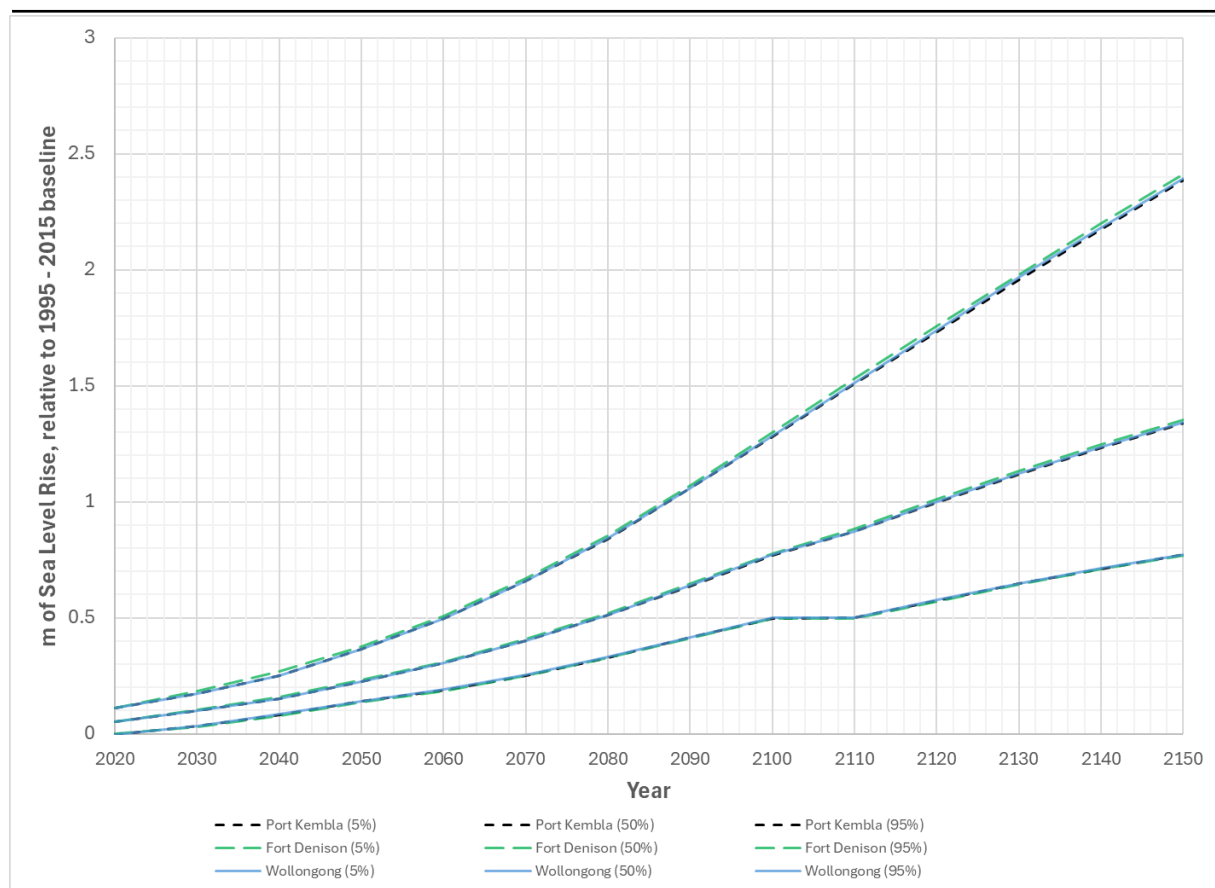


Figure A.5 SSP5-8.5 (Mid Confidence) Sea level rise Projection

We ultimately recommend the values presented in Table A.2 for Wollongong’s Sea level rise projection. These values have been modified from the tabulated values published by NASA by:

- Adding 0.04m, to adjust the values to Australian Height Datum (as discussed above)
- Linearly interpolating onto the years 2025, 2045, 2075 and 2125, representing the time frames of “Present day”, 20 years, 50 years, and 100 years, which are appropriate for delivery of Council’s CMP, as required under the CM Act.

Consistent with the results presented by NASA, values are presented for different probabilities of non-exceedance (5, 17, 50, 83 and 95%).

Table A.2 Recommended Sea level rise Projection for Wollongong Coastal Hazard Studies (m above AHD)

	Chance that Mean Sea Level Won't be Exceeded (assuming SSP5-8.5)				
Year	5%	17%	50%	83%	95%
2025	0.05	0.08	0.11	0.15	0.18
2045	0.15	0.18	0.23	0.29	0.35
2075	0.33	0.39	0.50	0.65	0.79
2125	0.65	0.78	1.1	1.54	1.89

A.5 Wollongong City Council's Resolution

On 20 March 2023, alongside endorsing the Scoping Study prepared for Wollongong's open Coast CMP, Council also resolved unanimously that:

"Council endorse AR6 SSP5-8.5 Sea level rise Projection Values, for use in modelling of coastal hazards in Stage 2 of the CMP process (modelling a sea level rise range for each time horizon)."

The values provided in Table A.2, represent an appropriate set of values for application in coastal hazard modelling, in accordance with the wishes of Council expressed at that meeting.

Appendix B Dune Vegetation

B.1 Introduction

Sand dunes are found on the landward side of sandy beaches and function as a barrier between open coastline and terrestrial areas. They are formed through the accumulation of sand, mostly transported by wind.

Beaches follow a cyclical process where storm waves erode the beach berm and parts of the dune, depositing the sand a short distance offshore (in the surf zone). After a storm, gentler waves carry sand back towards the dunes, reforming the beach berm. Once waves deposit sand onto the berm and it dries, wind carries it landward until the wind slows and the sand is deposited further landward on the berm and dunes (Doyle et al., 2024). This sand is loose and may be lost from the beach system if winds continue to pick up and carry it further landward. Along developed coastlines, that sand can accumulate in areas where it interferes with roads, car parks, footpaths, and other infrastructure.

Where dune vegetation is present, it acts to:

- Help slow the wind velocity, allowing sand grains to deposit on the dune.
- Shelter the deposited sand grains from the effects of wind, preventing them from being carried further.

The trapping of sand encourages vegetation growth which starts off with grasses and ground creepers. As you move away from the beach there is a gradient of soil development with old leaf matter and plant debris adding nutrients that help to develop soil and establish foredunes (Jones et al., 2008). These foredunes protect higher dunes behind them from salt spray and sand inundation leading to more established vegetation growth in the form of shrubs and trees. The foredunes also act as a sand reservoir which buffers against the effects of storm erosion (Sigren et al., 2014).

The sheltering effects of foredunes result in more mature and fertile soil profiles further landward, which are less erodible and better at retaining moisture, although there can be significant variability. As these factors change with landward distance, the soil profile can support different types of vegetation. If foredunes remain undisturbed, for example during a long period without large storms, the dune field and associated vegetation may expand seawards. In turn, areas further landwards become more protected and support a more complex ecosystem including larger trees (NSW Department of Land and Water Conservation, 2001).

B.2 Dune Formation and Vegetation

Development of dunes tends to happen in a natural sequence, with the different zones (incipient dune, foredunes, hind dunes) developing in succession. These zones are illustrated in Figure B.1. The most dynamic part of the system is the incipient dune.

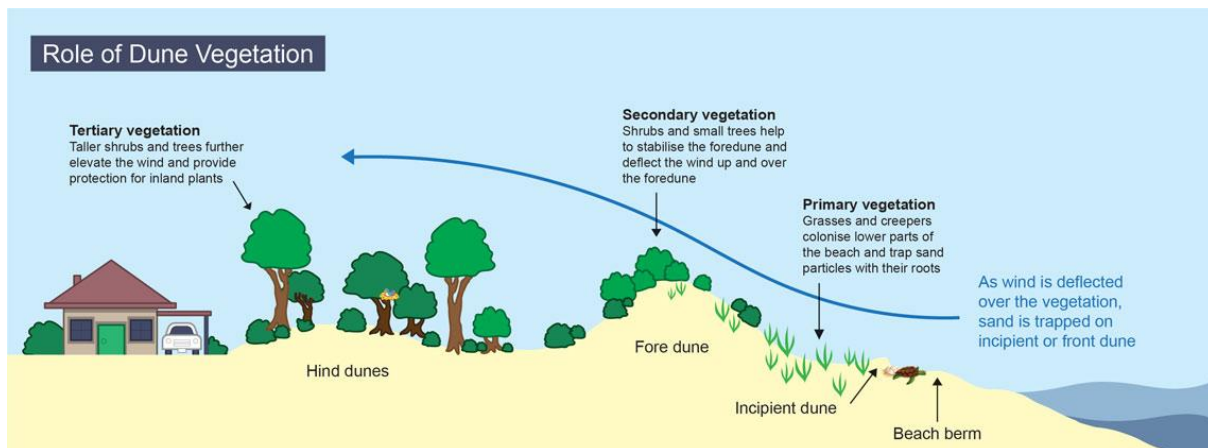


Figure B.1 Idealised Dune Development¹³

Depending on the local landscape and if landward urban development has occurred, it might not be possible for all zones to develop.

Incipient dunes are located on the seaward side of dune systems and form reasonably rapidly from windblown sand following an erosion event. Conversely, they can be eroded rapidly during storms, particularly when coinciding with high tides. If undisturbed, vegetation cover can form. In NSW, incipient dunes are often colonised by grasses and creepers such as Beach Fescue (*Poa billardierei*) and beach spinifex (*Spinifex sericeus*). Beach spinifex is a vital pioneer species using runners which spread rapidly across the surface of sand, putting roots down intermittently. This forms low ridge like formations and is the first stage in development of incipient dunes (Bird, 2008).

Foredunes are more permanent beach features that form gradually through the accretion of sand. Their shape, stability and resilience are controlled by wind energy, wave inundation, and the vegetation present. Grasses, creepers, and herbs like beach flax lily (*Dianella congesta*), coastal pigface (*Carpobrotus glaucescens*), fan flower (*Scaevola calandulacea*) and beach spinifex dominate the seaward edge, within the incipient dune. Vegetation transitions to shrubs and bushy vegetation in the foredune, dominated by species such as native juniper (*Myoporum insulare*), coast tea tree (*Leptospermum laevigatum*) and coastal wattle (*Acacia longifolia* subsp. *Sophorae*). Hind dunes are protected from wind and wave energy by the foredune vegetation, allowing woody

¹³ <https://www.moretonbay.qld.gov.au/Services/Environment/Waterways/Coastal-Vegetation>, accessed 29/07/2021

trees and coastal shrubs such as swamp she-oak (*Casuarina glauca*), coastal banksia (*Banksia integrifolia*) and Acacias to grow. On dunes where wind exposure is especially high, there is lower canopy height and reduced leaf growth (Hesp, 1991).

The type of vegetation on dunes affects the amount of sand that can be trapped and therefore the size to which the dune may grow. This ultimately determines how much sand remains in the dune system (Duran and Moore, 2013; Walker and Zinnert, 2022).

Roots and the underground biomass of dune vegetation help to develop a more mature soil profile, improving water retention and introducing nutrients¹⁴. The improved soil supports the growth of a more diverse plant community and ultimately supports the growth of larger shrubs and trees. As this happens, sands are stabilized and physically reinforced, becoming more resilient to wind erosion (Walker and Zinnert, 2022).

B.3 Dunes as Part of a Broader Beach System

The active beach, as shown in Figure B.2, extends landward to the extent of expected erosion from an extreme coastal storm, including the sand dunes, and seaward to where waves can no longer cause change to the seabed¹⁵. The entire active beach is expected to move upward and landwards with sea level rise (Aagaard and Sørensen, 2012). The beach includes nearshore bars, the surf zone, swash zone and dunes.

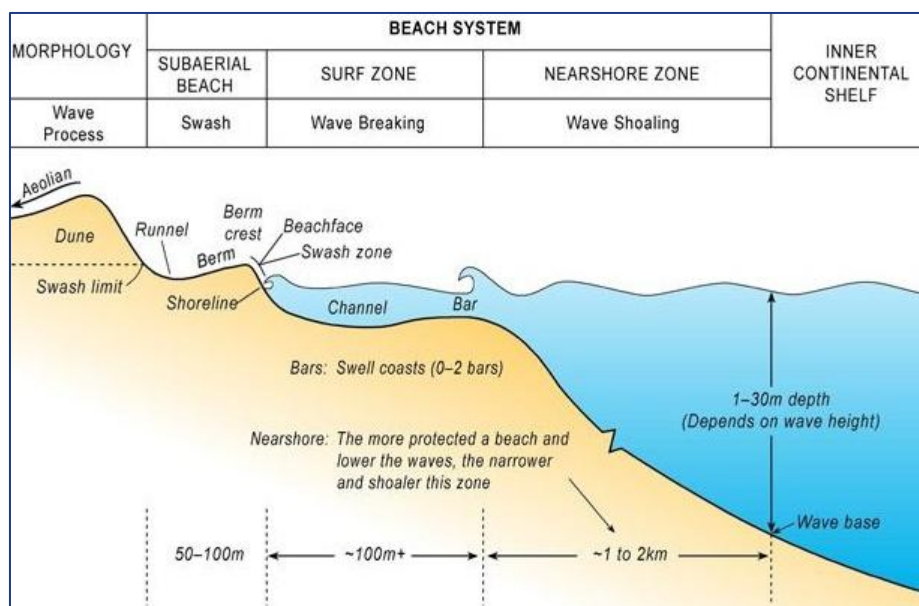


Figure B.2 Beach System Cross Section Note: Reprinted from Short and Woodroffe, 2009

¹⁴ [Geology of Indiana Dunes National Park | U.S. Geological Survey \(usgs.gov\)](https://www.usgs.gov/centers/ncm/indiana-dunes-national-park) (accessed 22.7.24)

¹⁵ As an example, the *Coastal Management Act 2016* defines a “beach fluctuation zone” extending from the landward erosion extent of a “1% storm event” offshore to a depth of around 40m.

Wave energy creates a constant state of change with natural cycles of beach building and beach erosion. As waves enter the coastal zone they are transformed as they interact with the seabed (at the “wave base”). Processes of refraction, shoaling, breaking, and runup modify the waves and generate currents across the surf zone and on the beach face. These interactions constantly change the beach shape, although there are three general zones which can be considered:

- The shoaling wave zone is where waves interact with the seabed, causing them to slow down and increase in steepness and height. This creates an underwater slope with a concave upward profile, with smooth outlines, small ripples and sediment typically directed towards the shore.
- The surf zone extends from where waves start breaking to the shoreline. This area is highly dynamic. Breaking waves here can be classified as spilling, plunging, or surging, depending on how steep the wave is compared to the slope of the bed. In the surf zone, currents transport sediment onshore, along the shore, and offshore, shaping sandbars and troughs.
- The swash zone is where waves collapse and run up the beach face. This swash action forms a steeply sloping beach face, typically ranging from 1 in 10 (~ 6°) to 1 in 30 (~2°). During non-storm conditions, the action of swash on the beach face tends to deposit sand, growing the near horizontal beach berm seaward.

Wright and Short’s (1984) characterization of beach types presents a spectrum of beach types governed by wave energy and beach shape, between “Reflective” beaches, which typically have a steep nearshore profile and low wave energy, and “Dissipative” beaches, which have a flat nearshore profile, broad surf zone and high energy waves. Wright and Short consider that most of the beaches in NSW are “intermediate” beaches which sit between these two types.

B.4 Sediment in the Broader Beach System and Dune Behaviour Before and After Storms

Understanding the connectivity between the lower shoreface and beach recovery is important following a major erosion event. As waves reach the beach, sediment is stirred up and deposited onto the beach face and beach berm. From there, it can be dried and transported landward by onshore winds.

Vegetation in the dune system helps to capture this sand, preventing it from being carried further landwards and keeping it in the beach system where it can function as a buffer against erosion during storm events. Beaches continually adjust to wave energy through transferring sand between the upper and lower parts of the overall

profile. The beach is continually changing as it tries to adjust to be balanced against the wave energy impacting the beach at any given time.

Large volumes of sand can be removed by storms, particularly if water levels are high. High waves combined with storm-surges that coincide with spring-high tides have a high likelihood of causing dune destruction and damage to infrastructure¹⁶.

Rip currents during storms can also cause substantial localised erosion, with sand removed from dunes carried offshore, sometimes well beyond the normal surf zone. Sand carried from the beach face, berm and dunes is commonly stored in nearshore bars. In this way, beaches exhibit self-limiting behaviour, where the nearshore bars formed from erosion of the beach reduce the amount of subsequent wave energy that makes it to the beach face. As a result, further erosion is reduced due to the significant reduction in wave height caused by waves breaking over multiple bars (Elgar et al., 2003).

After a storm passes, sand tends to move onshore to rebuild the beach. Wind then transports sand back into the dune system where incipient dunes reform and the cycle continues. This cycle of sand transport between dune systems and offshore bar formation is shown in Figure B.3.

The cycle is only able to function if a dynamic equilibrium exists whereby there is enough sand in the system for the pre storm beach profile to be reformed.

The removal of dune vegetation and sand from the beach threatens this equilibrium. There are notable locations along the NSW coast where this has occurred to build roads, houses, or beach access paths. In some locations, dunes have been rebuilt after sand mining, but the use of exotic species for recolonisation has upset the equilibrium. Vegetation clearing reduces the capacity of the beach to re-establish a natural sand reservoir where it is best placed to withstand the effects of subsequent erosion events.

When dune systems are unable to reestablish before another erosion event, more significant erosion and shoreline recession will occur. It is also more likely that infrastructure behind the beach will be threatened by water overtopping dunes, causing flooding and/or erosion which can undercut building foundations leaving them at risk of collapse.

Dune systems replenish slowly over the months following erosion events, and this process is more rapid if dune vegetation is present to trap wind-blown sand. Without dune vegetation, erosion events become more severe, and the lack of sediment restoration can lead to permanent beach loss.

¹⁶ [Introduction - Waves, Currents, and Storm Surges - An Overview of Coastal Land Loss: With Emphasis on the Southeastern United States](#) Accessed 1/7/24

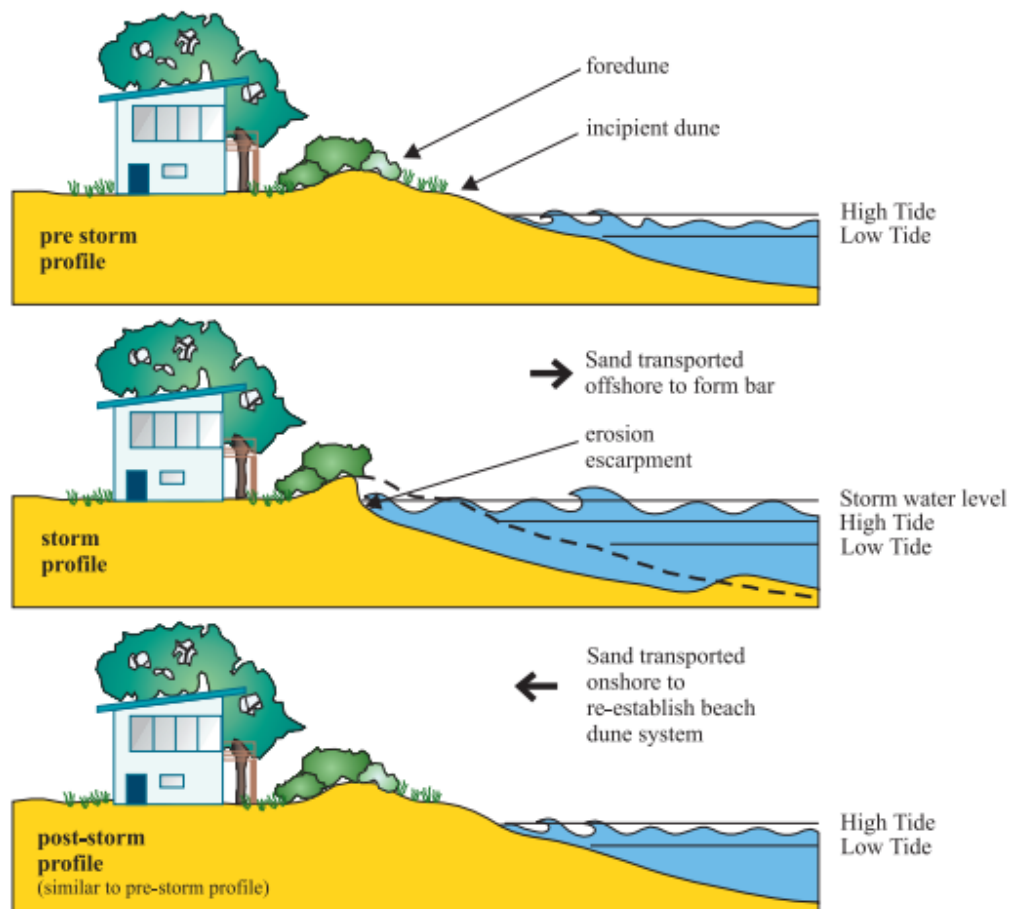


Figure B.3 Beach Erosion and Accretion Cycle. (adapted from NSW Department of Land and Water Conservation, 2001)

Beach recovery is also dependent on the potential transfer of sand between adjoining embayments, as illustrated in Figure B.4. Where sand is contained within a compartment and blocked from reaching adjoining beach systems by a prominent headland, sand volumes may remain stable. However, if sand can move to adjacent compartments there can be an overall loss or “leak” of sand. Headlands and infrastructure such as breakwaters can affect the recovery potential of a beach. As a result, beaches can be in ‘sediment deficit’, which can be due to either natural or anthropogenic factors.

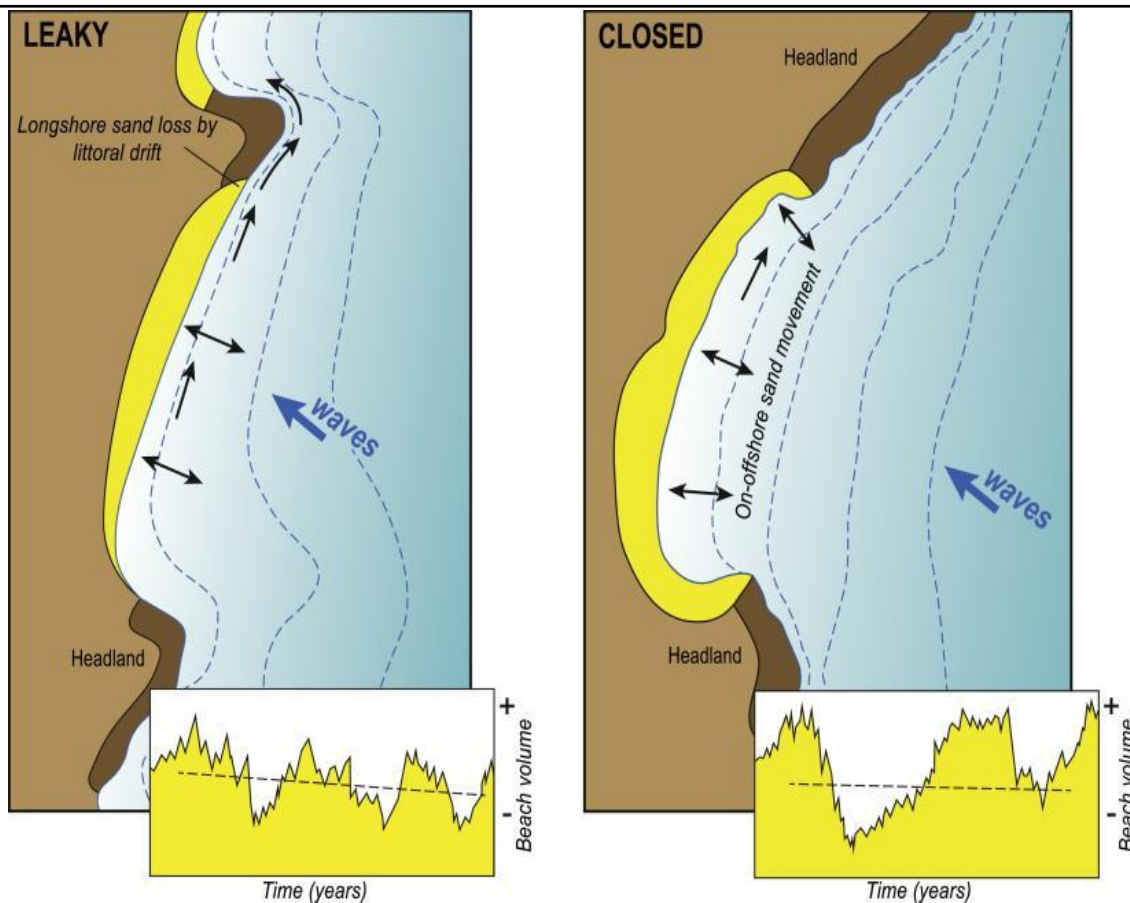


Figure B.4 Types of Sediment Compartment (from Thom et al., 2018)

Alongshore drift refers to the dominant movement of sediment along (parallel to) the shoreline. It is this mechanism which can transfer sand between compartments. In NSW, this process typically results in a net northward movement of sand, although the process is more important along the north coast of NSW, which is characterised by long connected beach compartments which are less embayed. This south to north movement of sand is caused by the dominant south to south east swell direction along the NSW Coastline (Carvalho and Woodroffe, 2015).

Where development has been allowed along the coast within the dune system, or even on top of foredunes, that infrastructure is often threatened by coastal erosion and there are “legacy” issues that need to be addressed. These areas are particularly vulnerable to impacts from coastal storms and can take longer to recover following storms. Areas such as Collaroy/Narrabeen, Wamberal, and Jimmys Beach are regularly threatened by large coastal storms, such as those caused by East Coast Lows.

When the beach system is lacking sand and foredunes are repeatedly lost, hard protective works such as seawalls may be constructed to protect coastal infrastructure or residences, functioning as a barrier. The issue with these types of ‘hard’ protective works is that they are often expensive for the protection they offer, particularly when considering long term performance with the coastline changing due to sea level rise.

As long as they remain structurally sound, these hard structures act to lock up any sand behind them completely, preventing its removal by erosion. The trapping of sand behind these structures, results in enhanced erosion at the ends (aka “end effects”). Seawalls and hard infrastructure are a way of protecting coastlines from severe erosion impacts however dune rehabilitation should be considered as a preferable solution wherever this is feasible. Vegetated dune systems provide a more flexible reservoir of sand, with vegetation tending to resist erosion for smaller storms, while releasing sand during more intense events. In this way, dune vegetation does not completely isolate parts of the existing reservoir of sand and is less prone to severe end effects.

Infrastructure and development built too close to the beach hinders the establishment of dune systems and is commonly at an enhanced risk of inundation and destruction during erosion events.

B.5 Historical Vegetation Along the Wollongong Coastline

In 1770 the first landing on Australian soil by British colonizers was attempted at Collins Point, just to the north of the more prominent Bellambi Point (Organ, 2016). As the crew sailed up and down the coastline looking for a suitable spot to land, they were close enough to observe the beach and landward area.

Lieutenant James Cook recorded the following *“In the woods were several trees of the Palm kind and no under wood and this was all we were able to observe of the country from the boat after which we returned to the Ship about 5 in the evening”*

Joseph Banks described the following *“The Countrey today again made in slopes to the sea covered with wood of a tolerable growth tho not so large as some we have seen...The trees were not very large and stood separate from each other without the least underwood; among them we could discern many cabbage trees but nothing else which we could call by any name.”*

and

“The country looked very pleasant and fertile; and the trees, quite free from underwood, appeared like plantations in a gentleman's park”

The area of Thirroul in Wollongong gets its name from the Aboriginal language of the Wodi Wodi people, with the word ‘Thurrual’ meaning ‘the Valley of the Cabbage Tree Palms’¹⁷. Early colonial interest arose from the red cedar forests, and in the 1800s rapid clearing began, with the bulk of available cedar removed by the 1840s (Hope, 2018). Cattle grazing was introduced in 1815 as the land was cleared and the dairy industry boomed in the 1840s (Hope, 2018). With much of the land being grazed for pasture, it is likely that cows were allowed up to and along beach vegetation, permanently

¹⁷ Thirroul – Northern Illawarra Chamber of Commerce (nicc.net.au) Accessed 8/10/2024

modifying the landscape, resulting in areas behind beaches and along creek lines being unvegetated moving towards the 1900s (Wollongong City Council, 2013).

Prominent early colonial artists Edward Charles Close, John Skinner Prout, and Captain Robert Marsh Westmacott recorded the landscape throughout the 1800s, providing rich visual depictions of vegetation, landforms, and the changing landscape. Vegetation present along the beach can be seen in Captain Robert Marsh Westmacott's lithograph of Bulli (reproduced in Figure B.5). Drawn between 1840 and 1846, it shows grasses and shrubbery along the length of the beach. The NSW Environment and Heritage site 'Trees Near Me'¹⁸ identifies the indigenous vegetation along the Wollongong coastline to be 'Spinifex Strandline Grassland' and 'Coastal Foredune Wattle Scrub'. While considered abundant along the coastline prior to clearing, these communities are now restricted to narrow corridors and nature reserves along the beach front. These communities are dominated by grasses and groundcover (*Spinifex sericeus*, *Carpobrotus glaucescens*) and taller growth like *Leptospermum laevigatum* and *Acacia longifolia*.



Figure B.5 Depiction of Bulli, Illawarra Region c. 1840-46, Captain Robert Marsh Westmacott

B.6 Aboriginal Cultural Significance

The dunes in the Wollongong area, and associated lagoon landscapes, have significant cultural importance. Dunes are often tied to Aboriginal heritage, commonly containing

¹⁸ <https://www.treesnearme.app/explore>

middens, artefact scatters, and ancestral remains, as they were important areas for habitation and resource use. While dune vegetation south of the Royal National Park has become highly fragmented, remaining patches of dune vegetation, particularly along watercourses and within dune systems, may still hold significant archaeological potential (Illawarra Local Aboriginal Land Council, 2024).

B.7 Ecological Communities

In New South Wales, beach dunes have suffered from the introduction of species such as European marram grass (*Ammophila arenaria*) and bitou bush (*Chrysanthemoides monilifera* subsp. *rotunda*). These species were introduced, in part, to rehabilitate dunes which were subject to sand mining, particularly following economic expansion within the Sydney Basin following World War II. Environmental concerns during the 1960s and 1970s however, have ultimately resulted in sand mining along the open coast being banned in NSW.

While these exotic species were introduced to stabilise dunes, they were found to permanently alter dune development and are now classed as invasive weeds. Over time they have spread into areas hundreds of kilometres from where they were initially (deliberately) planted ¹⁹.

Areas colonised by introduced species illustrate the effect that vegetation can have on dune development and shape. Dunes dominated by bitou bush, like those shown in Figure B.6 are described as ‘hummocky’ in appearance as sand builds up around the shrubs rather than more uniformly across the beach face (Doyle and Woodroffe, 2023). Foredune ridges which form around marram grass are higher and narrower than those which form around spinifex (Bird, 2008; Hayes and Kirkpatrick, 2012). These plants also tend to outcompete native vegetation and form a “monoculture” with reduced biodiversity and a simpler ecosystem.

¹⁹ <https://nre.tas.gov.au/Documents/MarramGrass.pdf> (accessed 22.7.24)

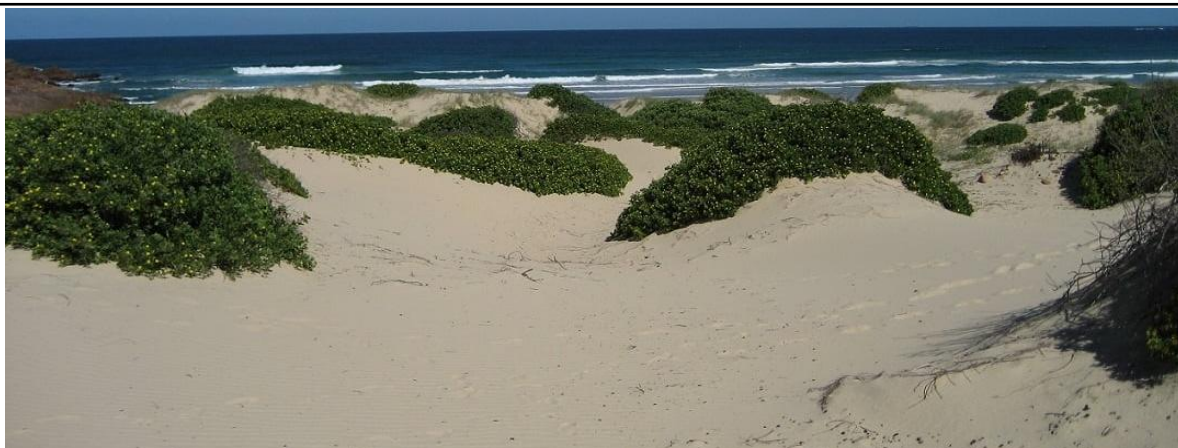


Figure B.6 Bitou Bush Dominated Sand Dunes²⁰.

The unique composition of flora communities in dune vegetation links with other coastal ecosystems such as wetlands, headlands and nearby islands providing wildlife corridors for species including the Eastern Pygmy Possum, Gang-gang and Glossy Black Cockatoo, and Large Bent-winged Bat. These species engage in foraging and nesting behaviours moving between sites. A number of threatened migratory shorebirds and waders have also been recorded within foredunes.

There is a need to protect, restore and maintain foredunes as they play a key role in supporting biodiversity in the Wollongong LGA. Healthy and functioning coastal dunes also support other ecosystem services, such as tourism, recreation, and economic values. Beach and dune systems in Wollongong are key drivers of local tourism and the local economy (Salients 2020).

Dunes also form part of the broader landscape, such as at Puckeys Estate, which includes threatened vegetation communities such as Swamp Oak Floodplain Forest, Swamp Sclerophyll Forest, Coastal Saltmarsh, and Bangalay Sand Forest. The connection between communities is important for local ecology and should continue to be supported. Puckeys Estate is subject to a Biobanking Agreement managed under the Biodiversity Conservation Act (Agreement ID 163) and is home to around 130 different species of birds.

B.8 History of Dunes and Sand Mining in Wollongong

Similar to other coastal cities around Australia, the 20th century saw significant changes for the Wollongong area and its coastline, with significant population growth and rapid urbanisation. A number of developments were placed in areas with beach views and vantage points (Reffell, 1980).

Small-scale sand mining occurred along Wollongong's coast prior to the 1940s. Sand extraction accelerated from 1935 when BHP acquired Australian Iron and Steel (Reffell,

²⁰ Sourced from <https://worimiconservationlands.com/weeds/>, 10 September 2024.

1980). Through both legal and illegal sand mining activities, beaches along the Wollongong coast provided an estimated three million tonnes of sand between 1948 and 1955, with a further two million tonnes in the 1960s (Carvalho et al., 2017a). The sand was extracted from the foredune and main dunes to be used as construction material. Sand mining focused on beaches in the southern section of Wollongong at Port Kembla (North Windang), Corrimal, Fairy Meadow, and Towradgi with the greatest volume of sand removal occurring at North Windang. Historical reports before the 1950s all indicate tall, high (8-20m) dunes at the North Windang (see Figure B.7) site prior to the intensification of mining in this area²¹.



Figure B.7 Port Kembla (North Windang) Sand Dunes, 1940 (Courtesy of Wollongong City Council)

Perhaps of more concern than commercial operations was the relatively unregulated extraction from smaller dune systems at Stanwell Park, where residents were able to legally obtain sand in small quantities. The smaller volume of sand originally present at Stanwell Park has meant sand removal has a proportionally larger impact. The site was home to a steep sand hill which remained intact until 1934, and within a decade was reduced to a third of its original height (Adams, 2005). The sand hill protected the landward vegetation behind it and supported a thriving lagoon ecosystem with tall semi-tropical flora, lilli pillies, ferns, and cabbage tree palms. After sand extraction

²¹ <https://shellharbourlocalhistory.blogspot.com/2015/10/sand-dunes.html> Accessed 10/8/2024

began, the lagoon was filled in and the increased wind exposure caused vegetation to diminish in the area (Adams, 2005).

There are reports of illegal sand mining from Towradgi, Woonona and Austinmer beaches (Reffell, 1980; Bryant, 1981). And the removal of sands from dune systems at Bulli and Corrimal Beach, over 1949-1953 left remaining sand unstable. Without rehabilitation works and mitigative measures to trap sand, the sand was blown landward (See Figure B.8), allowing it to drift across roads. The sand leases were reopened for a short while to continue removing sand and prevent the sand drifting. There are reports in 1951 of individuals ‘hacking away vegetation’ to encourage sand blow outs at Towradgi Point where illegal sand extraction was occurring (Reffell, 1980).



Figure B.8 Windblown Sand Landward of Bulli Beach, South of Bulli SLSC, August 1986 (Courtesy of Wollongong City Council)

Initial sand removed from North Windang in the early 1950s was used to raise the level of reclaimed land on the western foreshore of Tom Thumb Lagoon, to enable construction of the steel mills. To manage illegal extraction at North Windang, sand leases were granted in 1967 with 20 leases given for a period of 10 years, including one year for rehabilitation. Although bonds were taken, it appears that environmental rehabilitation was not completed.

B.9 Dune Vegetation Management along Wollongong’s Coastline

A major turning point in realising how depleted the sand dune systems were a series of intense storms that battered the coast in the early 70s. These made the physical loss of sand apparent. In 1974 three storms occurred within a 23 day period in May and

June, coinciding with spring tides causing wave heights in exceedance of 9m (Bryant, 1988, p. 19; E. A. Bryant and Kidd, 1975; Lord and Kulmar, 2001). The depleted dune systems and sand reserves resulted in prominent, steep erosion escarpments, threatening infrastructure, and property; Figure B.9 highlights how close the City Beach SLSC was to being undermined after a 1964 storm which left a steep erosion escarpment.



Figure B.9 City Beach SLSC after 1964 Storm (Courtesy of Wollongong City Council)

Gradually, the shift in public attitudes towards the environment overcame the demand for commercial profit, and sand mining within dunes in New South Wales is now subject to strict environmental controls.

Aerial imagery is available along the Wollongong coastline from 1938 to the present day. The earliest images show vegetation at its most landward position in 1938, as a result of land clearing that occurred in the early 1900s. The vegetation line has tended to move steadily seaward to its current position, with the exception of the 1960s and 70s where it receded inland (Talbert, 2012). This resulted from a series of intense storms affecting the coast and causing recurring erosion over this period, with eroded dunes not having a chance to fully recover.

A jump in seaward progression of the vegetation line can be seen in the 1986 aerial photography as a result of large-scale dune shaping and revegetation works that occurred in the late 1970s and 1980s. Revegetation works were carried out at 10

beaches across the Wollongong local government area, with the goal of trapping windblown sand, preventing sand drift onto residential areas, and protecting community assets such as Surf Life Saving Clubs from erosion. Works were funded by Council and the NSW Public Works Department and undertaken by the NSW Soil Conservation Service. Foredunes were reshaped and revegetated with grasses such as *Spinifex sericeus* and *Ammophila arenaria* (Marram Grass), whilst landward dune revegetation focused on shrubs and trees like *Acacia longifolia* subsp. *sophorae*, *Lomandra longifolia*, *Westringia fruticosa*, *Banksia integrifolia*, and *Leptospermum laevigatum* to increase stabilisation (Wollongong City Council, 2013). 25 years later, the vegetation had extended seaward over twice the area originally planted in 1986 (Beardsmore et al., 2014; Talbert, 2012).

The replanting of vegetation during the late 1970s and 1980s successfully achieved the intended management goals of stabilising the dunes. However, the reduced beach width and higher dunes and vegetation led to community concerns about the impact on recreational beach usage, beach amenity and line of sight for lifeguard and surf lifesaver patrols. Beach width data were collected on beaches in the south and middle section of the Wollongong LGA during the 2010s to guide Council management strategies. Cross-sections were taken at beaches (Bellambi, Bulli, Corrimal, Fairy-Meadow, Woonona, Towradgi, and Wollongong) and dune volume, beach volume and beach width were assessed. It was also noted that dune scarps formed after erosion events, impacting on council lifeguards and SLSC abilities to deploy gear and presenting a safety concern for the community.

In 2014, dune reprofiling was recommended at a range of high use patrolled beaches as a way to address beach amenity, degradation of sight lines for lifeguards and lifesavers, and access issues raised by the community, while considering biodiversity values and the role of dunes in coastal processes (Wollongong City Council, 2014). Design documents and environmental assessments were prepared for each beach, specifying the volume of sand removal and new beach profile needed to optimise beach amenity, restore sightlines and access, and revegetation needed to keep dunes stable. An example of such works was at Woonona Beach, where 15-30m strip of dune vegetation along a 250m stretch of beach was removed to match the 1986 vegetation line, and the foredune was reprofiled by up to a metre in height, regaining metres of sandy beach width (Gangaiya et al., 2017).

This increased beach width at Woonona remained steady for 8 months before decreasing gradually over the study period (21 months). An effort was made to reestablish lower growing vegetation in the incipient dune and keep shrubs and taller vegetation contained within the fence lines, as to not impact SLSC sight lines which led to the reprofiled areas being more susceptible to erosion during storm events (Gangaiya et al., 2017). Additionally the *Spinifex sericeus* that colonised the incipient

foredune was found to accumulate more sand after 21 months then was initially removed (Gangaiya et al., 2017). The Wollongong Beach and Dune Topographic Surveys Summary Report (Wollongong City Council, 2021) observed the different species composition in Woonona's dunes, with photo imagery since 2014 showing the removal of taller vegetation in the incipient dune and subsequent replanting of *Spinifex* which eventually moved seaward past the fence lines.

This was also observed at Corrimal Beach where similar beach reshaping works were undertaken in response to community concern over loss of sandy beach area. The same report detailed the re-profiling works undertaken between 2014 and 2019, examining how the beaches responded up to and including 2021, and accounting for any significant storm events. This report re-affirms that beaches on the Wollongong coastline from Port Kembla northwards to Woonona respond to coastal processes similarly. Observations across beaches noted a trend of stability in the southern and mid sections of beaches and the greatest variability seen in the northern ends of beaches. Recovery following erosion events is fastest in this northern section. Dune volume has not returned to levels seen prior to the 2016 East Coast Low event, with the exception of transects at Woonona Beach which underwent profiling in 2014 and have reestablished with a higher volume of sand. The initial periods after re-profiling works show volumes increasing at faster rates, likely meeting an equilibrium, and becoming steadier, adjusting to external environmental influence.

Council also developed beach dune vegetation site plans for beaches including, but not limited to, Bellambi, Woonona, Corrimal, and Towradgi Beach. The plans included:

- Vegetation maps for the site, showing the percentage of native vegetation present at the time.
- Management actions and priorities. Planned works were prioritised and marked off as they were completed with updated revisions of the site plans published.
- General planting guidelines.
- Plant species lists for dune planting, split into categories of the dune e.g. incipient dunes, fore-dune and crest, hind-dune, and creek mouth.

Each vegetation map was accompanied by a set of management objectives (e.g. sight lines, recreational amenity, beach access). Within the beach dune vegetation site plans, subspecies of *Acacia longifolia* were identified as creating sight line issues for SLSC and Council lifeguard patrol towers at Towradgi, Fairy Meadow, Corrimal, Bellambi, Woonona and Bulli Beaches, with a recommendation to trim all subspecies of *Acacia longifolia* to less than 1m or remove them completely. Recommendations to plant using

low growing species were mentioned several times through the vegetation site plans. There is reference to introducing 'species other than *Lomandra longifolia*, *Westringia*, *Correa*, *Rhagodia* and *Tetragonia*' to increase biodiversity.

The planting of seedlings and low growing shrubs is undertaken to attempt to stabilise exposed dunes and increase diversity of species, including after reprofiling projects. Vegetation vandalism has occurred in some of the dune systems, including removal of newly planted *spinifex* and native grass spp., uprooting of other seedlings, and illegal poisoning or cutting back of mature trees (Wollongong City Council, 2018). Tree and vegetation vandalism is managed under Council's Public Tree Management Policy 2023 and Compliance and Enforcement Policy 2022. Council has response procedures in place to address tree vandalism proactively and reactively, including a range of methods to prevent, minimise and discourage vandalism to public trees.

B.10 Conclusion

Dune systems play a vital role in coastline protection, acting as a buffer between harsh wind and wave energy. During erosion events and times of heavy storm activity the vegetation growth ensures sand that would otherwise be swept back into the ocean is retained on the beach, with any sand lost during these erosion events cycling through the process of beach recovery before being deposited on the beach face and in the dunes again. This cycle relies on an equilibrium which has been disrupted in many beach systems by sand and vegetation removal causing permanent losses of sand to the system. Dune vegetation provides vital ecological habitat for a number of local flora and fauna with the addition of migratory species (the Pied Oystercatcher), which with increasing coastal development is now providing wildlife corridors because of the complex habitat dune vegetation can support.

Key objectives regarding dunes from the *Coastal Management Act 2016* (CM Act) outline the need to maintain the presence of dunes, while considering how the beach system operates in a given location. This means understanding where waves approach from and how headlands can cause them to reflect and change direction causing them to hit certain parts of the beach with different energy levels. In the Wollongong area southerly swells cause sand to move north, often causing increased sand deposits at the northern end of beaches (Carvalho and Woodroffe, 2015). Additionally, the CM Act encourages land use that reduces exposure to risks from coastal hazards while maintaining dunes. The intention is to provide space for dune systems to function as a natural buffer against storm surges and wave energy. While Wollongong Council undertook dune management works between 2014 and 2019 at some patrolled beaches to address issues regarding lifesaving site lines, beach amenity, and access, restoration or enhancement of coastal dunes and vegetation should be prioritised to provide that buffer against coastal hazards.