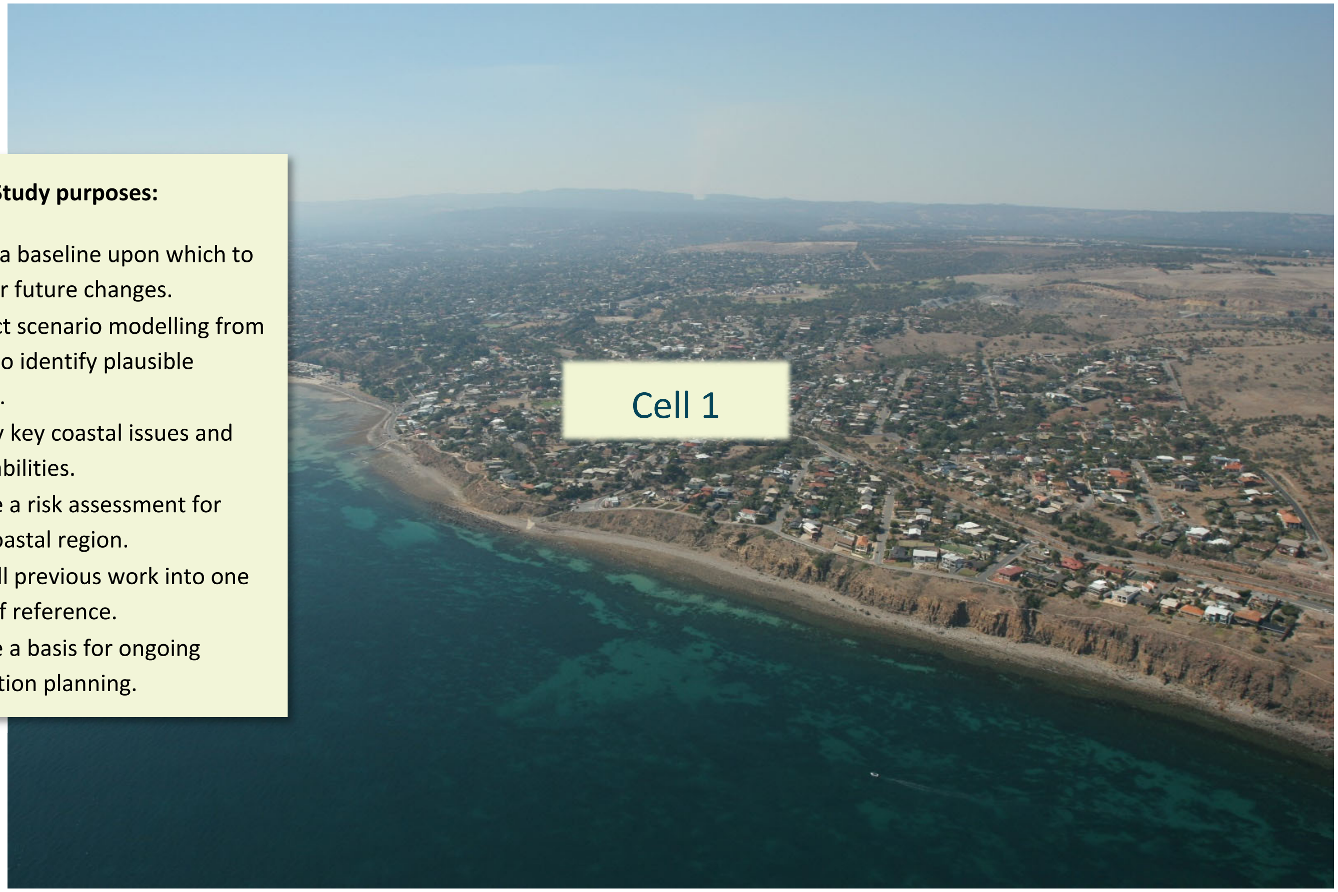
Coastal Adaptation Study

MARINO CLIFFS

Study purposes:

- Create a baseline upon which to monitor future changes.
- Conduct scenario modelling from which to identify plausible futures.
- Identify key coastal issues and vulnerabilities.
- Provide a risk assessment for each coastal region.
- Bring all previous work into one place of reference.
- Provide a basis for ongoing adaptation planning.



By Integrated Coasts

Review date 1 December 2022

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Mark Western, Project Leader, Integrated Coasts (2018, 2022).

Joram Downes, Integrated Coasts, (2022).

Dr Graziela Miot da Silva, geology assessment (2018).

Professor Robert Bourman, geology and inherent risk assessment (2018).

Report reference:

Western, M. et al, 2022, Coastal Adaptation Study, Marino Cliffs, for City of Marion, Adelaide, South Australia.

Front cover:

South Australian Coast Protection Board, oblique photograph, 2014.

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1. Introduction

This coastal cell report is a review of the *Coastal Adaptation Study for City of Marion, 2018*. These cell reports are now structured within a template so that future reviews can also build upon this report. The final section, *Summary and Recommendations*, is designed as a standalone section that can be used in other reporting contexts and acts in a similar way to an Executive Summary.

PROJECT SCOPE

Climate Variables

Managing projected climate change impacts involves dealing with 'deep uncertainty'[1]. This uncertainty is primarily related to the nature of long-term projections which are based on climate models. These models are computer-based simulations of the Earth-ocean-atmosphere system. Models are effective at simulating temperature, but their accuracy is much less for the simulation of rainfall[2]. Overall rainfall is expected to decline in our region over the coming century and the intensity of rainfall events is expected to increase, but these projections are not assigned with as much confidence as for temperature or sea level rise. Furthermore, the climate is a complex system and the variables interdependent. For example, on the one hand we might predict that declining rainfall would produce a more arid climate and therefore less vegetation but a recent study by NASA has found that over the last 35 years the planet has been greening, and that increased carbon dioxide in the atmosphere is 70% responsible[3]. As we learn more about the climate system and obtain more data over time, observable trends and projections will also become more certain.

Direct and indirect impacts

Some climate change impacts are more direct than others. Rising sea levels will directly impact the landforms adjacent the coast, either through increasing inundation of lower lying areas, or increasing erosion. Other impacts will be less direct. For example, projections for a drier climate are often associated with less vegetation in dunes, and the increased cracking of cliffs[5]. Increased intensity of rainfall events may increase the erosion and gullying of cliff-tops thereby increasing the potential for increased rates of recession and instability. The impact of rising sea levels can be assessed through sea flood modelling within digital models. The impact of vegetation loss cannot be easily quantified and as noted above, is based upon less certain projections. Attempting to incorporate too many impacts into a coastal study is likely to compound the level of uncertainty and deliver less clear outcomes.

Direct and indirect risks

Direct risks relate to the impact of rising sea level on the fabric of the coast. Different areas of coast will be vulnerable to different risks. Low lying areas will be more likely to be vulnerable to inundation and soft sediment backshores more vulnerable to erosion. In this study we evaluate the direct impact of *inundation* and *erosion* in four main receiving environments:

- Public assets
- Private assets
- Safety of people
- Ecosystem disruption.

Associated with these direct risks are a range of indirect risks. For example, the potential loss of a beach from erosion is a potential social and economic risk (if the beach is related to an activity such as tourism). A political risk may occur when the decision makers act in ways the communities do not support.

Project focus

To increase certainty, this project evaluates the *direct impacts* of inundation and erosion in the context of *rising sea levels*. In a bid to contain focus, this study assesses the *direct risks* to assets, people and ecosystems that are positioned within coastal regions.

[1] https://coastadapt.com.au/pathways-approach
[2] https://coastadapt.com.au/how-to-pages/how-to-understand-climate-change-scenarios
[3] https://www.nasa.gov/feature/goddard/2016/carbon-dioxide-fertilization-greening-earth
[5] Resilient South (2014) Regional Climate Change Adaptation Plan, URPS and Seed Consulting, p.22 (and technical report p.3)

1. Introduction

ASSESSMENT FRAMEWORK

Coastal hazards experienced along a section of a coastline can be assessed in three main ways.

Coastal fabric (geology)

Intuitively we understand that if we are standing on an elevated coastline of granite that the coast is not easily erodible. Conversely, we understand if we are standing on a low sandy dune that erosion may indeed be a factor. It is the geology of the coast upon which our settlements are situated that determines one side of the hazard assessment in terms of elevation (height above sea level), and the nature of the fabric of the coast (how resistant it is to erosion). Coastal geology is assessed in four main ways:

(1) Low erodibility
(2) Moderate erodibility
(3) High erodibility
(4) Very high erodibility

Coastal modifiers (human intervention)

In some locations there are additional factors that modify this core relationship between fabric and exposure. For example, an extensive rock revetment has been installed from Brighton to Glenelg which has modified the fabric of the coast from dunes to rock.

Coastal exposure (actions of the sea)

If we find ourselves on the shore of a protected bay, or in the upper reaches of a gulf, we intuitively know that the impact from the ocean is likely to be limited. On the other hand, if we are standing on a beach on the Southern Ocean and listening to the roar of the waves, we understand that we are far more exposed. Coastal exposure is assessed in four main ways:

(1) Very sheltered
(2) Moderately sheltered
(3) Moderately exposed
(4) Very exposed

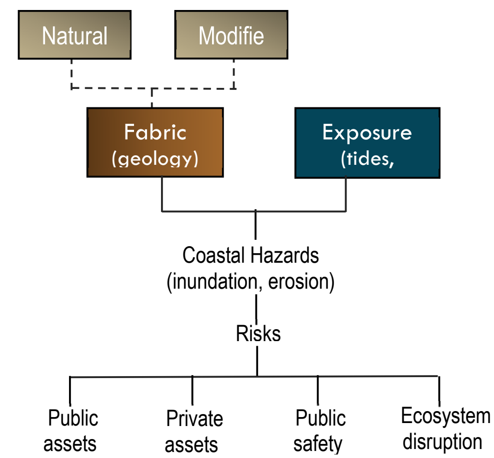
CHANGES IN THE RELATIONSHIP

Finally, we are also interested to know how this relationship between ***fabric*** and ***exposure*** may change over time, and what this may mean in the context of our coastal settlements.

Our sea levels have been quite stable for several thousand years after a ~1m drop in sea level ~6000-4000 years ago. However, in recent times, the rate of sea level rise has increased. Last century, sea levels rose on average ~1.7mm per year. Since 1990, seas are rising on average at ~3-4mm per year in our region[6][7]. The consensus is that the rate of sea level rise will escalate towards the end of this century.

While the projected rate of sea level remains uncertain, what is certain is that if seas rise as projected, then the relationship between fabric and exposure will change significantly in coastal locations.

Figure a: Conceptual framework



The aim of this project is to evaluate the relationship between the ***fabric*** of the coastline and its current ***exposure*** to actions of the sea and how this relationship may change with rising sea levels. We conduct this evaluation within the regional setting of secondary coastal cell **Adelaide Coast** (CoastAdapt) and within tertiary cell, **Marino Cliffs Cell 1.**

6 Watson, P., 2020, Updated mean sea level analysis: Australia. Outer Harbor 2.5mm (1945 – 2018), satellite 3.5mm since 1990.

7 See also sealevel.info and calculate rises from 1945 to 1990 (2.09mm) and compare with 1990 to 2022 (3.6mm).

1. Introduction

Regional Setting

Cell 1
Secondary Cell: Adelaide Coast
Tertiary Cell: Marino Cliffs
Secondary Cell

Australian regional setting
Marino Cliffs is situated within the Adelaide Coast secondary cell.

Geomorphology of the cell:
The northern section of this compartment comprises ~30km of Holocene sandy coast.

South of Adelaide, the coast is dominated by a series of arcuate north-easterly trending faults, uplifted zones associated with prominent cliffs and headlands, with sandy embayments occupying fault angle depressions.

There is minimal sediment supply, with small creeks and rivers. Littoral drift is to the north and sand supply is expected to decline causing recession to embayed beaches.

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The dominant regional processes influencing coastal geomorphology in this region are the Mediterranean to humid cool-temperate climate, micro-tides, high energy south-westerly swells, westerly seas, carbonate sediments with interrupted swell driven longshore transport, and the Southern Annular Mode (driving dominant south-westerly swells and storms). Much of the Adelaide coast is protected from south-westerly swell waves because of the sheltering effect of Kangaroo Island. The tidal range increases from microtidal to mesotidal towards the head of Gulf St Vincent. **Source: https://coastadapt.com.au/sites/default/files/docs/sediment_compartments/SA02.01.04.pdf**

1. Introduction

Regional Setting

Cell 1
Secondary Cell: Adelaide Coast
Tertiary Cell: Marino Cliffs
Tertiary Cell

Relative Exposure
Moderate

Wave energy
Low

Shoreline class
Rocky Platform

Substrate
Exposed bedrock with both cobble and coarse sand present.

Source: Nature Maps (SA)

Notes:
Minor cells represent in blue are areas where geomorphologic factors are different from neighbouring areas and require independent analysis.

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2. SETTLEMENT HISTORY

A historical review ensures that the circumstances in which the settlement was founded are understood, identifies how actions of the sea have interacted with the settlement, and builds appropriately on previous study. In this section we:

- Give a brief history of the settlement
- Review archives at Coastal Management Branch
- Identify key coastal studies
- Identify implementation of key coastal structures

2. Settlement history

The first purpose of this section is to identify the key factors of settlement history in the context of the coastal environment. In particular, we identify human interventions, ocean impacts, and past protection and management strategies. The second purpose is to identify key studies and plans so that we bring all previous work into one place of reference.

BRIEF HISTORY

Prior to European settlement, most of the Adelaide Plains was inhabited by the Kaurna tribe.

Early industry

Early in the history of European settlement of South Australia, limestone, sand, quartzite and gypsum were quarried in the Marino area. The South Australian Company quarried building and paving stone. A pier was built at Marino Rocks beach in 1840 to transport this stone to building sites in Port Adelaide and Adelaide. The ridges of the pier, extending out to a marker buoy, are still visible today, at low tide[8].

In 1882, a limestone quarry supported the first cement manufactured in South Australia by Brighton Hydraulic Cement Works, competing with Portland cement, which was imported in great quantities[9].

Residential settlement and expansion.

Marino was subdivided for residential occupation in 1912[10]. The research conducted into the cliff collapse at Hallett Cove (Cell 2) in 1996 concluded that the initial subdivision was likely to have been completed in England with an esplanade road designed impractically over deep gullies[11].

A preliminary search of Coast Protection Board archives revealed no significant residential expansions in the Marino area and development along the foreshore has remained predominantly large homes on larger allotments (~600m2 and greater).

<u>Development Applications: 100/1791/97 and subdivision 100/0049/98 (1 into 5 allotments)</u>

Coast Protection Board provided comments for the abovementioned Development Applications for the Marino Rocks Café and residence, the1 into 5 subdivision approved in 1998, and general comments about the carpark. In summary CPB noted:

- The coastline adjacent to the proposal may be at risk by coastal storm flooding and erosion and recommends against approval unless an adequate flood erosion strategy is in place.
- The coastline at this location has been subject to slow coastal erosion and the proposed development is less than 50m from the top of the cliff edge which was considered 'sufficient'. [Project note: only minor shoreline recession since 1949, see historical aerial photographs].
- Marine Parade and the parking is much closer to the cliff top and is likely to be at threat from coastal erosion within the next 100 years. Protection options might need to be considered.
- A condition of approval was that 'Council accepts responsibility for future protection of Marine Parade and the carpark if it becomes necessary' and SA Coast Protection Board accepts no 'responsibility for any loss of life and property'.

<u>Development Application 100/2253/01</u>

This was a proposal for a 2 into 3 land division (Allotments 243, 244 in DP 2194) at the southern end of Marine Parade. The Council was advised to seek a geotechnical report to satisfy themselves of the stability of the cliff and its suitability for future development. Council was also advised to consider storm water design so that its impact was limited on the 'cliff line'. [Project note: it is unknown if Council obtained a geotechnical report.]

8 Presumably, this pier was built on The Esplanade, Marino.

9 https://en.wikipedia.org/wiki/Marino,_South_Australia

10 Dolling, A (1981) Marion on Sturt

11 Fotheringham, D (1996) Communication to Minister for Environment regarding potential collapse of cliff at The Esplanade.

2. Settlement history

COASTAL STRUCTURES

A pier was once located at Marino Rocks beach (presumably on The Esplanade), was demolished by 1935. The 1949 aerial photograph indicates the location of a dredged channel, and this may have been the location of the pier. Note also, the early shacks in the 1949 aerial photograph (Figure a).

In the 1960s (or prior) a boat ramp was installed in a similar location (Figure b). This boat ramp was likely to be superseded by the boat ramp constructed at the end of Jervios Terrace.

Informal rock protection appears to have been installed by 1979 likely using local rocks, and by ~2000 rock had been imported to construct the rock sea wall of the current era. A rock and concrete protection structure was constructed in front of a former building on the southern end of the carpark (Figure c).

The coastal walking trail was installed along Marino foreshore in the late 1990s which also coincided with the construction of the pedestrian ramp at the end of Jervios Terrace, approved in 1999 (100/1999/1972). Parts of the walking trail were closed in 2019 and repairs undertaken before reopening in 2020.

In ~2000, the carpark north of The Esplanade was removed and the 'Contemplation' sculptures installed in 2006 with connecting pathway.

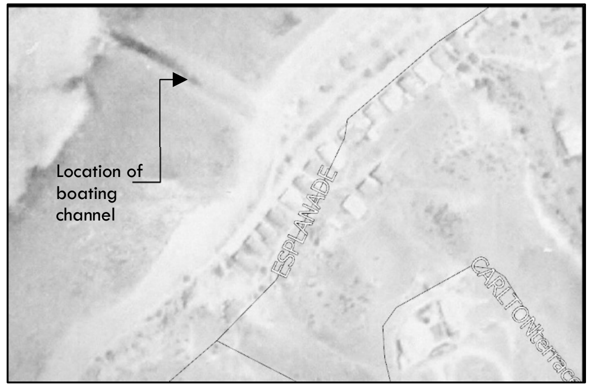

Figure a. Location of boating channel and shack site at The Esplanade, Marino (Aerial photograph, 1949).

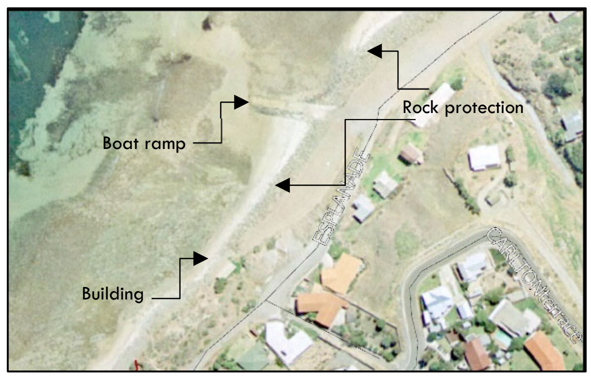

Figure b. A small boat ramp installed 1960s (or prior), later superseded by the boat ramp at Jervois Terrace, Marino. Rocks were informally placed along the foreshore, later consolidated into its current form ~2000.

Figure c. Rock and concrete sloping seawall protected former building in this location (see aerial photograph, 1979).

Figure d. View to Marino Rocks from Kingston Park, 1935. Note rock flats visible at low tide. South Australian State Library, PRG 1435-3-9.

2. Settlement history

COASTAL STUDIES AND PLANS

The purpose of this section is to bring all previous work into one place of reference for the Hallett Cove Cliffs (South) (Cell 4). No studies or plans were identified that focussed solely on Cell 4 and therefore the following are 'council wide' studies. It is also recognised that the production of studies and plans is always ongoing, and future studies and plans can be located from the City of Marion website.

Coastal Management Strategy Plan, 1997.

This report prepared by Kinhill Engineers provides insight into issues under consideration at the time, including storm water run-off over cliffs, dune erosion, cliff stability issues. One of the main issues under consideration was the forming of the coastal walkway. The report also provides a full inventory of coastal features including storm water outlets, and coastal protection measures. The study stated,

> 'the coastal management strategy for Marion seeks to promote improvements in the management of the coastal strip by developing a coastal management plan which identifies appropriate uses and adjoining buffer areas, access paths, traffic management, car parking, the location of visitor facilities and tourist opportunities'.

In particular, and of relevance to this study the report recommends to:

- Develop opportunities for stormwater management improvements,
- Augment existing initiatives to protect sand dune areas where necessary to ensure the retention of dunes,
- Develop a revegetation programme for the coastal areas[12].

Resilient South, 2014.

The Southern Adelaide region (Holdfast Bay, Mitcham, Marion and Onkaparinga Councils) cooperated together to produce the Resilient South Climate Change Adaptation Plan (2014).

In relation to coastal adaptation, the plan explains the general impacts of rising sea levels, changes to rainfall patterns, and increased erosion, but does not specifically review the coastal environs of City of Marion. The plan did identify some general options for coastal adaptation but did not identify any preferred coastal adaptation options for City of Marion.

Resilient South now has a website where all studies and projects can be accessed. Resilient South.

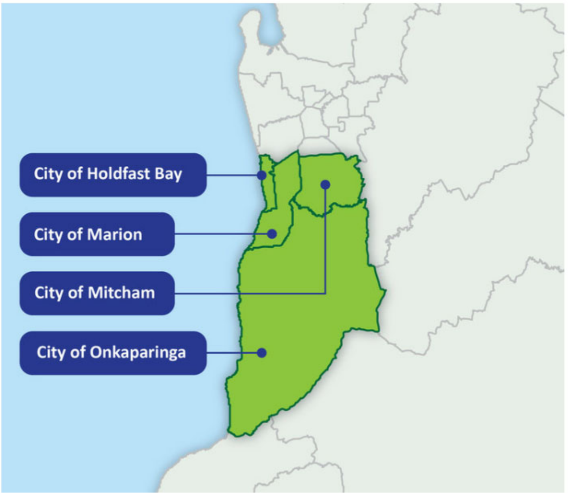

Figure a. Resilient South, and ongoing partnership between City of Holdfast Bay, City of Marion, City of Mitcham and City of Onkaparinga.

Climate Change Adaptation Governance Assessment Report for the City of Marion 2019.

This study prepared by Climate Planning and Seed Consulting Services in 2019 assessed how well City of Marion is incorporating climate change adaptation governance into their corporate processes and frameworks.

[12] Kinhill Engineers (1997) Draft Coastal Management Strategy Plan

2. Settlement history

The Project Team conducted a governance assessment of the City of Marion to explore how climate change was considered in their corporate documents. The City of Marion was assessed against ten quantitative governance indicators, with Figure a displaying Council's performance.

The report concluded that City of Marion has considerable inclusion of climate change in its formal governance documents. This meant that not only could staff identify key physical climate risks to the functions of Council, they could also identify clear corporate strategic drivers for decision making. There was also consistent understanding of climate change risks from an officer to senior executive level.

The fact that climate change has been considered in all of the ten key governance indicators sees it placed as the leader in Australia (compared to the 200 councils who have been assessed).

Figure a. Results of governance assessment for the City of Marion, 2019.

STRATEGIC PLANS AND POLICIES

City of Marion develops and updates strategic plans and policies on a regular basis and these can be located on the City of Marion website:

Climate Change Policy (2021-2025)

City of Marion Climate Change Policy was adopted on 11 May 2021 and will be reviewed by 11th May 2025. The primary objectives of the policy are:

- To incorporate climate change mitigation and adaptation into strategic and operational activity…,
- To support residents, businesses, and local ecosystems to build resilience and adapt to the impacts of a changing climate.
- To work in collaboration with regional partners and the wider community.

Other strategic plans and policies

- Community Vision: Towards 2040 (adopted 26 July 2016)
- Strategic Plan 2019 – 2029 (endorsed August 2019)
- Business Plan 2019 – 2023 (June 2019)
- Environmental Policy (November 2019)
- Carbon Neutral Plan, 2020 – 2030.

[Project note: a full list of plans and updates is available from City of Marion website.]

Settlement History
Key Points

Marino was subdivided for residential occupation in 1912. The subdivision plan was likely completed in England with an esplanade road designed over deep gullies (with only portions eventually constructed). There have been no significant residential expansions in the Marino area and development along the foreshore has remained predominantly large homes on larger allotments (~600m2 and greater).

Coast Protection Board gave advice in relation to two development applications:

- A warning in relation to carpark at Marino Rocks in context of future sea level rise.
- A recommendation to obtain a geotechnical report regarding cliff stability and to adequately control storm water.

Coastal structures in Cell 1 are limited to:

- Rock revetment to Esplanade and seaward of 'Contemplation' display (installed progressively from 1970s to ~2000.
- Boat ramp, end of Jervios St installed ~1960s.
- Coastal walking trail and on ramp at Jervios Street installed in late 1990s.

All studies and plans can be located on the City of Marion website, apart from Coastal Management Strategy Plan, 1997.

3. GEOMORPHOLOGY

The study of coastal geomorphology analyses how the coast was formed and how the coast has changed over time. The study provides the 'bigger picture' for understanding how sea level rise may interrelate with the coastline in the future.

For a fuller explanation of the coastal geomorphology of the region see Hallett Cove Coastal Management Study by D. Lord completed for City of Marion, 2012.

3. Geomorphological context

GEOLOGICAL SETTING

Structure of the coastline[13]

The basic structure of the Adelaide Metropolitan coast is influenced by a series of prominent arcuate (curved) faults. In particular, the Eden-Burnside Fault, the Clarendon-Ochre Cove Fault and the Willunga Fault have produced major escarpments, which intersect the coastline and run out to sea, where the faults are best exposed. Uplift and back tilting of the fault blocks has produced associated fault angle depressions occupied by the Adelaide Plains Sub-Basin, the Noarlunga Embayment and the Willunga Embayment (Figure a), which have been infilled with sediments over the past 40 million years. More recently in the Holocene period, the sandy beaches and dunes were formed on the low-lying embayments. The City of Marion coastline is entirely positioned within the elevated Eden-Burnside Fault which separates the Noarlunga embayment to the south and the long stretch of low-lying Metropolitan beaches to the north.

Resistant Neoproterozoic rocks extend from the Marino Rocks boat ramp to Hallett Cove Conservation Park (Cell 1,2). Cliff exposures of siltstone, shales and sandstones from this period get progressively younger from north to south. Despite these sedimentary rocks now being metamorphosed into harder rocks, sedimentary layers are still distinguishable and form distinct shore platforms. There is very little sand, and any beaches are mainly shingles (smaller rocks).

Hallett Cove Beach (Cell 3) is an internationally important site geologically because features of the Permian glaciation are preserved here, and numerous large boulders (glacial erratics) occur on the beach. The host sediments to the boulders, deposited during the Permian glaciation, have been more recently exposed by coastal erosion. The only river in this section of coast is the Field River at the southern end of Hallett Cove.

From Hallett Cove to Port Stanvac (Cell 4), resistant folded Neoproterozoic strata form cliffs up to 20 m high, with the adjacent serrated shore platforms revealing complex folds of the Delamerian Orogeny period (>500 million years).

Sea levels have cycled between 2m above present sea level during the Last Interglacial Maximum (the last time the earth was free of ice, 132-118ka) to 125m below present sea level during the Last Glacial Maximum (the maximum ice extent, 21 ka). These major cyclic fluctuations in sea level meant that the present area of Gulf St Vincent was periodically exposed as dry land, and some higher sea level events such as the Last Interglacial experienced even larger areas of sea coverage. Furthermore, the climate at that time was warmer and wetter than today, with the Leeuwin Current bringing warmer ocean surface waters from Indonesia and the north-eastern Indian Ocean.

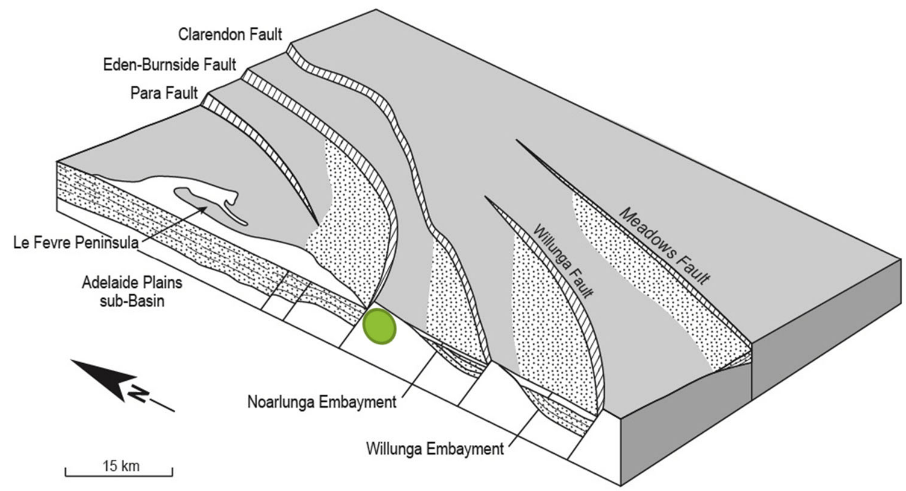

Figure a: The geological setting of the coastline between Sellicks Beach and the metropolitan area. The prominent fault scarps consist of uplifted ancient rocks, resistant to erosion, while the embayments are occupied by younger and more easily eroded rocks and sediments. The City of Marion coastline is positioned within the Eden-Burnside Fault.

[13] Bourman et al, 2016, Coastal Landscapes of SA, University of Adelaide Press.

3. Geomorphological context

GEOLOGICAL SETTING

In simple terms, the geomorphology of coasts is assessed in three main parallel zones: the subtidal, intertidal and backshore. The intertidal zone consists of the area between low and high-water marks. The backshore is typically characterised as up to 500m inland of the intertidal zone[10].

The Marion Coastline has been divided into coastal cells based upon geological layout (Figure a). The Marion coastline is predominantly a combination of *sloping hard-rock shores* and *sloping soft-rock shores*. Sections of *undifferentiated rock shores* refer to locations which are not easily classified as hard or soft rock and can generally be assigned an erosion classification between the two. The Field River area is assigned as 'river mouth'. Hallett Cove Beach is assigned 'sloping soft-rock shores'. The elevated geology of the Marion Council coastline means that the coastline is not subject to inundation. The exceptions are The Esplanade, Marino, and the Field River area, but these are also backed by steeply sloping backshores. The extensive areas of cliff categorised as *sloping hard rock shores and undifferentiated rock shores* suggest that the City of Marion coastline is not subject to rapid erosion. Areas categorised as *sloping soft rock shores* such as Hallett Cove Beach are more likely to be vulnerable to erosion. This assessment is supported by analysis by CoastAdapt which assigns almost the entire coast as *dominantly hard rock shores* with a low erodibility outlook[14].

Dr Miot da Silva and Dr Robert Bourman assess the cliff vulnerability in this region as 'low to moderate' erodibility composed by sedimentary to meta-sedimentary rocks ranging from Pleistocene to Neoproterozoic ages. These rocks are not the very 'low erodibility' type of rock associated with basement rocks such as igneous basalts and granites, nor high erodibility of the unconsolidated sediments of the recent Holocene period, and therefore fall between the two classifications. As such, these rocks are not readily erodible, but the presence of rock platforms indicate that cliffs have eroded and retreated in the past over long time periods.

[10] http://www.ozcoasts.gov.au/coastal/introduction.jsp
[14] https://coastadapt.com.au/coastadapt-interactive-map

3. Geomorphological context

SEDIMENT BALANCE - SAND SUPPLY FOR THE COAST

Gulf St Vincent

Sand deposits along the coast were likely deposited by the wind in the last ice age when seas were up to 120m lower than present. As the ice melted and sea levels rose, these sediments formed the current layout of the beaches. Since sea levels stabilised over the last 7000 years the coast has slowly been losing sand which is unable to be replaced. This lack of sand supply to Gulf St Vincent is compounded because littoral drift (sand movement) is to the north and the Adelaide coastline only has small creeks and rivers that deliver minimal sediment to the coast. Therefore, sand supply is expected to decline causing recession to embayed beaches[15].

Hallett Cove and Marino beaches

The Hallett Cove Coastal Management Study (HCCMS) has thoroughly evaluated the coastal processes in Gulf St Vincent as they impact upon the Marion coastline and should be relied upon in the final coastal adaptation plan[16].

The HCCMS summarises the sediment environment in Hallett Cove Beach region:

> The foreshores of Hallett Cove present as a slowly receding coastline, starved of sediment. The available coastal process modelling indicates the potential for sand transport out of the Hallett Beach compartment (100,000m^3 / year) is an order of magnitude greater than the natural rate of sand supply along the coastline from the south (5000m^3/ year)[17]….
>
> While the community perception that the sand cover has reduced over the past 30 years may be true, the likelihood is that over historical times the volume of sand on the beach has always been small and variable, providing a thin sand veneer from time to time over sections of the exposed shingle [and that] additional sand cover is unlikely to be a practically achievable outcome.

Geomorphology

Key Points

1. The coastal lands of City of Marion are set in the vicinity of the Burnside-Eden fault (area of uplifted land) and therefore generally elevated well-above risk of inundation from current and future storm activity. The exceptions are The Esplanade at Marino and the area around Field River. However, in both these locations the backshores slope upward.

2. The coastline consists predominantly of hard-rock sloping shores (Coast Adapt) and Bourman et al (2016) characterise the cliffs areas as 'resistant'. Exceptions to this resistant characterisation exist with Hallett Cove Beach and Field River area (Cell 3) which are backed by softer sediments. Pockets of less resistant rocks also exist at Marino (The Esplanade and Marino Rocks carpark).

3. The City of Marion coastline is much older than the Onkaparinga coastline to the south and the Metropolitan beaches to the north (both which were formed in the Holocene Period, 11.7ka) when seas rose to their current level.

4. Generally, the City of Marion coastline has always consisted of rock platforms and pebble beaches. In relation to Hallett Cove Beach, it is likely that sand levels were higher in the past, but sand cover has always been limited to a thin veneer over a rocky beach.

5. Within Gulf St Vincent sand levels are expected to decline due to the inability of the coastal environment to replace sediments that were deposited at the last interglacial period. The movement of sand is northward, and Gulf St Vincent contains only small rivers and creeks that deliver minimal sediment to the coast.

[15] Bourman et al, Coastal Landscapes of SA, p. 66.
[16] D. Lord., Coastal Management Study, Hallett Cove, SA. 2012, pp 17-26.
[17] HCCMS suggests that this calculation is based on modelling at O'Sullivan Beach boat ramp.

4. COASTAL FABRIC

In this section we evaluate coastal fabric in more detail:

- Overview of the current coastal fabric
- Changes to shoreline over seventy years
- Human intervention (coastal modifiers)

Viewing instruction:

View the coastal fabric section utilising full screen mode within your PDF software (Control L). Then use arrow keys to navigate.

4.1 Coastal fabric - overview

Introduction

It is the geology of the coast upon which our settlements are situated that determines one side of the hazard assessment in terms of elevation (height above sea level), and the nature of the fabric of the coasts (how resistant it is to erosion). In some locations, humans have intervened and changed the nature of the coastal fabric. For example, a construction of a seawall changes the fabric from sand to rock. The construction of an esplanade road too close to the coast can install rigidity in the backshore, which formerly could naturally adapt to erosion and accretion cycles. Some interventions change the way in which the beach operates, and new erosion problems are created.

Why evaluate shoreline change?

Beaches undergo normal cycles of accretion and erosion which may span time measured in decades. These changes can be observed in two main ways. The position of the shoreline changes, and the levels of sand change on the beach. In times of erosion, the shoreline tends to recede, and sand levels become lower. In times of accretion, the opposite is true. If sea level rises as projected, then shorelines are likely to go into longer term recession. The purpose of evaluating the historical changes to the shoreline is to formulate a baseline understanding of how the coast has been operating in the past. In the context of rising sea levels, identifying future shoreline recession trends will assist us to identify when the beach begins to operate outside its normal historical range.

What is the shoreline?

The shoreline is the position of the land-water interface at one instant in time. But in reality, the shoreline position changes continually through time because of the dynamic nature of water levels at the coastal boundary. The best indicator of shoreline position is the location of the vegetation line. In other circumstances the shoreline may be the base of a cliff, an earthen bank at the toe of a slope, or a seawall in locations where humans have intervened.

How will we analyse the shoreline?

The analysis includes:

- Comparisons of aerial photography from 1949 to current day. This requires very fine-grained georeferencing of photography to ensure that comparisons are accurate.
- Comparison of surveyed profile lines which have been conducted by SA Coast Protection Board since the 1970s (if within the cell).
- Evaluation as to how humans may have intervened in the coastal fabric and how this intervention may have changed the natural operation of the coast.

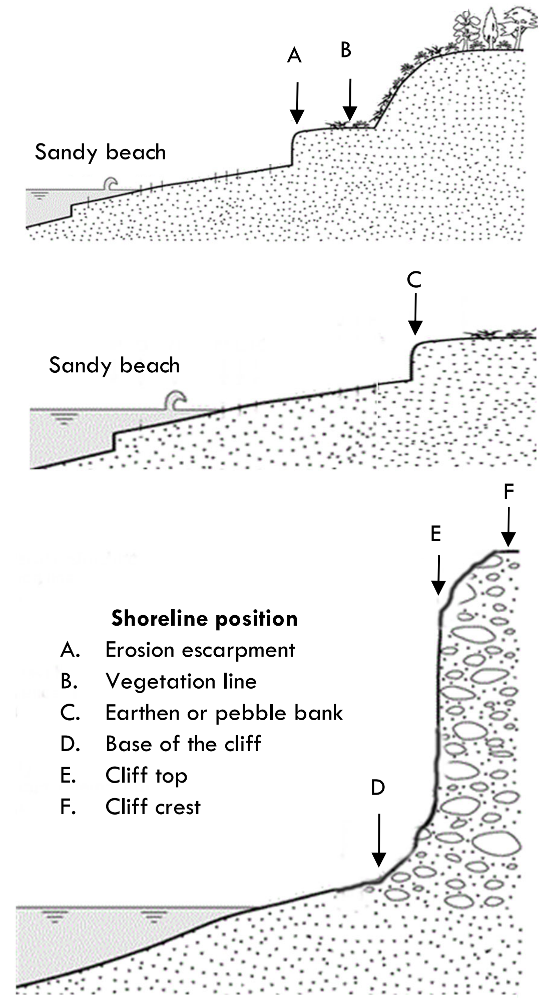

Figure a. Adapted from Boak and Turner (2005), Shoreline definition and detection.

4-1 Coastal fabric - overview

Overview

Cell 1

Secondary Cell: Adelaide Coast
Tertiary Cell: Marino Cliffs

Form

Beach
Rocky platform with areas of high tide cobbles below the cliffs.

Backshores
5 – 20m high cliffs which are likely resistant

Bathymetry
Overall slope of ocean floor:
-5m ~250 to 1450m from beach (overall slope ratio ~1:240).

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4-1 Coastal fabric - overview

Overview

Cell 1

Secondary Cell: Adelaide Coast

Tertiary Cell: Marino Cliffs

Geology

Backshore 1.1: The northern section of Marino Cliffs is composed of 'friable Pleistocene clay' which is more susceptible to erosion. The southern section of Marino Cliffs is more resistant Neo-Proterozoic siltstone.

Backshore 1.2-3: This section is composed of the Neo-Proterozoic Marino Arkose formation. The arkose is a resistant material however it is covered by undifferentiated material. Cliff morphology suggests that subaerial erosion (e.g., caused by water flowing down cliff) is more significant here than wave-driven erosion at this time.

Backshore 1.4-5: Heterogeneous cliff with sandstone and siltstone members of the Wilmington Formation overlying the Marino Arkose. All relatively resistant rock types. Well-developed stone ridge will offer protection from tidal and storm surge impacts (but sea level rise will increase impact).

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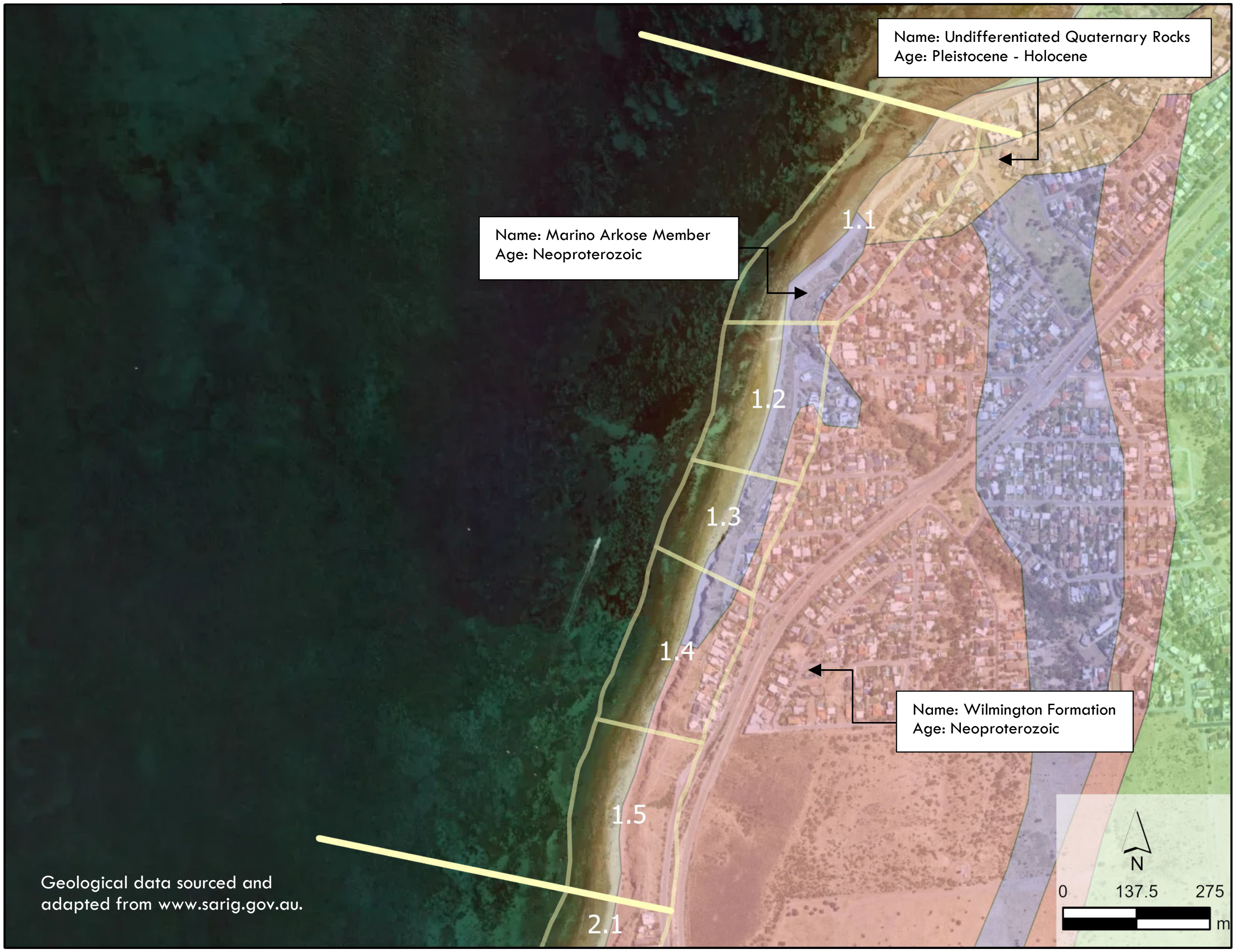

4-1 Coastal fabric - overview

Overview

Cell 1

Secondary Cell: Adelaide Coast
Tertiary Cell: Marino Cliffs

Benthic

Benthic

The nearshore zone is dominated by seagrass meadow with some low-profile reef in the intertidal zone and a discrete covering 1km from shore.

Benthic data sourced from Nature Maps (SA).

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4-2 Coastal fabric – geology (Cell 1.1)

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Notes

In the north, the cliff is composed of alluvial clay (Pleistocene Ochre Cove and Ngaltinga Formations) which terminate at about 200m south of the Esplanade into more resistant Neo-Proterozoic siltstone (Wilmington Formation). The most vulnerable part of this section is where the cliff is composed of alluvial clay, which is evidenced by active slopes and gullying. Subaerial erosion is operating here.

Map

Marino Cliffs 1:1

Geological assessment

Dr Graziela Miot da Silva (2019)

4-2 Coastal fabric – geology (Cell 1.2)

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Notes

This section is composed of the Neo-Proterozoic Marino Arkose formation, which is a resistant material but is covered by undifferentiated material. Cliff morphology suggests that subaerial erosion is currently more significant than wave-driven erosion. There is undercutting (scars) at cliff top and slumping material, nonetheless, vegetated suggesting the movement is not recent. Rocky beach reduces ocean impacts, but sea level rise of 1m will cause major recession of toe.

Map

Marino Cliffs 1:2

Geological assessment

Dr Graziela Miot da Silva (2019)

4-2 Coastal fabric – geology (Cell 1.3)

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This section is composed of the Neo-Proterozoic Marino Arkose formation, which is a resistant, lime-cemented sandstone rich in feldspar. Some slump material but cliff face mostly exposed. The narrower intertidal rock platform also indicates less cliff recession over the last 7000 yrs in comparison to northerly sections. Hence more wave impact. Sea-level rise of 1m will impact cliff toe with potential for significantly increased rate of erosion (noting it is resistant rock here).

Map

Marino Cliffs 1:3

Geological assessment

Dr Graziela Miot da Silva (2019)

4-2 Coastal fabric – geology (Cell 1.4)

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Heterogeneous cliff with sandstone and siltstone members of the Wilmington Formation overlying the Marino Arkose (relatively resistant rock types). The gully where the staircase is located is an area of concern. Rock falls at some places. Well-developed storm ridge will offer protection, however narrow rock platform will decrease potential for wave energy dissipation. Sea-level rise will increasingly undermine the base of the cliff (but rock types are 'resistant').

Map

Marino Cliffs 1:4

Geological assessment

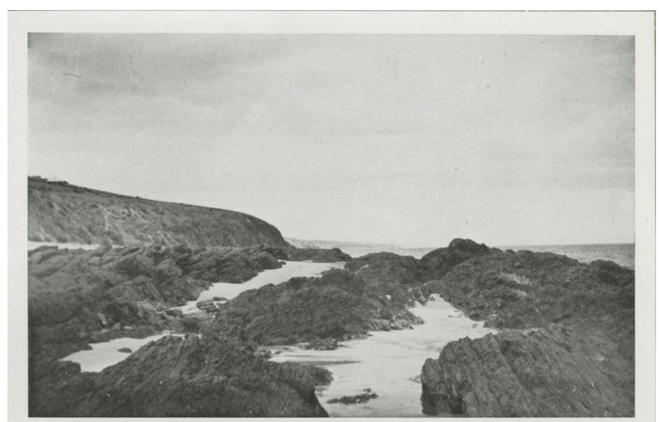
Dr Graziela Miot da Silva (2019)

4-3 Coastal fabric – shoreline changes (Cell 4)

Why compare historical photographs?

Comparing photographs taken from the ground rather than the air provides an alternative perspective on changes to coasts over time. Furthermore, aerial photographs are only available from 1949. The assessment is more qualitative, but we can evaluate:

- Changes to beach levels,
- Changes to backshores (behind the beach),
- Rates of erosion of rocks,
- History of human intervention such as protection items or other coastal infrastructure.



MARINO ROCKS

Historical comparisons 1883-2022

Figure a. People at Marino Rocks, 1883, State Library of SA, PRG742.5.193.

Figure b. Same location as Figure a., M. Western, 30 June 2022 (at low tide 0.9m, Outer Harbor).

Figure c. Marino Rocks, 1940, State Library of SA, B43434.2.

Early photographs likely taken in summer at low tide which can be as low as 0.2m, Outer Harbor. Sand levels appear higher, sea level rise since 1883 ~300mm.

4-3 Coastal fabric – location map (Cell 1.1)

Medium Term Changes

Cell 1.1

Marino Cliffs
Historical comparison

Location Map

Location:
The Esplanade, Marino

Aerial photograph from 2017 provides the basis for comparison of coastal change over the last 70 years. Comparisons are made with aerial photography from:

- 1949
- 1976
- 1989
- 2002
- 2007
- 2012
- 2017

In this location the shoreline position is the base of the cliff. Note, it is not always possible to determine the position of the base of the cliff.

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4-3 Coastal fabric – shoreline changes (Cell 1.1)

Medium Term Changes

Cell 1.1

Marino Cliffs

Historical comparison

Shoreline

Location:
The Esplanade, Marino
Year 1949

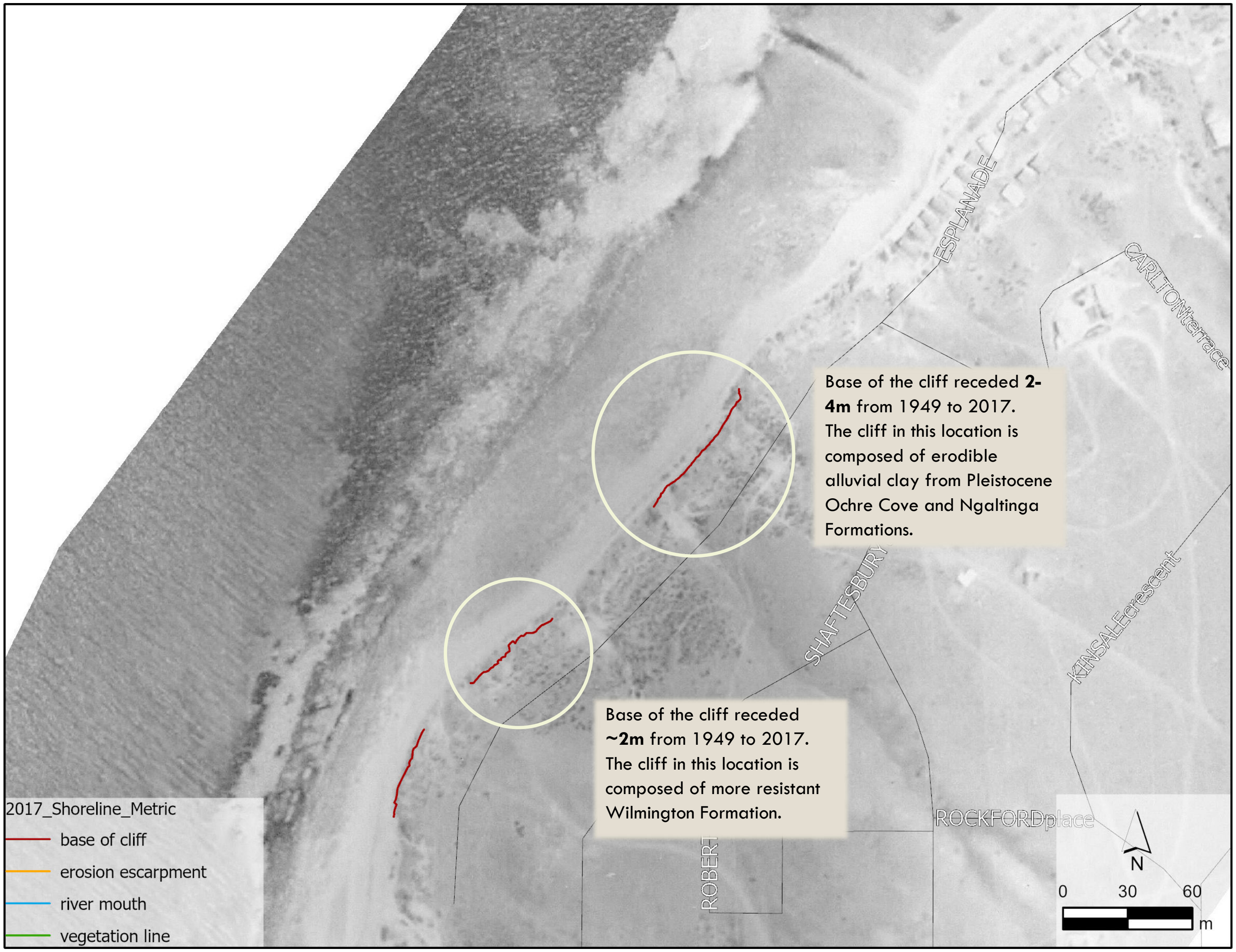
Shoreline recession:

Shoreline in this location is the toe of the cliff slope. Recession has been 2-4m 1949 to 2017.

Vegetation cover:

Sparse vegetation.

Project note: Assessment is limited by clarity of photograph, shadows, accurate positioning, and geometric distortion due to different flight paths and camera angles in the context of vertical faces.



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4-3 Coastal fabric – shoreline changes (Cell 1.1)

Medium Term Changes

Cell 1.1

Marino Cliffs

Historical comparison

Shoreline

Location:
The Esplanade, Marino
Year 1979

Shoreline recession:

Shoreline in this location is the toe of the cliff slope. Recession has been 1-2m 1979 to 2017.

Cliff top recession:
Nil

Rock falls/slumps:
Nil

Vegetation:
Increasing cover.

Project note: Assessment is limited by clarity of photograph, shadows, accurate positioning, and geometric distortion due to different flight paths and camera angles in the context of vertical faces.

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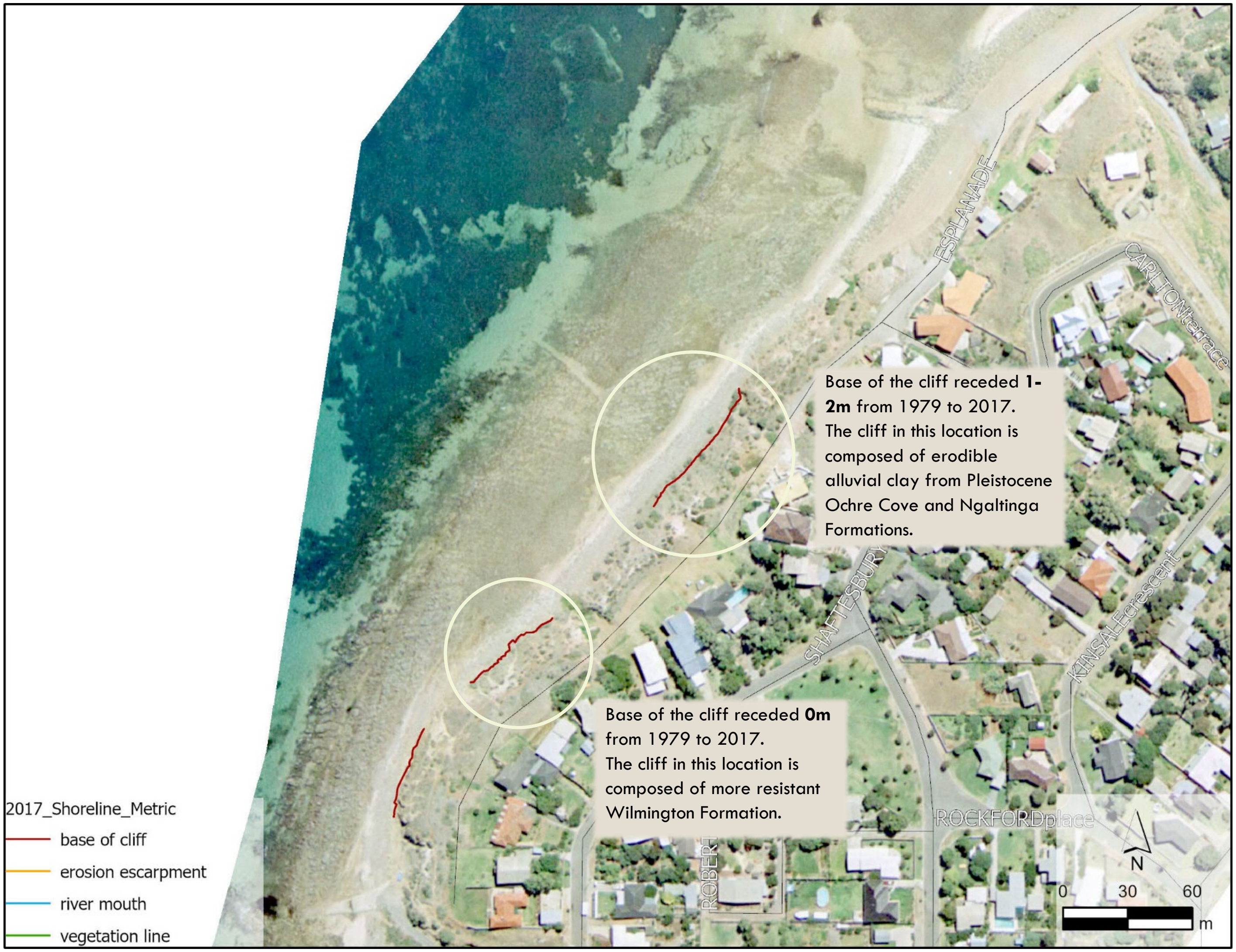

4-3 Coastal fabric – shoreline changes (Cell 1.1)

Medium Term Changes

Cell 1.1

Marino Cliffs
Historical comparison

Shoreline

Location:
The Esplanade, Marino
Year 1989

Shoreline recession:

Shoreline in this location is the toe of the cliff slope. The shoreline is in a similar position as 2017.

Cliff top recession:
Nil

Rock falls/slumps:
Nil

Vegetation
Similar cover to 1979

Project note: Assessment is limited by clarity of photograph, shadows, accurate positioning, and geometric distortion due to different flight paths and camera angles in the context of vertical faces.

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4-3 Coastal fabric – shoreline changes (Cell 1.1)

Medium Term Changes

Cell 1.1

Marino Cliffs

Historical comparison

Shoreline

Location:
The Esplanade, Marino
Year 2002

Shoreline recession:

Shoreline in this location is the toe of the cliff slope. The shoreline is in a similar position as 2017.

Cliff top recession:
Nil

Rock falls/slumps:
Nil

Vegetation:
Increasing cover

Project note: Assessment is limited by clarity of photograph, shadows, accurate positioning, and geometric distortion due to different flight paths and camera angles in the context of vertical faces.

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4-3 Coastal fabric – shoreline changes (Cell 1.1)

Medium Term Changes

Cell 1.1

Marino Cliffs

Historical comparison

Shoreline

Location:
The Esplanade, Marino
Year 2007

Shoreline recession:

Shoreline in this location is the toe of the cliff slope. The shoreline is in a similar position as 2017.

Cliff top recession:
Nil

Rock falls/slumps:
Nil

Vegetation:

Increasing cover.

Project note: Assessment is limited by clarity of photograph, shadows, accurate positioning, and geometric distortion due to different flight paths and camera angles in the context of vertical faces.

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4-3 Coastal fabric – shoreline changes (Cell 1.1)

Medium Term Changes

Cell 1.1

Marino Cliffs

Historical comparison

Shoreline

Location:
The Esplanade, Marino
Year 2012

Shoreline recession:

Shoreline in this location is the toe of the cliff slope. The shoreline is in a similar position as 2017.

Cliff top recession:
Nil

Rock falls/slumps:
Nil

Vegetation:

Increasing cover

Project note: Assessment is limited by clarity of photograph, shadows, accurate positioning, and geometric distortion due to different flight paths and camera angles in the context of vertical faces.

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4-3 Coastal fabric – summary (Cell 1.1)

Medium Term Changes

Cell 1.1

Marino Cliffs

Historical comparison

Shoreline

Location:
The Esplanade, Marino
Year 2017

70 years
The shoreline (bass of the cliff) has receded ~2-4m since 1949 in the northern section (see map).

40 years
The shoreline (bass of the cliff) receded ~1-2m and has been stable since 1979. Vegetation cover has increased since 1979.

10 years
Recession over last decade is nil.

Summary

Mostly stable section of cliff, with some recession in places, most significant in the northern section.

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4-3 Coastal fabric – location map (Cell 1.2)

Medium Term Changes

Cell 1.2

Marino Cliffs

Historical comparison

Location Map

Location:
Jervios Tce to Emma St

Aerial Photograph from 2017 provides the basis for comparison of coastal change over the last 70 years. Comparisons are made with aerial photography from:

- 1949
- 1976
- 1989
- 2002
- 2007
- 2012
- 2017

In this location the shoreline position is the base of the cliff. Note, the base of the cliff cannot be determined in all locations.

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4-3 Coastal fabric – shoreline changes (Cell 1.2)

Medium Term Changes

Cell 1.2

Marino Cliffs

Historical comparison

Shoreline

Location:
Jervios Tce to Emma St
Year 1949

Shoreline recession:
Unclear, but likely 2m overall recession in north.

Cliff top recession:
Can't be observed.

Rock falls and slumps:
Nil

Vegetation
Very sparse

Project note: Assessment is limited by clarity of photograph, shadows, accurate positioning, and geometric distortion due to different flight paths and camera angles in the context of vertical faces.

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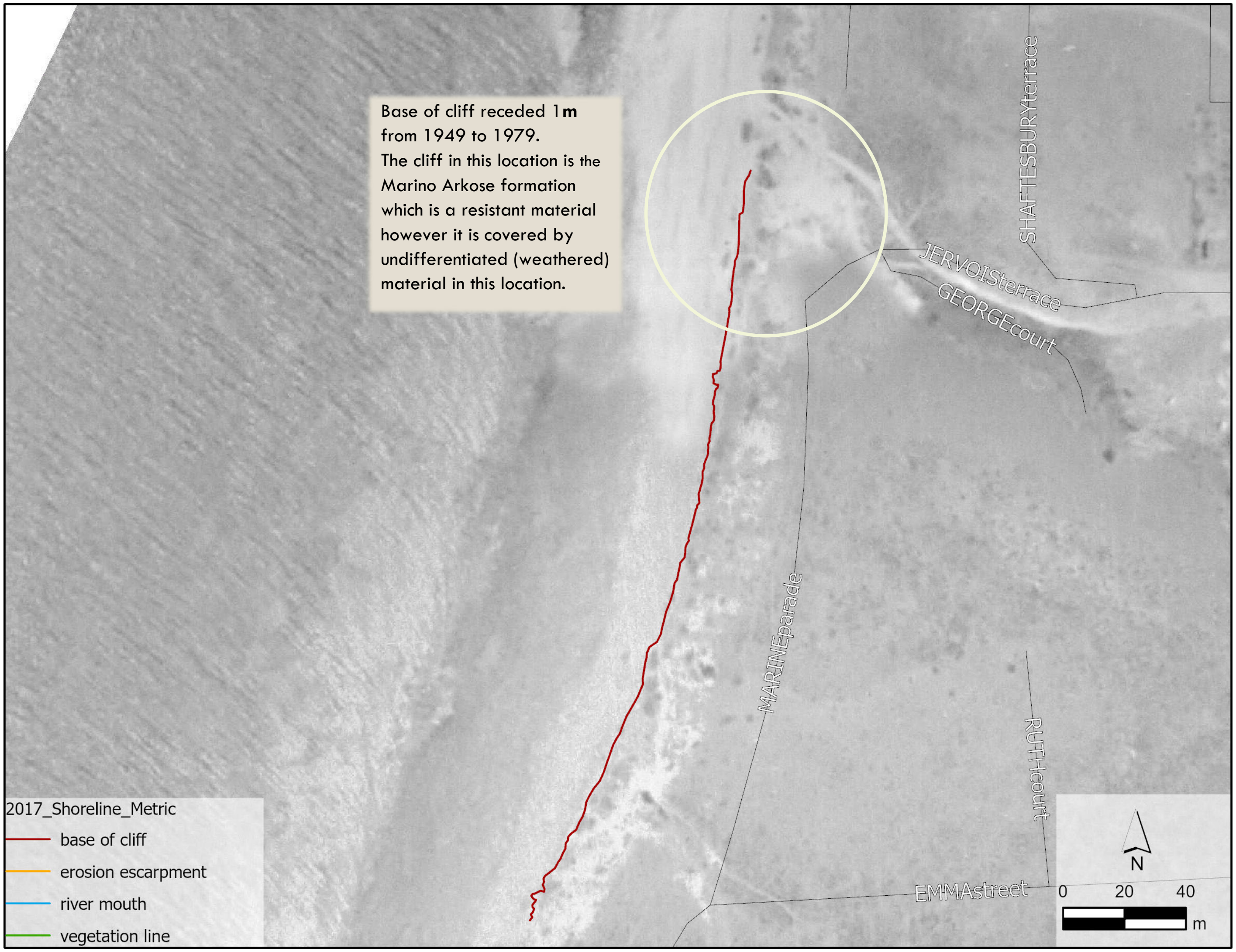

4-3 Coastal fabric – shoreline changes (Cell 1.2)

Medium Term Changes

Cell 1.2

Marino Cliffs

Historical comparison

Shoreline

Location:
Jervios Tce to Emma St
Year 1979

Shoreline recession:
Recession of 1m from 1949 to 1979.

Cliff top recession:
Road on cliff top prior to 1979 – zero recession.

Rock falls/ slumps
Nil

Vegetation
Vegetation is less in 1979 than in 2017.

Project note: Assessment is limited by clarity of photograph, shadows, accurate positioning, and geometric distortion due to different flight paths and camera angles in the context of vertical faces.

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4-3 Coastal fabric – shoreline changes (Cell 1.2)

Medium Term Changes

Cell 1.2

Marino Cliffs

Historical comparison

Shoreline

Location:
Jervios Tce to Emma St
Year 1989

Shoreline recession:
No change since 1989.

Cliff top recession:
Road on cliff top prior to 1979 – zero recession.

Rock falls/ slumps
Nil

Vegetation
Vegetation cover is similar to 1979.

Project note: Assessment is limited by clarity of photograph, shadows, accurate positioning, and geometric distortion due to different flight paths and camera angles in the context of vertical faces.

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4-3 Coastal fabric – shoreline changes (Cell 1.2)

Medium Term Changes

Cell 1.2

Marino Cliffs

Historical comparison

Shoreline

Location:
Jervios Tce to Emma St
Year 2002

Shoreline recession:
No change from 1989 to 2002.

Cliff top recession:
Road on cliff top prior to 1979 – zero recession.

Rock falls/ slumps
Nil

Vegetation
Vegetation cover is similar to 2017.

Project note: Assessment is limited by clarity of photograph, shadows, accurate positioning, and geometric distortion due to different flight paths and camera angles in the context of vertical faces.

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4-3 Coastal fabric – shoreline changes (Cell 1.2)

Medium Term Changes

Cell 1.2

Marino Cliffs

Historical comparison

Shoreline

Location:
Jervios Tce to Emma St
Year 2007

Shoreline recession:
No change from 2002 to 2007.

Cliff top recession:
Road on cliff top prior to 1979 – zero recession.

Rock falls/ slumps
Nil.

Vegetation
Vegetation is similar to 2017.

Project note: Assessment is limited by clarity of photograph, shadows, accurate positioning, and geometric distortion due to different flight paths and camera angles in the context of vertical faces.

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4-3 Coastal fabric – shoreline changes (Cell 1.2)

Medium Term Changes

Cell 1.2

Marino Cliffs

Historical comparison

Shoreline

Location:
Jervios Tce to Emma St
Year 2012

Shoreline recession:
1m recession in north – due to 2 extreme events between 2007 and 2012.

Cliff top recession:
Road on cliff top prior to 1979 – zero recession.

Rock falls/ slumps
Nil

Vegetation
Vegetation cover is similar to 2017.

Project note: Assessment is limited by clarity of photograph, shadows, accurate positioning, and geometric distortion due to different flight paths and camera angles in the context of vertical faces.

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4-3 Coastal fabric – summary (Cell 1.2)

Medium Term Changes

Cell 1.2

Marino Cliffs

Historical comparison

Shoreline

Location:
Jervios Tce to Emma St
Year 2017

70 Years
Unclear photograph, but base of cliff and top of cliff appear in similar location apart from northern section.

40 years
The shoreline has receded approximately 1m-2m in the northern section and nil everywhere else (at least 1m observed since 2007 due to three extreme events).
Vegetation cover increased to 1989 and remained similar since. No cliff top recession due to the positioning of Marine Parade prior to 1979.
No observed rock falls, slumps.

10 years
1m observed in places in the north (due to 3 large events).

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4-3 Coastal fabric – location map (Cell 1.3)

Medium Term Changes

Cell 1.3

Marino Cliffs
Historical comparison

Location Map

Location:
Emma St to Murto Road

Aerial Photograph from 2017 provides the basis for comparison of coastal change over the last 70 years. Comparisons are made with aerial photography from:

- 1949
- 1976
- 1989
- 2002
- 2007
- 2012
- 2017

In this location the shoreline position is the base of the cliff. Note, the base of the cliff cannot be determined in all locations.

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4-3 Coastal fabric – shoreline changes (Cell 1.3)

Medium Term Changes

Cell 1.3

Marino Cliffs

Historical comparison

Shoreline

Location:
Emma St to Murto Road
Year 1949

General observations

Photograph unclear, but cliff top and cliff base are in similar position to 2017.

Project note: Assessment is limited by clarity of photograph, shadows, accurate positioning, and geometric distortion due to different flight paths and camera angles in the context of vertical faces.

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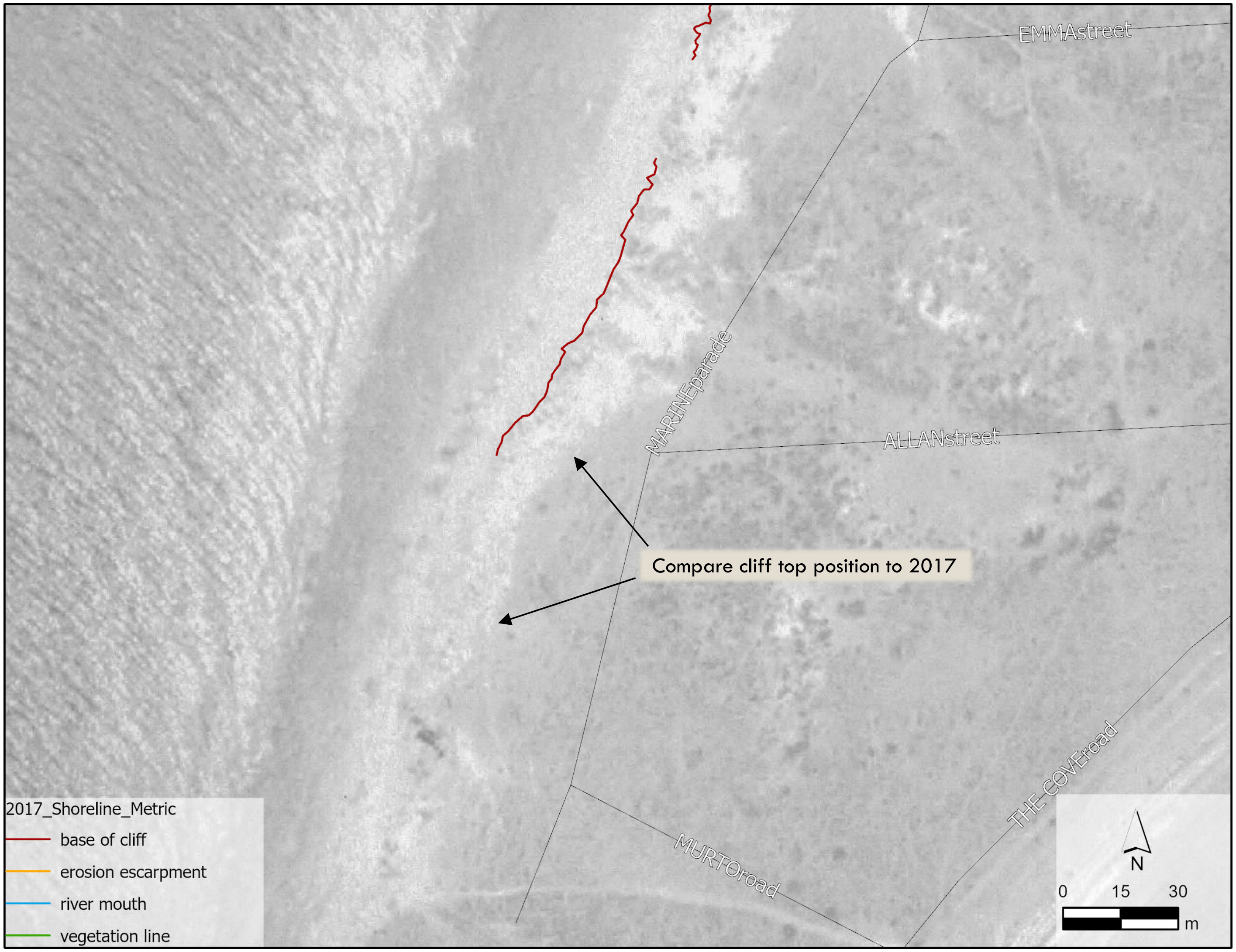

4-3 Coastal fabric – shoreline changes (Cell 1.3)

Medium Term Changes

Cell 1.3

Marino Cliffs

Historical comparison

Shoreline

Location:
Emma St to Murto Rd
Year 1979

Shoreline recession:
Nil

Cliff top recession:
Nil

Rock falls/slumps:
Nil

Vegetation
Vegetation sparser than 2017.

Project note: Assessment is limited by clarity of photograph, shadows, accurate positioning, and geometric distortion due to different flight paths and camera angles in the context of vertical faces.

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4-3 Coastal fabric – shoreline changes (Cell 1.3)

Medium Term Changes

Cell 1.3

Marino Cliffs

Historical comparison

Shoreline

Location:
Emma St to Murto Road
Year 1989

Shoreline recession:
Nil

Cliff top recession:
Nil

Rock falls/slumps:
Nil

Vegetation
Vegetation sparser than 2017.

Project note: Assessment is limited by clarity of photograph, shadows, accurate positioning, and geometric distortion due to different flight paths and camera angles in the context of vertical faces.

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4-3 Coastal fabric – shoreline changes (Cell 1.3)

Medium Term Changes

Cell 1.3

Marino Cliffs

Historical comparison

Shoreline

Location:
Emma St to Murto Road
Year 2002

Shoreline recession:
No recession.

Cliff top recession:
Can't be observed due to position of the road.

Rock falls/slumps:
Nil

Vegetation

Increasing cover from 1989.

Project note: Assessment is limited by clarity of photograph, shadows, accurate positioning, and geometric distortion due to different flight paths and camera angles in the context of vertical faces.

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4-3 Coastal fabric – shoreline changes (Cell 1.3)

Medium Term Changes

Cell 1.3

Marino Cliffs

Historical comparison

Shoreline

Location:
Emma Street to Murto Road
Year 2007

Shoreline recession:
Possible 2m of recession north of Allan Street (but may be loss of vegetation).

Cliff top recession:
Can't be observed due to position of road.

Rock falls/slumps:
Nil

Vegetation
Reduction of grass/ vegetation (likely due to drought).

Project note: Assessment is limited by clarity of photograph, shadows, accurate positioning, and geometric distortion due to different flight paths and camera angles in the context of vertical faces.

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4-3 Coastal fabric – shoreline changes (Cell 1.3)

Medium Term Changes

Cell 1.3

Marino Cliffs

Historical comparison

Shoreline

Location:
Emma Street to Murto Road
Year 2012

Shoreline recession:
No change from 2007.

Cliff top recession:
Can't be observed due to road position.

Rock falls/slumps:
Nil

Vegetation

Vegetation recovering from 2007.

Project note: Assessment is limited by clarity of photograph, shadows, accurate positioning, and geometric distortion due to different flight paths and camera angles in the context of vertical faces.

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4-3 Coastal fabric – summary (Cell 1.3)

Medium Term Changes

Cell 1.3

Marino Cliffs

Historical comparison

Shoreline

Location:
Emma Street to Murto Road
Year 2017

70 years
Unclear, but it appears as though cliff base and top are similar position.

40 years
Minor changes to at base cliff, possibly related to wave impact. Increasing vegetation from 1979 to 2002, stable thereafter (with less cover in 2007). No increase of rock falls on beach or observed slumping.

10 years
No change.

Summary
A stable section of coastal cliffs consistent with Marino Arkose formation, which is a resistant to erosion.

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4-3 Coastal fabric – location map (Cell 1.4)

Medium Term Changes

Cell 1.4

Marino Cliffs

Historical comparison

Location Map

Location:
The Cove Road, Marino

Aerial Photograph from 2017 provides the basis for comparison of coastal change over the last 70 years. Comparisons are made with aerial photography from:

- 1949
- 1976
- 1989
- 2002
- 2007
- 2012
- 2017

In this location the shoreline position is the base of the cliff. Note, the base of the cliff cannot be determined due to shadows.

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4-3 Coastal fabric – shoreline changes (Cell 1.4)

Medium Term Changes

Cell 1.4

Marino Cliffs

Historical comparison

Shoreline

Location:
The Cove Road, Marino
Year 1949

General observations

Interpretation not possible due to unclear photographs.

Gullies in 1949, are now often used for storm water runoff.

Vegetation very sparse.

Project note: Assessment is limited by clarity of photograph, shadows, accurate positioning, and geometric distortion due to different flight paths and camera angles in the context of vertical faces.

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4-3 Coastal fabric – shoreline changes (Cell 1.4)

Medium Term Changes

Cell 1.4

Marino Cliffs

Historical comparison

Shoreline

Location:
The Cove Road, Marino
Year 1979

Shoreline recession:
Nil

Cliff top recession:
Nil observed.

Rock falls/slumps:
Nil

Vegetation

Vegetation sparser than 2017.

Project note: Assessment is limited by clarity of photograph, shadows, accurate positioning, and geometric distortion due to different flight paths and camera angles in the context of vertical faces.

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4-3 Coastal fabric – shoreline changes (Cell 1.4)

Medium Term Changes

Cell 1.4

Marino Cliffs

Historical comparison

Shoreline

Location:
The Cove Road, Marino
Year 1989

Shoreline recession:
Not possible to observe

Cliff top recession:
Possible recession of cliff top since 1979 where shown (see right)

Rock falls/slumps:
Nil

Vegetation

Vegetation sparser than 2017.

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4-3 Coastal fabric – shoreline changes (Cell 1.4)

Medium Term Changes

Cell 1.4

Marino Cliffs

Historical comparison

Shoreline

Location:
The Cove Road, Marino
Year 2002

Shoreline recession:
Not possible to observe.

Cliff top recession:
Nil observed.

Rock falls/slumps:
Nil

Vegetation

Vegetation increasing from 1989.

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4-3 Coastal fabric – shoreline changes (Cell 1.4)

Medium Term Changes

Cell 1.4

Marino Cliffs

Historical comparison

Shoreline

Location:
The Cove Road, Marino
Year 2007

Shoreline recession:
Not possible to compare.

Cliff top recession:
Nil observed.

Rock falls/slumps:
Nil

Vegetation

Vegetation similar to 2017, with possible less cover on cliff top.

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4-3 Coastal fabric – shoreline changes (Cell 1.4)

Medium Term Changes

Cell 1.4

Marino Cliffs

Historical comparison

Shoreline

Location:
The Cove Road, Marino
Year 2012

Shoreline recession:
Not possible to assess due to vertical faces and shadows.

Cliff top recession:
Nil observed.

Rock falls/slumps:
Nil

Vegetation

Vegetation similar to 2017.

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4-3 Coastal fabric – summary (Cell 1.4)

Medium Term Changes

Cell 1.4

Marino Cliffs

Historical comparison

Shoreline

Location:
The Cove Road, Marino
Year 2017

70 years
Unclear photograph

40 years
No observed erosion/ recession of cliff top apart from possible recession (see 1989). No increases in rock falls to the beach. Shadows at base of cliff made interpretation of shoreline recession impossible.

10 years
No change

Summary
A stable section of coastal cliffs consistent with sandstone and siltstone members of the Wilmingotn Formation overlying the Marino Arkose.

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4-3 Coastal fabric – location map (Cell 1.5)

Medium Term Changes

Cell 1.5

Marino Cliffs

Historical comparison

Location Map

Location:
Marino South

Aerial Photograph from 2017 provides the basis for comparison of coastal change over the last 70 years. Comparisons are made with aerial photography from:

- 1949
- 1976
- 1989
- 2002
- 2007
- 2012
- 2017

In this location the shoreline position is the base of the cliff. Note, the base of the cliff cannot be determined due to shadows.

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4-3 Coastal fabric – shoreline changes (Cell 1.5)

Medium Term Changes

Cell 1.5

Marino Cliffs

Historical comparison

Shoreline

Location:
Marino South
Year 1949

Shoreline recession:
It is possible that the shoreline has receded since 1979 (~2m), but this also may just be vegetation or pebble bank changes.

Cliff top recession:
Nil observed.

Rock falls/slumps:
Nil

Vegetation

Vegetation very sparse..

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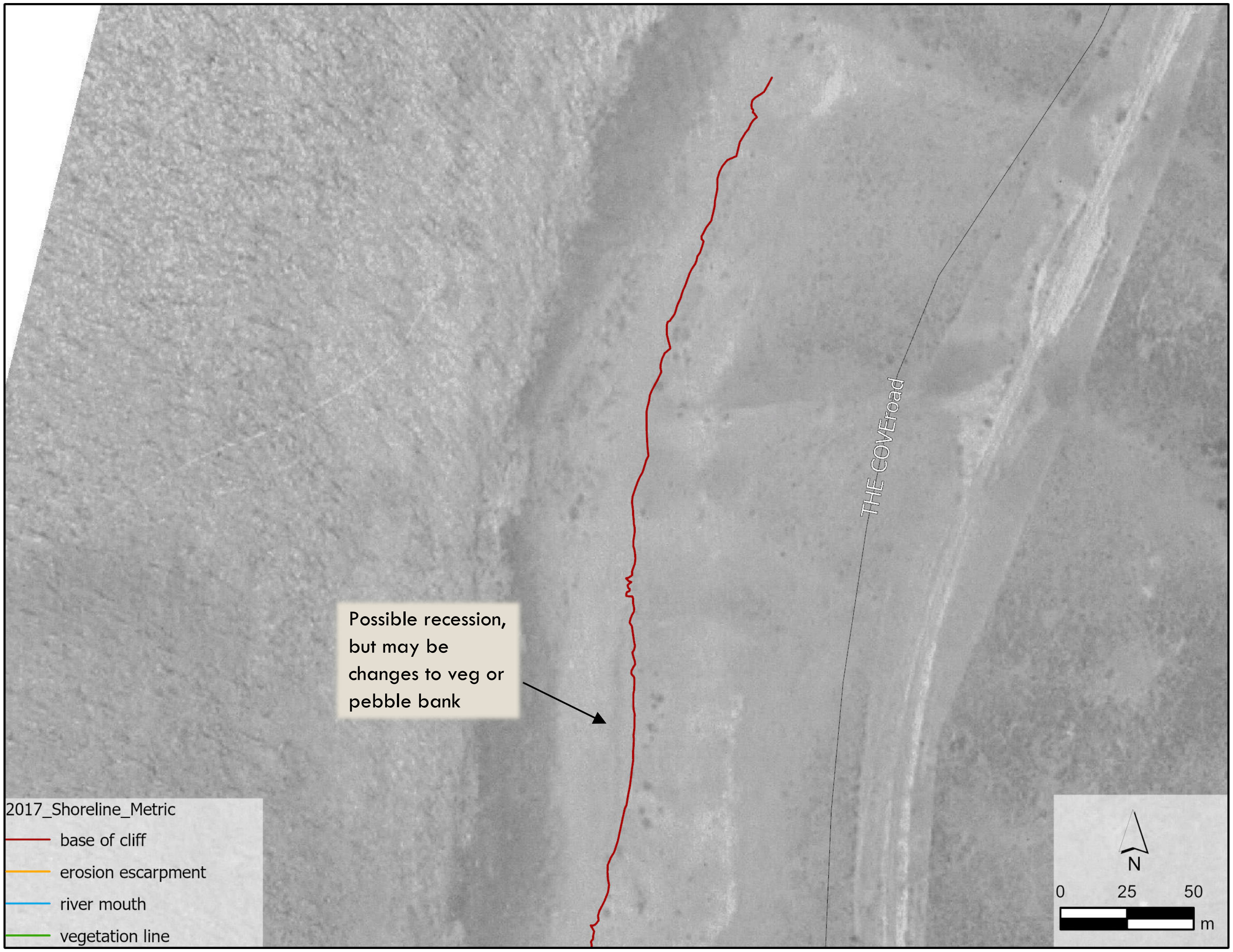

4-3 Coastal fabric – shoreline changes (Cell 1.5)

Medium Term Changes

Cell 1.5

Marino Cliffs

Historical comparison

Shoreline

Location:
Marino South
Year 1979

Shoreline recession:
It is possible that the shoreline has receded since 1979 (~2m), but this also may just be vegetation changes.

Cliff top recession:
Nil observed.

Rock falls/slumps:
Nil

Vegetation

Vegetation sparser than 2017.

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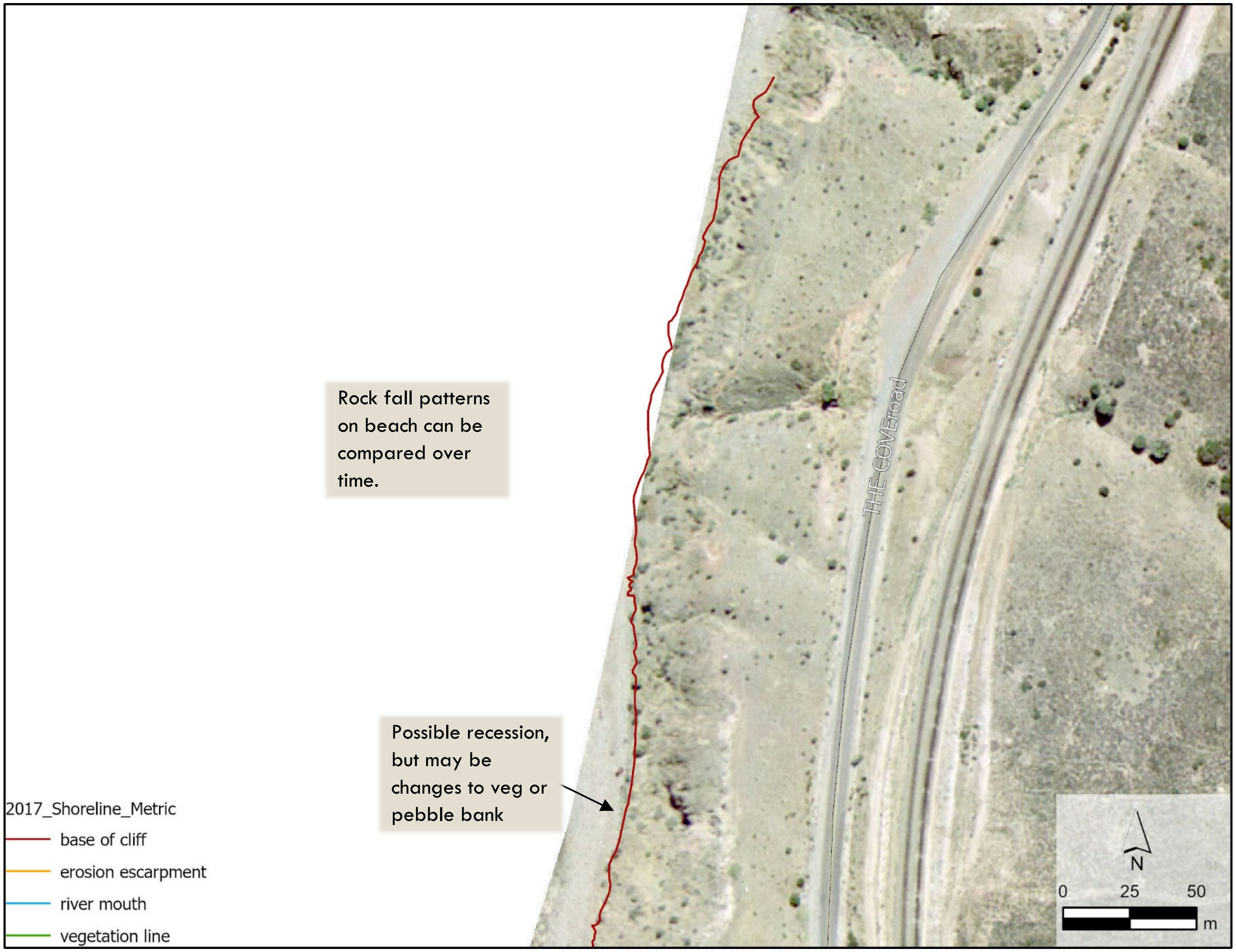

4-3 Coastal fabric – shoreline changes (Cell 1.5)

Medium Term Changes

Cell 1.5

Marino Cliffs

Historical comparison

Shoreline

Location:
Marino South
Year 1989

Shoreline recession:
Nil

Cliff top recession:
Nil observed.

Rock falls/slumps:
Nil

Vegetation

Vegetation sparser than 2017.

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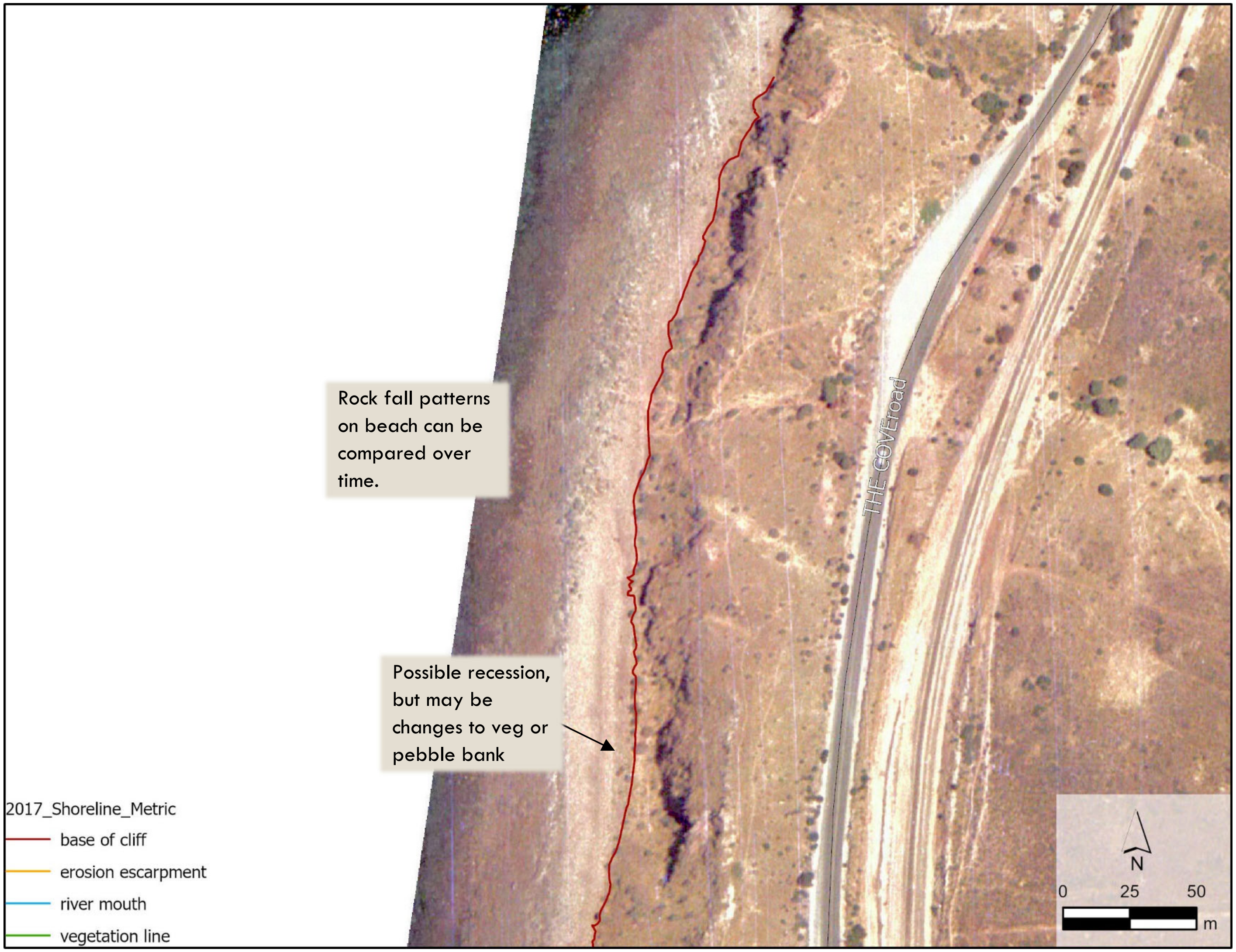

4-3 Coastal fabric – shoreline changes (Cell 1.5)

Medium Term Changes

Cell 1.5

Marino Cliffs

Historical comparison

Shoreline

Location:
Marino South
Year 2002

Shoreline recession:
Nil

Cliff top recession:
Nil observed.

Rock falls/slumps:
Nil

Vegetation

Vegetation similar to 2017. Changes in vegetation due seasonal and rainfall changes.

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4-3 Coastal fabric – shoreline changes (Cell 1.5)

Medium Term Changes

Cell 1.5

Marino Cliffs

Historical comparison

Shoreline

Location:
Marino South
Year 2007

Shoreline recession:
Shoreline (vegetation line) appears to be ~2ms seaward of the 2002 line due to seasonal changes between photographs (this one in May).

Cliff top recession:
Nil observed.

Rock falls/slumps:
Nil

Vegetation

Vegetation similar to 2017.

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4-3 Coastal fabric – shoreline changes (Cell 1.5)

Medium Term Changes

Cell 1.5

Marino Cliffs

Historical comparison

Shoreline

Location:
Marino South
Year 2012

Shoreline recession:
Nil

Cliff top recession:
Nil observed.

Rock falls/slumps:
Nil

Vegetation

Vegetation similar to 2017.

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4-3 Coastal fabric – summary (Cell 1.5)

Medium Term Changes

Cell 1.5

Marino Cliffs

Historical comparison

Shoreline

Location:
Marino South
Year 2017

70 years
Very little change observed. Possible recession of shoreline (but this may be pebble bank/ vegetation changes).

40 years
Very little change observed. Possible recession of shoreline (but this may just be decadal changes in pebble bank and not due to wave attack).

10 years
Recession over last decade is nil.

Summary:
Very stable section of cliff which is expected with Wilmington Formation overlying the Marino Arkose.

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4-5 Coastal fabric – human intervention (Cell 1.1)

MODIFIED COASTS

Modifications: Roads and footpaths have been constructed close to the backshore/cliff. These create ‘hold points’ that would come under threat if cliffs receded. Dwellings in this section of Marino Cliffs (Cell 1) are all constructed behind the esplanade roads.

Protection items: Rock revetment to backshore adjacent the Esplanade (installed by 2000, now in fair condition), and a concrete and stone seawall protected a previous building in that location. The groyne was likely installed when the site was used for boat launching (superseded by the boat ramp at Jervois Terrace).

4-5 Coastal fabric – human intervention (Cell 1.2)

MODIFIED COASTS

Modifications: Marine Parade and the carpark have been constructed close to the top of the cliff. These structures place 'hold points' at the top of the cliff and would come under threat if the cliff receded. Dwellings and other private infrastructure are positioned landward of Marine Parade. The material under the carpark is likely to have been formed partly by fluvial sediments carried down from the gully above when volumes of water runoff were much greater. A concrete boat ramp was installed prior to 1970s. Storm water drains from an outlet set in the base of the cliff. **Protection items:** Nil.

4-5 Coastal fabric – human intervention (Cell 1.3)

MODIFIED COASTS

Modifications: Marine Parade has been constructed close to the top of the cliff which places a 'hold point' at the top of the cliff and would come under threat if the cliff receded. Dwellings and other private infrastructure are positioned landward of Marine Parade. The geology analysis noted it was composed of the Neo-Proterozoic Marino Arkose formation which is resistant to erosion.

Protection items: Nil

4-5 Coastal fabric – human intervention (Cell 1.4)

MODIFIED COASTS

Modifications: Dwellings are generally well setback from the cliff top at 15m to 30m (measured to the walking trail). Access to dwellings in Cell 1.4 is predominantly from The Cove Road. The walking trail is predominantly constructed on natural ground with some sections of board walk. Beach access stairs are positioned in a gully.

4-5 Coastal fabric – human intervention (Cell 1)

LAND USE ZONING

The current urban planning controls are briefly reviewed here to ascertain if existing development controls are adequate in the context of coastal areas.

Zoning and policy areas

Hills Neighbourhood

Desired Outcome: Low density housing minimises disturbance to natural landforms and existing vegetation to mitigate the visible extent of buildings, earthworks and retaining walls.

Performance outcome (sample): Predominantly low-density residential development with complementary non-residential uses compatible with natural landforms and a low-density residential character.

Allotment widths (20m-24m) and *allotment areas* depend on gradient of the land: 700m^2 -1100m^2.

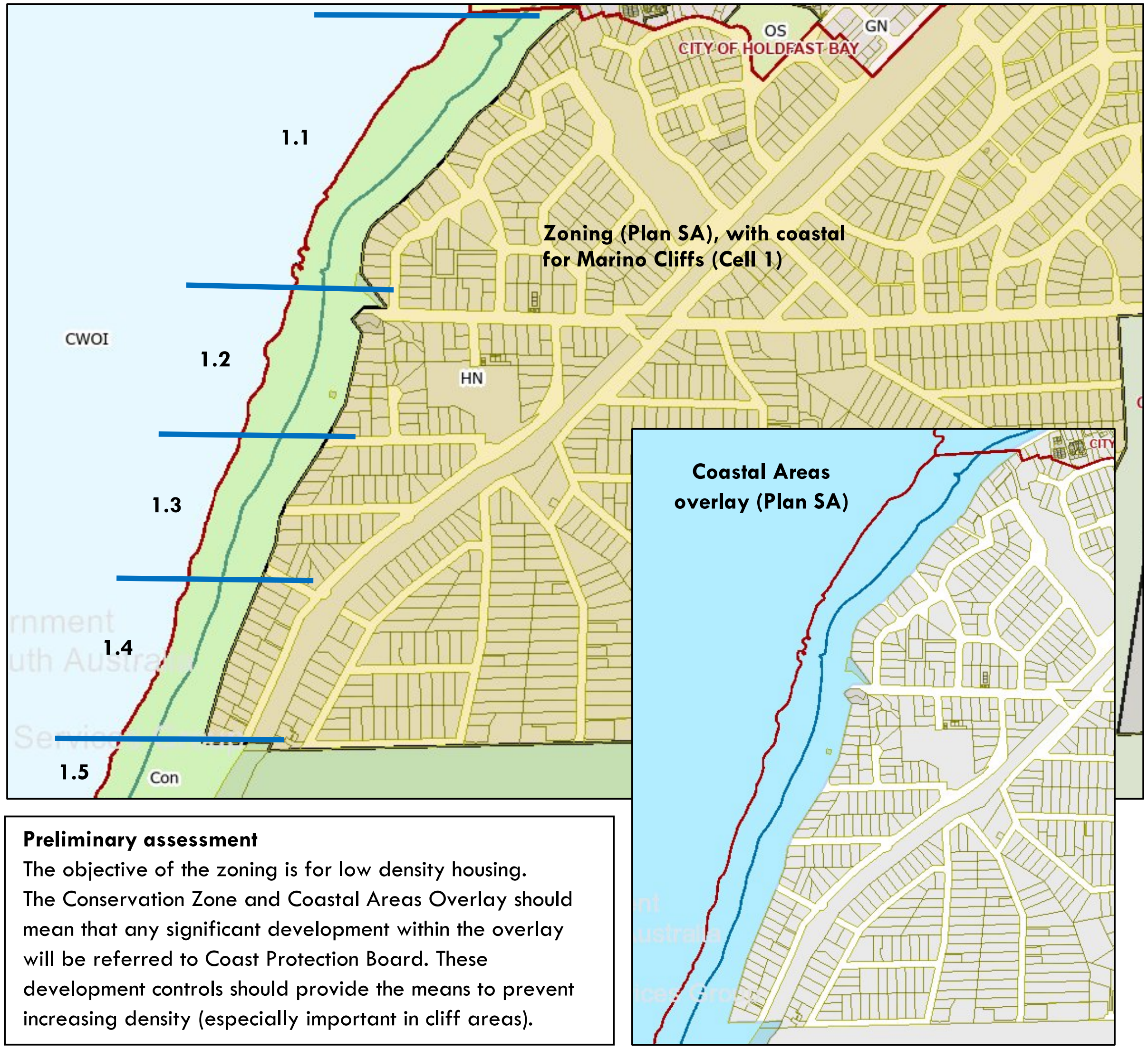
Conservation Zone

A Conservation Zone is positioned along the coast which significantly reduces development options.

Overlays

Coastal Areas (only one reported here)

The Coastal Areas overlay is positioned in a similar location as the Conservation Zone and will trigger a referral to Coast Protection Board for some types of development applications.



Zoning (Plan SA), with coastal for Marino Cliffs (Cell 1)

Coastal Areas overlay (Plan SA)

Preliminary assessment
The objective of the zoning is for low density housing.
The Conservation Zone and Coastal Areas Overlay should mean that any significant development within the overlay will be referred to Coast Protection Board. These development controls should provide the means to prevent increasing density (especially important in cliff areas).

4. Coastal fabric – summary table (Cell 1)

Marino Cliffs		Coastal context - natural				Modified	Coastal changes		Marino Cliffs (Cell 1)
Cell	Location	Bathymetry	Benthic	Beach	Backshore	Human	70 years	10 years	**Erodibility**
1.1-2	Marino: The Esplanade to Emma Street	Slope: -4m at 600m offshore from The Esplanade (1:150) and 320m offshore from Marino Rocks (1:75).	Nearshore dominated by low profile reef to 300m offshore.	Rocky platform, cobbles below the cliffs.	Cliffs from 5m in the north to 20m in the south. (Soft rock sloping cliff under The Esplanade and Marino carpark).	Esplanade roads and carpark. Rock revetment to The Esplanade. Walking trail, boat ramp.	2-4m recession below The Esplanade, 1-2m just south of boat ramp (Marino Rocks).	Nil change (apart from minor wave scarping at base of cliff of Marino Rocks carpark).	Predominantly **low**, but The Esplanade (southern end) and Marino Rocks carpark, **moderate.**
1.3	Emma Street to Murto Road.	Slope 1:75 (-4m at 250m to 320m offshore). Slope becomes steeper moving south	Low profile reef to 100m offshore then medium seagrass bed	Rocky platform, shingles below the cliffs.	Hard rock cliffs with mostly vertical faces, 20m to 25m high.	Marine Parade positioned on top of the cliff, houses behind.	No cliff base or top recession observed. No increases in rock falls or slumps.	Nil change.	Resistant rock cliffs, dominated by low profile offshore reef and rocky beach platform, and therefore assessed as **low erodibility.**
1:4-5	Murto Road to Cove Road	Slope 1:70 (-4m at 250m offshore).	Low profile reef to 100mthen medium seagrass bed	Rocky platform, shingles below the cliffs	Hard rock cliffs 20m to 25m high (1.4) and sloping backshore (1.5)	Walking trail set on top of the cliff. Houses set well back.	No cliff base or top recession. No increases in rock falls or slumps.	Nil change.	Hard rock cliffs, sloping cliffs, dominated by low profile offshore reef and rocky beach platform - **low erodibility.**

Marino Cliffs: key points

Predominantly hard rock sloping shores that are resistant to erosion, dominated by low profile offshore reef and rocky beach platform, and therefore assessed as **low erodibility.** Exceptions at The Esplanade (south) and Marino carpark are assessed as **moderate erodibility.** The historical photographic analysis supports this assessment with some recession and scarping observed in these locations. Human interventions include esplanade roads close to the top of the cliff, and minor infrastructure such as walking trail, beach access stairs, boat ramp. Rock revetment protects The Esplanade and wire netting limits rock falls at Murto Road beach stairs.

5. COASTAL EXPOSURE

To evaluate how actions of the sea currently impact the coastal fabric and how actions of the sea are projected to impact in the future in this section we complete the following:

- Review impact of storms (if any)
- Apply current 1 in 100 sea-flood risk scenario,
- Analyse routine high-water impact,
- Analyse these scenarios in time frames: 2020, 2050, 2100,

Viewing instruction:
View sea-flood modelling using full screen mode within your PDF software (Control L). Then use arrow keys to navigate.

5. Coastal exposure – overview

COASTAL EXPOSURE EXPLAINED

The concept of coastal exposure is something we tend to understand intuitively. For example, if we find ourselves on the shore of a protected bay, we know that the impact from the ocean is likely to be limited. On the other hand, if we are standing on a beach on the Southern Ocean and listening to the roar of the waves, we understand that we are far more exposed.

In this study we are primarily concerned with the exposure of coastal landscapes to wave energy and ocean swell. However, coastal landforms can also be vulnerable to exposure from rainfall run-off or from the impact of wind. These can also increase the erosion of coastal landscapes, especially in cliff regions of softer constituency.

Due to its location within Gulf Saint Vincent, which is afforded protection by Kangaroo Island from the Southern Ocean, Nature Maps (SA) has assigned the exposure rating for City of Marion coastline as 'moderate' and the wave energy as 'low'[1].

Storm surges

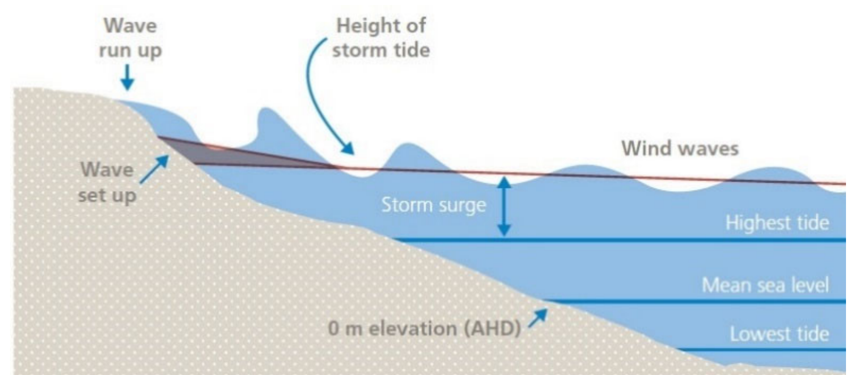
Despite this protection, when several meteorological conditions combine, storm surges can produce water levels up 1-2m higher than the predicted astronomical tide in Gulf St Vincent. To manage the risk of these events upon human infrastructure, SA Coast Protection Board has set storm surge policy risk levels for the 1 in 100-year event. In terms of probability, this event is predicted to occur once every hundred years. However, 'nature' does not read our probability charts and there is no reason why these large events could not occur closer together, albeit less likely. While storm surges may have significant impact on the coast, these by their very nature are rare events. Over time beaches may rebuild and we can repair the damage.

[1] https://data.environment.sa.gov.au/NatureMaps
[2] CD stands for Chart Datum and relates to tide heights recorded in the local tide charts.
[3] Australian Height Datum (AHD) is the same measurement system that a surveyor would utilise and generally relates to mean sea level (the middle height of water between high and low water).

The event of 9 May 2016 was the highest event recorded at the Outer Harbor tide gauge and was recorded at 3.80m CD[2] or 2.35 AHD[3]. This event came close to the *1 in 100-year event* set by South Australian Coast Protection Board at 2.50m AHD. *Wave setup* of 0.30 has been adopted for the entire City of Marion coastline[4]. *Wave runup* allocations have been made for each cell based upon surveys conducted of seaward strands from four storms in 2021-2022 (Figure a).

Routine high water

While storm surges can have a significant impact on the coast, these are rare events. If seas rise as projected, routine tidal action is likely to have a greater impact on beaches and backshores over time. In the context of a cliff coast, areas that are currently receiving intermittent wave impact will receive constant wave impact and this is likely to increase the rate of erosion. To calculate the height of this tide, the average monthly high tide from March to September from the tidal record at Port Stanvac was calculated at 1.40m AHD[5]. It is likely that this tidal regime would occur on average one to three times per month.



[4] Set by SA Coast Protection Board. In the context of a storm surge, the water from wave action cannot flow back to the sea and water levels rise against the coast. This is known as 'wave setup'.
[5] Port Stanvac gauge operated from 1992 to 2010. Actual height was calculated at 1.42m AHD which represents 90% of the height at Outer Harbor for the same period at 1.59m AHD.

5. Coastal exposure – overview

COASTAL PROCESSES

Wave action on the Marion Council coastline

The degree of susceptibility of a coastline to wave erosion is related to the degree of exposure of the coast to wind, current and wave attack. There are two main types of waves which fashion beaches: storm (forced waves); and swell (constructional waves). Forced waves scour the beach, erode sand from beach faces and form offshore bars. When storms subside, constructional waves tend to push sand back onto the beach.

The alignment of Marion's coastline tends more to the north-east/ south-west in contrast to Onkaparinga and Adelaide metropolitan coastline which tends to orientate north-south. Swell waves are generated in the Southern Ocean, but after passing through Investigator Strait, and having 'refracted, diffracted and attenuated due to bottom friction', wave heights are much reduced as they approach the Marion coastline. Swell waves that propagate to the Marion coastline region have 12-16 second periods, heights below 1m, and directions close to 260˚. Sea waves within the Gulf St Vincent are generally of short-wave period and quite steep, frequently with white caps and approach the shore from the direction of the wind, mostly west-south-west winds, but can roll in at range 250˚ - 310˚. Combine with south-west swells, the net wind-wave direction is northward. Wind waves are generally lower than swell waves but have been recorded at 2.6m in Gulf St Vincent[6] (Figure a).

Storm action on the Marion Council coastline

The conditions that produce the highest levels of water in Gulf St Vincent have been documented by Flinders Ports[7]. With the passage of a deep depression across the Southern Ocean, the winds are from the North which then swings to the North-West. A strong gusty north-westerly wind, with a depression in the Southern Ocean, backing to the south-west at about the time of low water, will cause a storm surge of maximum amplitude from the Southern Ocean, and heights may be expected from 1m to 2m

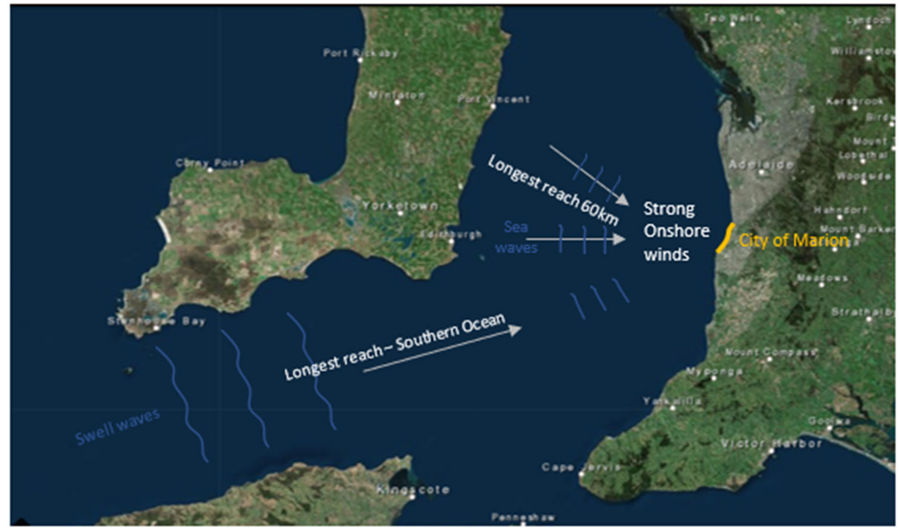


Figure a. The orientation of the City of Marion coastline to wave energy (M. Western, 2018)

Tidal Range on the Marion City Council coastline

The effect of tides pushing up through a narrowing Gulf increases the tidal range in the northern parts of the Gulf. In the Marion region, the categorisation is borderline in the upper ranges of micro-tidal as assessed by Doug Lord 2012.

Level	Chart Datum (m)	AHD (m)
Lowest astronomical tide	0.00	-1.45
Mean sea level	1.30	-0.15
Australian Height Datum	1.45	0.00
Mean high water neaps	1.30	-0.15
Mean high water springs	2.40	0.95

Figure b. The tidal range at City of Marion is characterized as micro-tidal (upper range).

[6] D. Lord., Coastal Management Study, Hallett Cove, SA. 2012

[7] Flinders Ports (ND) Port User Guide – General Information

5. Coastal exposure – overview

SEA LEVEL RISE

Climate change occurs over long timescales in response to solar variations, changes in the Earth's orbit around the Sun, volcanic eruptions, and natural variability. Sea levels reflect the state of the climate system. During ice ages a large volume of water is stored on land in the form of ice sheets and glaciers, leading to lower sea levels, while during warm interglacial periods, glaciers and ice sheets are reduced and more water is stored in the oceans[8]. Over the last few thousand years sea levels have stabilised, and also within this time frame, urban settlements have been established near the coast all over the world.

Global mean sea levels

The average level of the ocean is known as *global mean sea level* (GMSL). Long term tide gauges show that seas began to rise in the 19th century and this trend has continued throughout the 20th century at on average rate of 1.7mm per year. However, this average rate of rise was not constant. Rates of sea level rise were higher in the period 1920s to1940s[9] (in the context of higher temperatures and melting of the Greenland ice sheets[10]). In the 1990s sea levels again rose at a faster rate, comparable to that of the 1920s to 1940s. Since 1990, satellites have been tracking mean sea level rise at 3-4mm per year in our region[3]. However, this shorter-term record is likely to contain an element of natural variability and the current rate of rise not unusual in the context of natural variability and the data record from last century[11]

Regional sea levels

Regional changes occur in sea level, but these do not change the overall mass of the ocean. For example, regional sea levels change in accordance with the climate variability associated with El Nino and La Nina cycles. During El Nino years sea level rises in the eastern Pacific and falls in the western Pacific, whereas in La Nina years the opposite is true. Longer term changes are also associated with changes in the Trade Winds which bring increases in sea levels in the Western Tropical Pacific region[2]. Sea levels can also change in relationship to the vertical movement of land. If an area of land is falling, then in relative terms, sea levels will rise, and vice versa.

Projected sea level rise

Projections of future climate change are carried out using climate models that use various greenhouse gas emissions scenarios. These models are computer-based simulations of the earth-ocean-atmosphere system that identify plausible futures as to how the climate will respond over the coming century[4]. Sea level rise projections are based upon these various scenarios. In 1993, South Australian Coast Protection Board (CPB) adopted sea level rise allowances into planning policy of 0.3m rise by 2050 and 1.0m rise by 2100. These sea level rise projections are similar to the high emissions scenario shown in Figure a.

Scenario modelling

In this project we take the current storm surge risk levels and current routine high-water data and model the impact of these in a digital model captured in 2018. We then take the sea level allowances set by CPB at 0.3m by 2050 and 1.0m by 2100 and model the projected impact of sea level rise upon the coast.

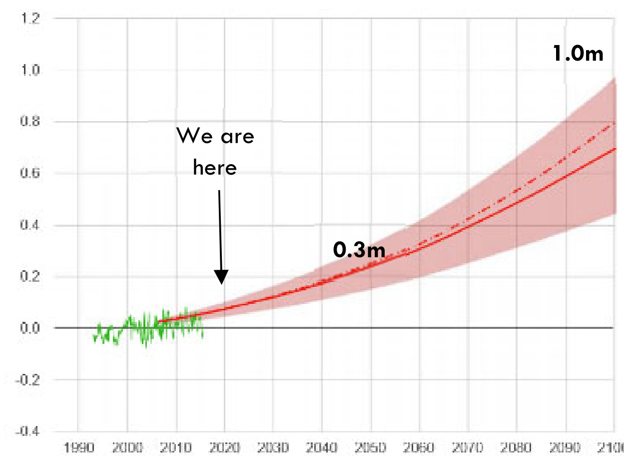


Figure a: Sea level rise high emissions scenario (Coast Adapt, 2017). Coast Protection Board sea-level rise policy added.

[8] Coast Adapt, 2017.
[9] IPCC, WG1AR5, Sea level change, 2014, Watson, P, 2020.
[10] Curry, J., Sea level and climate change, 2019.
[11] CSIRO, 2020, Sea level, waves and coastal extremes.

5. Coastal exposure – previous storm impact

HISTORICAL STORMS

The analysis of previous storms provides a window into the past to assist us to identify where the coast is most vulnerable. This analysis also provides a window into the future because it provides a context from which to consider how storms will impact the coast if seas rise as projected. In some ways, storms are 'natures' vulnerability assessment of how resilient our coast currently is, and how it may respond in the future.

Storm events

The three highest storm surges on record at Outer Harbor tide gauge occurred:

- 9 May 2016 – 2.35m AHD (3.80 CD)
- 3 July 2007 – 2.27m AHD (3.71 CD)
- 25 April 2009 – 2.22m AHD (3.65 CD)

Of these three events, data is only available for the Marino area for event 9 May 2016. Photographs taken at 17.20 show minor overtopping of the rock revetment and water streaming up the concrete path on to the road reserve (Figures a,b). Inspection of the base of the cliff under the Marino Rocks carpark indicated increased wave scarping and erosion because of this event.

Using a comparison of Port Stanvac and Outer Harbor gauges from 1992 to 2010 it is likely that the event of 9 May 2016 was 2.12m AHD along the City of Marion coast (see inset table).

Figures a. & b. Photographs taken at 17.20, 9 May 2016 by Bill and Glenys Summersides, residents on The Esplanade at Marino (used with permission).

Figure c. Minor scarping and erosion were observed at the base of the cliff under the Marino Rocks carpark as a result of the 9 May 2016 storm.

<u>Comparison of Port Stanvac and Outer Harbor tidal data</u>

A comparison of all monthly high tides showed Port Stanvac was on average 87% lower than Outer Harbor.

A comparison of monthly high tides (April to September) revealed that Port Stanvac was 90% lower.

A comparison of storm events within the period:

- 3 July 2007 (2.07 PS, 90% of 2.27OH is 2.04m)
- 25 April 2009 (1.95 PS, 90% of 2.22m is 2.00m)

Therefore, 9 May 2016 was likely to have been in vicinity of 2.12 at Port Stanvac and is adopted for this event.

5. Coastal exposure – location map (Cell 1.1)

Location

Cell 1.1

Marino Cliffs

Location Map

The Esplanade, Marino

The scenarios modelled are:

- Routine tidal action is likely to have greater impact on the backshore over time. Routine high-water events are expected to occur a few times per month from April to September.
- 1 in 100-year ARI storm surge event (CPB)

The timing of the scenarios:

- Current
- 2050
- 2100

Nature Maps (SA) assigns:

Relative exposure:
Moderate

Wave energy:
Low

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5. Coastal exposure – routine high water (2020)

Routine high water

Cell 1.1

Marino Cliffs

2020 scenario

Event: Routine high water

The Esplanade, Marino

Routine high-water events are expected to occur a few times per month from April to September.

Inputs are based on analysis on data from Outer Harbor and analysis of five storms in the CoM monitoring project (2021, 2022)

The event modelled:

Routine highwater	1.60m AHD
Wave set-up	0.20m
Total risk	1.80m AHD

Wave run-up is an additional 0.60m and depicted in light blue.

Assessment: The modelling is congruent with observations and the current impact on beach and backshore is low.

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5. Coastal exposure – routine high water (2050)

Routine high water

Cell 1.1

Marino Cliffs

2050 scenario

Event: Routine high water

The Esplanade, Marino

Sea level rise will increase the frequency of routine interactions between the sea and coastal fabric so that the impact on backshore will become greater over time.

The event modelled:

Routine highwater	1.60m AHD
Sea level rise	0.30m
Wave set-up	0.20m
Total risk	2.10m AHD

Wave run-up is an additional 0.60m and depicted in light blue.

Routine highwater events at 0.30m higher than present are likely to impact the base of the clay portion of the cliff with minor recession measured in metres (1-3m).

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5. Coastal exposure – routine high water (2100)

Routine high water

Cell 1.1

Marino Cliffs

2100 scenario

Event: Routine high water

The Esplanade, Marino

Sea level rise will increase the frequency of routine interactions between the sea and coastal fabric so that the impact on backshore will become greater over time.

<u>The event modelled:</u>

Routine highwater	1.60m AHD
Sea level rise	1.00m
Wave setup	<u>0.20m</u>
Total risk	2.80m AHD

Wave run-up is an additional 0.60m and depicted in light blue.

Routine highwater events at 1.00m higher than present are likely to impact the base of the clay portion of the cliff with possible significant recession (>3m)..

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5. Coastal exposure – storm surge (2020)

Storm surge

Cell 1.1

Marino Cliffs

2020 scenario

Event: 1 in 100 sea-flood risk

The Esplanade, Marino

The current 1 in 100-year event risk set by SA Coast Protection Board is:

Storm surge	2.40m AHD.
Wave set-up	0.30m
Risk	2.70m AHD

Wave run-up is an additional 0.80m and depicted in light blue.

Left: It is likely that minor overtopping would occur in similar way to 9 May 2016 (see storm review above).

This is a rare event and unlikely to have any longer-term impact on the cliffs at right.

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5. Coastal exposure – storm surge (2050)

Storm surge

Cell 1.1

Marino Cliffs

2050 scenario

Event: 1 in 100 sea-flood risk

The Esplanade, Marino

The current 1 in 100-year event risk set by SA Coast Protection Board is:

Storm surge	2.40m AHD.
Sea level rise	0.30m
Wave setup	0.30m
Risk	3.00m AHD

Wave run-up is an additional 0.80m and depicted in light blue.

Assessment.
Left: wave overtopping would be significant (see event for 9 May 2016). This type of modelling does model the effect of vertical walls on wave action.

Right: Wave runup would have significant energy at the base of the cliff. Combined with higher routine events, some recession is likely.

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Acknowledgement
The inundation mapping for future events is super-imposed over current beach and backshore layouts which are likely to change over time. The purpose is to illustrate the potential impact of sea level rise.

5. Coastal exposure – storm surge (2100)

Storm surge

Cell 1.1

Marino Cliffs

2100 scenario

Event: 1 in 100-year event

The Esplanade, Marino

The current 1 in 100-year event risk set by SA Coast Protection Board is:

Storm surge	2.40m AHD.
Sea level rise	1.00m
Wave set-up	0.30m
Risk	3.70m AHD

Wave run-up is an additional 0.80m and depicted in light blue.

Assessment.
Left: wave overtopping would be significant (see event for 9 May 2016) but unlikely to impact private dwellings. This type of modelling does model the effect of vertical walls on wave action.

Right: Wave runup would have significant energy at the base of the cliff. Combined with higher routine events, recession is likely.

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Acknowledgement
The inundation mapping for future events is super-imposed over current beach and backshore layouts which are likely to change over time. The purpose is to illustrate the potential impact of sea level rise.

5. Coastal exposure – summary (Cell 1.1)

Summary

Cell 1.1

Marino Cliffs

Summary

The Esplanade, Marino

2020-2050

Significant storm events will overtop the rock revetment on the Esplanade. Routine tidal events are unlikely to cause significant recession to the escarpment under the walking trail in this period.

2050-2100

If sea levels rise as projected, frequent over topping of the Esplanade is expected. Recession to the base of the clay escarpment is likely which may eventually destabilise this slope.

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5. Coastal exposure – location map (Cell 1.2)

Location

Cell 1.2

Marino Cliffs

Location Map

Jervios Tce to Emma St

The scenarios modelled are:

- Routine tidal action is likely to have greater impact on the backshore over time. Routine high-water events are expected to occur a few times per month from April to September.
- 1 in 100-year ARI storm surge event (CPB)

The timing of the scenarios:

- Current
- 2050
- 2100

Nature Maps (SA) assigns:

Relative exposure:
Moderate

Wave energy:
Low

Integrated Coasts
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5. Coastal exposure – routine high water (2020)

Routine high water

Cell 1.2

Marino Cliffs

2020 scenario

Event: Routine high water

Jervios Tce to Emma St

Routine high-water events are expected to occur a few times per month from April to September.

Inputs are based on analysis on data from Outer Harbor and analysis of five storms in CoM monitoring project (2021, 2022)

The event modelled:

Routine highwater	1.60m AHD
Wave set-up	0.20m
Total risk	1.80m AHD

Wave run-up is an additional 0.80m and depicted in light blue.

Assessment: The modelling is congruent with observations and the current impact on beach and backshore is low.

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5. Coastal exposure – routine high water (2050)

Routine high water

Cell 1.2

Marino Cliffs

2050 scenario

Event: Routine high water

Jervios Tce to Emma St

Sea level rise will increase the frequency of routine interactions between the sea and coastal fabric so that the impact on backshore will become greater over time.

The event modelled:

Routine highwater	1.60mAHD
Sea level rise	0.30m
Wave setup	0.20m
Total risk	2.10mAHD

Wave run-up is an additional 0.80m and depicted in light blue.

Assessment: Combined with storm activity, routine highwater events are likely to cause minor recession to the escarpment.

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5. Coastal exposure – routine high water (2100)

Routine high water

Cell 1.2

Marino Cliffs

2100 risk:

Event: Routine high water

Jervios Tce to Emma St

Sea level rise will increase the frequency of routine interactions between the sea and coastal fabric so that the impact on backshore will become greater over time.

The event modelled:

Routine highwater	1.60m AHD
Sea level rise	1.00m
Wave setup	0.20m
Total risk	2.80m AHD

Wave run-up is an additional 0.80m and depicted in light blue.

Assessment: The cliff under the carpark contains undifferentiated material (i.e. not rock). Routine impact to the base of the cliff will cause recession that is likely to destabilise the cliff slope under the carpark.

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5. Coastal exposure – storm surge (2020)

Storm surge

Cell 1.2

Marino Cliffs

2020 scenario

Event: 1 in 100 sea-flood risk

Jervios Tce to Emma St

The current 1 in 100-year event risk set by SA Coast Protection Board is:

Storm surge	2.40m AHD.
Wave set-up	0.30m
Risk	2.70m AHD

Wave run-up is an additional 1.00m and depicted in light blue.

Assessment:
Impact to the base of the cliff is likely, in a similar way the event of 9 May 2016 scarped the base of the cliff.

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5. Coastal exposure – storm surge (2050)

Storm surge

Cell 1.2

Marino Cliffs

2050 scenario

Event: 1 in 100 sea-flood risk

Jervios Tce to Emma St

The current 1 in 100-year event risk set by SA Coast Protection Board is:

Storm surge	2.40m AHD.
Sea level rise	0.30m
Wave setup	0.30m
Risk	3.00m AHD

Wave run-up is an additional 1.00m and depicted in light blue.

Assessment:

Wave runup would likely scarp the base of the slope (at higher impact than 9 May 2016).

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Acknowledgement
The inundation mapping for future events is super-imposed over current beach and backshore layouts which are likely to change over time. The purpose is to illustrate the potential impact of sea level rise.

5. Coastal exposure – storm surge (2100)

Storm surge

Cell 1.2

Marino Cliffs

2100 scenario

Event: 1 in 100-year event

Jervios Tce to Emma St

The current 1 in 100-year event risk set by SA Coast Protection Board is:

Storm surge	2.40m AHD.
Sea level rise	1.00m
Wave setup	0.30m
Risk	3.70m AHD

Wave run-up is an additional 1.00m and depicted in light blue.

Assessment:

Combined with routine highwater events, significant recession of the base of the escarpment with likely destabilisation of the cliff slope.

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Acknowledgement
The inundation mapping for future events is super-imposed over current beach and backshore layouts which are likely to change over time. The purpose is to illustrate the potential impact of sea level rise.

5. Coastal exposure – summary (Cell 1.2)

Summary

Cell 1.2

Marino Cliffs

Summary

Jervios Tce to Emma St

2020-2050

Current storm events do not impact the base of the escarpment apart from significant events such as 9 May 2016. Increases in sea level will increase the impact and minor recession is likely.

2050-2100

If sea levels rise as projected, the base of the escarpment can be expected to erode and recede, potentially cause instability in the slope under the carpark.

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5. Coastal exposure – location map (Cell 1.3)

Location

Cell 1.3

Marino Cliffs

Location Map

Emma St to Murto Road

The scenarios modelled are:

- Routine tidal action is likely to have greater impact on the backshore over time. Routine high-water events are expected to occur a few times per month from April to September.
- 1 in 100-year ARI storm surge event (CPB)

The timing of the scenarios:

- Current
- 2050
- 2100

Nature Maps (SA) assigns:

Relative exposure:
Moderate

Wave energy:
Low

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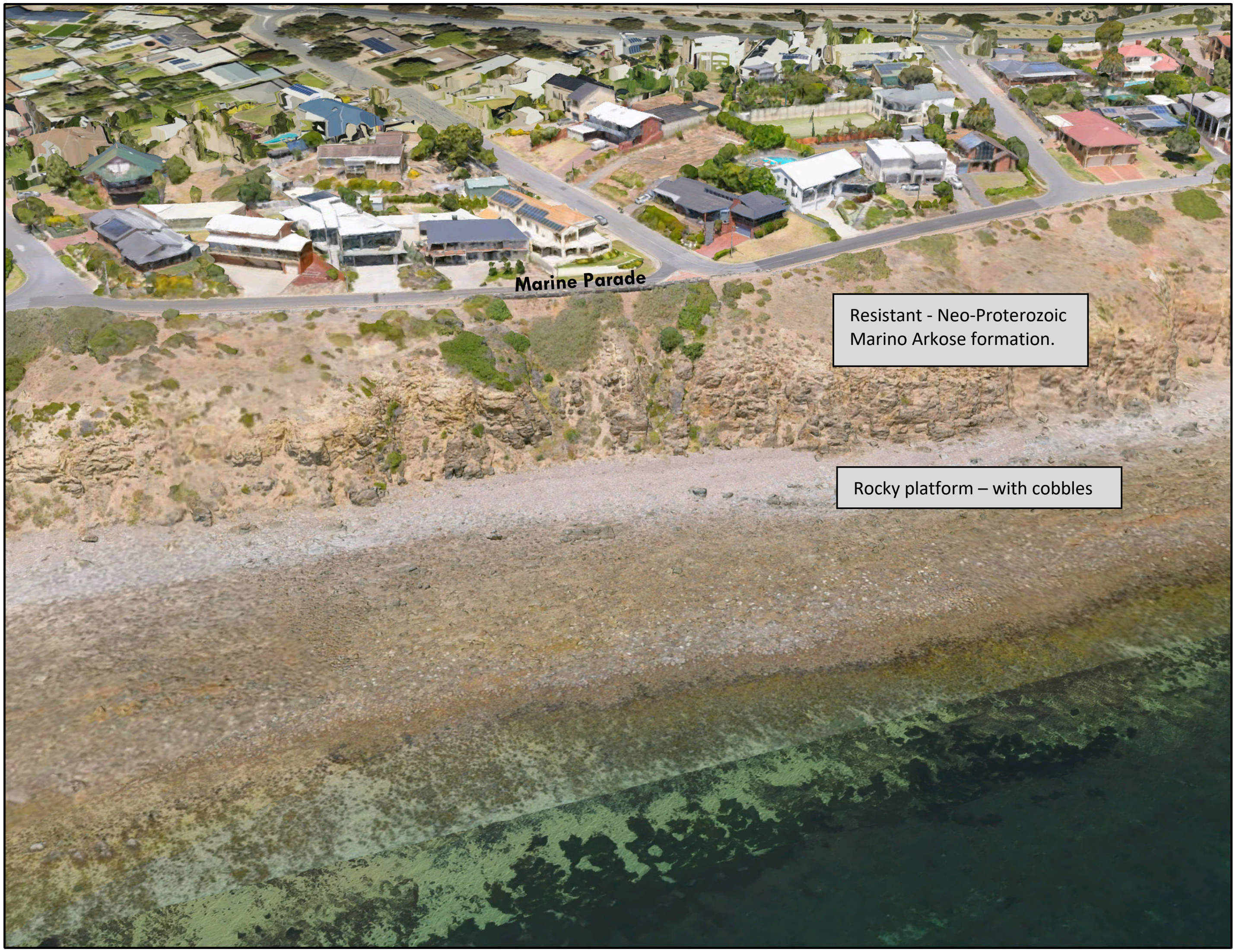

5. Current exposure – routine high water (2020)

Routine high water

Cell 1.3

Marino Cliffs

2020 scenario

Event: Routine high water

Emma St to Murto Road

Routine high-water events are expected to occur a few times per month from April to September.

Inputs are based on analysis on data from Outer Harbor and analysis of five storms in the CoM monitoring project (2021, 2022).

The event modelled:

Routine highwater	1.60mAHD
Wave set-up	0.20m
Total risk	1.80mAHD

Wave run-up is an additional 0.80m and depicted in light blue.

Assessment: The modelling is congruent with observations and the current impact on beach and backshore is low.

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5. Coastal exposure – routine high water (2050)

Routine high water

Cell 1.3

Marino Cliffs

2050 scenario

Event: Routine high water

Emma St to Murto Road

Sea level rise will increase the frequency of routine interactions between the sea and coastal fabric so that the impact on backshore will become greater over time.

Inputs are based on analysis on data from Outer Harbor and analysis of five storms in the CoM monitoring project (2021, 2022).

The event modelled:

Routine highwater	1.60m AHD
Sea level rise	0.30m
Wave setup	0.20m
Total risk	2.10m AHD

Wave run-up is an additional 0.80m and depicted in light blue.

Assessment: Rocky beach backed by resistant rock cliffs. Impact will likely be low.

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Dark blue – tide height
Mid blue – wave setup
Light Blue – wave runup

Acknowledgement
The inundation mapping for future events is super-imposed over current beach and backshore layouts which are likely to change over time. The purpose is to illustrate the potential impact of sea level rise.

5. Coastal exposure – routine high water (2100)

Routine high water

Cell 1.3
Marino Cliffs
2100 scenario
Event: Routine high water

Emma St to Murto Road

Sea level rise will increase the frequency of routine interactions between the sea and coastal fabric so that the impact on backshore will become greater over time.

Inputs are based on analysis on data from Outer Harbor and analysis of five storms in the CoM monitoring project (2021, 2022).

The event modelled:

Routine highwater	1.60m AHD
Sea level rise	1.00m
Sea level rise	0.20m
Total risk	2.80m AHD

Wave run-up is an additional 0.80m and depicted in light blue.

Assessment: Rocky beach and resistant rock cliffs in backshore. There will be higher impacts on the cliffs but effects unknown (likely low).

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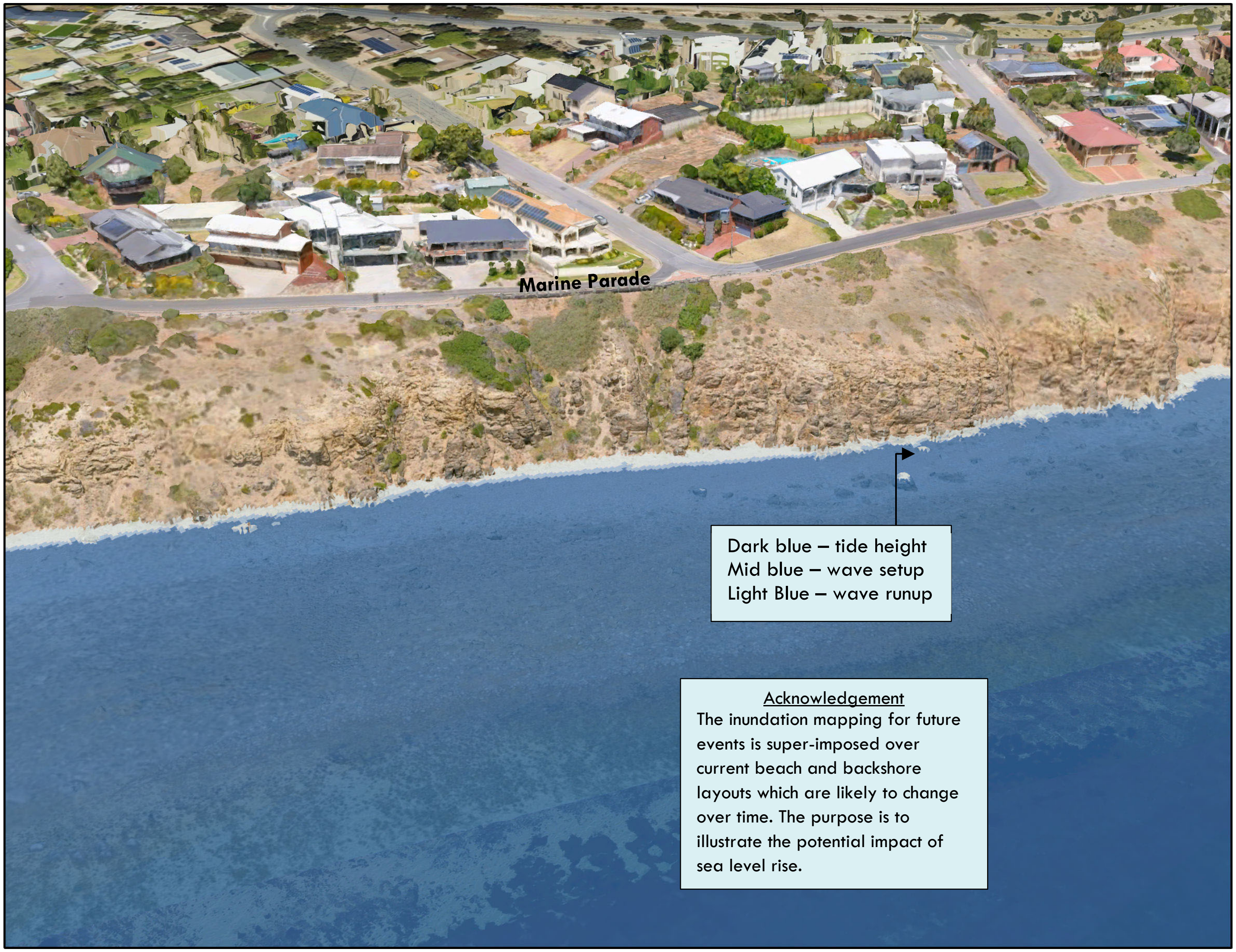

Dark blue – tide height
Mid blue – wave setup
Light Blue – wave runup

Acknowledgement
The inundation mapping for future events is super-imposed over current beach and backshore layouts which are likely to change over time. The purpose is to illustrate the potential impact of sea level rise.

5. Coastal exposure – storm surge (2020)

Storm surge

Cell 1.3

Marino Cliffs

2020 scenario

Event: 1 in 100 sea-flood risk

Emma St to Murto Road

The current 1 in 100-year event risk set by SA Coast Protection Board is:

Storm surge	2.40m AHD.
Wave set-up	0.30m
Risk	2.70m AHD

Wave run-up is an additional 1.00m and depicted in light blue.

Assessment: Rocky beach and resistant rock cliffs in backshore. This event is very rare and therefore no impacts are likely on the backshore.

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5. Coastal exposure – storm surge (2050)

Storm surge

Cell 1.3

Marino Cliffs

2050 scenario

Event: 1 in 100 sea-flood risk

Emma St to Murto Road

The current 1 in 100-year event risk set by SA Coast Protection Board is:

Storm surge	2.40m AHD.
Sea level rise	0.30m
Wave runup	0.30m
Risk	3.00m AHD

Wave run-up is an additional 1.00m and depicted in light blue.

Assessment: Rocky beach and resistant rock cliffs in backshore. This event is very rare and therefore no impacts are likely on the backshore.

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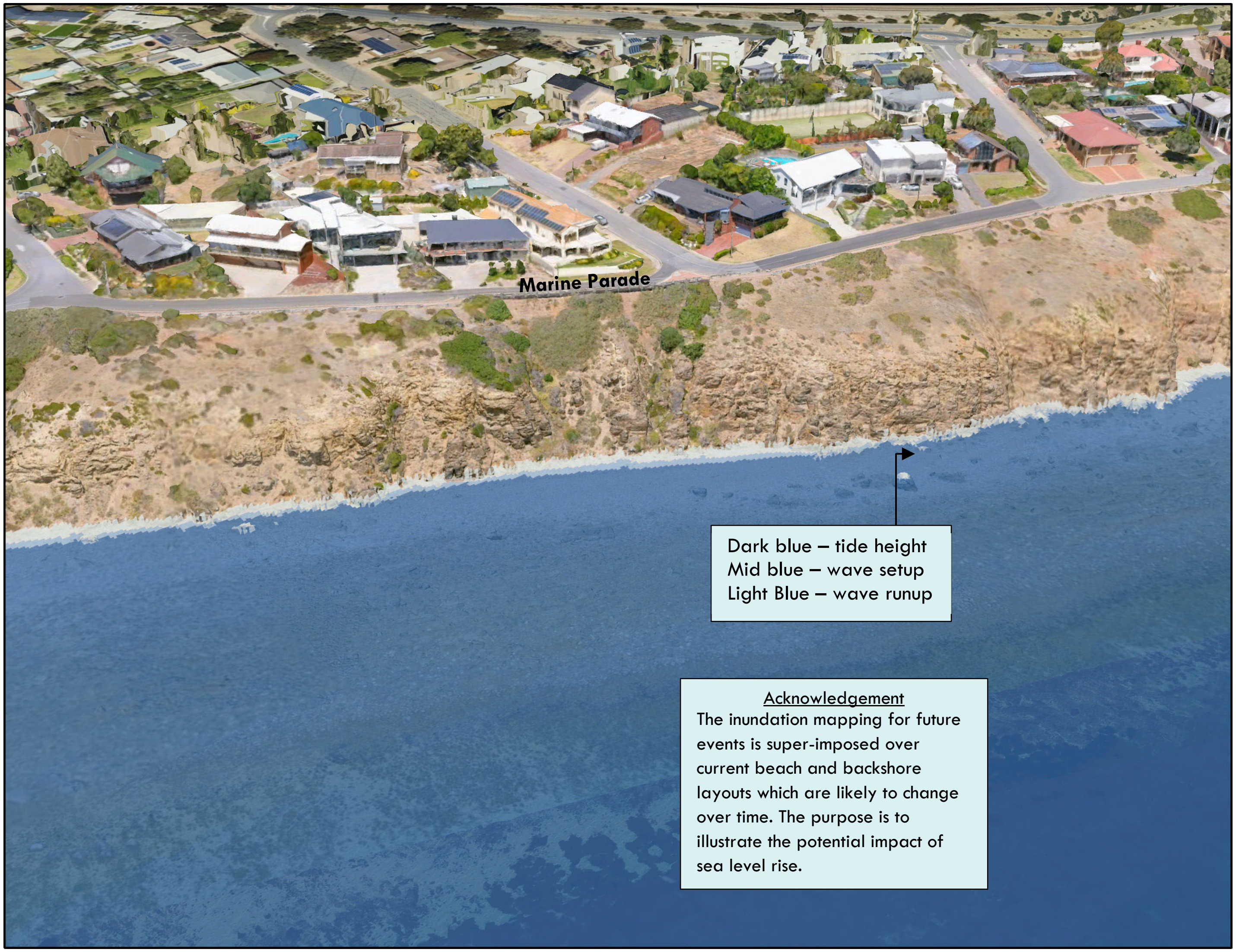

5. Coastal exposure – storm surge (2100)

Storm surge

Cell 1.3

Marino Cliffs

2100 scenario

Event: 1 in 100 sea-flood risk

Emma St to Murto Road

The current 1 in 100-year event risk set by SA Coast Protection Board is:

Storm surge	2.40m AHD.
Sea level rise	1.00m
Sea level rise	0.30m
Risk	3.70m AHD

Wave run-up is an additional 1.00m and depicted in light blue.

Assessment: Rocky beach and resistant rock cliffs in backshore. This event is very rare and therefore no impacts are likely on the backshore. However, combined with routine highwater events at 1.00m higher than present the overall impact will be greater.

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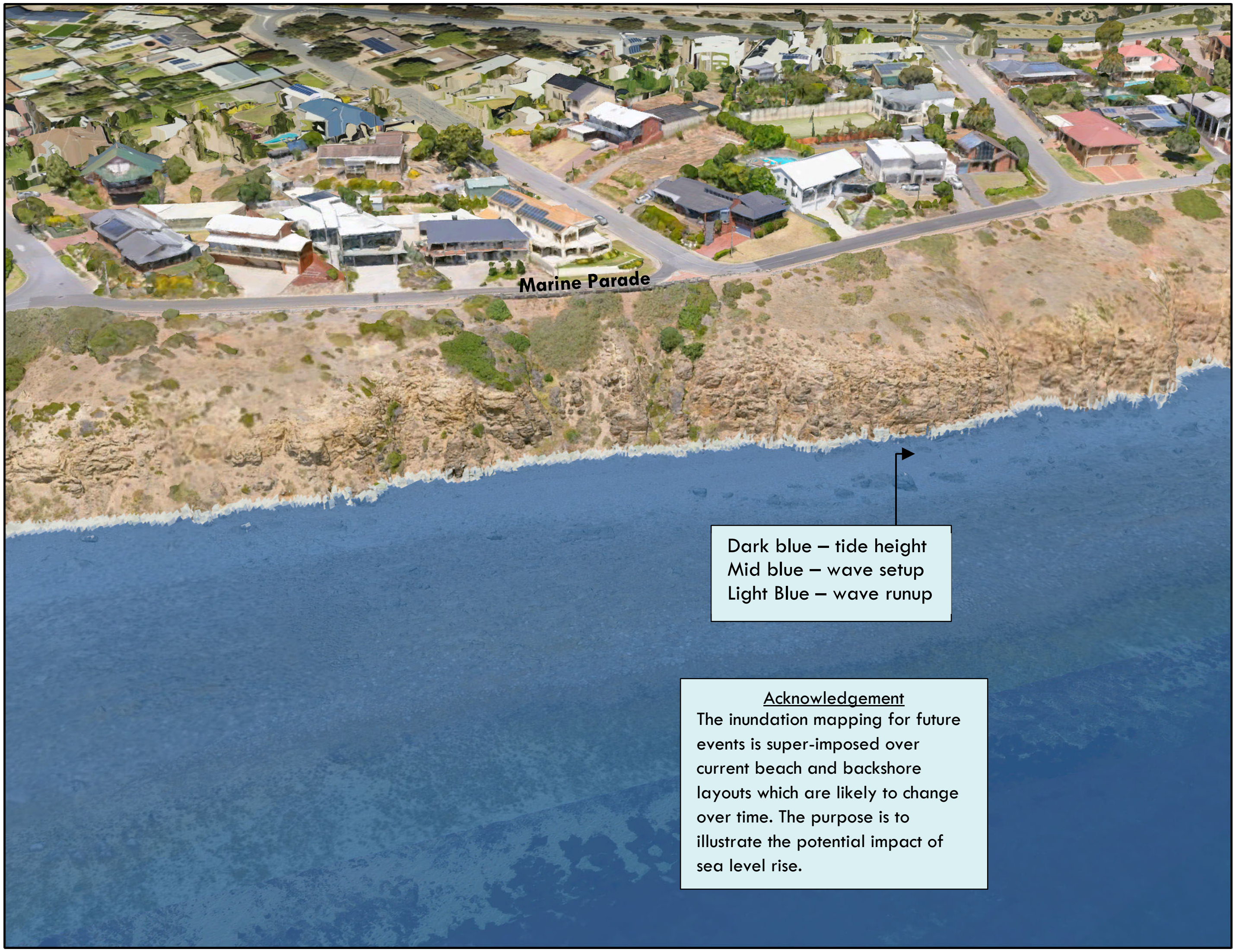

5. Coastal exposure – summary (Cell 1.3)

Summary

Cell 1.3

Marino Cliffs

Summary

Emma St to Murto Road

2020-2050

Current impact in coastal layout of rocky beach and resistant rock cliffs is low and 0.30m of sea level rise will be unlikely to change this assessment.

2050-2100

If seas rise as projected post 2050, then there will be increased impact on the base of the cliff, especially from routine tidal events. However, these cliffs are of a resistant type and therefore any undercutting is likely to be slow.

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5. Coastal exposure – location map (Cell 1.4)

Location

Cell 1.4

Marino Cliffs

Location Map

The Cove Road (residential)

The scenarios modelled are:

- Routine tidal action is likely to have greater impact on the backshore over time. Routine high-water events are expected to occur a few times per month from April to September.
- 1 in 100-year ARI storm surge event (CPB)

The timing of the scenarios:

- Current
- 2050
- 2100

Nature Maps (SA) assigns:

Relative exposure:
Moderate

Wave energy:
Low

Integrated Coasts
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5. Coastal exposure – routine high water (2020)

Routine high water

Cell 1.4

Marino Cliffs

2020 scenario

Event: Routine high water

The Cove Road (residential)

Routine high-water events are expected to occur a few times per month from April to September.

Inputs are based on analysis on data from Outer Harbor and analysis of five storms in the CoM monitoring project (2021, 2022).

The event modelled:

Routine highwater	1.60m AHD
Wave set-up	0.20m
Total risk	1.80m AHD

Wave run-up is an additional 0.80m and depicted in light blue.

Assessment: The modelling is congruent with observations and the current impact on beach and backshore is low.

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5. Coastal exposure – routine high water (2050)

Routine high water

Cell 1.4
Marino Cliffs
2050 scenario
Event: Routine high water

The Cove Road (residential)

Sea level rise will increase the frequency of routine interactions between the sea and coastal fabric so that the impact on backshore will become greater over time.

Inputs are based on analysis on data from Outer Harbor and analysis of five storms in the CoM monitoring project (2021, 2022).

The event modelled:

Routine highwater	1.60m AHD
Sea level rise	0.30m
Wave setup	0.20m
Total risk	2.10m AHD

Wave run-up is an additional 0.80m and depicted in light blue.

Assessment: Rocky beach backed by resistant rock cliffs. Impact will likely be very low.

Integrated Coasts
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Acknowledgement
The inundation mapping for future events is super-imposed over current beach and backshore layouts which are likely to change over time. The purpose is to illustrate the potential impact of sea level rise.

5. Coastal exposure – routine high water (2100)

Routine high water

Cell 1.4

Marino Cliffs

2100 scenario

Event: Routine high water

The Cove Road (residential)

Sea level rise will increase the frequency of routine interactions between the sea and coastal fabric so that the impact on backshore will become greater over time.

Inputs are based on analysis on data from Outer Harbor and analysis of five storms in the CoM monitoring project (2021, 2022).

The event modelled:

Routine highwater	1.60m AHD
Sea level rise	1.00m
Wave setup	0.20m
Total risk	2.80m AHD

Wave run-up is an additional 0.80m and depicted in light blue.

Assessment: Rocky beach and resistant rock cliffs in backshore. There will be higher impacts on the cliffs but effects unknown (likely low).

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5. Coastal exposure – storm surge (2020)

Storm surge

Cell 1.4

Marino Cliffs

2020 scenario

Event: 1 in 100 sea-flood risk

The Cove Road (residential)

The current 1 in 100-year event risk set by SA Coast Protection Board is:

Storm surge	2.40m AHD.
Wave set-up	0.30m
Risk	2.70m AHD

Wave run-up is an additional 1.00m and depicted in light blue.

Assessment: Rocky beach and resistant rock cliffs in backshore. This event is very rare and therefore no impacts are likely on the backshore.

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5. Coastal exposure – storm surge (2050)

Storm surge

Cell 1.4
Marino Cliffs
2050 scenario
Event: 1 in 100 sea-flood risk

The Cove Road (residential)

The current 1 in 100-year event risk set by SA Coast Protection Board is:

Storm surge	2.40m AHD.
Sea level rise	0.30m
Wave setup	0.30m
Risk	3.00m AHD

Wave run-up is an additional 1.00m and depicted in light blue.

Assessment: Rocky beach and resistant rock cliffs in backshore. This event is very rare and therefore no impacts are likely on the backshore.

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Acknowledgement
The inundation mapping for future events is super-imposed over current beach and backshore layouts which are likely to change over time. The purpose is to illustrate the potential impact of sea level rise.

5. Coastal exposure – storm surge (2100)

Storm surge

Cell 1.4

Marino Cliffs

2100 scenario

Event: 1 in 100 sea-flood risk

The Cove Road (residential)

The current 1 in 100-year event risk set by SA Coast Protection Board is:

Storm surge	2.40m AHD.
Sea level rise	1.00m
Wave setup	0.30m
Risk	3.70m AHD

Wave run-up is an additional 1.00m and depicted in light blue.

Assessment: Rocky beach and resistant rock cliffs in backshore. This event is very rare and therefore no impacts are likely on the backshore.

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Acknowledgement
The inundation mapping for future events is super-imposed over current beach and backshore layouts which are likely to change over time. The purpose is to illustrate the potential impact of sea level rise.

5. Coastal exposure – summary (Cell 1.4)

Summary

Cell 1.4

Marino Cliffs

Summary

The Cove Road (residential)

2020-2050

Current impact in coastal layout of rocky beach and resistant rock cliffs is low and 0.30m of sea level rise will be unlikely to change this assessment.

2050-2100

If seas rise as projected post 2050, then there will be increased impact on the base of the cliff, especially from routine tidal events. However, these cliffs are of a resistant type and therefore any undercutting is likely to be slow.

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5. Coastal exposure – location map (Cell 1.5)

Location

Cell 1.5

Marino Cliffs

Location Map

The Cove Road (reserve)

The scenarios modelled are:

- Routine tidal action is likely to have greater impact on the backshore over time. Routine high-water events are expected to occur a few times per month from April to September.
- 1 in 100-year ARI storm surge event (CPB)

The timing of the scenarios:

- Current
- 2050
- 2100

Nature Maps (SA) assigns:

Relative exposure:
Moderate

Wave energy:
Low

Integrated Coasts
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www.integratedcoasts.com

5. Coastal exposure – routine high water (2020)

Routine high water

Cell 1.5

Marino Cliffs

2020 scenario

Event: Routine high water

The Cove Road (reserve)

Routine high-water events are expected to occur a few times per month from April to September.

Inputs are based on analysis on data from Outer Harbor and analysis of five storms in CoM monitoring project (2021, 2022).

The event modelled:

Routine highwater	1.60m AHD
Wave set-up	0.20m
Total risk	1.80m AHD

Wave run-up is an additional 0.80m and depicted in light blue.

Assessment: The modelling is congruent with observations and the current impact on beach and backshore is low.

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5. Coastal exposure – routine high water (2050)

Routine high water

Cell 1.5

Marino Cliffs

2050 scenario

Event: Routine high water

The Cove Road (reserve)

Sea level rise will increase the frequency of routine interactions between the sea and coastal fabric so that the impact on backshore will become greater over time.

Inputs are based on analysis on data from Outer Harbor and analysis of five storms in the CoM monitoring project (2021, 2022).

The event modelled:

Routine monthly tide	1.60m AHD
Sea level rise	0.30m
Wave setup	0.20m
Total risk	2.10m AHD

Wave run-up is an additional 0.80m and depicted in light blue.

Assessment: Rocky beach backed by resistant rock cliffs. Impact will likely be low. Removal of unconsolidated material at the base is likely.

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5. Coastal exposure – routine high water (2100)

Routine high water

Cell 1.5

Marino Cliffs

2100 scenario

Event: Routine high water

The Cove Road (reserve)

Sea level rise will increase the frequency of routine interactions between the sea and coastal fabric so that the impact on backshore will become greater over time.

The event modelled:

Routine monthly tide	1.60m AHD
Sea level rise	1.00m
Wave setup	0.20m
Total risk	2.80m AHD

Wave run-up is an additional 0.80m and depicted in light blue.

Assessment: Rocky beach backed by resistant rock cliffs. Long term impact is unknown (likely low). Removal of unconsolidated material at the base is likely.

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5. Coastal exposure – storm surge (2020)

Storm surge

Cell 1.5

Marino Cliffs

2020 scenario

Event: 1 in 100 sea-flood risk

The Cove Road (reserve)

The current 1 in 100-year event risk set by SA Coast Protection Board is:

Storm surge	2.40m AHD.
Wave set-up	0.30m
Risk	2.70m AHD

Wave run-up is an additional 1.00m and depicted in light blue.

Assessment: Rocky beach and resistant rock cliffs in backshore. This event is very rare and therefore no impacts are likely on the backshore.

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5. Coastal exposure – storm surge (2050)

Storm surge

Cell 1.5

Marino Cliffs

2050 scenario

Event: 1 in 100 sea-flood risk

The Cove Road (reserve)

The current 1 in 100-year event risk set by SA Coast Protection Board is:

Storm surge	2.40m AHD.
Sea level rise	0.30m
Wave setup	0.30m
Risk	3.00m AHD

Wave run-up is an additional 1.00m and depicted in light blue.

Assessment: Rocky beach and resistant rock cliffs in backshore. This event is very rare and therefore no impacts are likely on the backshore.

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5. Coastal exposure – storm surge (2100)

Storm surge

Cell 1.5

Marino Cliffs

2100 scenario

Event: 1 in 100 sea-flood risk

The Cove Road (reserve)

The current 1 in 100-year event risk set by SA Coast Protection Board is:

Storm surge	2.40m AHD.
Sea level rise	1.00m
Wave setup	0.30m
Risk	3.70m AHD

Wave run-up is an additional 1.00m and depicted in light blue.

Assessment: Rocky beach and resistant rock cliffs in backshore. This event is very rare and therefore no impacts are likely on the backshore.

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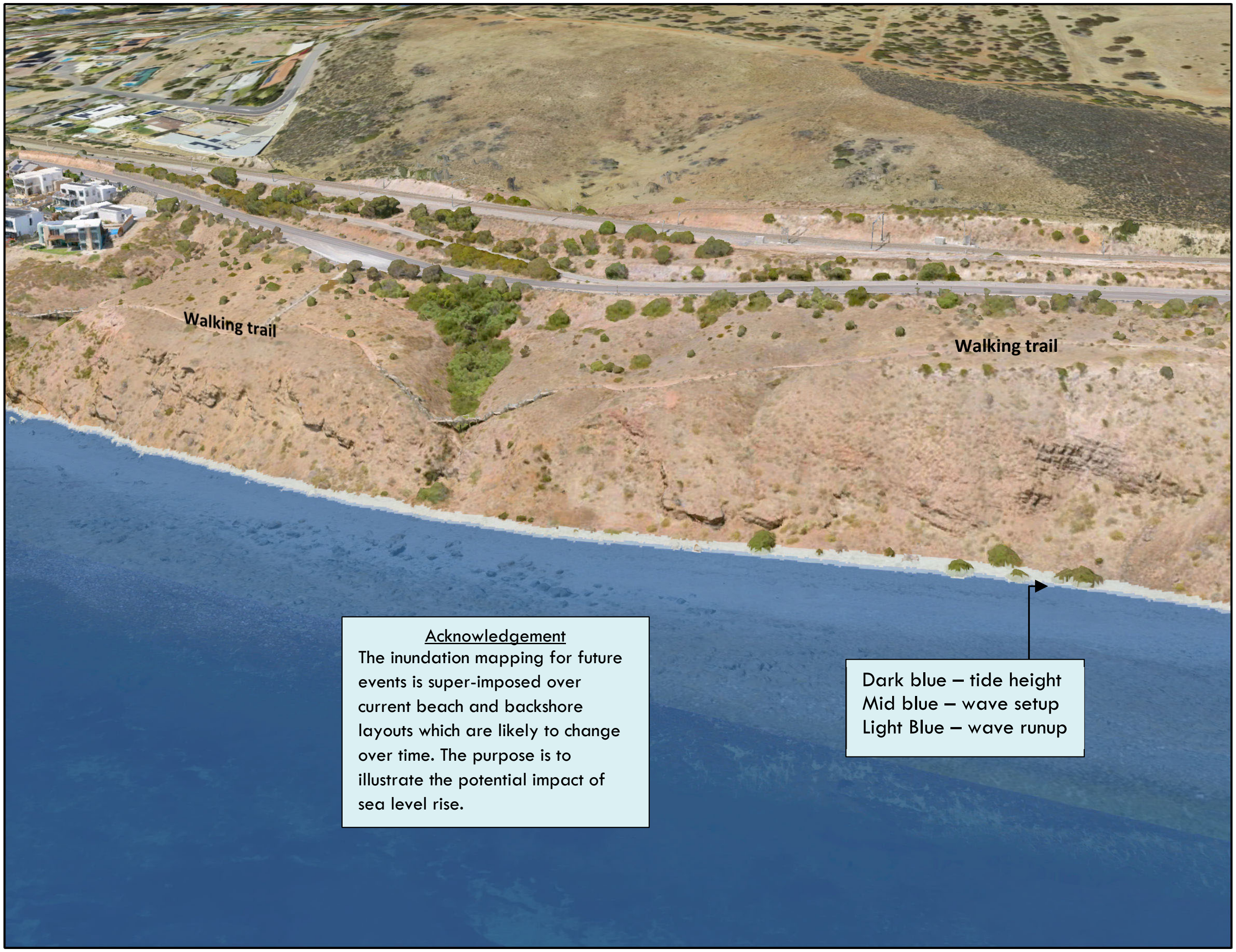

5. Coastal exposure – summary (Cell 1.5)

Summary

Cell 1.5

Marino Cliffs

Summary

The Cove Road (reserve)

2020-2050

Current impact in coastal layout of rocky beach and resistant rock cliffs is low and 0.30m of sea level rise will be unlikely to change this assessment.

2050-2100

If seas rise as projected post 2050, then there will be increased impact on the base of the cliff, especially from routine tidal events. However, these cliffs are of a resistant type. The unconsolidated material at the base of these cliffs is expected to erode away.

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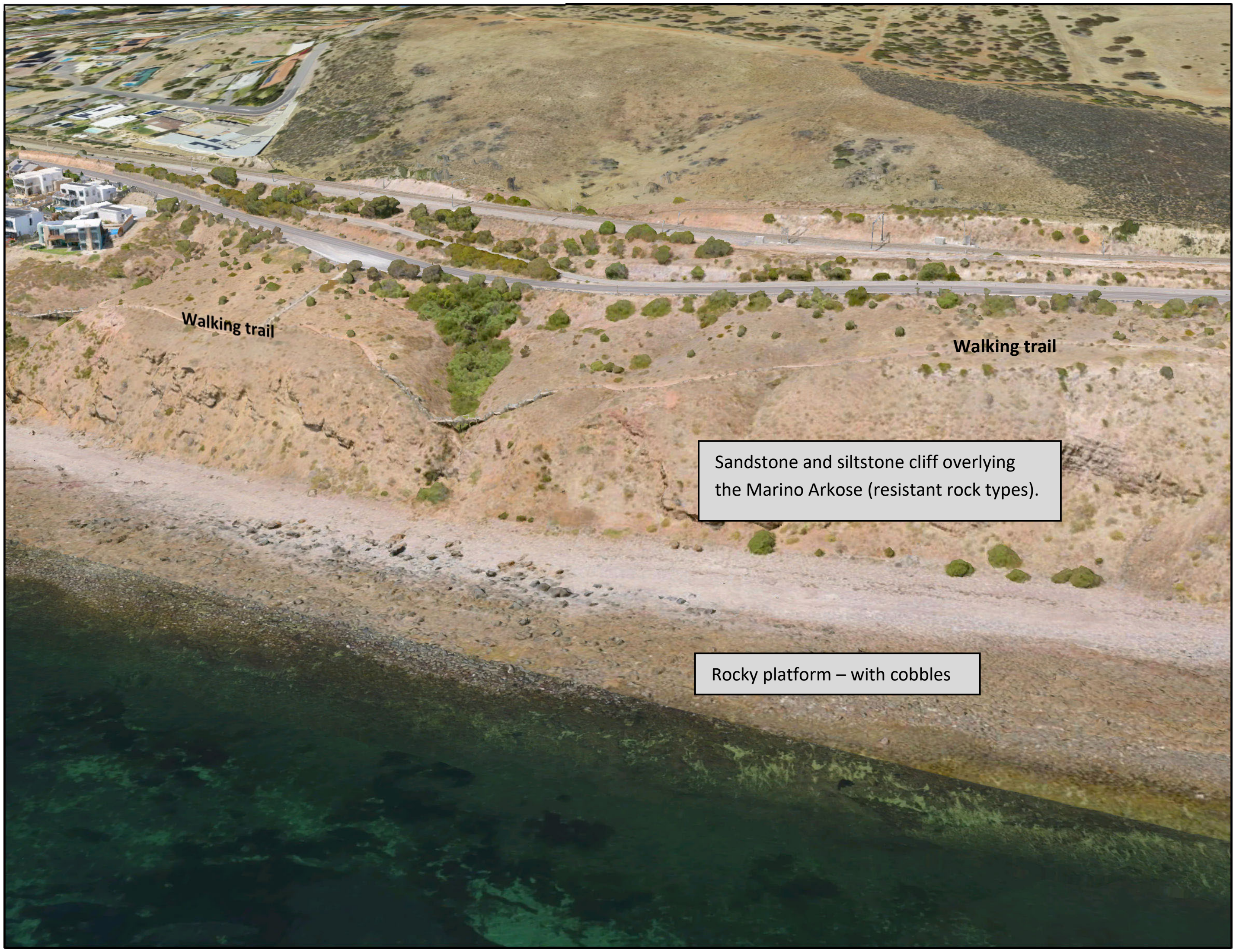
www.integratedcoasts.com

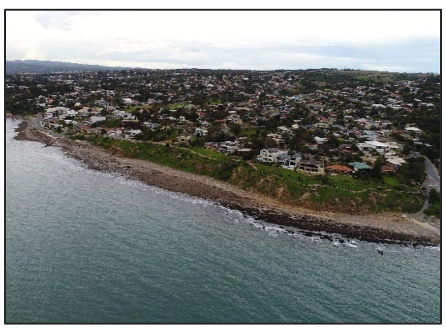


COASTAL EXPOSURE – Summary table

Marino Cliffs (Cell 1)

Marino Cliffs		Coastal context - natural				Modified	Exposure*	Scenario Modelling	
Cell	Location	Bathymetry	Benthic	Beach	Backshore	Human	Waves	2020 - 2050	2050-2100
1.1-2	Marino: The Esplanade to Emma Street	Slope: -4m at 600m offshore from The Esplanade (1:150) and 320m offshore from Marino Rocks (1:75).	Nearshore dominated by low profile reef to 300m offshore.	Rocky platform, rocky shingles below the cliffs	Cliffs from 5m in the north to 20m in the south. (Soft rock sloping cliff under Burnham Rd and Marino Rocks carpark.	Esplanade roads and carpark. Rock revetment to The Esplanade. Walking trail, boat ramp.	Moderate exposure Low wave energy	Significant storm events will overtop the rock revetment on the Esplanade. Routine tidal events are unlikely to cause significant recession to the base of cliffs.	Frequent over topping of the Esplanade is expected. Recession to the base of the clay cliff in 1.1 and undifferentiated cliff in 1.2 is likely, potentially with destabilisation of slopes.
1.3	Emma Street to Murto Road	Slope 1:75 (-4m at 250m to 320m offshore). Slope becomes steeper moving south.	Low profile reef to 100m offshore then medium seagrass bed	Rocky platform, rocky shingles below the cliffs.	Hard rock cliffs, mostly vertical.	Marine Parade positioned on top of the cliff.	Moderate exposure Low wave energy	Current impact in coastal layout of rocky beach and resistant rock cliffs is low and 0.30m of sea level rise will be unlikely to change this assessment.	Increased impact on the base of the cliff, especially from routine tidal events. However, these cliffs are of a resistant type and therefore any undercutting is likely to be slow.
1.4-5	Murto Road to Cove Road	Slope 1:70 (-4m at 250m offshore).	Low profile reef to 100mthen medium seagrass bed	Rocky shingles below the cliffs	Hard rock cliffs (1.4) and sloping cliff (1.5).	Beach access stairs. Walking trail set on top of the cliff. Houses set well back.	Moderate exposure Low wave energy	Current impact in coastal layout of rocky beach and resistant rock cliffs is low and 0.30m of sea level rise will be unlikely to change this assessment.	Increased impact on the base of the cliff slope may remove unconsolidated material at the base and cliff slope increase.

***Exposure Rating: Moderate (3)** (assigned by SA Nature Maps)



Marino Cliffs – Key Points

1.1-1.2 Rocky beach and resistant cliffs. Exceptions are under the Esplanade (Marino) and the slope under the Marino Rocks carpark. If seas rise as projected, then these can be expected to recede.

1.3 Rocky beach and resistant cliffs. Impact in the near term (2020-2050) expected to be low. If seas rise as projected, increased impact will occur on these cliffs with unknown consequences (but likely to be low due to their resistant nature).

1.4-5 Rocky beach with resistant cliffs but overlain by some unconsolidated material. Increases in sea level will cause removal of this material with likely recession.

6. Storm water runoff from urban settlement

6. Storm water runoff from urban settlement

Purpose of the study

The purpose of this study is to evaluate the impact of storm water that flows from urban areas to the coast. Large volumes of rainwater can quickly accumulate and flow from the impervious surfaces of urban settlements. Storm water flowing over softer embankments can cause gullying and instability and scouring of dunes and beaches. Over time cliffs, embankments and dunes break down and sand levels are likely to drop on the beach. In the context of sea level rise, the locations where storm water is impacting beaches and backshores may be locations where incursions of seawater occur first. Finally, in some locations the potential exists for a confluence of events where storm water and sea storms combine and produce greater levels of flooding.

Four questions are assessed in this project:

(1) Does Council manage storm water from urban settlement so that it does not flow uncontrolled over backshores and beaches?

(2) What impact is occurring on the backshores and beach due to storm water runoff?

(3) Is there any potential for increased flooding due to confluence of rain events with sea storm events?

(4) Do any storm water outlets require review[12]?

[12] In this cell, Question 4 was not relevant due to the elevated nature of backshores.

Methodology

A drone was utilised to capture photography of the City of Marion coastline after rain events to check for scouring of backshores and beaches, or debris deposits on beaches. Two captures were achieved, one in 2021 and one in 2022.

Storm water monitoring (2021)

In the last two weeks of July, rain fell on 11 out of 14 days. The rain fall for July was ~50% above the 20-year mean. Specifically, 14mm of rain fell on 31st July. No evidence of scouring or slides within cliff escarpments, nor sediment transfer to the beach was observed apart from some moderate mud staining on the beach at Hallett Cove from storm water runoff from the Conservation Park[13].

Storm water monitoring (2022)

Significant rain events occurred in early June 2022, but these have not been evaluated at the time of writing this report[14]. For example, 52mm rain fell on 5 June 2022 and 15.4mm on 6th June (Happy Valley gauge). The drone photographic capture of the whole coast was undertaken on 9th June 2022. The findings were similar to those of 2021 (see above).

[13] See Cells 1-4, Coastal Monitoring program for City of Marion, year 2021.

Storm water outlet review

On 9 and 10 June 2022 (after significant rain events), every storm water outlet that could be located was reviewed, photographed, and assessed within the GIS environment. In particular, the following items were catalogued and assessed:

1. Location of outlet (e.g. top of cliff)
2. Outlet type (e.g. 300mm pipe)
3. End control (e.g. Headwall)
4. Condition of infrastructure
5. Vegetation cover (e.g. overgrown)
6. Nature of backshore (e.g. cliff, embankment)
7. Nature of beach (e.g. rocky, sandy)
8. Impact on backshore (e.g. scouring, gullying)
9. Impact on beach (e.g. scouring, gullying)
10. Comments and recommendations.

Outputs from the study

Two main outputs are generated from this study:

- A digital file (GIS) with locations, photographs, and an attribute table for each of the storm water outlets.
- This report which provides a summary of the findings on the following pages.

[14] See Cells 1-4, Coastal Monitoring Program for City of Marion, year 2022 (not completed at date of writing).

6. Storm water runoff from urban settlement

Studies and plans

Hallett Cove Creeks Storm Water Management Plan, Southfront, 2012.

<u>Overview of the study</u>

The Hallett Cove Creeks Stormwater Management Plan (2012) produced by Southfront is a thorough investigation of the current storm water system for three catchment areas located in Cell 2 and 3, and a suggested improved management strategy.

This area of interest for this study did not include Cell 1, Marino Cliffs.

The remainder of this page intentionally left blank as a place to record any future storm water studies for this cell.

6. Storm water runoff from urban settlement

Storm water

Cell 1.1
Marino Cliffs
Storm Water
2022

1. Is storm water managed appropriately?

Storm water from urban environments drains to the beach, sometimes over cliffs.

2. What impact is occurring on the backshores and beach due to storm water runoff (if any)?

Some gullying on backshores (rated 2, moderate) but nil impact on beaches.

3. Outlets requiring review.

1.3 could not be located.
1.4 is damaged and undercut.

Integrated Coasts
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www.integratedcoasts.com

6. Storm water runoff from urban settlement

Storm water

Cell 1.2
Marino Cliffs
Storm Water
2022

Storm water outlet assessment
Jervois to Emma Street

1. Is storm water managed appropriately?

Storm water from urban environments flows to the beach by way of pipes or outlets higher in the cliff.

2. What impact is occurring on the backshores and beach due to storm water runoff (if any)?

Only minor impacts observed. Minor gullying in cliffs (1) and no impact to beaches.

3. Outlets requiring review.

1.7 Unable to locate.

Integrated Coasts
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6. Storm water runoff from urban settlement

Storm water

Cell 1.3

Marino Cliffs

Storm Water

2022

Storm water outlet assessment Emma to Murto Road

1. Is storm water managed appropriately?

Storm water flows from side entry pits across the cliffs.

2. What impact is occurring on the backshores and beach due to storm water runoff (if any)?

Storm water flowing down cliffs is not ideal, but only minor impacts were observed (in context of rain events).

3. Outlets requiring review.

Nil.

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6. Storm water runoff from urban settlement

Storm water

Cell 1.4

Marino Cliffs

Storm Water

Current design

Storm water outlet assessment
The Cove Road (Residential)

1. Is storm water managed appropriately?

Storm water flows down gully from PVC pipe at the top.

2. What impact is occurring on the backshores and beach due to storm water runoff (if any)?

Minor gullying (after significant rain events).

3. Outlets requiring review.

Nil.

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6. Storm water runoff from urban settlement

Storm water

Cell 1.5

Marino Cliffs

Storm Water

Current design

Storm water outlet assessment
The Cove Road (Reserve)

1. Is storm water managed appropriately?

Storm water is collected from Cove Road and piped under the road, draining from pipe down the gully. End of pipe not located.

2. What impact is occurring on the backshores and beach due to storm water runoff (if any)?

Minor gullying (1)

3. Outlets requiring review.

Nil.

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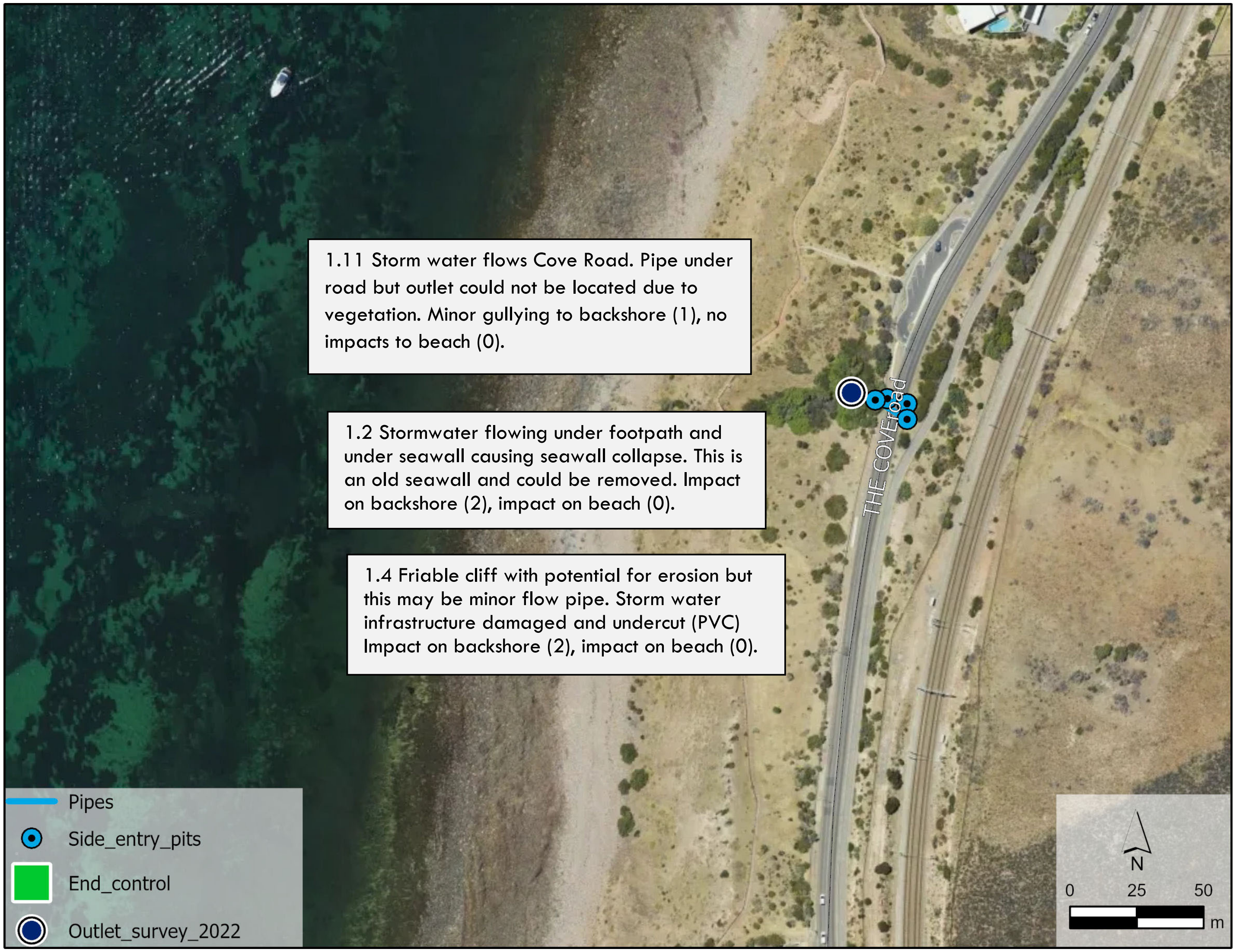
www.integratedcoasts.com



6. Storm water runoff from urban settlement

Summary of findings[15]:

1. Does Council manage the flow of storm water from urban settlement so that it does not flow uncontrolled over coastal backshores and dunes?

In a location such as Marino cliffs it is inevitable that storm water will need to drain to the coast. Storm water is usually either piped to the beach (1.5) or is collected in the road reserve and flows from the top of the cliff.

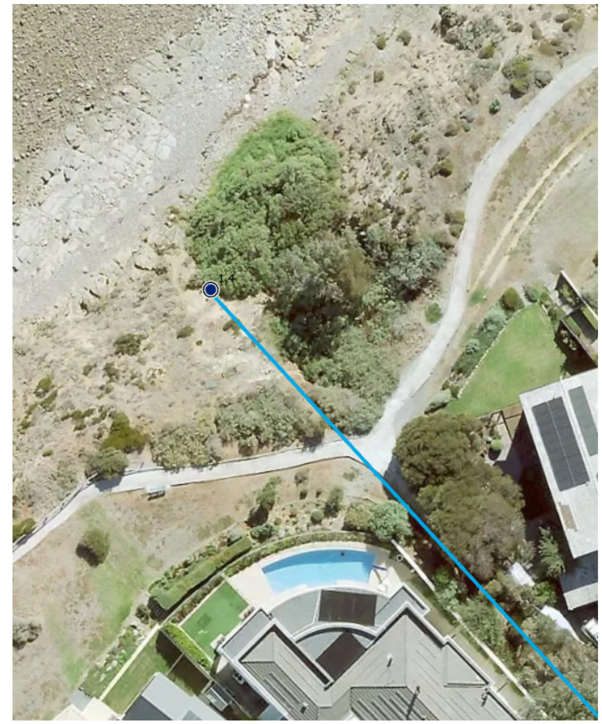
2. What impact is occurring on the beach or backshore due to storm water runoff?

The storm water outlets were reviewed after significant rains in June 2022, and only minor gullying was observed in backshores (cliffs) and no impact to the beach.

3. Do any storm water outlets require review?

1.2 Stormwater flows under footpath near art installation and flows under old concrete seawall causing it to collapse.
1.4 This is a friable cliff, but volume may be low. Piping at top is in poor repair and undercut.
1.10 May need repair to the end.

Figures (a) Stormwater flows down cliff (1.2), under footpath and under the old seawall causing it to collapse.



Figures (b) This is a friable cliff but volume of storm water may be low. Piping at the top is in poor repair and undercut.

[15] In some coastal locations whether a confluence of rain events and sea storm events could create potential for increased flooding would be considered. This cell is elevated above any risk of confluence of events.

7. HAZARD IMPACTS AND RISKS

The purpose of this section of work is to consider the inputs from the first part of the study and undertake an assessment of hazard impacts and risks within this cell. We undertake this in two steps:

1. Assign an inherent hazard rating,
2. Conduct a risk assessment utilising the risk framework of City of Marion.

7. Hazard impacts and risks

Methodology

South Australian Coast Protection Board considers three main coastal hazards: inundation, erosion, and sand drift. Only the first two are under consideration in this project as there are no assets at risk from sand drift. The assessment of hazard impacts and risks is undertaken in two main steps.

1. Assign an inherent hazard rating

It is the combination of the characteristics of the coastal fabric and the nature of the exposure that determines the degree of hazard risk. This reality is most simply understood when considering inundation risk. Whether a coast is at risk from inundation depends entirely on the topography of the coast. If we explain this another way, a low-lying coast is inherently more at risk from flooding whereas an elevated coast is inherently not at risk from flooding.

The assessment of the erosion hazard is more complex, but it is still the relationship of fabric to exposure that determines whether a coast is inherently more at risk from erosion or less at risk. A coastal fabric of granite is less at risk from erosion than a coast backed by sand dunes. In some locations the natural fabric of the coast has been altered by human intervention. For example, the Adelaide metropolitan beaches were once backed by sand dunes, but installation of rock revetment has changed the nature of the fabric to rock.

The application of an inherent risk rating does not suggest that areas rated as 'low' are entirely free from vulnerability, nor conversely that areas rated more highly are necessarily vulnerable now. The aim is to assess the underlying inherent vulnerability of the fabric of the coastal location. This assessment takes into consideration the following elements and has meaning (context) in relation to all South Australian coasts:

- The geological layout
- Sediment supply/ balance
- The erodibility of beach and backshores
- The historical analysis as to how the coastline has performed over time
- The exposure (set by Nature Maps)
- Whether any human intervention has altered the nature of the coastline.

The risk assignments range from 'low' to 'very high' and may include a 'no risk' category. For example, coastal land that is elevated above any inundation risk will be assigned 'no risk'. A dotted circle to the right of the main assignment indicates that the risk assignment requires intensifying due to unique factors, or to indicate a higher risk that does not qualify for an overall higher rating (Example, Figure a).

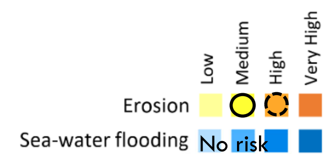


Figure a. Example of inherent risk output

7. Hazard impacts and risks

2. Conduct a risk assessment using the risk framework of City of Marion.

In this study we are primarily concerned with the way that coastal hazards may impact urban settlements over the coming century. How inundation and erosion impact human settlement will vary according to location. For example, at Hallett Cove Beach public assets are positioned in the immediate backshore, whereas at Field River some private assets directly adjoin the beach. Additionally, if seas rise as projected then seawater may flow further inland in low-lying areas and change the ecology. To evaluate public safety, how easily people may be able to retreat to a safe place is considered.

Direct impacts

In summary, while the impact of sea level rise may be somewhat uniform on a coastal region, the impact will be felt differently in the context of human experience. To bring appropriate focus, hazard impacts are described within four main receiving environments:

- Public infrastructure (assets)
- Private assets
- Public safety
- Ecosystem disruption

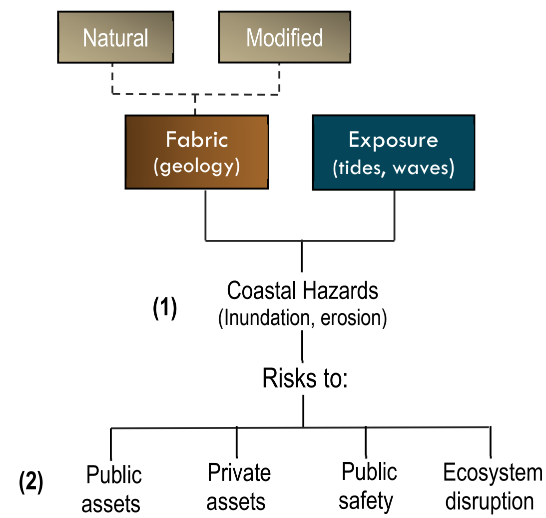
Note, the term ecosystem disruption is used to describe the situation where changes in a coastal region might bring about larger scale changes that may threaten to disrupt the entire ecological system, for example seawater flooding into freshwater ecologies.

Indirect impacts

To provide focus and contain variables, this risk assessment is confined to direct impacts upon physical receiving environments. Indirect impacts may arise because of these direct impacts. For example, the loss of a beach in some coastal locations may cause indirect impacts – loss of tourism resulting in a declining economy, and may also diminish social well-being and community pride.

This assessment utilises the Council's risk assessment framework and assessment is provided for two eras: the current era, and the 'future outlook'. In this study, future outlook means the end of this current century. This is a long-term frame, but infrastructure such as houses and roads, have long lifespans.

The overall risk assessment strategy is summarised in the diagram below (Figure a).



7-1 Inherent hazard risk assessment (SA)

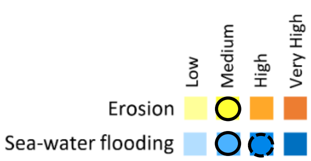
Inherent risk assessment:

Inherent risk assessments are established using set criteria outlined above that apply to the whole State of South Australia[1].

Marino – Esplanade to Jervois Tce (Cell 1.1)

Erodibility is predominately low, with exceptions under the Esplanade (upper section) Therefore, overall inherent erosion rating is medium.

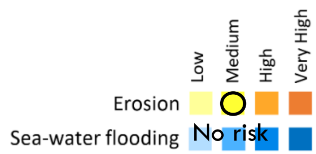
Predominantly elevated backshore is at no risk from inundation. The Esplanade overtopped in 2016 and therefore rated as medium to high risk from sea-water flooding.



Marino – Jervois Tce to Emma St (Cell 1.2)

Erodibility is predominately low, exception is the cliff slope under the Marino rocks carpark. Therefore, overall inherent erosion rating is medium.

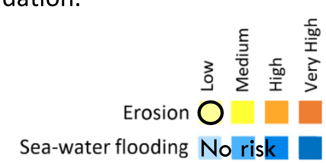
The elevated backshore is at no risk from inundation.



Marino – Emma St to Murto Rd (Cell 1.3)

Resistant rock cliffs, mostly vertical dominated by low profile offshore reef and rocky beach platform, and therefore assessed as low erodibility.

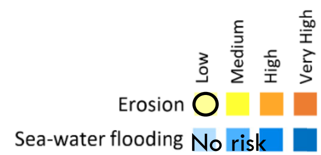
The elevated backshore is at no risk from inundation.



Marino – Cove Road (Cell 1.4-5)

Resistant sloping rock cliffs (with some unconsolidated material at the base in Cell 1.5). Dominated by low profile offshore reef and rocky beach platform, and therefore assessed as low erodibility.

The elevated backshore is at no risk from inundation.



[1] Worksheets that underpin the evaluation are available from Integrated Coasts.

7-2 Risk assessment using Council's risk framework

Risk assessment on receiving environments:

The following pages contain the risk assessments for Marino Cliffs:

- Esplanade to Jervois Terrace (Cell 1.1)
- Jervois Terrace to Emma Street (Cell 1.2
- Emma Street to Murto Road (Cell 1.3)
- Cove Road (Cell 1.4-5)

The risk assessment template draws on City of Marion risk framework, Policy RM-PRO-1.01 (v8.0) dated 25/02/2020.

Location: The Esplanade (1.1) | Erosion | **Risk assessment using Council's risk framework**

Coastal setting The Esplanade	Rock platform beach with shingles. The nearshore zone is dominated by seagrass meadow with low-profile reef in the intertidal zone. Rock revetment protects the lower section of The Esplanade. Underneath the upper section of The Esplanade is 'friable Pleistocene clay' which is more susceptible to erosion. Monitoring storm events (2021-2022) demonstrated that actions of the sea do not interact with the base of the cliff. The southern section of Marino Cliffs is more resistant rock. Private assets are set behind the Esplanade Road or the walking trail.

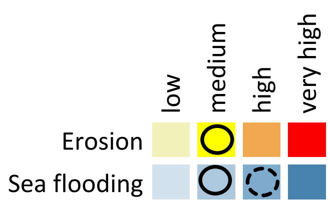
Risk identification: The cliff slope underneath the Esplanade (upper section) contains more friable material.

Current risk mitigation: Rock revetment along the lower section of The Esplanade.

Receiving environment	Risk description	Time	Likelihood	Consequence	Risk
Public infrastructure	The Esplanade, walking trail, and coastal furniture and installations. Rock revetment protects the Esplanade (fair condition). The section of cliff under the Esplanade (upper section) and portion of the walking trail contains friable material.	2020	*rare*	*moderate*	low
		2100	*possible*	*major*	high
Private assets*	Private properties are situated landward of roads and the walking trail. If seas rise as projected in the second half of the century, private properties may become vulnerable, but this is unlikely given the nature of the geology.	2020	*no risk*	*no risk*	no risk
		2100	*rare*	*major*	medium
Public safety	The public use the footpaths, roads and walking trails. This assessment assumes that people remain on these surfaces. This assessment relates to erosion risk and does not relate to the structural stability of the walking trail..	2020	*rare*	*insignifcant*	Low
		2100	*unlikely*	*minor*	low
Ecosystem disruption	The coastal setting is rocky beach and predominantly hard rock cliff backshores. Ecosystem disruption is not anticipated from rising sea levels.	2020	*no risk*	*no risk*	no risk
		2100	*no risk*	*no risk*	no risk

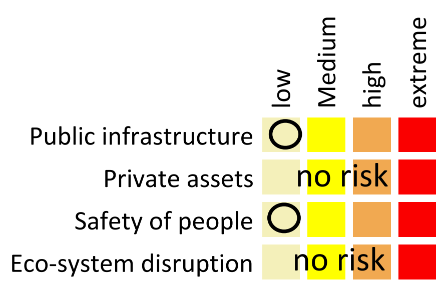
Inherent hazard rating

Inherent vulnerability



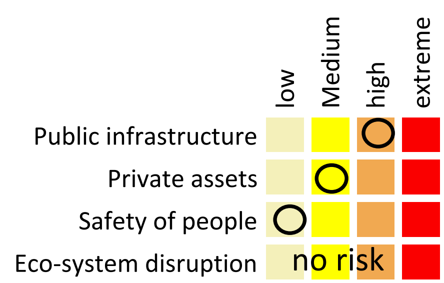
Erosion hazard rating

Current Outlook 2022



Erosion hazard rating

Future Outlook 2100



Assumptions

Rain water events have not been assessed in this project.

The assignment of future risks assumes that seas rise as projected and that no adaptation responses are employed.

*Governments are not necessarily liable for private assets.

Location: The Esplanade (1.1)

Inundation

Risk assessment using Council's risk framework

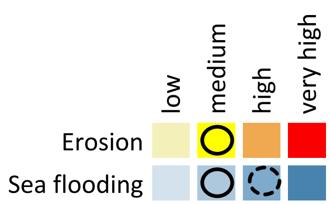
Coastal setting	This inundation assessment relates only to the lower section of The Esplanade on the northern border of Council. Beach is rocky platform with shingles. The remainder of the coastline south of the coastal artwork is elevated well above actions of the sea. Minor overtopping occurred on the Esplanade in the event of 9 May 2016. Any rises in sea level will exacerbate the overtopping and inundation of the road.

Risk identification: Minor overtopping occurred on the Esplanade in event 9 May 2016. Increases in sea levels will exacerbate the risk.

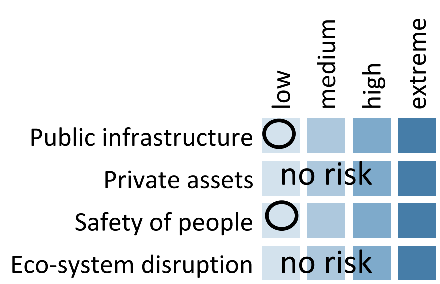
Current risk mitigation: Rock revetment has been installed along this section of roadway.

Receiving environment	Risk description	Time	Likelihood	Consequence	Risk
Public infrastructure	The Esplanade, foorpath, coastal furniture and art installation. Minor overtopping occurred on 9 May 2016. Sea level rise will exacerbate this risk. The surfaces are mostly hard concrete and water is likely to drain quickly.	2020	*rare*	*minor*	low
		2100	*likely*	*moderate*	high
Private assets*	Private properties are situated landward of the roads and waking trail and currently not at risk from inundation. If seas rise as projected, private properties along the Esplanade may be impacted but this is unlikely and impact low.	2020	*no risk*	*no risk*	no risk
		2100	*unlikely*	*minor*	low
Public safety	People use roads, footpaths and walking trails and this risk assessment assumes that they remain on these surfaces. Increased overtopping as a result of projected sea level rise will increase risk to safety (but these can be mitigated with controls).	2020	*rare*	*minor*	Low
		2100	*possible*	*minor*	medium
Ecosystem disruption	Rocky beach and intertidal zone. Backshore is rock revetment. No broad scale ecosystem disruption is anticipated due to sea level rise.	2020	*no risk*	*no risk*	no risk
		2100	*no risk*	*no risk*	no risk

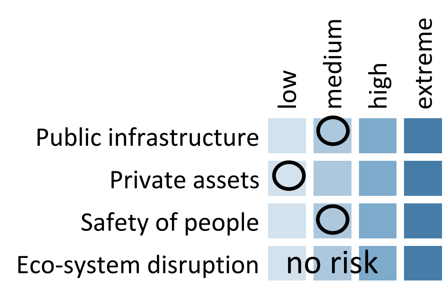
Inherent hazard rating
Inherent vulnerability



Inundation hazard rating
Current Outlook 2022



Inundation hazard rating
Future Outlook 2100



Assumptions

Rain water events have not been assessed in this project.

The assignment of future risks assumes that seas rise as projected and that no adaptation responses are employed.

*Governments are not necessarily liable for private assets.

Location: Jervois Tce to Emma St (1.2)

Erosion

Risk assessment using Council's risk framework

Coastal setting Jervois Tce to Emma St	Rock platform beach with shingles. The nearshore zone is dominated by seagrass meadow with some low-profile reef in the intertidal zone. Cliffs in this location are more resistant Neo-Proterozoic siltstone but under the Marino Rocks carpark is undifferentiated material, which was scarped in the event of 9 May 2016. Storm monitoring (2021-2022) demonstrated that moderate storm events do not impact the base of this slope. It is more likely to be only impacted in larger events (perhaps 1 in 10 year).

Risk identification: The slope underneath the Marino Rocks carpark and Marine Parade consists of friable material, storm event 9 May 2016 impacted.

Current risk mitigation: Nil

Receiving environment	Risk description	Time	Likelihood	Consequence	Risk
Public infrastructure	Marine Parade and Marino Rocks carpark. Erosion has occurred at the base of Marino Rocks Carpark. Recent storm assessment indicates that this is a rare event.	2020	*rare*	*moderate*	low
		2100	*possible*	*major*	high
Private assets*	Private properties are situated landward of roads. If seas rise as projected in the second half of the century, private properties may become vulnerable, but this is unlikely given the nature of the geology.	2020	*no risk*	*no risk*	no risk
		2100	*rare*	*major*	medium
Public safety	The public use the footpaths, roads and walking trails. This assessment assumes that people remain on these surfaces. This assessment relates to erosion risk and does not relate to the structural stability of the walking trail..	2020	*rare*	*insignifcant*	Low
		2100	*unlikely*	*minor*	low
Ecosystem disruption	The coastal setting is rocky beach and predominantly hard rock cliff backshores. Ecosystem disruption is not anticipated from rising sea levels.	2020	*no risk*	*no risk*	no risk
		2100	*no risk*	*no risk*	no risk

Inherent hazard rating

Inherent vulnerability

	low	medium	high	very high
Erosion		○		
Sea flooding	no risk			

Erosion hazard rating

Current Outlook 2022

	low	Medium	high	extreme
Public infrastructure	○			
Private assets	no risk			
Safety of people	○			
Eco-system disruption	no risk			

Erosion hazard rating

Future Outlook 2100

	low	Medium	high	extreme
Public infrastructure			○	
Private assets		○		
Safety of people	○			
Eco-system disruption	no risk			

Assumptions

Rain water events have not been assessed in this project.

The assignment of future risks assumes that seas rise as projected and that no adaptation responses are employed.

*Governments are not necessarily liable for private assets.

Location: Emma St to Murto Rd (1.3) | Erosion | **Risk assessment using Council's risk framework**

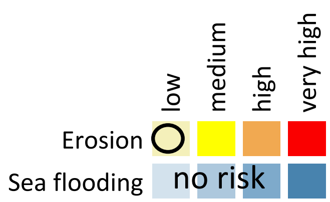
Coastal setting Emma St to Murto Rd	Predominantly hard rock vertical cliffs (Neo-Proerozoic Marino Arkose, in some places over lain by Wilmington Formation) that are resistant to erosion, dominated by low profile offshore reef and rocky beach platform, and therefore assessed as low erodibility. Sea flood modelling demonstrates that seas are routinely interacting with the base of the cliffs which will increase if seas rise as projected. However, these cliffs are resistent to erosion. Marine Parade is set close to the top of the cliff and private property landward of the road.

Risk identification: Actions of the sea currently interact with the relatively resistant base of the cliffs. Increases of sea level may increase rate of erosion.

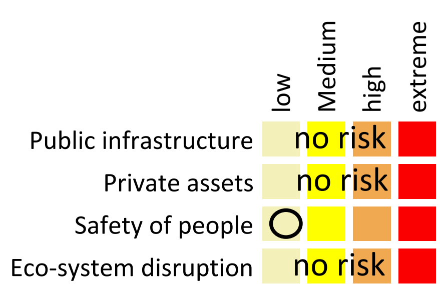
Current risk mitigation: Nil.

Receiving environment	Risk description	Time	Likelihood	Consequence	Risk
Public infrastructure	Marine Parade and associated road infrastructure. Not likely to be impacted in the short term (2050) and unknown how stable the cliffs would be with more constant wave attack at the base (but likely, stable).	2020	*no risk*	*no risk*	no risk
		2100	*rare*	*severe*	medium
Private assets*	Private properties are situated landward of roads and the walking trail. It is unlikely that private properties would be directly impacted but could be impacted by secondary issue of road access.	2020	*no risk*	*no risk*	no risk
		2100	*rare*	*severe*	medium
Public safety	The public use the footpaths, roads and walking trails. This assessment assumes that people remain on these surfaces. This assessment relates to erosion risk and does not relate to the structural stability of the walking trail..	2020	*rare*	*moderate*	low
		2100	*rare*	*moderate*	low
Ecosystem disruption	The coastal setting is rocky beach and predominantly hard rock cliff backshores. Ecosystem disruption is not anticipated from rising sea levels.	2020	*no risk*	*no risk*	no risk
		2100	*no risk*	*no risk*	no risk

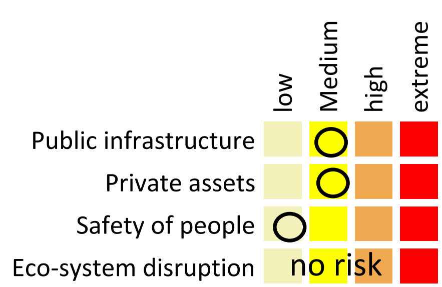
Inherent hazard rating
Inherent vulnerability



Erosion hazard rating
Current Outlook 2022



Erosion hazard rating
Future Outlook 2100



Assumptions

Rain water events have not been assessed in this project.

The assignment of future risks assumes that seas rise as projected and that no adaptation responses are employed.

*Governments are not necessarily liable for private assets.

Location: Cove Road 1.4-5 Erosion **Risk assessment using Council's risk framework**

Coastal setting Cove Road	Predominantly hard rock vertical cliffs (Neo-Proerozoic Marino Arkose) that are resistant to erosion, dominated by low profile offshore reef and rocky beach platform, and therefore assessed as low erodibility. Sea flood modelling demonstrates that seas are routinely interacting with the base of the cliffs which will increase if seas rise as projected. However, these cliffs are resistent to erosion. The walkin trail is positioned on top of the cliff, there is no esplanade road, and private property is set well back from the coast (20 to 40m).

Risk identification: Actions of the sea currently have low interaction with the backshore. This interaction will increase if seas rise as projected.

Current risk mitigation: Nil.

Receiving environment	Risk description	Time	Likelihood	Consequence	Risk
Public infrastructure	Walking trail set near the top of the cliff slope.	2020	*no risk*	*no risk*	no risk
		2100	*no risk*	*no risk*	no risk
Private assets*	Private dwellings are set well back from the cliff (20 to 40m).	2020	*no risk*	*no risk*	no risk
		2100	*no risk*	*no risk*	no risk
Public safety	This assessment assumes that people remain on official walking surfaces. While not strictly an erosion risk, rising sea levels will mean that people will be more prone to be 'caught' by tides at the base of the cliff if they use the access stairs.	2020	*rare*	*moderate*	low
		2100	*rare*	*moderate*	medium
Ecosystem disruption	The coastal setting is rocky beach and predominantly hard rock cliff backshores. Ecosystem disruption is not anticipated from rising sea levels.	2020	*no risk*	*no risk*	no risk
		2100	*no risk*	*no risk*	no risk

Inherent hazard rating
Inherent vulnerability

	low	medium	high	very high
Erosion	○			
Sea flooding	no risk			

Erosion hazard rating
Current Outlook 2022

	low	Medium	high	extreme
Public infrastructure		no risk		
Private assets		no risk		
Safety of people	○			
Eco-system disruption		no risk		

Erosion hazard rating
Future Outlook 2100

	low	Medium	high	extreme
Public infrastructure		no risk		
Private assets		no risk		
Safety of people		○		
Eco-system disruption		no risk		

Assumptions

Rain water events have not been assessed in this project.

The assignment of future risks assumes that seas rise as projected and that no adaptation responses are employed.

*Governments are not necessarily liable for private assets.

8. Cell summary and recommendations

This cell report is designed to be reviewed and updated over time so that the baseline data is continually brought forward and modified to reflect any changes in the coastal system. This part of the report contains three main parts:

- Summary – a snapshot of the state of the coastal system at the date of writing.
- Overview of adaptation options and strategies.
- Recommendations – a review of recommendations from the prior study and a list of amended recommendations for the future.

8.1 Summary – Marino Cliffs (Cell 1.1)

Esplanade to Jervois Tce

Coastal setting

Rock platform beach with shingles. The nearshore zone is dominated by seagrass meadow with low-profile reef in the intertidal zone. Rock revetment protects the lower section of The Esplanade. Underneath the upper section of The Esplanade is 'friable Pleistocene clay' which is more susceptible to erosion. Monitoring storm events (2021-2022) demonstrated that actions of the sea do not interact with the base of the cliff. The southern section of Marino Cliffs is more resistant rock. Private assets are set behind the Esplanade Road or the walking trail.

Coastal fabric – changes to beaches and backshores

Land based and aerial photography indicate that there have been minimal changes to the beach and backshores over last one hundred years due to the rocky nature of the coast. No new rock falls were observed.

Coastal exposure – sea level rise, storms, and projections.

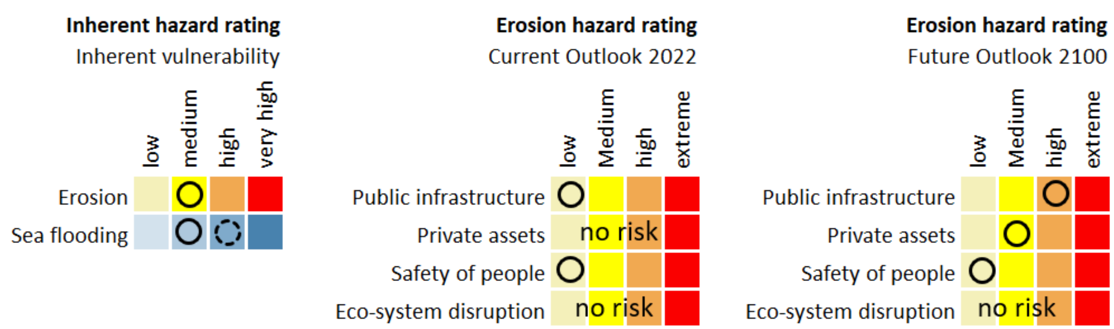
The rate of sea level rise remains relatively low at 3-4mm in this region. The event of 9 May 2016 overtopped the Esplanade, but storms monitored over the last 2 years had low impact. Sea levels 0.3m higher (2050) are likely to impact the base of the slopes under the Esplanade (upper section), and these will be further impacted if sea level rises as projected in the second half of this century.

Storm water runoff – impacts in the coastal zone

Stormwater is generally collected within the road reserves and either piped to the beach or flows down cliffs and slopes. Many of the outlets have no end controls but an inspection of outlets after significant rain events in June 2022 found that there was only minor gullying impact in backshores and no impacts to the beach.

Overview of Impacts and risk assessment

Current impact on the coast by actions of the sea is low due to the rocky nature of this location. Large storm events such as 9 May 2016 will overtop the Esplanade. Actions of the sea do not appear to be impacting the base of the friable cliff under the Esplanade (upper section), but rising seas is likely to increase this risk, and may place the Esplanade (upper section) at risk.



8.1 Summary – Marino Cliffs (Cell 1.2)

Jervois Tce to Emma Street

Coastal setting

Rock platform beach with shingles. The nearshore zone is dominated by seagrass meadow with some low-profile reef in the intertidal zone. Cliffs in this location are more resistant Neo-Proterozoic siltstone but under the Marino Rocks carpark and Marine Parade is undifferentiated material, which was scarped in the event of 9 May 2016. Storm monitoring (2021-2022) demonstrated that moderate storm events do not impact the base of this slope. It is more likely to be only impacted in larger events (perhaps 1 in 10 year).

Coastal fabric – changes to beaches and backshores

Land based and aerial photography indicate that there have been minimal changes to the beach and backshores over last one hundred years due to the rocky nature of the coast. No new rock falls were observed.

Coastal exposure – sea level rise, storms, and projections.

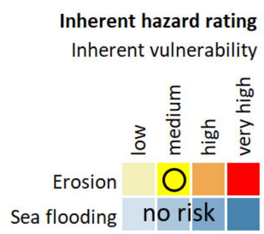
The rate of sea level rise remains relatively low at 3-4mm in this region. The event of 9 May 2016 scarped the base of the cliff under the carpark, but storms monitored over the last 2 years had low impact. Sea levels 0.3m higher (2050) are likely to scarp the base of the cliff more routinely, and this is likely to be significantly undercut and destabilised if sea level rises as projected in the second half of this century.

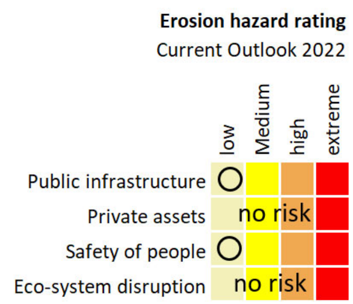
Storm water runoff – impacts in the coastal zone

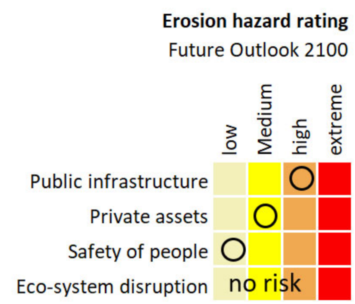
Stormwater is generally collected within the road reserves and either piped to the beach or flows down cliffs and slopes. The storm water outlet has concrete headwall and riprap end control. No impacts were observed on the beach after significant rain events.

Overview of Impacts and risk assessment

Current impact on the coast by actions of the sea is low due to the rocky nature of this location. Large storm events such as 9 May 2016 cause scarping at the base of the cliff. Any increases in sea level will increase the risk of scarping, and if seas rise as projected in the latter part of the century, then major undercutting is likely which would put the carpark and road at risk.







8.1 Summary – Marino Cliffs (Cell 1.3)

Emma Street to Murto Road

Coastal Setting

Predominantly hard rock vertical cliffs that are resistant to erosion, dominated by low profile offshore reef and rocky beach platform, and therefore assessed as low erodibility. Sea flood modelling demonstrates that seas are routinely interacting with the base of the cliffs which will increase if seas rise as projected. However, these cliffs are resistant to erosion. Private assets are set landward of Marine Parade which is positioned at the top of the cliff in some places, on the edge.

Coastal fabric – changes to beaches and backshores

Land based and aerial photography indicate that there have been minimal changes to the beach and backshores since 1949 due to the rocky nature of the coast. No new rock falls were observed.

Coastal exposure – sea level rise, storms, and projections.

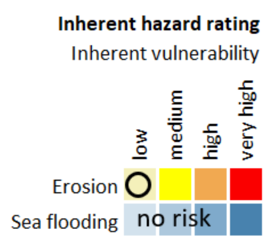
The rate of sea level rise remains relatively low at 3-4mm in this region. Storm monitoring show that actions of the sea regularly interact with these cliffs, but they are resistant to erosion. Sea levels 0.30m higher than present (2050) are unlikely to cause instability, but seas 1.00m higher than present may (2100). In reality the impact is unknown.

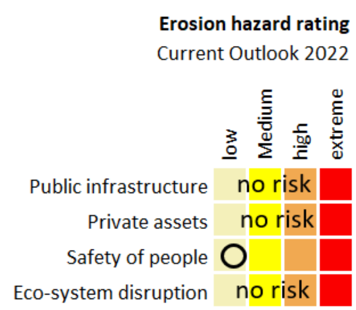
Storm water runoff – impacts in the coastal zone

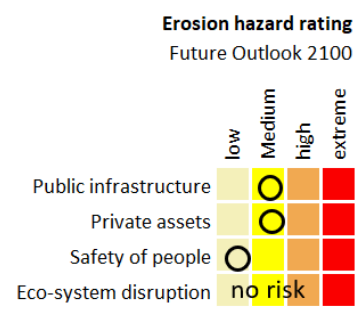
Stormwater is generally collected within the road reserves and either piped to the beach or flows down cliffs and slopes. Many of the outlets have no end controls but an inspection of outlets after significant rain events in June 2022 found that there was only minor gullying impact in backshores and no impacts to the beach.

Overview of Impacts and risk assessment

Current impact on the coast by actions of the sea is low due to the rocky nature of this location. Seas 0.30m higher than present is unlikely to cause instability, but seas 1.00m higher may (but this is unknown) The main risk is to Marine Parade, and possible loss of access to private residences if this was required to be closed.







8.1 Summary – Marino Cliffs (Cell 1.4-5)

Murto Road to Cove Road
Coastal Setting

Hard rock vertical cliffs in Cell 1.4 that are resistant to erosion and sloping cliffs in Cell 1.5, with some unconsolidated material at their base. Rocky beach platform and low-profile offshore reef. The walking trail is positioned on top of the cliff, there is no esplanade road, and private property (Cell 1.4) is set well back from the coast (20 to 40m). There are no private assets in Cell 1.5. Beach access stairs are positioned in the vicinity of Murto Road to provide pedestrian access to the beach.

Coastal fabric – changes to beaches and backshores

Land based and aerial photography indicate that there have been minimal changes to the beach and backshores since 1949 due to the rocky nature of the coast. No new rock falls were observed.

Coastal exposure – sea level rise, storms, and projections.

The rate of sea level rise remains relatively low at 3-4mm in this region. Storm monitoring show that actions of the sea regularly interact with cliffs in Cell 1.4 but they are resistant. Sea levels 0.30m higher than present are unlikely to cause instability, but seas 1.00m higher than present may. In reality the impact is unknown.

Storm water runoff – impacts in the coastal zone

Stormwater is generally collected within the road reserves and either piped to the beach or flows down cliffs and slopes. Many of the outlets have no end controls but an inspection of outlets after significant rain events in June 2022 found that there was only minor gullying impact in backshores and no impacts to the beach.

Overview of Impacts and risk assessment

Current impact on the coast by actions of the sea is low due to the rocky nature of this location. Seas 0.30m higher than present is unlikely to cause instability, but seas 1.00m higher may (but this is unknown). Public assets are relatively minor including access stairs and walking trail. In the context of rising sea levels, pedestrians accessing the beach may be more prone to be 'caught' by incoming tides.

Inherent hazard rating
Inherent vulnerability

	low	medium	high	very high
Erosion	O			
Sea flooding	no risk			

Erosion hazard rating
Current Outlook 2022

	low	Medium	high	extreme
Public infrastructure	no risk			
Private assets	no risk			
Safety of people	O			
Eco-system disruption	no risk			

Erosion hazard rating
Future Outlook 2100

	low	Medium	high	extreme
Public infrastructure	no risk			
Private assets	no risk			
Safety of people		O		
Eco-system disruption	no risk			

8-2 Overview of adaptation options and strategies

Adaptation options and strategies

An overview of adaptation approaches is provided on this page to provide context to the recommendations. There are generally six categories of adaptation options:

1. **Avoidance** – Avoid the impacts of coastal hazards by ensuring that assets are not placed in vulnerable locations.
2. **Hold the line** – Install protection infrastructure that reduces the impact of coastal hazards or use environmental practices to strengthen natural protective forms such as dunes.
3. **Accommodate** – Accept some degree of hazard and conduct limited intervention to manage the hazard (for example, in areas that may be subject to inundation, raise houses on poles).
4. **Managed retreat** – Progressively move assets or services away from areas that could be impacted by coastal hazards now or in the future.
5. **Monitor** – monitor the coast and use the data to form future strategies.
6. **Loss acceptance** - Accept that coastal hazards will cause negative impacts on assets and services and when this occurs, they will not be replaced.

Adaptation responses

Within the adaptation options there are a range of potential adaptation responses.

Planning

Planning responses are options that use planning legislation and regulations to reduce vulnerability and increase resilience to climate change and sea-level rise. For example, dwellings and sites required to be positioned at higher elevation or set back from the coastline.

Engineering

In the context of climate change adaptation 'engineering' has come to describe adaptation options that make use of capital works such as seawalls and levees. Such projects are 'engineered' to solve a particular challenge such as to protect coastal infrastructure from erosion and inundation.

Environmental management

Environmental management includes habitat restoration and enhancement through activities such as revegetation of coastal dunes or building structures to support growth of habitat such as seagrasses. It may also include sand nourishment to replace sand that has been lost from the beach system.

Adaptation timing

There are two broad ways in which adaptation can occur in relation to timing.

Incremental approach

A series of relatively small actions and adjustments aimed at continuing to meet the existing goals and expectations of the community in the face of the impacts of climate change.

Transformative approach

In some locations, incremental changes will not be sufficient. The risks created by climate change may be so significant that they can only be addressed through more dramatic action. Transformational adaptation involves a paradigm shift: a system-wide change with a focus on the longer term. A transformative approach may be triggered by an extreme event or a political window when it is recognised the significant change could occur.

Adaptation strategy (Cell 4)

Due to the elevated and rocky nature of this section of coastline, the adaptation strategy will fall into options ***(1) Avoid*** and ***(5) Monitor*** with an incremental approach over time.

8-3 Recommendations – Marino Cliffs

Recommended actions from 2018

The recommendations from the Coastal Adaptation Study of 2018 are listed below with reviews in the right-hand column.

	Action	Comments	Time Frame	Review 2022
1	Review nature of storm water outflows and assess impacts	Storm water drains into gullies. Undertake routine inspections of the outfall areas. Recommend that staff incorporate review of scouring impacts (use photography).	1-2 years	A two-year monitoring program was completed 2021-2022. Storm water impacts were reviewed using drone photography (2 rain events) and onsite inspection after rain events in June 2022. The findings of these studies are included in this report.
2	Quantify more accurately the nature of routine and storm surge interaction with cliff base.	Monitor tidal regime for period of three months (winter). Monitor impact of storm surge events (if, and when they occur)	1-2 years	A two-year monitoring program (2021-2022) monitored 5 storm events along the coast. Seaweed strands observed using drone photography and surveyed in Cells 1.1,2. In the context of a review of the tide gauge data from Outer Harbor, these inputs were used to generate routine tidal monitoring to a higher degree of accuracy and included in this report. This has quantified the nature of routine and storm surge interaction with the base of the cliff as of low impact.
3	Recapture digital model as basis for comparison.	Use appropriate software to quantify changes in the coastal environment.	3-5 years	This action is recommended for 2023.
4	Assess protection options for the Esplanade.	Rock revetment is in poorer condition than that within adjacent Holdfast Bay.	1-2 years	Unknown if this has been assessed.
5	Quantify more accurately the nature of the cliff below Marine Parade and the carpark.	The cliff escarpment appears stable at the moment, but due to the proximity of the public assets, the nature of the cliff should be further quantified.	3-5 years	Preliminary enquiries were made and it was found that only limited avenues were available (e.g. ground penetrating radar). The storm studies of the last two years has demonstrated that the base of the cliff is not under routine attack, and is only likely to be impacted by very rare events which as one off events will have low impact. Suggest not to bring this recommendation forward.

8-3 Recommendations – Marino Cliffs

Recommended actions 2022 to 2027 (five years)

This review and upgrade to the Coastal Adaptation Study (2018) and the City of Marion Coastal Monitoring Project provide the basis for the following recommendations in Cell 1. The summary at 8.1 above provides the immediate context for the recommendations.

	Action	Methodology	Time Frame
1	Incorporate the findings of the CoM coastal monitoring program (2021-2022) into this report.	This report represents an upgrade from the Coastal Adaptation Study (2018) by including tasks that were not included in the 2018 project and an upgrade to the format. This has coincided with the conclusion of the first two years of the CoM coastal monitoring project. Some of the findings from the monitoring project inform this upgrade, but they have not been formally integrated with this report.	2023
2	Recapture the digital model as a basis for comparison with 2018 capture.	Use appropriate software to quantify changes in the coastal environment. This is likely to be the most effective way to assess changes in cliff environments.	2023
3	Assess adaptation options for the Esplanade (overtopping)	This item is brought forward from 2018. Recommended that an options analysis be undertaken which can include, monitor, and any further actions could be deferred.	2023
4	Monitor changes in beaches and backshores.	Use aerial photography obtained every three months by City of Marion to assess changes to beaches and backshores. This could be done as an annual operation using 4 captures. In particular, identify locations of any new rock falls, slumps or landslides.	Annual (ongoing) (2023-2027)
5	Monitor the impact of moderate storm events, either rain or sea storm (2-3 per year).	Use the Coast Snap photo point to photograph storm events at the base of the Marino Rocks carpark. Use drone photography after storm events. For sea-storm events, monitor the location of seaweed strands in relation to the base of cliffs and any impacts to backshores. For rain events, monitor for any scouring of the backshores and beaches. For both events monitor for slumps, slides and falls in cliff environments. (Note, no survey).	Annual (ongoing) (2023-2027)
6	Assess the impact of any major sea storm.	Identify a suitable tidal benchmark at Outer Harbor to qualify as a major sea storm (for example, 1 in 2 year event). Inspect and survey the seaweed strands and update modelling parameters if required. Note, the proposals for task (4) and (5) simplify some of the current storm monitoring and therefore reduce cost, but still maintains the ability to track more significant storms which will be required in the context of rising sea levels.	As required (likely 3-5 in a five-year period).

7	Monitor the rate of sea level rise in Gulf St Vincent.	It is recognised that this action is not within the direct scope of City of Marion. However, periodic reviews are being done by others (e.g. Watson, 2020) and simple tools now exist at www.sealevel.info. It is recommended that when opportunities exist, City of Marion lobby for improved sea level monitoring in Gulf St Vincent (e.g. additional gauges, tracking vertical land movement). The reason for this action is that currently the rate of sea level rise is relatively low (3-4mm per year) whereas projections for the latter half of the century are high (10-15mm per year). An escalation in the rate at tide gauges will provide an early warning that these projections are being realised.	2023-2027