Coastal Adaptation Study

Murray Mouth to Boomer Beach

For Alexandrina Council

PART 1: Main Report

Western, Hesp, Bourman

November 2020

Integrated Coasts

Permissions

Citations

This document and the individual cell reports should be cited as:

Western, M, Hesp, P, Bourman, R 2019, Coastal Adaptation Study for Alexandrina Council, Integrated Coasts, South Australia

Front Cover

Horseshoe Bay, photographed by Coastal Management Branch, Department for Environment and Water in 2008.

Document Control

Report number	Version	Released	Approved
20181028_coastal_alexandrina	V.1 Draft		
20181206_coastal_alexandrina	V2 Draft	20181207	MW
20190826_coastal_alexandrina	V3 Draft		
20191101_coastal_alexandrina	V4 Draft	20191112	MW
20191214_coastal_alexandrina	V5 Draft	20191215	MW
20200110_coastal_alexadrina	V6 Final	20200114	MW

Contents

Executive Summary

Introduction

Alexandrina Council (the Council) engaged Integrated Coasts in March 2018 to produce a coastal adaptation study for the length of its coastline from Chiton Rocks to Goolwa Beach. The coastal border of the Council is situated further east than Goolwa Beach but work by others has shown that even in worse case scenarios the Young Husbandman Peninsula is not predicted to erode by 2100[1]. Two additional areas were added to the study within the Murray River estuary. The first of these was Beacon 19 boat ramp where Council required an understanding of the likely impact of sea level rise upon the access road to the ramp. The second of these was Sugars Beach where a proposed tourist upgrade is under consideration. Alexandrina Council added the settlement of Mundoo Channel to the project scope in March 2019 and the settlements within the Goolwa Channel downstream of the Goolwa barrages was added to the project scope in July 2019. The barrages and areas of water upstream of the barrages were excluded from this study because there are additional stakeholder interests at both Federal and State Government levels.

One area of difficulty with the study was the lack of data for wave set-up and wave run-up at locations other than Horseshoe Bay. A storm event on 22 November 2018 provided an opportunity to survey seaweed strands along the coast and identify the wave effects at most locations. However, no data was found at Chiton Rocks and this location was removed from the scope of works.

The main purposes for the study was to:

- Identify public and private assets at current and future risk of erosion and inundation, and
- Identify and identify potential adaptation strategies for the coastline of Alexandrina and within the Murray Estuary.

The full extent of Alexandrina Council's coastal borders and the location of Goolwa and Mundoo Channels is depicted in Figure 1.

Figure 1: Scope of works - The coast and estuarine environments within Alexandrina Council boundaries

[1] https://coastadapt.com.au/sites/default/files/docs/sediment_compartments/SA01.02.01.pdf

Document structure

The report is structured in two main sections. Part 1 reports the methodology utilised in the study and the coastal issues that are common to the entire coastline. Part 2 of the study creates stand-alone reports for the nine coastal conservation cells within Alexandrina Council as depicted in Nature Maps[2]. This reporting methodology ensures that relevant information is readily accessible for any coastal location without the requirement of reading a lengthy report. This document represents Part 1 of the study.

The eight reports that compile Part 2 are:

- The Murray Estuary settlements (Cells SF1-SF2)
- Goolwa Beach (Cells SF3-SF4)
- Middleton Beach (Cell SF5)
- Middleton Creek (Cell SF6)
- Ratalang-Basham (Cell SF7)
- Port Elliot – Horseshoe Bay (Cell SF8)
- Port Elliot – Green Bay and Crockery Bay (Cell SF8)
- Boomer-Knights Beach (Cell SF9)

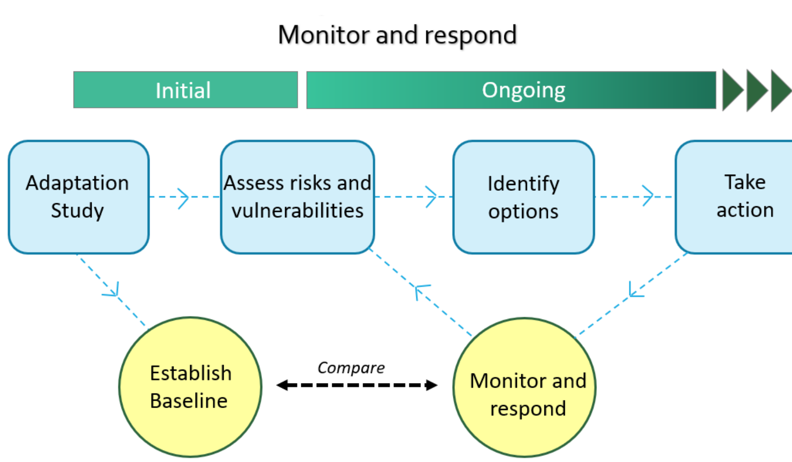
Model of coastal adaptation

Integrated Coasts has adopted three broad principles of adaptation:

- Coastal adaptation takes place in localities (and therefore analysis is required to be fine-grained within secondary and tertiary coastal cells),
- Coastal adaptation will take place over a long period of time (and therefore the prime decision-making tool will be the outputs from ongoing monitoring)
- Coastal adaptation should be based on the analysis of physical data (and therefore up-to-date digital models and access to tide and storm activity is essential).

In summary, a coastal adaptation study is only the initial starting point for coastal adaptation that will take place over decades. These principles are encapsulated in Figure 2.

Figure 2: Adaptation model (Integrated Coasts)



Integrated Coasts (2017)

[2] Nature Maps, Department for Environment and Water, SA Government.

Considering Figure 2 there are two main outputs from this study: a baseline study and an assessment of risks and vulnerabilities.

Baseline study

Included in the baseline study is a comparative analysis of aerial photography from 1949, 2009 and 2018 to establish shoreline movement trends. Other historical photography from as early as 1850s provides an insight into the changes in the coastline over 150 years. South Australian Coast Protection Board has been conducting profile surveys of the ocean floor, beach and backshore at 7 locations along the coast since the 1970s. Archival research at Department for Environment and Water has identified accounts of previous storm and erosion impacts as well as prior coastal studies and assessments. Analysis of sea-weed strands from the storm of 22nd November 2018 has provided an initial baseline understanding as to how storms interact with various sections of the coast.

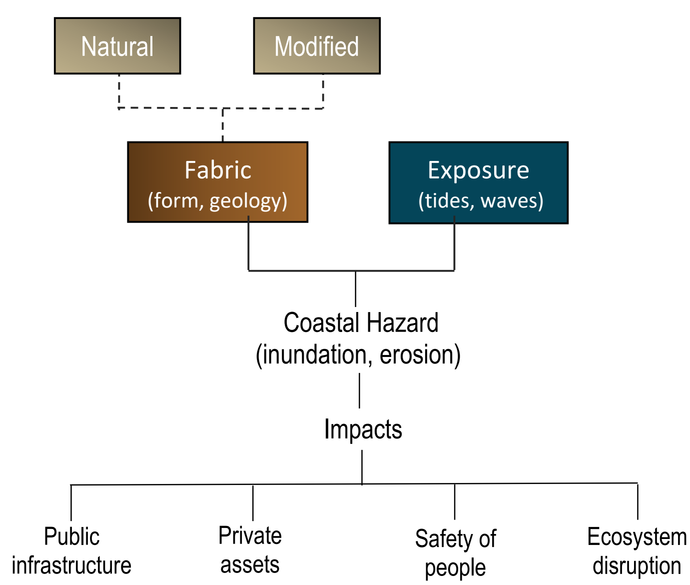
Assess risks and vulnerabilities

The second output from the study is an assessment of risks and vulnerabilities. Historical shoreline analysis and a review of storm activity identifies erosion hotspots. Inundation mapping within the digital elevation model for current risk, 2050 risk, and 2100 risk, serves two purposes. In a location such as the Murray Estuary, inundation mapping provides a risk outlook for dwellings and infrastructure in relation to flooding. In areas that are not vulnerable to inundation, an analysis of the impact of wave setup and wave runup on the backshore provides a way to identify the coastal areas that are likely to be vulnerable to impacts of sea level rise first. Erosion modelling using the Bruun Rule and shoreline translation/ recession methodology provides an outlook for erosion.

Conceptual framework

Coastal hazards experienced along a section of a coastline can be generally framed in terms of the nature of the 'fabric' (the nature of the geology and form) in the context of the nature of the 'exposure' (the impact of wind, tides, waves) (Figure 3). A conceptual framework provides a consistent way to evaluate a complex issue, and in such a way that communication with all levels of stakeholders is enhanced. The flow of the assessment within this study follows the flow of the conceptual framework for each of the coastal sections (also known as *cells*).

Figure 3: Conceptual assessment framework



Risks assessment

Risk assessment is conducted at two levels within the conceptual framework. The first risk classification categorises the risk to a coastal cell in relation to the hazards of inundation and erosion. The focus of this risk assessment is upon the inherent characteristics of the coast and not focussed on any potential threat to human infrastructure or natural ecology.

Impacts of erosion and inundation hazards are then considered within four receiving environments:

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

Hazard impacts are also considered in two eras: the 'current outlook', and the 'future outlook'. In this study, future outlook means the end of this century.

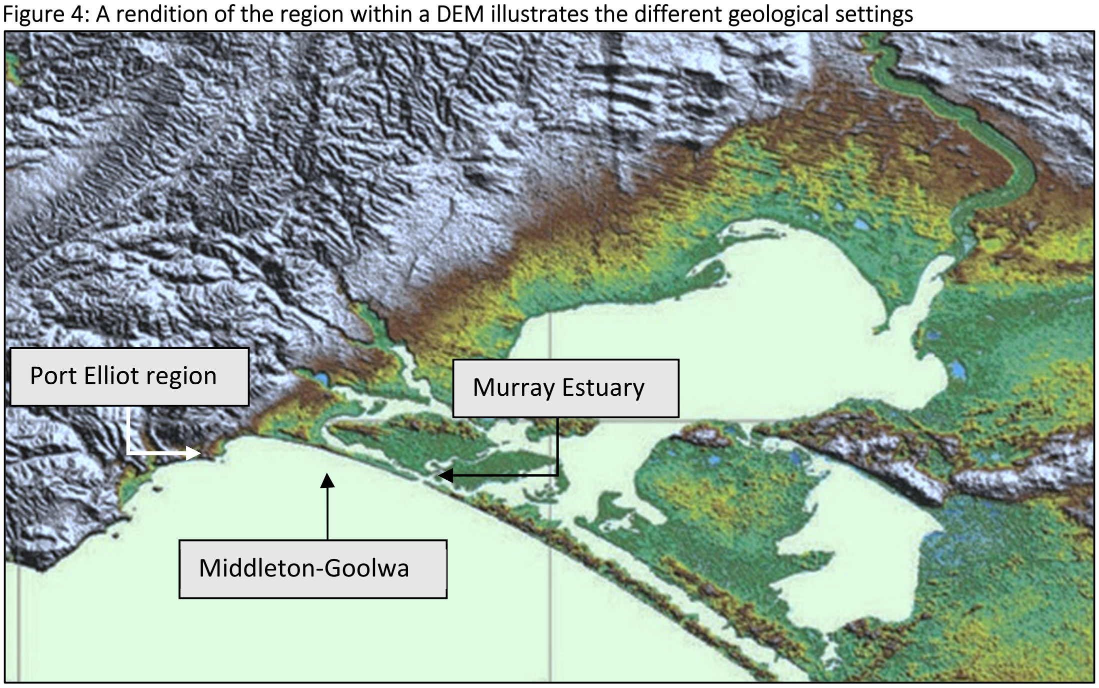
Summary of project findings

The Alexandrina coastline can be considered in three main geological layouts:

- Chiton Rocks to Ratalang-Basham (Port Elliot region) is situated within the Mount Lofty Ranges and therefore the coastline is elevated, dominated by rocky outcrops and offshore reefs, and interspersed with embayed beaches.
- Middleton Beach and Goolwa Beach are situated within the Murray Basin and are dominated by unconsolidated sand and high energy dissipative beaches.
- Goolwa Channel and Mundoo Channel settlements are situated within the Murray Estuary.

The variation in geological layouts is demonstrated by the digital elevation model in Figure 4.

Figure 4: A rendition of the region within a DEM illustrates the different geological settings



Source: Adapted from Jarvis et al, 2008, depicted in Bourman, Murray-Wallace, Harvey 2016, Coastal Landscapes of South Australia, University of Adelaide Press, p 112

General findings

The Alexandrina coastline presents as having been stable over the last 70 years. However, it is likely that the coast normally progresses through cycles of erosion and accretion. It is unlikely that sea level rise has moved the coastline beyond these normal cycles. Therefore, the almost universal adaptation response is for a 'monitor and respond' approach. If seas rise as projected, then the balance between fabric and exposure will shift, and the fabric can be expected to be impacted. Ongoing monitoring will provide the decision-making basis moving forward.

As far as impacts on urban infrastructure is concerned, the Alexandrina coastline has generally developed over time with human infrastructure that is set well-back from the shoreline and possible areas of impact. Early urban planners in the State of South Australia held the view that the coast belonged to 'the people' and thus a coastal reserve backed by a public esplanade road was the standard way to establish a coastal settlement. This principle has generally been followed in the Alexandrina region apart from a few sites on Barbara Street in Port Elliot, and the shack sites that were established in the 1950s and 1960s in the Goolwa and Mundoo Channels of the Murray Estuary. Some carparks established in the Middleton-Goolwa region are set close to the foreshore.

Furthermore, adaptation response tended to be grouped in accordance with broad geological layouts (Figure 4) and these are identified on the following pages. There are exceptions to this rule, but this observation does assist in creating an overall adaptation framework that considers the coastline as a whole.

Murray Estuary Settlements

Settlements situated along the Goolwa and Mundoo Channels are positioned on a 'sand-flat' predominantly at elevations below 2m AHD. If seas rise as projected, then this area will increasingly be subject to increased inundation. Erosion is expected to continue along the riverbank, but this factor is expected to be manageable in the short term with various forms of protection. However, if the terrain becomes increasingly inundated at greater depths and higher frequency, then the unconsolidated sand is likely to be scoured, and the terrain altered over time so that it becomes increasingly unstable. The prime adaptation response for the Murray Estuary is to provide perimeter protection to the region using low height levees (and similar protection strategies) to provide protection to cater for the 1 in 100-year 2050 scenario. The longer-term outlook to 2100 is more uncertain as protection options will become increasingly unviable if seas rise as projected.

Goolwa Channel settlements

Goolwa Channel settlements are located on the northern side of Goolwa Channel on the seaside of the barrage. Flows of water in the area relate to the tidal regime at the Murray Mouth. Within Sugars Beach region, 40-60m erosion has occurred on the western end, but more recently the eastern section is accreting. Rock revetment protects infrastructure in this region. Erosion has been less of an issue further west up the Channel which have experienced minor erosion, and some accretion. Sea-flood modelling for the latter part of the century suggests that maintaining access to the settlements may be difficult. Increasing frequency of flood flows across the sandy terrain is likely to undermine and scour roads and sites upon which houses are currently positioned.

Protection strategies are recommended for Sugars Beach area to the east of the boat ramp where the current rock revetment is in poor repair and set too low, and at the end of the revetment to the east where seawater is eroding behind the line of the rock revetment.

Mundoo Channel Settlements

Mundoo Channel settlement is located within the Mundoo Channel on the seaside of the barrage. Flows of water in the area relate to the tidal regime at the Murray Mouth. Mundoo Channel settlement is generally set about 0.3m lower than Goolwa Channel settlements and therefore is at risk of flooding at an earlier stage if seas rise as projected. Access in and out of the settlement is likely to become increasingly difficult and similar to Goolwa Channel settlements, increased flood flows will destabilise and scour the terrain.

A proposal for low height levees around the perimeter of the area in which Goolwa and Mundoo Channel settlements are situated is likely to be feasible to protect for inundation projected for sea level rises to 2050.

Adaptation Proposals: Goolwa Channel and Mundoo Channel settlements (Cell SF1 - SF2)					
Approach	**Short term strategy 2020**	**Mid-term strategy 2050**	**Long term strategy 2100**	**Adaptation Type**	**Monitoring strategy**
Incremental [monitor and respond].	Community engagement [then identify preferred adaptation response and develop plan].	Hold the line: provide protection (low height levees) to perimeter of Goolwa and Mundoo settlements.	Unknown: subject to further sea rise monitoring.	Engineering: Low height quarry rubble levees. In front of shacks, other methods are likely to be required. Rock revetment and/or sandbags required now at Sugars Beach.	Impact of storm events upon settlements, Monitoring of sea level rise (within SA).

Goolwa to Middleton Creek

The section of coast that includes Middleton and Goolwa Beach is dominated by unconsolidated sand within the context of a high energy dissipative beach. Because the current location of the shoreline is determined primarily by the current coastal processes (tides, waves, winds), sea level rise of 1m will cause recession of this coastline by up to 100m by 2100. Therefore, the predominant adaptation response within this region is for **managed retreat.** Long term protection strategies are deemed unsuitable for this region. It is expected that interim protection will be necessary to protect existing carpark infrastructure, but that in the long term these carparks and associated infrastructure will be required to be reconfigured further away from the coastline. Erosion is the key hazard factor in these cells and not inundation. The exception to this general observation is likely to be Tokuremoar Reserve region where dune fields protecting the swamp behind are low-set and narrow.

Goolwa Beach (Carpark area) (Cell SF3)

Currently Goolwa Beach is in an accretion cycle, and it is expected that the beach will return to an erosion cycle at some stage. Should the seas rise as projected, then the dunes will be impacted and recede accordingly by up to 100m. Over time the current buffer between the dune escarpment and the carpark will be lost, and actions of the sea will impact the carpark and associated infrastructure.

It is recommended that the master plan for the Goolwa Beach carpark be reviewed and that a larger dune buffer installed to allow for coastal recession over the coming century.

Adaptation Proposals: Goolwa Beach (Carpark area) Cell SF3					
Approach	**Short term strategy 2020**	**Mid-term strategy 2050**	**Long term strategy 2100**	**Adaptation Type**	**Monitoring strategy**
Incremental [monitor and respond].	Monitor [no immediate works are likely to be required].	Monitor [managed retreat].	Overall strategy: Allow retreat of dunes. The exception is the carpark area which may need protection later in this century.	Environmental: Increase dune field at the carpark. Continue use of dune fencing and planting. Engineering: Reorientate beach access point.	Shoreline position, Sand volumes, Storm impacts on backshore.

Tokuremoar Reserve (Goolwa Beach) (Cell SF4)

Goolwa Beach is situated on a dissipative high energy beach facing the Southern Ocean. Over a seventy-year period, the coast has remained relatively stable while going through its natural cycles of accretion and erosion. There is evidence that rates of erosion were higher at the beginning of last century.

Should the seas rise as projected, then the dunes will recede accordingly. The dunes in this cell are of lower height and width and are likely to erode away in the latter part of the century. If seawater traverses through the dune system, the ecology of the reserve would alter irreversibly. Dune stabilisation is likely to be an appropriate first response, and then if this fails a low height levee set further inland to limit the extent of seawater inundation. Ongoing monitoring will provide the appropriate basis for decision making.

Adaptation Proposals: Tokuremoar Reserve (Goolwa Beach) Cell SF4					
Adaptation Approach	**Short term strategy 2020**	**Mid-term strategy 2050**	**Long term strategy 2100**	**Adaptation Type (when required)**	**Monitoring strategy**
Incremental [monitor and respond].	Monitor [hold the line: remediate dunes at points they become vulnerable].	Monitor [hold the line: remediate dunes at points they become vulnerable].	Managed Retreat: if hold the line becomes unviable, provide low height levees inland to prevent the inland flow of seawater.	Environmental: Use soft options such as dune fill, sandbags, fencing and planting. Engineering: Longer term may require low height levees set inland.	Shoreline position, Sand volumes (dunes), Storm impacts on backshore.

Middleton Beach (Surfers Beach) (Cell SF5)

This is a high energy beach where backshores varying from low-height dunes, to soft rock cliffs. The inherent hazard risk rating is categorised as 'high' to 'very high'. Historical comparisons showed that between 1949 and 2006 the shoreline has retreated 10-12m in places, but since 2006 the shoreline has showed signs of accretion. Exceptions to this rule include ongoing erosion at the Skye Ave carpark.

If seas rise as projected, then this area of coast is expected to recede by up to 100m and therefore 'managed retreat' is the overriding strategy. Over time carparks should be reconfigured/ relocated further away from the shoreline. Short term protection works may be warranted, but only if the overall retreat strategy is kept in play. The esplanade road may become vulnerable in the latter part of this century. Engineering works proposed for this cell are:

- Reconfiguration of storm water outflow to beach (including detention pond)
- Collapse overhanging section of cliff and install protection to carpark.

Adaptation Proposals: Middleton Beach (Surfers) (Cell SF5)					
Adaptation Approach	**Short term strategy 2020**	**Mid-term strategy 2050**	**Long term strategy 2100**	**Adaptation Type**	**Monitoring strategy**
Incremental [monitor and respond].	Monitor [upgrade storm water infrastructure at Chapman St].	Monitor [relocate carparks as upgrades are required, interim protection may be required].	Managed retreat [carparks and associated infrastructure relocated/ reconfigured.	Engineering: Storm water, relocate or reconfigure carparks. Environmental: Interim protection works as required (ie sandbags).	Shoreline position, Storm impacts on backshore, sand volumes.

Middleton Creek (east) (Cell SF6-2)

Middleton Beach (cliff section) marks the beginning of the long dissipative beach that stretches eastward to Cape Jaffa. The beach is backed by a small dune system that has formed over the last ten years. Behind the dunes are alluvial cliffs. Historical research found that this area underwent large scale erosion at the turn of the 19th century. Since 1949, the cliffs have receded 12-15m, but the rate of erosion appears to have almost ceased.

If sea levels rise as projected, it is likely the small foredune would be eroded away and then the alluvial cliffs would follow. The carparks on top of the cliff are likely to be positioned far enough back that these will not come under attack until the second half of the century. However, if any upgrades were envisaged, the carparks could be reconfigured to allow a greater distance between the carparks and the cliff tops.

Ongoing monitoring will provide the appropriate basis for decision making.

Adaptation proposals: Middleton Creek (east) (SF6-2)					
Approach	**Short term strategy 2020**	**Mid-term strategy 2050**	**Long term strategy 2100**	**Adaptation Type (when required)**	**Monitoring strategy**
Incremental [monitor and respond].	Monitor [no immediate works are likely to be required].	Monitor [It is unlikely that erosion will impact carpark in this time frame].	Managed retreat [Carpark is set well back – reconfigure further away from shoreline at time of upgrade].	Engineering: Construct carpark further away from shoreline.	Shoreline position, Storm impacts on backshore, Sand volumes.

Middleton Creek to Boomer Beach

Within the Port Elliot region, which geologically is situated within the Mount Lofty Ranges, adaptation proposals are predominantly **'hold the line'**. These are likely to succeed in a geologically stable environment which is resistant to erosion and dominated by rocky outcrops and offshore reefs. The exception to this general observation includes Boomer Beach, and within Horseshoe Bay where it is recognised that some recession is likely to take place in the eastern portion of the bay. Erosion is the prime hazard factor within these cells and inundation is not a key hazard factor.

Middleton Creek (west) (Cell SF6-1)

Middleton Creek (west - beach area) is underpinned by reef and bordered by sandstone outcrops which dissipate wave energy. The beach is backed by a small dune system in the east and an embankment in front of the carpark. Historical analysis indicates that the backshore of the beach is impacted by larger events and has eroded 2-4m since 1949. Sea level rise is likely to bring increased impact to the rear of the beach and this may undermine the base of the embankment and dune system. The carpark and walking trail are likely to come under threat from erosion later in this century (may be impacted earlier by larger events).

Storm water diversion is recommended so storm water can drain to resistant rocky outcrop to the west rather than draining to the beach.

Adaptation Proposals: Middleton Creek (west) (SF6-1)					
Adaptation Approach	**Short term strategy 2020**	**Mid-term strategy 2050**	**Long term strategy 2100**	**Adaptation Type**	**Monitoring strategy**
Incremental [monitor and respond].	Monitor [storm water infrastructure required to provide alternative flow path].	Monitor [protection may be required by 2050, or the latter part of this century].	Hold the line: protect backshore [Car park and walking track behind beach].	Engineering: Storm water diversion Protection to carpark (if required).	Shoreline position (dunes) Storm impacts, on backshore.

Ratalang-Basham Beach (Cell SF7)

Ratalang-Basham is backed by dunes and then by soft sediment rising to elevation of 12-18m at ~500m inland. The beach is categorised as 'moderate' exposure. Historical analysis demonstrates that Ratalang-Basham beach has been stable over a seventy-year period.

The modelling suggests that a significant storm event is likely to penetrate the existing gaps within the dunes. Left unchecked, these gaps are likely to become more significant in the context of rising sea levels. The erosion assessment indicates the following scenarios are likely: if no action is taken, the dunes may break down over time and the shoreline recede by up to 60 to 70m, if some action is taken, the dunes may remain intact and traverse landward by ~36m, or a combination of these. If significant amount of sea water flowed into vegetated areas behind the dune system and remain for any length of time, then the ecosystem in these areas are likely to be significantly impacted. It is recommended that the low sections of dunes be Increased and stabilised.

Adaptation Proposals: Ratalang-Basham (Cell SF7)					
Adaptation Approach	**Short term strategy 2020**	**Mid-term strategy 2050**	**Long term strategy 2100**	**Adaptation Type (when required)**	**Monitoring strategy**
Incremental [monitor and respond].	Hold the line for as long as feasible: maintain the dune system [Freshwater ecology is situated behind the dune system].	Monitor [continue strategy begun in 2020].	Monitor [raise height and width of dunes to prevent sea water incursion].	Environmental: Sandbags, dune fencing, planting.	Shoreline position, Storm impacts on backshore, Sand volumes.

Horseshoe Bay (Cell SF8)

Horseshoe Bay is backed by seawalls on western end, an embankment in the centre, and dunes on eastern end. The bay is 'bedrock backed' with backshore rising above 10m at 100m inland from the shore. Historical analysis reveals a significant recession in height and width of the dunes in the mid-section and eastern end of the bay.

The immediate backshore has declined in sand, especially in the mid-section of the bay which has been reduced to an earthen embankment. Sea level rise is likely to place increased pressure on this embankment, and then toward the carpark and bowling greens. Erosion modelling indicates a recession of 26-29m. The rigid edges imposed to the bay are likely to be increasingly impacted with sea level rises, with loss of sand a by-product of the current strategy. A new master plan is recommended for Horseshoe Bay that increased flexibility in the backshore.

Adaptation Proposal: Horseshoe Bay (8-1)					
Adaptation Approach	**Short term strategy 2020**	**Mid-term strategy 2050**	**Long term strategy 2100**	**Adaptation Type (when required)**	**Monitoring strategy**
Transformational [new master plan for the bay].	Create increased flexibility in the backshore [allowing some natural initial retreat if required].	Maintain sand nourished dune system.	Hold the line [Assumes strategy at 2020 is implemented].	<u>Planning:</u> New Master Plan <u>Environmental:</u> Implement dune system in mid-section. <u>Engineering:</u> Implement protection on western end to absorb coastal impacts.	Initial monitoring required to quantify sand movement / volumes in the bay. Ongoing monitoring required.

Knight Beach (Cell SF9-2)

Knight Beach is backed by cliffs 5-10m high of Pleistocene aeolianite or calcarenite. The bay is bedrock backed, a former sand dune now hardened, rising above 30m at 500m inland. Historical analysis suggests that the backshore of the beach has not and is currently not being impacted by actions of the sea. Scenario modelling suggests that only extreme events may reach the backshore. Even if these do occur, Knight Beach is likely to be a contained cell, and the beach will rebuild over time. Sea level rise is likely to bring increased impact to the rear of the beach over time and this may undermine the base of the cliffs.

Adaptation Proposal: Knight Beach (9-2)					
Adaptation Approach	**Short term strategy 2020**	**Mid-term strategy 2050**	**Long term strategy 2100**	**Adaptation Type (when required)**	**Monitoring strategy**
Incremental [monitor and respond].	Monitor [no immediate works are likely to be required].	Monitor [protection may be required by 2050].	Protect backshore [Infrastructure is positioned behind Knight Beach].	Engineering: rock revetment or similar at base of cliff Planning: review planning policy for allotments on Barbara St.	Shoreline position, Storm impacts on backshore, Sand volumes.

Boomer Beach (Cell SF9-1)

Boomer Beach is backed by sand dunes varying in height from 10m AHD (in west) to 18m AHD (in east). Historical analysis suggests that the backshore of the beach undergoes periodic accretion and recession over periods of decades. Currently the beach has been in an accretion cycle for ~10 years. The main threat that sea level rise will bring is the permanent recession of the dune at the base, coupled with the inability of the dune to translate landwards due to the trainline positioned on top of the dune system.

Adaptation Proposal: Boomer Beach (9-1)					
Approach	**Short term strategy 2020**	**Mid-term strategy 2050**	**Long term strategy 2100**	**Adaptation Type (when required)**	**Monitoring strategy**
Incremental [monitor and respond].	Monitor [no immediate works are likely to be required].	Monitor [hold the line using soft-protection options].	Managed retreat [Recession of dune projected at 18-23m by 2100].	Environmental: Use soft options to hold the line as long as feasible.	Shoreline position, Storm impacts on backshore, Sand volumes.

1. Introduction

1.1 Study Areas

Alexandrina Council contracted Integrated Coasts in March 2018 to produce a coastal adaptation study for the length of its coastline from Chiton Rocks to the Murray Mouth. Two additional areas of interest were included at locations where Council needs to manage existing and proposed assets in the context of projected sea level rise. The first of these is Beacon 19 boat ramp where Council requires an understanding of the likely impact of sea level rise upon the access road to the ramp. The second of these is Sugars Beach where a proposed tourist upgrade is under consideration.

In March 2019, Alexandrina Council added the settlement of Mundoo Channel to the project scope, and in July 2019, the human settlements within Goolwa Channel (downstream of the barrage) were also added to the scope of works.

One area of difficulty with the study was the lack of data for wave set-up and wave run-up at locations other than Horseshoe Bay. A storm event on 22 November 2018 provided an opportunity to survey seaweed strands along the coast and identify the wave effects at most locations. However, no data was collected from Chiton Rocks and this location was removed from the scope of works.

Figure 5: Study Area 1 - The coast within Alexandrina Council boundaries

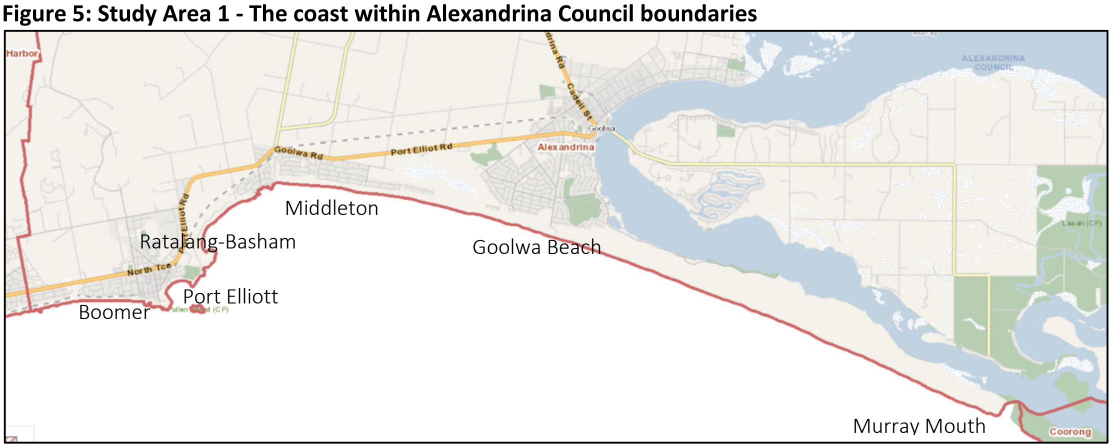
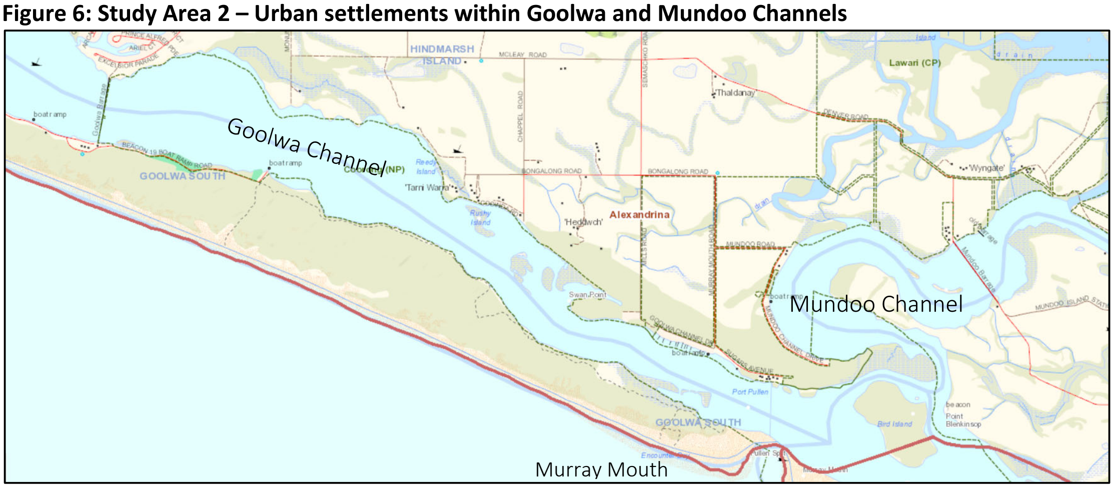


Figure 6: Study Area 2 – Urban settlements within Goolwa and Mundoo Channels



Source: Nature Maps

The main objectives of the project are to:

- Identify public and private assets at current and future risk of erosion and inundation within the study areas
- Identify and evaluate potential adaptation strategies for the study areas with the main focus on Council assets and infrastructure.

1.2 Document structure

The report is structured in two main sections. Part 1 reports the methodology utilised in the study and coastal issues that are common to the entire coastline. Part 2 of the study creates eight stand-alone reports for the nine coastal conservation cells (SF1 to SF9) within the Alexandrina Council area as depicted in Nature Maps[3]. This reporting methodology ensures that relevant information is readily accessible for any coastal location without the requirement of reading a lengthy report.

This document represents Part 1 of the study.

1.3 Underpinning principles:

Over the last few years, Integrated Coasts has been a key architect in developing and utilising the Local Government Association's *Coastal Adaptation Decision Pathways* tool[4]. The tool has been successfully used in major coastal adaptation studies for eight settlements around Gulf St Vincent. In the last eighteen months, Integrated Coasts has conducted two case studies for National Climate Change Adaptation Research Facility (NCCARF) to test the CoastAdapt tool. Based on this experience, Integrated Coasts has developed a model of coastal adaptation based on three principles.

1. **Coastal adaptation takes place in localities.**

In comparison to other climate change hazards, sea-level-rise and associated erosion, is unique. For example, a uniform increase of temperature of 1 to 2 degrees will uniformly affect a region such as the Fleurieu Peninsula. In contrast, a uniform increase of sea level of 0.5m is likely to produce a vast array of impacts, even within a ten-minute walk along the coast. The reason for the difference in the way that the hazards are experienced is that the impact of sea level rise (and associated erosion and inundation) is dependent like no other on the thresholds and tipping points that the geological layout presents at each location. Furthermore, the geological structure and rock types, the bathymetry of the sea-floor, and the orientation of the coast to wind and wave exposure, all act as modifiers in the way in which sea level rise and associated erosion are experienced. Therefore, coastal adaptation, including the underpinning risk assessment procedures, must operate in a fine-grained way that appropriately deals with the local nature of the impacts.

[3] Nature Maps, Department for Environment and Water, SA Government.

[4] Balston, J.M., Kellett, Western, M, J., Wells, G. Li, S., Gray. (2012). Climate change decision support framework and software for coastal Councils, Local Government Association of South Australia, Adelaide, SA, and Western/ Kellett (2014) Dealing with sea level rise on coastal assets, PPT tool.

2. Coastal adaptation is on ongoing process.

Integrated Coasts recognises that coastal adaptation is a process that will take place over decades, and even centuries. Therefore, appropriate attention should be placed on forming the basis for a future monitoring program. And wherever a monitoring program is envisaged, a baseline is required. Without forming a baseline, future monitoring is likely to have less meaning. In the context of coastal adaptation, the *Ecology Dictionary* provides the most appropriate definition of a baseline:

> A quantitative level or value from which other data and observations of a comparable nature are referenced… [and]
>
> Information accumulated concerning the state of a system, process, or activity before the initiation of actions that may result in changes.

Two basic elements reside in the definition. To illustrate:

> A georeferenced aerial image from 1940s is likely to provide a baseline to assess how much erosion has occurred over the last century. Comparisons utilising aerial photography over the last fifteen years will assist in forming a picture of what has occurred in very recent history. Once this baseline rate is established, projections can be formulated about the possible future impact of erosion along the shoreline (in the context of other data).
>
> A digital model created recently with associated imagery creates a digital baseline against which future erosion can be compared (ie monitored). Recapturing the data in five or ten years time will enable further comparisons to the historical baseline, and improvements to the projections made.

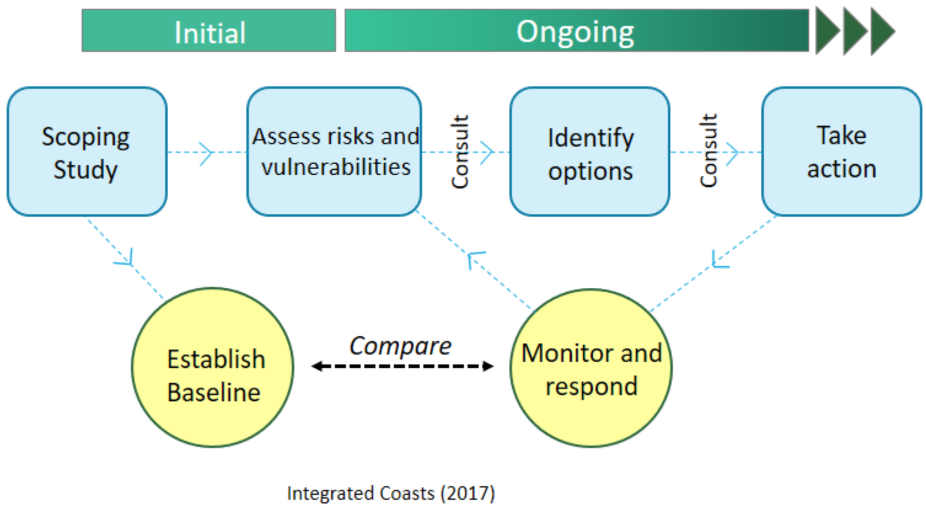
What is known as 'pathways' adaptation methodology is the preferred way to undertake coastal adaptation and attempts to deal with uncertainty using three main ingredients: scenario planning, time, and triggers or thresholds. A 'pathways' approach outlines plausible futures from which to identify key thresholds and triggers, and then to consider alternative pathways when these are breached. However, Integrated Coasts is of the view that in most cases less time should be given to extensive analysis to the timing of the likely breaching of thresholds, and more time given to initiating monitoring programs to track change over time. The only exception to this rule is when Council is considering whether to invest in upgrading or installing infrastructure. In these cases, an analysis of the timing of impacts is useful, and the precautionary principle should apply.

3. Coastal adaptation should be initially 'data-driven'.

Community engagement is best sought once the physical context of adaptation has been established as outlined in (2) above. The first steps in any coastal adaptation process should be to identify the physical baseline, then to conduct scenario analysis to identify plausible futures, and then to communicate these realities to the community. This principle ensures that community engagement is based on informed decision making, and that community expectations are managed as much as possible within physical realities. If all stakeholders have a shared understanding of the local context then it is more likely they will work together to arrive at common solutions.

These three principles are effectively illustrated in the diagram below (Figure 7).

Figure 7: Coastal adaptation model (Integrated Coasts)



Conclusion:

This project adopts a methodology that ensures that analysis takes place within localities at a sufficiently fine-grained scale. Wherever possible, reporting is conducted within a visual representation of the locality. Historical baselines are identified using aerial photography, and a recently obtained digital elevation model provides a baseline against which to analyse future changes. This report is designed so that a user may quickly refer to any location along the Alexandrina coast and be able to access all the relevant data in an accessible manner.

2. Methodology

The purpose of this section of the report is to provide an overview of the methodology utilised in this coastal adaptation study. The main purpose for explaining the methodology here is not to provide comprehensive technical explanations, but rather as basis for all stakeholders to understand the procedures and analysis utilised in the study. Readers requiring a deeper understanding of technical aspects of the methodology should refer to the noted sources.

2.1 Introduction

This coastal adaptation study utilises five main strategies:

1. Wherever possible, concepts and findings are explained in plain English so that the study is readily accessible to all stakeholders.
2. The study primarily adopts concepts and terminology from CoastAdapt[5] and OzCoasts[6].
3. The study adopts the national secondary coastal cells from CoastAdapt and utilises the South Australian Coastal Conservation Cells as tertiary cells[7].
4. The study initially reports findings from publicly known sources such as CoastAdapt, NatureMaps, South Australian Resources Information Gateway, and Local Government Development Plans.
5. The study reports within a prepared coastal adaptation study template.

These strategies are explained in more detail in the following sections.

2.2 Study classification

CoastAdapt recommends a three-tiered climate change risk assessment process[8]:

- First pass risk assessment
- Second pass risk assessment
- Third pass risk assessment

This approach enables coastal climate change adaptation to occur at any level of expertise and difficulty, with the ability to recommend further action at the next level of assessment.

The context of this project is best categorised as a 'second-pass risk assessment' with some elements of 'third-pass risk assessment' included. It is expected that some localities will require additional data and further analysis. This will be especially true in locations where significant expenditure is proposed to implement new coastal infrastructure, or where existing infrastructure may require increased protection expenditure.

The coastal adaptation study template designed by Integrated Coasts can be utilised at any level of study but is especially useful at first and second pass assessment stages.

Figure 8 below depicts an overview of the aims and scope of each tier of assessment[9].

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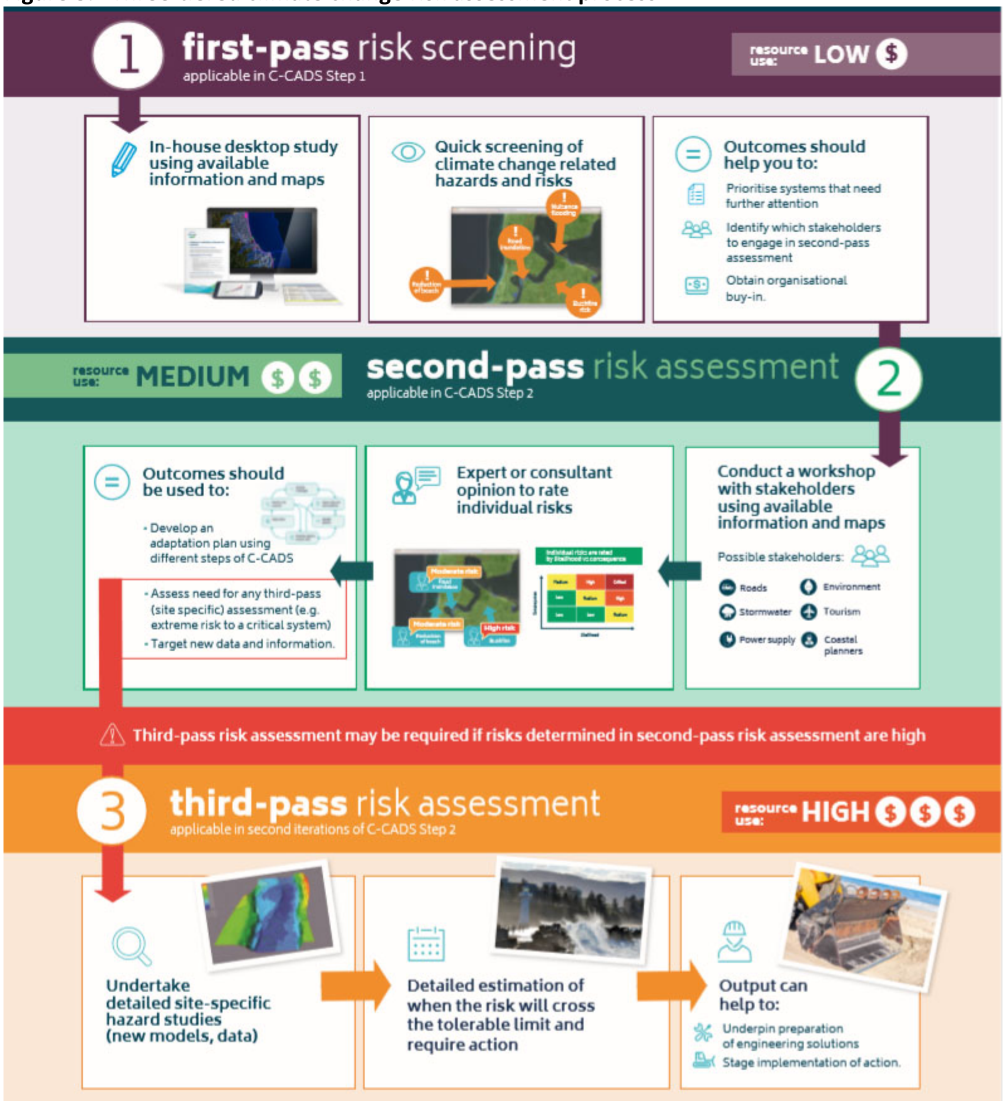
[5] https://coastadapt.com.au/sites/default/files/factsheets/CoastAdapt_Glossary_2017-02-06_FINAL.pdf
[6] CoastAdapt's Shoreline Explorer is based upon the work completed by OzCoasts and found within Sharples et al, 2009, Australian Coastal Smartline Geomorphic and Stability Map Manual.
[7] https://data.environment.sa.gov.au/NatureMaps/Pages/default.aspx
[8] See also, https://coastadapt.com.au/sites/default/files/tables/T3M2_Local_scale_assessment_Table1.pdf

Figure 8: Three-tiered climate change risk assessment process



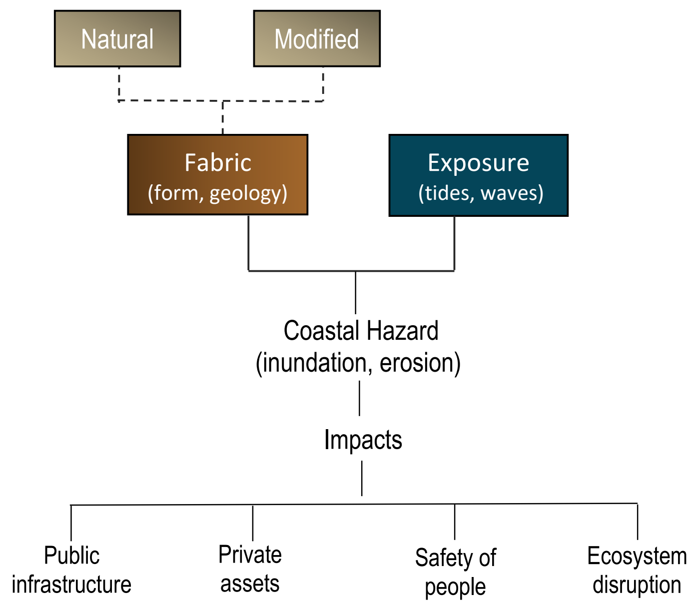
Source: https://coastadapt.com.au/sites/default/files/infographics/Three_tier_risk_assessment.pdf

[9] See also https://coastadapt.com.au/sites/default/files/tables/T3M4_Risk_assessment_Table_1.pdf.

2.3 Conceptual framework

This coastal assessment tool adopts a simple and intuitive framework. Coastal hazards experienced along a section of a coastline can be generally framed in terms of the nature of the 'fabric' (the nature of the geology and form) in the context of the nature of the 'exposure' (the impact of wind, tides, waves) (Figure 9). There are two reasons for adopting a conceptual framework. The first reason is to ensure that reporting of the study is accessible to all stakeholders including: Council staff, elected members, and the general public. The second reason is to provide a consistent framework through which to evaluate coastal locations both within Alexandrina Council region, and other regions around South Australia.

Figure 9: Conceptual assessment framework



2.3.1 Coastal fabric (geology)

Intuitively we understand that if we are standing on an elevated coastline of granite that the coast is not easily erodible and that landforms are high enough above sea level so that they are not impacted by coastal inundation. Conversely, we understand if we are standing on a low sandy dune that erosion or inundation may indeed be a factor. It is the geology (form and fabric) of the coast upon which our settlements are situated that determines one part of the hazard assessment in terms of: topography, and the nature of the fabric of the coasts (how resistant it is to erosion).

Why use the term 'fabric'?

The use of the word 'fabric' utilised in this methodology is adopted from *Smartline* developed by OzCoasts[10]. The stability of a landform depends primarily on its fabric (hard or soft constituents) and secondarily on its form (e.g. low lying, steep slope). OzCoasts and CoastAdapt classifies landforms found in each coastal area firstly based on 'fabric' (composition, constituency), and secondly on 'form' (topography).

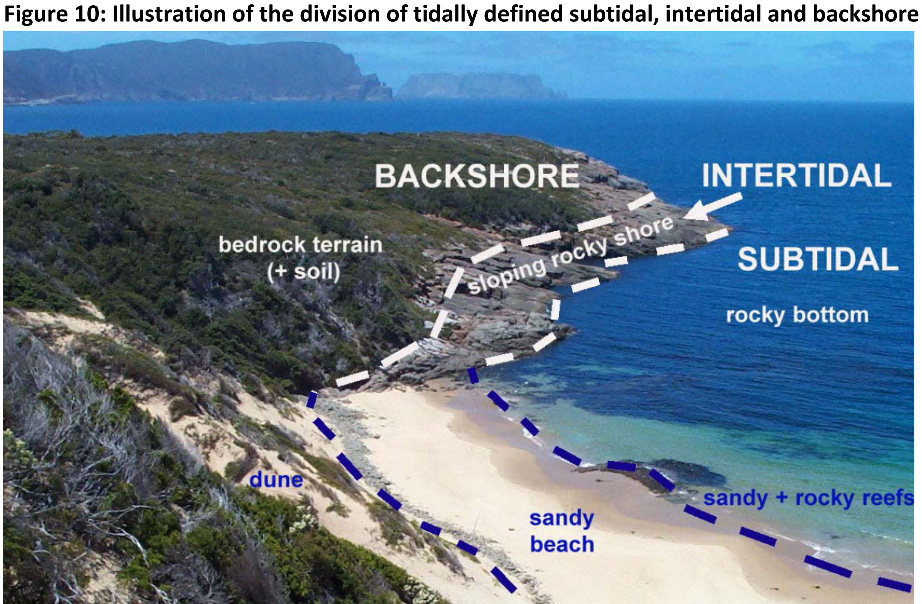
[10] Sharples et al 2009, Australian Coastal Smartline Geomorphic and Stability Map Manual, University of TAS.

In common usage, the word 'fabric' is used to denote both *form* and *fabric*. Oxford's online dictionary www.lexico.com lists the synonyms for 'fabric' as: *structure, frame, form, make-up, constitution, composition, construction, organization, foundations….essence*. The word 'fabric' is therefore deemed suitable to convey coastal concepts as it has relevant technical meaning but is also readily accessible to all stakeholders. Within South Australian State and Local Governments, the word 'fabric' also carries a similar idea to 'sensitivity' within integrated vulnerability assessments that have been completed throughout all regions of the State.

Parallel zones utilised in coastal study

In this study, the fabric and form of the coastline is analysed in three main parallel zones: subtidal, intertidal, and backshore (Figure 10). Tidal zonation is a virtually universal coastal phenomenon which divides coasts into linear shore-parallel zones, each with distinctive landform types resulting from differing exposure to marine and terrestrial processes[11].

Figure 10: Illustration of the division of tidally defined subtidal, intertidal and backshore zones.



Source: Australian Coastal Smartline Geomorphic and Stability Map Manual

Coastal compartments (coastal cells)

The explanation above relating to coastal fabric has tended to focus on the three parallel zones to evaluate a shoreline's characteristics in profile. Identifying coastal compartments (or coastal cells) is a way to evaluate the way in which coastal processes operate alongshore. A coastal compartment is also defined primarily by fabric and form as illustrated in the definition from CoastAdapt:

> An area of coast bounded along shore by large geologic structures, changes in geology or geomorphic features[12].

Regions can then be divided into primary, secondary and tertiary compartments or cells. A project was undertaken to divide the Australian coastline into 359 secondary compartments based on landforms and patterns of sediment movement[13]. The South Australian Conservation Cells within the Alexandrina region have been adopted as tertiary cells.

[11] Sharples et al 2009, Australian Coastal Smartline Geomorphic and Stability Map Manual, University of TAS, p. 26

[12] https://coastadapt.com.au/sites/default/files/factsheets/CoastAdapt_Glossary_2017-02-06_FINAL.pdf

[13] https://coastadapt.com.au/sites/default/files/factsheets/Datasets_guidance_1_present.pdf

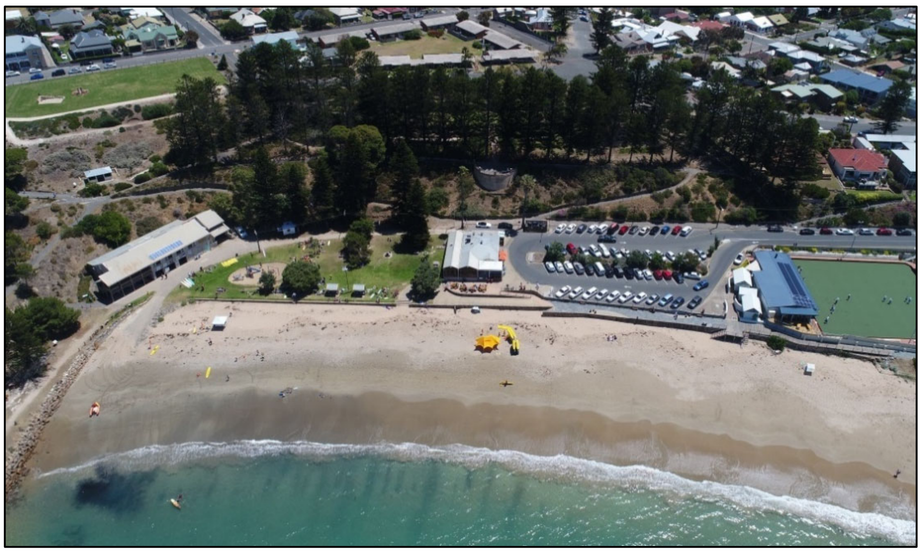
2.3.2 Coastal modifiers (human intervention)

In some locations human intervention has modified the natural fabric. These interventions include the implementation of protection structures (or other coastal control measures), and the construction of urban infrastructure.

Protection structures

The introduction of protection structures is likely to change the nature of the natural fabric of the coast. For example, an extensive rock revetment has been installed along the Adelaide coastline. This installation has modified the fabric of the coast from dunes to rock. Other examples include the use of seawalls (e.g. Port Elliott), geotextile sandbags (e.g. Moana), groynes (e.g. Victor Harbor), earthen levees (e.g. Port Parham), and similar mechanisms that modify the natural coastal fabric.

Figure 11: Seawalls at Horseshoe Bay have altered the nature of the backshore



Source: Integrated Coasts

Urban infrastructure

The installation of esplanade roads, carparks, walking trails, houses and other urban infrastructure in close proximity to the shoreline impose rigid structures into backshores. In non-urban contexts, if seas rise as projected and associated erosion causes increased recession, a shoreline can recede and find its own equilibrium further back from the current shoreline. But in urban contexts, urban structures act as 'hold points' that either require protection or they are undermined and become increasingly unstable. For example, the train line that runs along the top of the dune system at Boomer Beach acts as a hold point. If erosion causes recession at the base of the escarpment, but the top of the escarpment cannot recede due to the presence of the trainline, then over time the whole escarpment will become increasingly steep and unstable.

2.3.3 Coastal Exposure (Current)

If we find ourselves standing 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. In this project our assessment of 'exposure' is focussed mainly on 'actions of the sea' and the impact of storm water run-off. However, sub aerial processes (weathering and mass movement) are considered if relevant.

Why use the term 'exposure'?

The term 'exposure' has a narrower technical sense within coastal study and refers to the degree to which a section of coastline receives swell wave energies that impinge on that section of coast[14]. Within Nature Maps, each section of South Australian coast has been assigned a relative exposure rating:

- Sheltered
- Moderately exposed
- Exposed

The exposure rating is assigned in the context of wave energy:

- High
- Moderate – high
- Moderate
- Low

In climate change adaptation study, the word is utilised within integrated vulnerability assessments with a wider meaning:

> Exposure relates to the influences or stimuli that impact on a system. In a climate change context, it captures the important weather events and patterns that affect the system but can also represent broader influences such as changes in related systems brought about by climate effects. Exposure represents the background climate conditions against which a system operates, and any changes in those conditions[15].

All South Australian Government regions have completed climate change adaptation studies which incorporated the concept of 'exposure'.

In common usage, the word is often used in relation to a person being 'exposed to weather', and it is generally understood that people can die from 'exposure'. Therefore, even in common usage, 'exposure' is generally understood to relate to the influences or stimuli that impact on a system.

Evaluation of exposure in this study

In this study, exposure is evaluated in two main contexts: exposure of the fabric to actions of the sea, and exposure of the fabric to stormwater runoff. Sub aerial processes (weathering and mass movement) are considered if relevant.

[14] Sharples et al 2009, Australian Coastal Smartline Geomorphic and Stability Map Manual, University of TAS, p. 7

[15] Allen Consulting Group 2005, Climate Change Risk and Vulnerability, Report to Australian Greenhouse Office, Department for Environment and Heritage, p.20.

2.3.3 Coastal Exposure (Future)

Our sea levels have been quite stable for 6-7 thousand years. However, in recent times, the rate of sea level rise has escalated. Last century, sea levels rose at ~2-3mm per year. In this century, seas are rising on average at ~4-5mm per year in our region. The general consensus of the scientific community is that the rate of sea level rise will continue to escalate towards the end of this century (~10-15mm per year). These projections are based on sound physics, but the exact rate is uncertain.

What is certain is that if seas rise as projected then the relationship between ***fabric*** and ***exposure*** will change significantly in many coastal locations.

2.3.4 Coastal Hazards

Coast Adapt identifies two prime coastal hazards[16]:

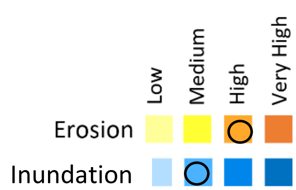
- Coastal inundation
- Coastal erosion

Other coastal assessment systems such as Coastal Hazard Wheel (UNEP) include hazard assessment for 'salt water intrusion' or 'gradual inundation' to differentiate the hazard of storm flooding from the gradual increase of tides that may occur within larger tidal flats or in locations such as islands of low elevation in the Pacific Ocean[17]. In most instances, these geological settings are not relevant to South Australia. In the methodology developed by Integrated Coasts, a second-tier assessment analyses any potential impact in the category of 'ecosystem disruption'.

<u>Inherent hazard risk assessment</u>

Integrated Coasts has developed a risk classification system to operate over the State of South Australia that categorises the risk to a coastal cell in relation to the hazards of inundation and erosion[18]. The focus of the assessment is upon the inherent characteristics of the coast and not focussed on any potential threat to human infrastructure or natural ecology. 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 using a process that will also benchmark the locality in the context of all of South Australia.

Broadly speaking the inputs for the assessment are the analysis of the fabric of any given location in the context of its exposure. How the assessment is conducted is explained in the next section of this report. The visual output from the inherent risk assessment process is purposefully designed so that it is immediately accessible and meaningful to a wide range of personnel involved in managing the coastal environs.



Example output

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[16] https://coastadapt.com.au/coast-and-climate-dynamics

[17] Rosenthal et al 2016, Managing climate change hazards in coastal areas: The Coastal Hazard Wheel decision support system, United Nations Environment Programme.

[18] This version of the risk classification system should be viewed as 'beta' with more development required.

2.3.5 Hazard impacts

Hazard impacts are considered within four receiving environments:

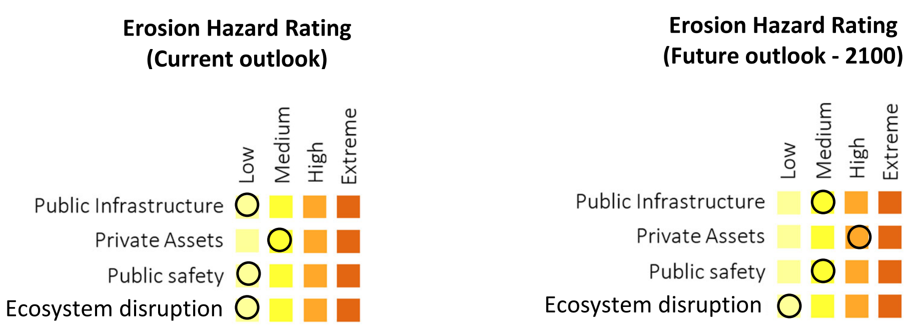
- Public infrastructure
- Private assets
- Public safety
- Ecosystem disruption

Hazard impacts are also considered in two eras: the 'current outlook', and the 'future outlook'. In this study, future outlook means the end of this century.

The term ecosystem disruption is used to describe the situation where increasing inundation or erosion in a coastal region might bring about larger scale changes to the nature of the coastal environment that may threaten to disrupt the entire ecological system. For example, an area of land that is currently ecologically freshwater would become ecologically 'disrupted' if it became inundated by sea water.

The visual output for assessment process is only produced where the inherent risk assessment has provided the rationale for a second pass assessment. The output is purposefully designed so that it is immediately accessible and meaningful to a wide range of personnel involved in managing the coastal environs including: politicians, elected members, policy makers in all levels of Government, coastal managers, and the general public.

Figure 12: Risk assessment conducted within receiving environments (Example outputs)



Example outputs

2.3.6 Conceptual framework - summary

A conceptual framework provides a consistent way to evaluate a complex issue, and in such a way that communication with all levels of stakeholders is enhanced.

2.4 Specific steps

2.4.1 Partition the coastline into sedimentary cells (compartments)

The Australian Coastal Sediment Compartments Project has divided the Australian coastline into primary and secondary sediment cells[19]. Department for Environment and Water (DEW) has further divided the South Australian coastline into tertiary cells. These are depicted as 'conservation cells' on the Nature Maps website[20].

This study has first reviewed this tertiary division and then further segmented the coastline into quaternary cells where appropriate.

Rationale:

Partitioning the coastline will:

- Create study areas of manageable size
- Create regions with similar characteristics for risk assessment procedures
- Form the foundation of a future monitoring program

Methodology:

- Adopt the secondary cells depicted on CoastAdapt
- Adopt the conservation cells depicted on Nature Maps as tertiary cells with minor variations
- Where required by changes in geology and coastal processes, divide tertiary cells into quaternary cells or note areas of interest

2.4.2 Review settlement history

Rationale

The main focus of this project is to assess coastal impacts (current and future) in relation to human settlements and activities. A review of settlement history provides a context to understand how humans have managed coastal impacts in the past. Identifying past inundation and erosion events, and what action was taken to mitigate the risks, is an important way to understand current vulnerabilities of the coastline. In relation to Council liability, when a settlement was founded, and whether it has undergone any substantial expansion are key issues to be assessed.

The general purpose of this section of work is to 'draw a line' in this current time and bring into one place everything that is known about coastal processes and coastal events from a historical context.

Methodology:

- Review Alexandrina file held at Coastal Management Branch
- Review files provided by Alexandrina Council
- Review key historical documents for the Alexandrina region
- Search for and review historical photographs

[19] McPherson et al. 2015. *The Australian Coastal Sediment Compartments Project: methodology and product development*.
[20] http://spatialwebapps.environment.sa.gov.au/naturemaps/?locale=en-us&viewer=naturemaps

Step 2.4.3 Analyse coastal fabric (geology)

Rationale

The nature of a coastline can be explained in terms of its geological formation and how actions of the sea have interacted with that geology. Areas of softer sediments erode faster and create beaches. Areas of resistant material such as rock, remain as headlands. In other words, the various embayed beaches in the Alexandrina region exist because they have eroded faster than the surrounding resistant rock. Sea level has altered in times past until finding a level ~7000 years ago that has remained largely unchanged until now. The remnants of older shorelines can be determined throughout the Alexandrina coastline.

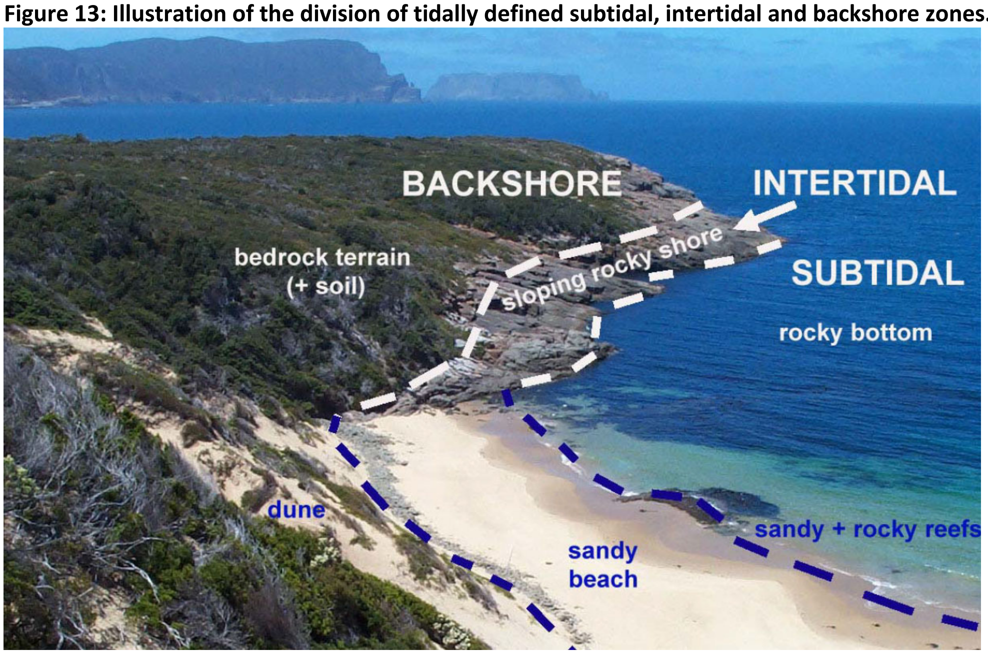
Sea level rise will alter the way in which the sea interacts with the geology and in ways that are likely to impact human settlement.

The purpose of this section of work is to identify ancient coastal formation, the nature of the current fabric and form of each coastal cell, and the shorter-term changes to the geology of the region in the context of actions of the sea.

Parallel zones utilised in coastal study

In this study, the fabric and form of the coastline is analysed in three main parallel zones: subtidal, intertidal, and backshore (Figure 13). Tidal zonation is a virtually universal coastal phenomenon which divides coasts into linear shore-parallel zones, each with distinctive landform types resulting from differing exposure to marine and terrestrial processes[21].

Figure 13: Illustration of the division of tidally defined subtidal, intertidal and backshore zones.



Source: Australian Coastal Smartline Geomorphic and Stability Map Manual

[21] Sharples et al 2009, Australian Coastal Smartline Geomorphic and Stability Map Manual, University of TAS, p. 26

<u>Intertidal zone</u>

The intertidal zone is the area of the coast that is regularly but not permanently inundated by seawater. These are areas extending from the Mean Low Water Mark to the normal upper limit of wave run-up that is frequent enough as to prevent the establishment of terrestrial vegetation. The upper limit is generally a little above Highest Astronomical Tide due to the impact of storm activity.

Colloquially, the intertidal zone is commonly known as ‘the beach’ even though technically a beach is generally defined as a ‘wave-deposited sand body’. The use of the word ‘shore’ is preferred but it also accepted that in a study aimed at communicating with a wide range of stakeholders more commonly used terms may be utilised. The fabric of the intertidal zone may be composed of various materials including: muddy shores, sandy shores, shingle shores, or rock shelf (wave-cut platform).

<u>Subtidal zone</u>

Subtidal areas are permanently inundated by the sea. These are areas of the ocean floor which are below the Mean Low Water Mark. In this study the subtidal zone is the area from the Mean Low Water Mark to approximately 1000m offshore. Within the Alexandrina coastal region, 1000m is also the length of the coastal profile lines for which Coast Protection Board (Coastal Management Branch) has been collecting data since the 1970s.

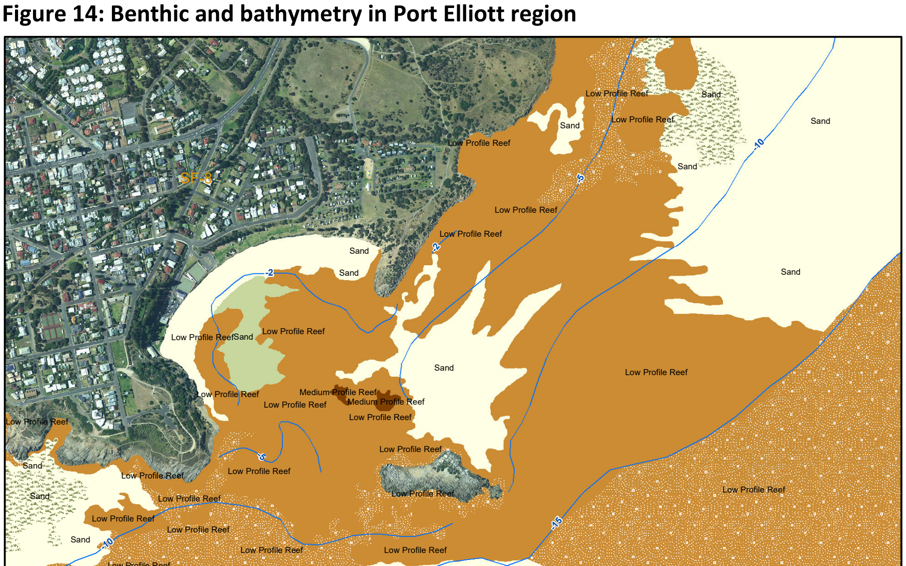
Two areas of assessment within the subtidal zone are relevant to coastal adaptation study:

- Bathymetry (or slope of the ocean floor) has a bearing on tidal range, wave formation, and ocean currents. The slope of the ocean floor is also utilised in more technical erosion assessments such as those that use the Bruun Rule.

- Benthic mapping (i.e. the fabric of the ocean floor) identifies the key composition of the ocean floor including the presence of reefs of varying constituencies, and the presence of sea grasses. These findings assist in determining how stable a shore may be in the context of sea level rise, and whether the presence of reefs and seagrasses effectively reduces exposure to actions of the sea and vulnerability to erosion.

One example is provided below from Nature Maps to illustrate benthic and bathymetry.

Figure 14: Benthic and bathymetry in Port Elliott region



Source: Nature Maps (SA Department for Environment and Water)

Backshore zone

The *backshore* is the area of coast generally up to 500m landward from Highest Astronomical Tide[22]. Analysis of the backshore is separated into two areas of interest. The *proximal*, is the backshore immediately at the back of the beach (e.g. sand dunes, soft rock cliffs, hard rock cliffs). In coastal adaptation study, this area is usually the most critical when evaluating the likely impact of erosion in the context of rising seas. The *distal* is the general geological layout landward of the beach. This is an area of interest because understanding the form and fabric of the backshore assists in broad framing of coastal adaptation issues[23]. Within this study the proximal backshore is known as 'backshore 1' and the distal backshore is known as 'backshore 2'.

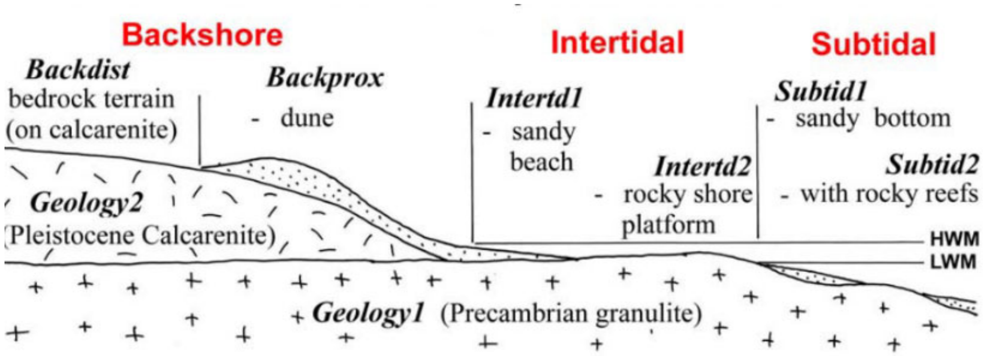
For example, the slope of coastal land in the Alexandrina region generally eliminates inundation as a coastal hazard. The slope and fabric of a backshore will also determine the extent of possible erosion. If seas rose 1-2 metres, then potential erosion in areas such as Middleton and Goolwa Beach may be measured in terms of 100s of metres, whereas the slope and nature of the fabric of Horseshoe Bay will limit the possible extent of erosion.

This study adopts the general rule adopted by Coastal Hazard Wheel (UNEP) and measures the height of land at 300-500m inland. As a general guide, where the elevation of land exceeds 8m AHD at 300-500m inland these are characterised as sloping backshores, whereas those less than 8m are more likely to fit into the sedimentary plain category.

Within a South Australian context, the underlying geology can be determined from South Australian Resources Information Gateway (surface geology)[24]. In this study, expert advice has been obtained from Dr Robert Bourman (geomorphologist).

One example is provided from OzCoasts to illustrate the concepts explained above (Figure 15).

Figure 15: Calcarenite coast with exposed basement rocks (similar to Boomer Beach)



Source: Sharples et al (2009).

Note: in practice there is some overlap between the intertidal zone and subtidal zone when considering the fabric of the shore. For example, reef structures are likely to be located within both the intertidal and subtidal zones.

[22] Five hundred metres is utilised by CoastAdapt, Ozcoasts, Coastal Hazard Wheel (UNEP) and is also the width of South Australian Coastal Conservation Cells.
[23] Coastal Hazard Wheel methodology utilises 500m inland and elevation at this point above 8m is determining the various risk to hazards of erosion and inundation.
[24] South Australian Resources Information Gateway, viewed at https://map.sarig.sa.gov.au/

Classes of fabric

The classes of fabric developed by OzCoasts and adopted by CoastAdapt are listed below.

Muddy Shores

This class identifies shores having dominantly mud-grade (clay, silt) soft sediments in the intertidal zone, and may include sandy muds and pebbly muds where the mud fraction is considered dominant. This class includes many estuarine, deltaic, saltmarsh and mangrove dominated shores comprising both narrow muddy shores and broad muddy intertidal flats.

Examples in South Australia: Samphire flats in Adelaide Plains Council region, Onkaparinga River estuary.

Sandy Shores

This class contains shores dominated by sand-grade soft sediments in the intertidal zone. Sandy shores may also include mixed sand and shingle where sand is dominant. This theme includes sandy beaches, sandy tidal flats, and narrow sandy shores (e.g. sandy tidal channel shores which are not true wave-deposited sand bodies).

Figure 16: Example of an open coast sandy shore backed by a low-lying sediment plain

Source: OzCoasts, 2009.

Sand dune and beach ridge coasts (Dunes)

This class contains shores dominated by sand-grade soft sediments in the intertidal zone and also with significant soft sand deposits in the backshore. This class includes aeolian sand-sheets, dunes, dune-fields or beach ridges (soft sands either having some exposure to wind erosion and/or originally deposited by wind)[25].

[25] OzCoasts does note that sand dunes can be found behind stable hard rocky shores (e.g. cliff-top dunes). This coastal form may not be prevalent in South Australia.

Figure 17: Ratalang-Basham Beach sand dunes

Source: M. Western (2019)

Coarse Sediment Shores

This class identifies shores dominated by coarse-grade unconsolidated sediment in the intertidal zone. These may include (wave-deposited & wave-worked) shingle and boulder beaches, as well as dominantly talus (colluvial) shores (coarse mass movement-deposited material, generally little clast rounding from wave action).

Examples in South Australia: Marino Rocks, Hallett Cove Cliffs

Figure 18: Shingle Beach at Marino Rocks

Source: M. Western (2019)

Undifferentiated soft sediment shores

This class identifies shores having soft sediment of unknown type in the intertidal zone.

Soft Rock Shores

This class identifies shores having 'soft' bedrock landforms dominating the backshore zone. Soft bedrock coasts often have sediment mantled intertidal zones with little or no bedrock outcrop, since the soft bedrock itself is quite erodible. Soft bedrock may be semi-lithified or inherently soft bedrock, strongly weathered bedrock or some other type of regolith. Examples include backshore landforms of clayey or gravelly semi lithified Cainozoic-age sediment, soft limestone types, intensely fractured and deeply weathered volcanic rocks, lateritic duricrust profiles or coarse boulder sediments.

Figure 19: Example of 'soft rock' shore (in this case, semi-lithified sandstone)

Figure 20: Example of 'soft rock' shore (in this case, semi-lithified clayey conglomerate and soft sandstone)

Source: OzCoasts

Hard Rock Shores (Hardrock)

This class identifies shores dominated by hard lithified bedrock landforms exposed in the intertidal zone and present with or without soil mantles or aeolian sand veneers in the backshore zone. The intention of this theme is to identify hard rock coasts where bedrock is
exposed at the shoreline (either in the intertidal zone and/or as backshore proximal cliffs).

Note: OzCoasts and CoastAdapt include further stability classes relating to the presence of coral and ice, neither of these being relevant to South Australian shores.

Terminology and descriptions

The classification system and descriptions were originally developed by Oz Coasts and have now been adopted by CoastAdapt. It is also noted that these terms and descriptions are similar to those adopted by Coastal Hazard Wheel (UNEP). Where appropriate, the methodology utilised in this study adopts similar terms and descriptors for fabric and form.

Table 2: Terminology and descriptions for coastal classification

FABRIC (dominant constituents)		**FORM** (coastal profile)	**STABILITY CLASSES & SUB-CLASSES** (styles of instability likely in response to CC & SLR)	
Soft Sediments (unlithified, essentially unconsolidated sediments)	Dominantly Muddy	Flat to gently sloping shores	**Muddy intertidal flats** e.g., mangrove flats (complex, significant instability likely)	Backed by bedrock or soft sediment
				On open coast or in coastal re-entrants (inlets)
		Gently to moderately sloping shores	**Narrow muddy shores**, e.g., many estuarine shores (instability likely)	Backed by bedrock or soft sediment
				On open coast or in coastal re-entrants (inlets)
	Dominantly Sandy	Flat to moderately sloping shores	**Sandy shores or beaches ± tidal flats** (complex but prone to erosion & retreat)	Backed by bedrock or soft sediment
				On open coast or in coastal re-entrants (inlets)
		Dunes, windblown sheets, beach ridge backshores exposed to wind	**Sand dunes , ridges or sheets** (prone to increased mobility; some may stabilise)	Isolated from or exposed to wave attack
	Dominantly Coarse (pebble to boulder grade)	Gently to moderately sloping shores	**Shingle to boulder – grade beaches** - wave-deposited coarse sediment (instability likely, but response to SLR may be complex)	Backed by bedrock or soft sediment
		Moderately to steeply sloping shores & backshores	**Dominantly colluvial (talus) shores** where not significantly cliffed or dominated by protruding *in situ* bedrock. (unstable shores, ongoing slumping likely).	Backed by bedrock or soft sediment (generally backed by bedrock rather than extensive soft sediments)
	Undifferentiated soft sediment	Undiff	**Undifferentiated soft sediment shores** (instability likely but style unknown)	Backed by bedrock or soft sediment
				On open coast or in coastal re-entrants (inlets)
"Soft Rock" (inherently soft, semi-lithified or deeply weathered lithic substrates)	Various types sharing similar coastal stability styles, e.g. :- - Semi-lithified or inherently soft sedimentary rocks (e.g., clayey-gravelly semi-lithified sediments, soft limestones); *or* - Weathered bedrock & regolith (laterites, residual materials)	Flat to gently sloping backshore	**Low profile soft-rock shores** (potential progressive erosion and shoreline retreat)	
		Moderately to steeply sloping backshore (may include sub-ordinate colluvium)	**Moderate to steep profile soft-rock shores** (progressive erosion, slumping and shoreline retreat)	
		Very steep to cliffed backshore (may include sub-ordinate colluvium)	**Very steep to cliffed soft-rock shores** (comparatively rapid progressive erosion, slumping, rock-falls, slab collapses and shoreline retreat)	
Hard Rock (hard well-lithified substrates)	Hard lithified bedrock or coastal precipitates dominant, not deeply weathered	Gently to moderately sloping shore & backshore	**Low to moderate profile hard-rock** shores (robust physically stable shores, negligible likely retreat over human time-frames)	
		Steep to cliffed shore (may include sub-ordinate colluvium)	**Steep to cliffed hard-rock shores** (progressive erosion, slumping, rock-falls, slab collapses and shoreline retreat)	

Source: Sharples et al 2009, Australian Coastal Smartline Geomorphic and Stability Map Manual, University of TAS

Methodology

Ancient coastal formation

Dr Robert Bourman has spent much of his professional life studying the Alexandrina coastal environs and has a significant knowledge regarding how the Alexandrina coastline has developed throughout the Holocene (~last 7,000 years) period. The analysis and work by Dr Bourman in this study provides the broader context from which to understand the current trends operating along the coastline.

Current fabric and form

Using publicly available tools, locate maps and analyse:

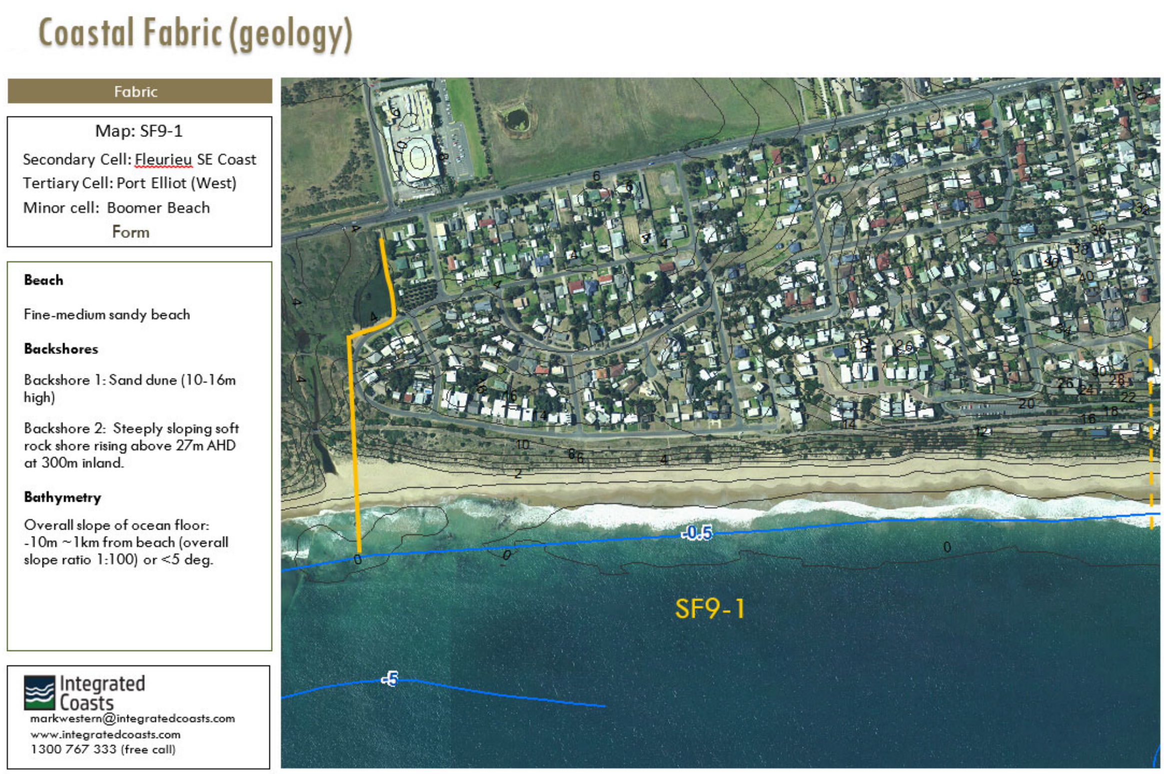
- Contours and bathymetry (Nature Maps)
- Surface geology (SARIG)
- Benthic (Nature Maps)

Identify and describe the form and fabric of:

- The intertidal zone (the beach)
- Backshore 1 (the area immediately behind the beach)
- Backshore 2 (the area from Highest Astronomical Tide to 300-500m inland)
- The subtidal zone (the benthic)

Record these findings within the Coastal Adaptation Study template (Figure 21).

Figure 21: Example from the template – the Form of Boomer Beach



Recent coastal changes

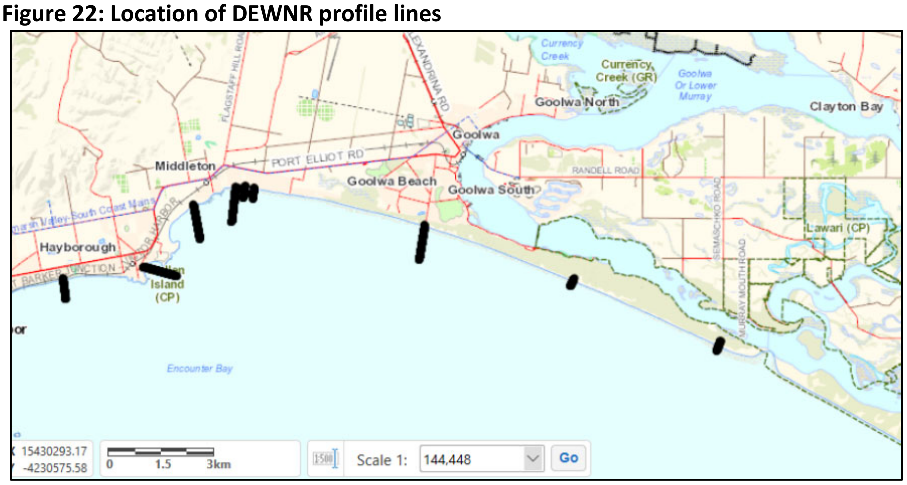
In the context of this study we assess more recent changes in terms of:

- Medium term changes (70 years)
- Short term changes (the last 10-15 years)
- Where available, historical photographs are used to compare the nature of the coast over the last 120 – 130 years.

Recent historical recession or accretion rates have been identified by comparing georeferenced aerial photographs primarily from 2003 to 2018, but also including one older set from 1949. Changes are evaluated within the Coastal Adaptation Study template.

Department for Environment Water and Natural Resources have seven profile lines within the region that were first captured in the 1970s. Changes to these profiles also provide a way to evaluate the trend of supply or deficit of sediment around the Alexandrina coastline.

Figure 22: Location of DEWNR profile lines



Source: NatureMaps, SA Gov (2018)

This project has added to this profile picture by obtaining additional bathymetric profiles by utilising the services of Magryn Engineering to obtain additional profile lines at: Chiton, Boomer, Green Bay, Horseshoe Bay, Ratalang-Basham, and Middleton Point. The existing profile data for Middleton to the Murray mouth were considered adequate for this project.

Step 2.4.4 Identify coastal modifiers (human intervention)

Rationale

In some locations human intervention has modified the natural fabric. These interventions include the implementation of protection structures (or other coastal control measures), and the construction of urban infrastructure.

Mitigation of sea-flooding and erosion is often managed with hard protection works, such as levees and groynes, or soft management options, such as beach nourishment or dune vegetation.

Two main reasons exist for analysing existing protection works and strategies. First, an analysis of existing protection works and strategies provides historical insight into prior coastal issues. A review of records subsequent to the implementation of the works or strategies will inform if protection works have been breached or repaired, or if the council has fulfilled any maintenance obligations over time. It is understood that this information may not be available in older settlements and where protection measures were implemented in the more distant past.

In the context of this project we are calling these works, 'coastal modifiers' because they change the way in which actions of the sea would normally interact with the coastline. Hard protection works tend to modify the coast more than softer management options.

Methodology:

- Review files at DEWNR and Council to obtain any reports or correspondence
- Identify protection works and strategies within each coastal cell
- Investigate and record the location of ad hoc protection works. Where these are on private property, this investigation will be conducted discreetly
- Identify the impact of urban infrastructure upon backshores

Step 2.4.5 Assign an erodibility rating

Assign an erodibility rating to the beach (intertidal zone), backshore 1 (proximal) and backshore 2 (distal). Inputs to the erodibility rating can be based upon: Shoreline Explorer in CoastAdapt[26], coastal classification in Nature Maps (SA), and assessment by experienced geomorphologists. In this study we have used the expert input from geomorphologists Dr Robert Bourman and Dr Patrick Hesp.

Erodibility ratings are:

- Low erodibility (generally assigned to hard rock shores)
- Moderate erodibility (generally assigned to soft rock shores)
- High erodibility (generally assigned to sediment shores)
- Very high erodibility (reserved for areas such as tidal flats)

[26] Shoreline Explorer does not always correctly identify the backshore of the Alexandrina coast. For example, two areas on the Middleton to Goolwa Beach section of beach are mis-classified as 'soft rock shores' and 'hard rock shores'.

2.4.6 Analyse current coastal exposure

Rationale

Impacts experienced in the coastal zone are a product of how actions of the sea (tides, wave action, sediment movements, and storms) combine over time with the physical features of a coastal area (geology and vegetation). Storm water run-off from the land can also impact the coastal fabric.

This area of work investigates and reports on the general coastal characteristics of the Alexandrina coastline including:

- Wave energy
- Tidal range
- Sediment dynamics
- Storm surge

A review of the impact of storm water upon the coastal zone is also undertaken. Sub aerial processes (weathering and mass movement) are considered if relevant.

Methodology

Nature Maps (Department for Environment and Water) has assigned an exposure rating for most of the South Australian coast and these ratings are adopted as a starting point for this study.

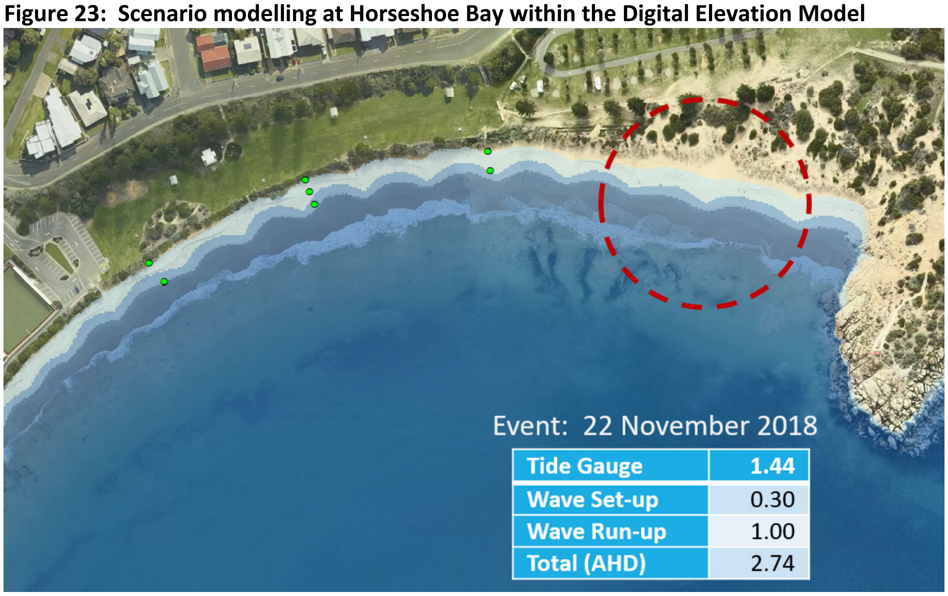
Exposure from actions of the sea is analysed by using modelling within a Digital Elevation Model.

Three scenarios have been modelled for each coastal cell:

- The storm event of 22nd November 2018 (from which wave effects were derived)
- Monthly high-water (based on average of all monthly high-water records at the local gauge)
- 1 in 100 ARI storm surge set by Coast Protection Board

In all three scenarios the height of water at the Victor Harbor tide gauge is modelled, as well as wave set-up and wave runup, and these are depicted in different shades of blue (Figure 23).

Figure 23: Scenario modelling at Horseshoe Bay within the Digital Elevation Model



Source: Integrated Coasts

The impact of storm water upon the beach and backshore is also assessed at each location.

Figure 24: Storm water catchment and impact upon beach and backshores assessed

Source: Integrated Coasts

Current erosion issues are assessed based on the findings of *Settlement History (Step 2)* and the *Geomorphology (Step 3)* section of the work. These findings are reported within each tertiary cell in Part 2 of this report.

2.4.7 Analyse future coastal exposure

Rationale

One way to envision the future of the coast is to take the current scenarios analysed in *Step 5*, add projected sea level rise, and evaluate the likely impact upon a shoreline.

The question is, will the dynamics of storm surge events be similar in 100 years time? Church et al (2016) address the potential for climate change to bring about changes to the weather systems that might change nature of storms that produce extreme water levels. While acknowledging that the research is limited, the initial conclusion is that the climate change is unlikely to significantly intensify the storms so that they produce higher extreme sea levels. What this means in the context of this study is that to add projected sea level rise to a current extreme event (such as 22 November 2018), is a valid way to view a future scenario[27].

On the other hand, within certain localities, storms with current intensity but at a higher mean sea level are likely to be experienced along the shoreline with more impact. For example, a reef that currently provides a degree of protection to a shoreline, is likely to provide less protection if seas were 1m higher over the top of the reef. The way in which currents and long-shore drift operate may change so that there is less sediment available to naturally nourish a beach.

[27] Church et al 2016 Sea-level rise and allowances for coastal Councils around Australia, Guidance Material, CSIRO report.

Methodology

Scenario modelling within a digital elevation model (DEM) enables us to envisage the impact of higher sea levels projected for the future.

Conduct scenario analysis

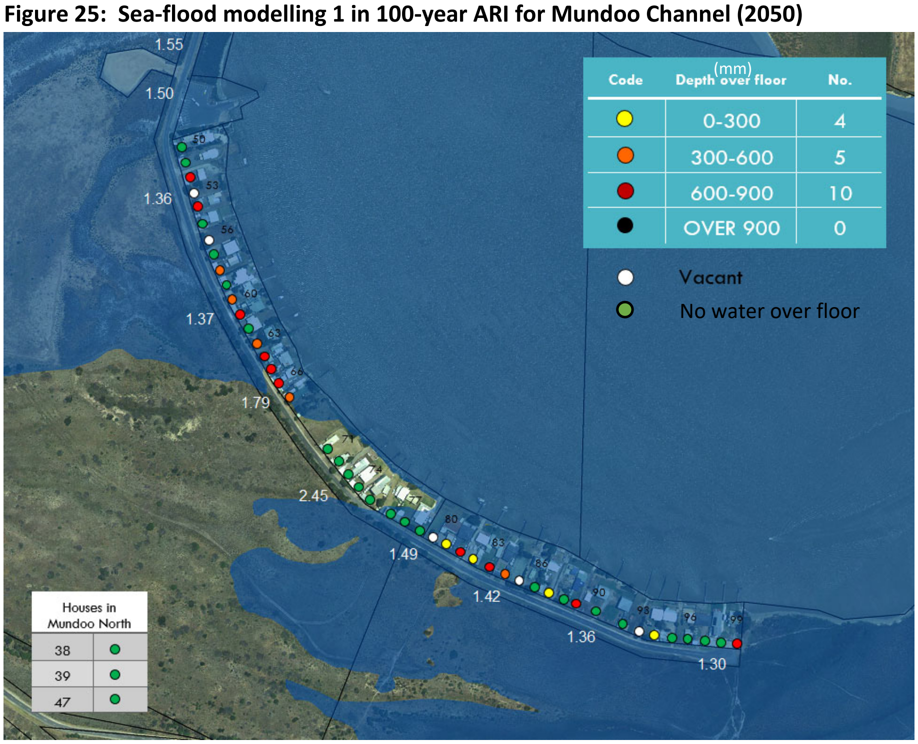
- Modelling has been produced within the digital environment for various sea level rise scenarios: storm surge modelling (1 in 100 ARI) for 2050 and 2100
- Routine highwater actions: using an average of monthly high water data from Victor Harbor tidal gauge provides a way to evaluate the current impact of the more routine high tidal action. Adding sea level rise increments of 0.3m and 1.0m to current routine tides provides a way to understand the likely future impact of routine tide action in the future

Purpose of tidal and storm surge scenario modelling

Inundation modelling is a useful medium to demonstrate the impact of sea level rise. This study utilises a modified 'bath-tub' methodology that analyses flow paths and considers duration of tides. The flood map is then drawn as an ArcGIS shapefile. However, it is important to recognise that this is not a full hydro-dynamic modelling technique and some limitations in the outputs are acknowledged.

Inundation modelling can be utilised in a number of ways. Firstly, it is a means to eliminate areas that are not vulnerable to inundation from sea level rise. In the context of the Alexandrina Council, this applies to almost all of the coastline. Secondly, in locations such as the low-lying areas of Mundoo Channel and Goolwa Channel on Hindmarsh Island, the inundation modelling is effective in determining the extent of future exposure (Figure 25).

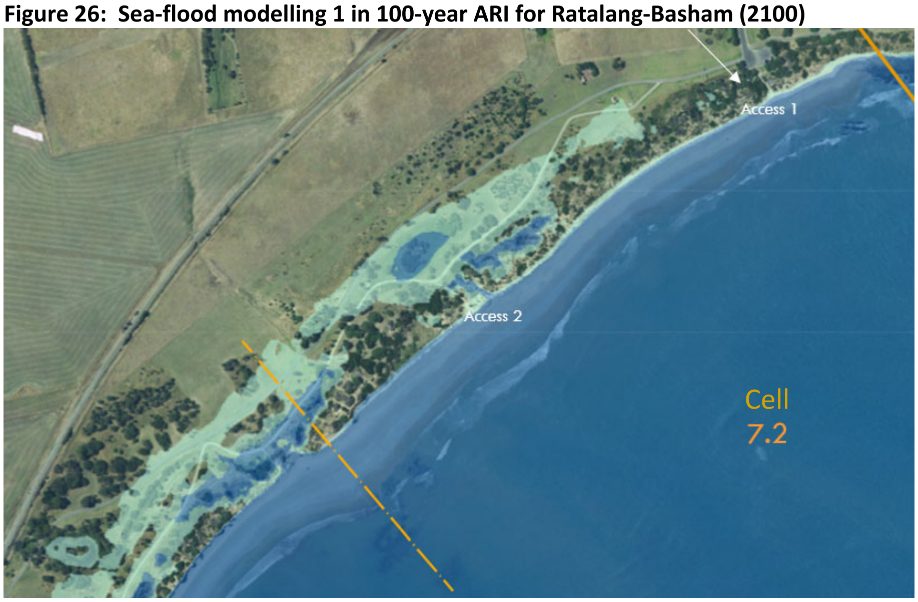
Figure 25: Sea-flood modelling 1 in 100-year ARI for Mundoo Channel (2050)



Source: Integrated Coasts

It is important to acknowledge that future coastal processes are being modelled within the current coastal fabric. If sea levels rise by 1.0m then the fabric of the coasts will change, especially in those dominated by sand such as the Middleton to Goolwa Beach, and within locations such as the Murray Estuary. However, the future inundation modelling does serve a number of useful purposes within an erosion context. For example, in a location such as Ratalang-Basham, the combination of inundation modelling and erosion modelling provides the basis to project that the frontal dunes are likely to be eroded, and the extent of the ecology behind the current dunes impacted by seawater.

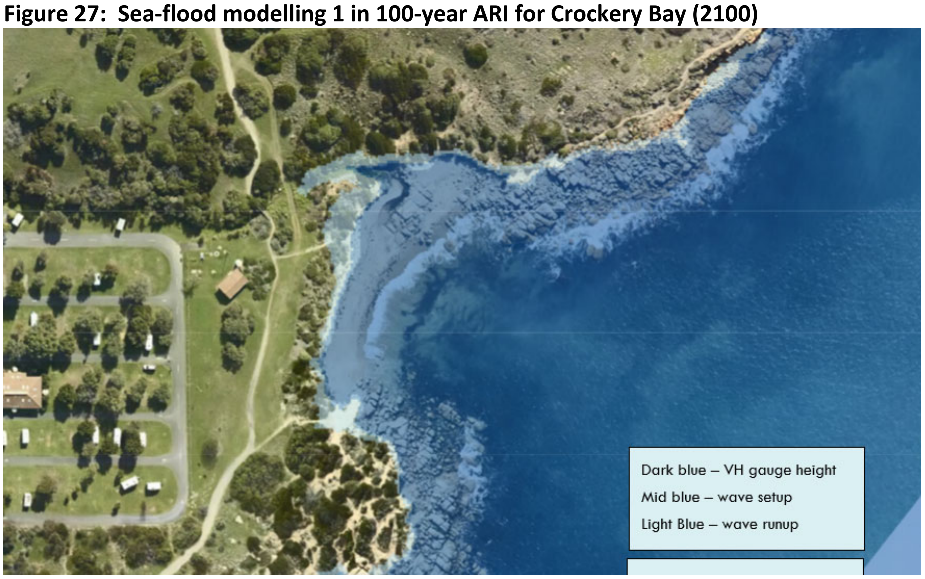
Figure 26: Sea-flood modelling 1 in 100-year ARI for Ratalang-Basham (2100)



Source: Integrated Coasts

The modelling does assist in determining the likely impact of erosion and when increased erosion may occur. For example, at Knight Beach monthly high-water modelling for 2100 indicates that the backshore is not likely to be impacted. In the case of Crockery Bay, storm surge modelling for 2100 suggests that this hazard is likely to be easily managed with minimal protection (Figure 27).

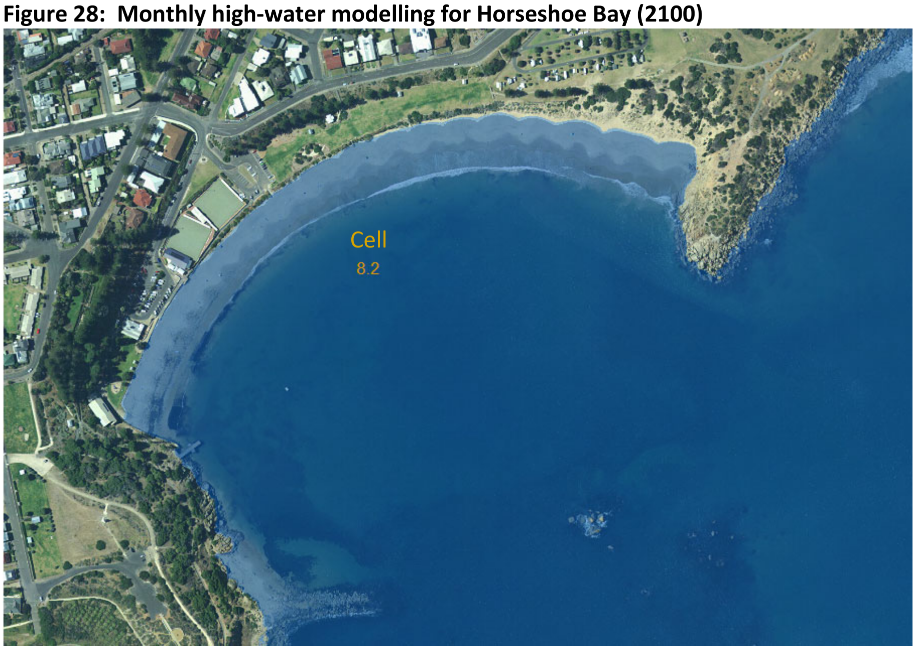
Figure 27: Sea-flood modelling 1 in 100-year ARI for Crockery Bay (2100)



Source: Integrated Coasts

Furthermore, the modelling does provide a way to communicate with the various stakeholders involved with decision making in the coastal zone. Three recent presentations, to Alexandrina staff, the executive, and elected members, have shown that as a communication medium it is effective way to visually demonstrate the increasing impact that sea level rise will bring to a coastal segment. For example, the modelling of the monthly high water for 2100 (without wave runup) at Horseshoe Bay demonstrates that wave set-up will be impacting the backshore on a regular basis.

Figure 28: Monthly high-water modelling for Horseshoe Bay (2100)



Source: Integrated Coasts

Future coastal exposure is considered based on modelling of monthly high water and 1 in 100-year ARI scenarios, but with the addition of the allowance of 0.3m sea level rise (indicatively by 2050), and 1.0m sea level (indicatively by 2100). Exposure from actions of the sea is analysed by using modelling within a Digital Elevation Model. Two scenarios have been modelled for each coastal cell:

- Monthly high-water (based on average of all monthly high-water records at the local gauge)
- 1 in 100 ARI storm surge set by Coast Protection Board

Erosion Assessment

Discussion

The consensus of the scientific community is that predicting coastal erosion is an uncertain science and providing an exact position of the shoreline in the future is misleading[28]. Erosion is a product of numbers of variables, and rapid erosion often occurs in single events at particular locations rather than in a steady and uniform manner. Sea level rise is predicted to increase erosion, but the rate of sea level rise is uncertain. Therefore, it is more prudent to consider erosion risk in terms of 'outlook' and within 'zones' rather than within strict lines.

[28] http://apps.environment-agency.gov.uk/wiyby/134808.aspx

Existing Methodologies

CoastAdapt notes that there are two main ways in which to undertake erosion assessment: the engineering approach, which focuses on beach response to short-term storm processes; and the geomorphological approach, which focuses on long-term change[29].

The engineering approach tends to favour the use of models and this approach tends to be used when short term change is of interest. Generally, a modelling approach requires the need for detailed inputs, they are expensive to create, and are much more useful within smaller environments, rather than an entire stretch of coastline such as Alexandrina Councils'[30].

The geomorphological approach focuses on long-term trends and tends to use conceptual models rather than numerical models. It is generally accepted that the establishment of a trend in beach change requires an observation dataset of at least 40 years. However, there are very few areas around Australia that have such long survey datasets of beach change[31]. In today's digital environment, we are able analyse some elements of beach change using historical digital photographs, digitised maps, coastal profile lines, within digital models (LiDAR).

In the context of a 'second pass' assessment (see p. 6) the Bruun Rule has been applied, plus a geomorphological approach is utilized for this project[32].

Erosion assessment inputs

This project takes into five main inputs as a basis for the erosion assessment:

1. In the broader context of the larger secondary sedimentary cell, the nature of the tertiary coastal cell in relation to the location's orientation, wave height, exposure, and fabric type.

2. The geomorphology of the location. How was the coast formed? Is it possible to identify locations of previous shorelines from when sea level rise was higher? What changes have occurred in the last 150 years? What trends are observed? Is the shoreline stable, accreting, or eroding? These are typical questions that are addressed in Step 3 and assist in defining the existing erosion trend, and possible future outlook.

3. The tidal and storm modelling (Step 4) provides an insight into current risk, especially in relation to sea-water flooding, but also allows future flooding and erosion scenarios to be assessed. Assessing tidal and storm surge modelling in the context of the nature of the fabric of a particular section of coastline provides insight as to which areas are likely to erode more quickly than others.

4. The Bruun Rule created by Per Bruun has been extensively used to predict the beach response to sea level rise:

   $S = - S p\ (W / dc + B)$

   Where S = Erosion due to sea level rise

   Sp = Sea level rise projection

   W = Width of the beach profile

[29] https://coastadapt.com.au/sites/default/files/information-manual/IM03_Available_datasets_0.pdf
[30] https://coastadapt.com.au/sites/default/files/information-manual/IM08_coastal_sediments.pdf
[31] https://coastadapt.com.au/sites/default/files/information-manual/IM03_Available_datasets_0.pdf (p.9)
[32] Insert coast adapt categorisation of first, second, third pass assessment.

dc = Depth of closure

B = Foreshore/Dune crest height

Depth of closure (d_c) was determined using Hallermeier (1981) as modified by Houston (1995). Following Houston's approach, the Hallermeier equation can be expressed in the form:

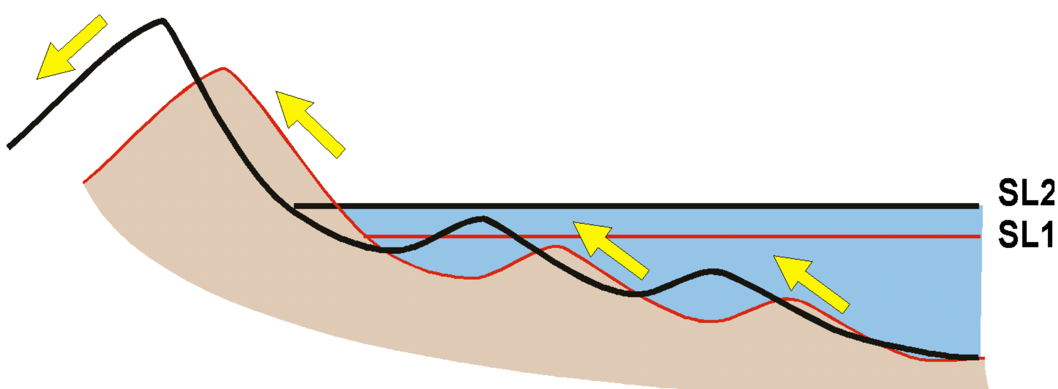
$Hin = 8.9\, Hs$ where Hs is mean annual significant wave height

Note that while the Bruun Rule has been extensively utilised in the past, it has also been criticized. For example, it does not provide accurate estimates of beach-dune recession where longshore drift processes are operating, where the closure depth cannot easily be determined, and where reef and rocky substrate exists in the surfzone-nearshore region. Given that some of these factors occur in this study area, the results of the Bruun Rule estimates must be regarded with caution.

5. Shoreface-Beach and Dune Translation Model

It is now a known fact that beaches and dunes can easily translate upwards and landwards as either shoreline erosion occurs or sea level rises. Therefore, another way to estimate the degree of shoreline retreat due to a given sea level rise is to take the latest topographic profile of the nearshore-beach-dune system and merely translate it entirely upwards and landwards by a given amount of sea level rise (in this case 1.0 m by 2100). The distance that the profile is translated horizontally is determined by maintaining the distance between two topographic points on the original profile in the projected future translated profile (i.e. by maintaining the original slope of the beach-surfzone profile). For example, if the distance between zero m or AHD on the current profile and the foredune toe is, say, 15m, then that distance between those two points is maintained in the translated 2100 profile. The shoreface-beach and dune translation model is illustrated in Figure 29 below.

Figure 29: Shoreface-Beach and Dune Translation Model

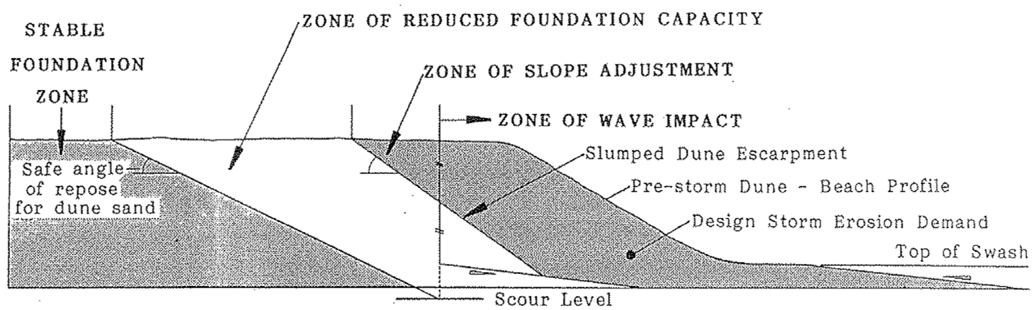


Source: P. Hesp, Flinders University

Erosion assessment in relation to assets and infrastructure

Figure 30 below illustrates zones of various types that develop following a storm event. Erosion modelling would first determine if any structure or infrastructure was within, or was likely to be within one of the first 3 zones (wave impact, slope adjustment, and reduced foundation capacity zones) following a storm event. In addition, subsequent modelling would then determine how much of the zones would move landwards and upwards as sea level rise of a certain amount took place.

Figure 30: A schematic representation of stability zones that may be identified for planning purposes following storm erosion and/or sea level rise.



The *Zone of Wave Impact* delineates an area where any structure or its foundations would suffer wave attack during a severe storm. It is that part of the beach seaward of the dune erosion escarpment.

A *Zone Of Slope Adjustment* was delineated to encompass that portion of the seaward face of the dune that would slump to the natural angle of repose of the dune sand following removal by wave erosion of the *design storm erosion demand.* This presents the steepest stable dune profile under the conditions specified.

A *Zone Of Reduced Foundation Capacity* for building foundations was delineated to take account of the reduced bearing capacity of the sand adjacent to the dune erosion escarpment. It was considered that structural loads should be transmitted only to soil foundations outside the zone within which the Factor of Safety was less than 1.5 during extreme scour conditions at the face of the dune. This allows for the design assumption that the soil may develop its full bearing capacity.

Structures not piled and located within the *Zone of Slope Adjustment* and seaward of that zone may be subject to foundation failure (soil slip and subsequent undermining) associated with a severe storm erosion event.

2.4.8 Assign an inherent coastal hazard rating

Coast Adapt identifies two prime coastal hazards[33]:

- Coastal inundation
- Coastal erosion

Other coastal assessment systems such as Coastal Hazard Wheel (UNEP) include hazard assessment for 'salt water intrusion' or 'gradual inundation' to differentiate the hazard of storm flooding from the gradual increase of tides that may occur in locations such as islands of low elevation in the Pacific Ocean[34]. In most instances, these geological settings are not relevant to South Australia. In the methodology developed by Integrated Coasts, a second-tier assessment also analyses any potential impact in the category of 'ecosystem disruption'.

Inherent hazard risk assessment

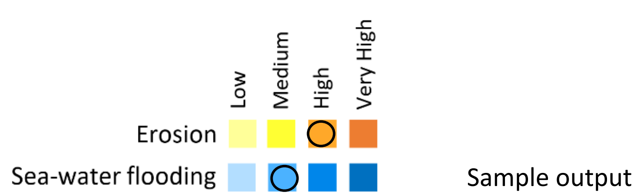
Integrated Coasts (in consultation with Dr P. Hesp) has developed a hazard risk assessment process with the aim that the outputs would have specific relevance and meaning within the various South Australian coastal settings. (Please note, that this system should be regarded as a *beta* version and further development and testing is envisaged.)

The focus of this assessment is upon the inherent characteristics of the coast and not focussed on any potential threat to human infrastructure or safety. For example, and at the simplest level, low lying land is inherently more vulnerable to inundation, and soft sediments are more vulnerable to erosion. 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 using a process that will also benchmark the locality in the context of all South Australia.

The inputs required to rate the coastal hazards of inundation and erosion will have been accumulated in the steps completed above.

The visual output from the inherent risk assessment process is purposefully designed so that it is immediately accessible and meaningful to a wide range of personnel involved in managing the coastal environs.

Figure 31: Visual output for the inherent hazard rating



[33] CoastAdapt, 2019, https://coastadapt.com.au/coast-and-climate-dynamics

[34] Rosenthal et al 2016, Managing climate change hazards in coastal areas: The Coastal Hazard Wheel decision support system, United Nations Environment Programme.

Inundation hazard risk

The hazard rating for inundation is usually defined solely by topography. However, in some cases, erosion assessments will demonstrate that low-lying areas behind a dune system would be inundated if the dune system was to erode (e.g. Ratalang Basham Beach, Cell SF7)[35].

The inputs required to make the assessment are based upon:

- Settlement history (i.e. analysis of former flooding events, protection works)
- Inundation modelling for current risk: monthly high-water, 1 in 100-year ARI risk
- Inundation modelling for 2050 risk and 2100 risk: monthly high-water, 1 in 100 ARI risk.

The inundation hazard risk is applied within the following categories and associated with the criteria noted in the table below[36].

Table 3: Inundation hazard rating criteria

Inundation Hazard Rating	Scenario Modelling	Other criteria
No risk	Modelling for 2100 scenarios depicts no risk (with some allowance of freeboard: 0.5m)	
Low	Modelling for 2100 scenarios depicts flooding of settlements	
Medium	Modelling for 2050 depicts flooding of settlements (but not for current scenario)	
High	Modelling of current 1 in 100 ARI year event depicts minor flooding of settlements	Have experienced minor to moderate flooding in past events (water over roads to depth of 0.1m)
Very High	Modelling of past events depicts flooding. Modelling of 1 in 100 ARI year events depicts substantial flooding.	Have experienced significant flooding in past events (water over roads above 0.1m)

Inundation within the Alexandrina region

Within the Alexandrina region, the vast majority of the coastline is rated as 'no risk' due to the elevated nature and slope of the shores. Exceptions along the coast include Watson Gap and Middleton Creek. In relation to the latter, the slope of the creek bed is such that significant sea-water flooding into the creek is unlikely in the short to medium term. In relation to the former, a sand bank tends to build at the mouth of the creek, and this is likely to continue.

However, within the Murray estuary, the south eastern part of the Hindmarsh Island is essentially a low-lying sand flat. Within areas such as these the inundation modelling is utilised to assign a hazard risk rating[37].

[35] Foul Bay on Yorke Peninsula is another location where ongoing erosion will increase flooding risk.
[36] This is preliminary criteria with recommendation that the criteria be developed further. Integrated Coasts has significant experience in coastal flooding and therefore in this study the outputs also rely on expert opinion.
[37] The classification requires more testing. However, the outputs for this project are sound and based on expert advice from Integrated Coasts.

Erosion hazard rating

The inherent erosion rating is not simply an assessment of the nature of the coastal fabric and form. CoastAdapt provides an 'erodibility rating' based just on fabric and form. Some coastal segments may be assigned high erodibility ratings, and yet they are not currently under attack from actions of the sea, nor subject to significant storm water runoff. The erosion hazard rating is concerned more about the inherent 'vulnerability' to erosion of a segment of coast in the context of a range of inputs.

Inputs required for the inherent hazard assessment:

The nature of the fabric and form of:

- Beach (intertidal zone)
- Backshore 1 (proximal)
- Backshore 2 (distal)
- Benthic (sub-tidal, intertidal)
- Bathymetry (slope – sub-tidal, intertidal)

The nature of exposure[38]:

- Wave height/ energy
- Tidal range
- Orientation
- Identification of impact upon backshores

The nature of the sediment balance:

- Analysis of sediment movement within a cell (or minor cell)
- Historical analysis of erosion/ accretion (indication of sediment supply)
- Outlook for sediment supply in the context of SLR (see CoastAdapt)

In contrast to numeric models that attempt to provide hazard ratings by assigning a weighting to the various inputs[39], this assessment weights those factors that make the largest contribution to an erosion rating by order of process. Sharples et al makes the following observation:

> The basis of this hierarchical ordering is the assumption that – as a very broad but useful generalization – the *fabric* of coastal landforms (whether they are made of hard or soft constituents of differing erodibility and transportability) will ultimately be the single most important determinant of their potential stability, with their *form* (and other factors such as their degree of exposure to wave energy, currents and other geomorphic processes) being secondary to this over-riding influence. Thus, for example, a granite shoreline will always be much more stable than a sand or mud shoreline, regardless of the forms of the shores or the wave climates (and other processes) to which they are exposed[40].

The Coastal Hazard Wheel (UNEP) process similarly begins by identifying and classifying the 'geological layout' as a way to identify both inundation and erosion risks to a coastline[41].

[38] In the context of this study, the exposure rating provided by Nature Maps is used as first input.

[39] The Victorian Coastal Hazard Assessment 2017 Project weighted various components of coastal attributes in accordance with their perceived influence on the erosion factor. For example, geological layout was weighted numerically higher than some of the exposure ratings (Victorian Department for Environment, Land, Water and Planning).

[40] Sharples et al 2009, Australian Coastal Smartline Geomorphic and Stability Map Manual, University of TAS, p.41

[41] Rosenthal et al 2016, Managing climate change hazards in coastal areas: The Coastal Hazard Wheel decision support system, United Nations Environment Programme.

Erosion hazard rating classification system

The erosion hazard rating classification system has been tailored to South Australian coastal environments. For example, South Australia has very few large rivers that make their way to the sea and form large deltas, coastal barrier systems or re-entrant settings. (Note: the way rivers and creeks are assessed and classified are managed as a separate step rather then classifying them within this system). On the other hand, samphire flats/ tidal flats are significant features within the South Australian context, but generally not in other places around Australia.

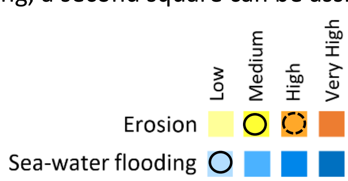
The initial step is to identify the geological layout and assign an initial erosion assessment rating. The subsequent steps allow the assessor to modify the erosion rating within a consistent assessment framework but also on a case by case basis. It is recognised that some expertise in coastal geomorphology is required to make the assessment. The system purposefully avoids a numeric system where numbers are input, weighted, and 'the lever pulled' to produce an erosion rating[42].

For practical purposes, any unaltered assignment of an initial 'very low' erosion rating is collapsed into 'low' in the final erosion assessment.

Step 1: Identify the appropriate form and fabric from the table below

Erosion assessment categories	Nature of Beach (Intertidal zone)	Nature of back shores
Very low	Hard rock platform	Hard rock coastal cliffs
		Stable hard rocky shore
Low	Hard rock platform or shingle beach (coarse sediment beach)	Sloping soft rock shore
		Soft rock coastal cliffs
Moderate	Sandy shore	Backed by bedrock rising above 8m AHD at 300-500 inland
		Backed by soft rock coastal cliffs
High	Sandy shore	Backed by sediments (less than 8m AHD at 300-500m inland
		Backed by dunes/ soft sediments
Very High	Tidal flats/ samphire flats[43]	Usually frontal dune backed by samphire or other tidal flats.

The inherent erosion rating can be assigned to just one square, or to partially reflect the impact of one or more factors within a rating, a second square can be assigned a dotted circle.



Example output

[42] Various reasons exist for not adopting this system in SA. One of those is this assessment process is designed for urban settlements (and nearby locations) and not a general assessment for the whole coast. There are many more reasons but beyond the scope of this project to report these.

[43] This category is especially related to the South Australian context. SA generally has a micro-meso tidal range and is not subject to tropical cyclones. Tidal flats are found within low exposure settings but are also highly erodible. Allocating a 'very high' erosion rating as a starting point could be moderated down where the exposure was very low.

Step 2: Identify and assess any human intervention that has altered the natural fabric

Human intervention is likely to relate to either the implementation of protection items (or other control measures such as groynes) or the construction of urban infrastructure within a coastal zone that tends to impede the coastal backshore from operating naturally. In practice the impact of these upon the erosion rating will need to be assessed on a case by case basis.

Examples of protection items from the Alexandrina region include:

- Seawalls in Horseshoe Bay
- Rock revetment at Sugars Beach

Examples of urban infrastructure within a coastal zone include:

- Carparks constructed at Middleton and Goolwa (produce a rigidity in the dune system which in some cases my impede the natural erosion and accretion cycles of the beach)
- Trainline along the top of the escarpment at Boomer Beach

Step 3: Quantify the impact of exposure upon the coastal fabric

The assignment of the exposure rating should be considered as a major factor that may alter the assignment at Step 1. It is likely that an increase in rating could be applied, but not normally a decrease in rating. The exception may be in the context of a tidal flat or samphire flat. Aspects of exposure include:

- Wave height/ energy
- Orientation
- Tidal range

Nature Maps (DEW) has assigned an exposure rating and a wave energy rating for all parts of the South Australian coastline. These assignments are generally adopted as inputs to this assessment, unless they are deemed to be incorrectly assigned.

A high exposure rating on everything but hard rock shores is likely to lift the erosion rating up one level (this will be judged on a case by case basis).

Some examples from Alexandrina and other locations around the State are:

- Example 1: Middleton – Goolwa Beach. Step 1 assigns a rating of ‘high’. Step 2 is not relevant. Step 3 with assignment of ‘highly exposed’ raises the erosion rating to ‘very high’.

- Example 2: Moana Conservation Park (south of Pedlar Creek). Step 1 assigns a rating of ‘high’. Step 2 is not relevant. Applying a ‘moderate’ exposure rating at Step 3 will tend to leave the assessment at ‘high’.

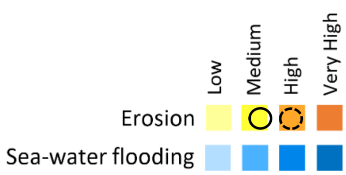
Step 4: Evaluate impact of actions of the sea on the beach (intertidal zone) and backshore 1

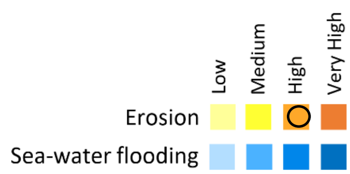
While an erodibility rating for the fabric of a backshore may be high, it may not be eroding because it isn't currently exposed to actions of the sea. For example, a highly erodible backshore may be set further back or elevated above the current routine tides, or the backshore may be protected in some way from attack. Conversely, inspection of the backshore and tidal regime may indicate that actions of the sea are already impacting and eroding a backshore.

Applying this step after step 3, further quantifies current exposure because the assessment relates to impacts caused by actions of the sea.

Some examples from Alexandrina and other locations around the State are:

- Example 1: At the northern side of Horseshoe Bay the dune system has been eroded away and currently actions of the sea are impacting the earthen embankment. Step 1 assigns a 'moderate' rating. Step 2 could be relevant because the nature of the back shore appears to incorporate fill (from the former caravan park). Step 3 assigns a 'sheltered' rating. Step 4 notes the ongoing impact to the backshore. Therefore, one of two assignments could be made depending on the degree to which the impact and frequency to which the backshore was deemed to be impacted:





- Example 2: At Knight Beach a comparison of photographs from 1949 with current day photographs demonstrates that actions of the sea have not impacted the backshore. The modelling of current storm surge risk and monthly high water also demonstrates that the backshore is not being impacted by actions of the sea.

- Example 3: The intertidal zone at Seaford Cliffs (north of Moana) is a sandy beach (with some shingle content). Seaweed strands from routine higher tides are regularly found at the base of the clay cliff escarpment. Seas have been observed interacting with the base of the cliff on a regular basis. It is likely that this factor would increase the inherent erosion rating from 'moderate' to 'high'.

- Example 4: The intertidal zone at Sellicks Beach south of the boat ramp is a sandy beach (with shingle content) but a 'high tide shingle beach backs the southern end of Sellicks Beach' (Nature Maps). It is likely that this factor will see the erosion hazard rating remain at 'moderate'.

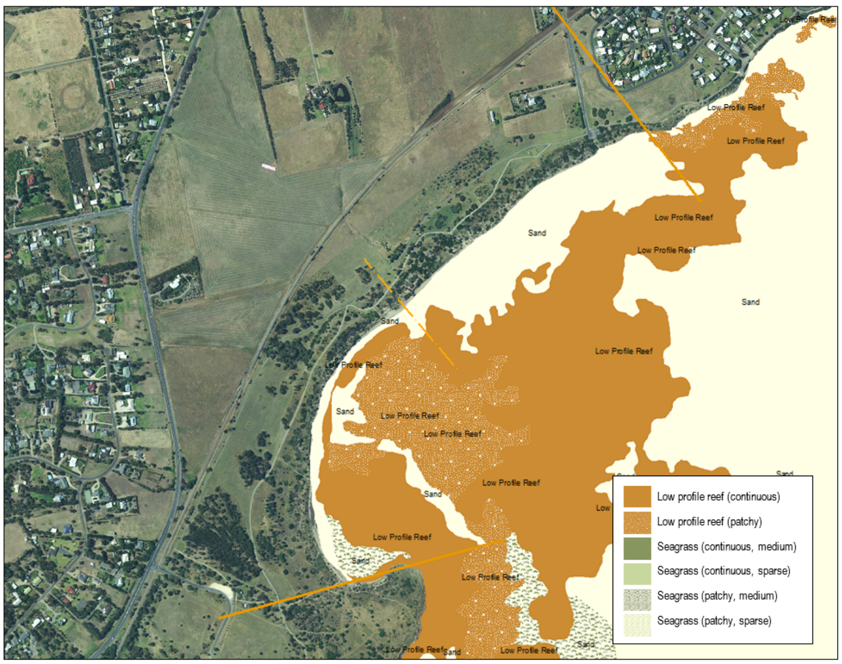
The factors involved in these examples may not raise the erosion rating on their own, but they may accumulate with all other factors (i.e. further steps below).

Step 5: Evaluate the impact of factors in the inter-tidal to sub-tidal

The presence of reefs or seagrasses in the inter-tidal or sub-tidal zones may partially reduce the exposure to actions of the sea. For example, a substantial low-profile reef, and some patches of seagrass are present at the southern end of Ratalang-Basham Beach. Combined with a low exposure rating due to the protection of the granite outcrop, the erosion hazard rating could be dropped from ‘moderate’ to low (but in this case other factors kept the rating at ‘moderate’).

Step 4 has already assessed the current exposure on the fabric, including the effect of exposure-reducing factors. Therefore, care would need to be taken not to overrate the exposure reducing factors. However, where these factors are more likely to play a part in the assessment are in the context of sea level rise. Coastal areas where reefs and seagrasses are currently lowering exposure are likely to become less effective over time with greater depth of water over the reef.

Figure 32: Ratalang-Basham: the impact of low profile reefs and sea-grasses tend to lower exposure

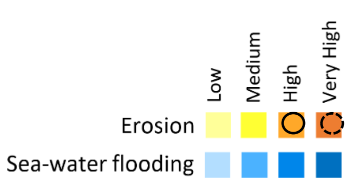


Source: Integrated Coasts

Some examples from Alexandrina and other locations around the State are:

- Example 1: The presence of reefs and seagrasses at Ratalang-Basham tend to lower the impact of exposure. However, increased depths of water may reduce this effect.

- Example 2: Seaford Cliffs are fronted by a substantial low-profile reef. Large tidal events and storms are already impacting the base of the clay cliffs. Sea level rise will not only add more depth of water, but the exposure lowering effect of the reef will be reduced. This outlook could also be reason to add a modifier above a solid circle.



Step 6: Assess the sediment balance within each cell

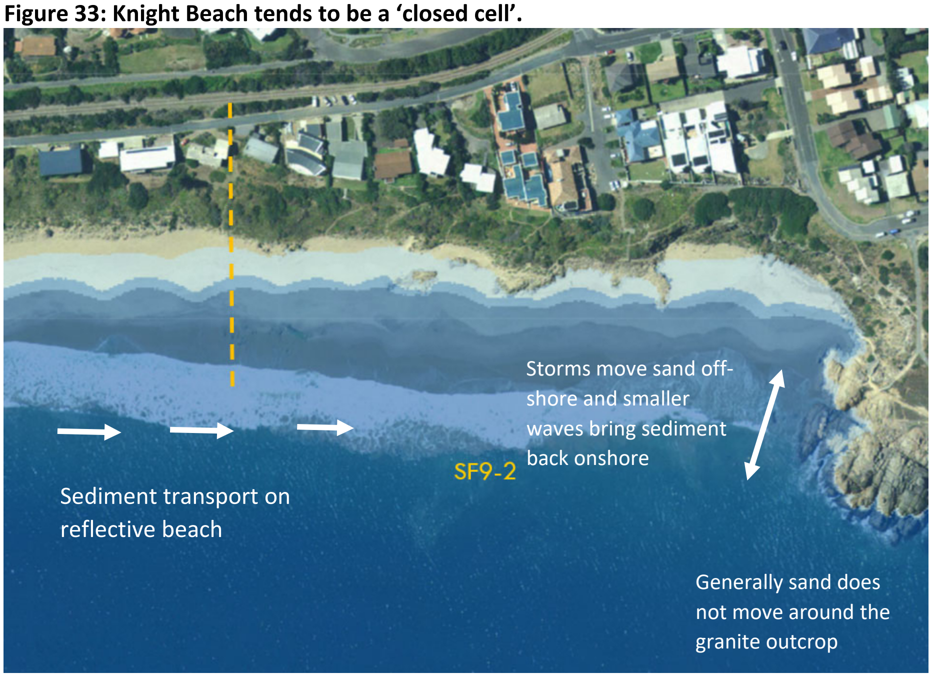
Cells that are losing sand will tend to erode, cells that are gaining sand will tend to accrete. The characteristics of some cells, due to the geological layout, tend to act as closed cells where very little sediment is lost. Evaluating sediment transport and connectivity with other cells will assist in identifying whether a cell is likely to erode or accrete. A comparison of historical aerial photographs will also provide an indication in relation to sediment balance. CoastAdapt provides a sediment balance outlook for each of the secondary coastal cells which can also be used as an input in this assessment process.

It is not envisaged that as a 'second pass' assessment that any detailed assessment of sediment transport would be undertaken. However, in problem locations, recommendations could be made for a 'third pass' assessment be undertaken by a suitably qualified coastal engineer using appropriate inputs and modelling within a digital environment.

Some examples in Alexandrina include:

- Example 1: Boomer Beach is a reflective beach that tends to transport sand towards the east. The granite outcrops to the east of Knight Beach effectively close the Boomer- Knight cell. In larger storms some sediment is lost towards Green Bay, but for the most part the sand is transported on and off of Knight Beach. This sediment pattern has kept Knight Beach well-nourished with sand and therefore actions of the sea do not impact the backshore.

Figure 33: Knight Beach tends to be a 'closed cell'.



- Example 2: A comparison of historical photographs and historical reports for the Middleton clay cliffs demonstrated that 100m of cliffs were eroded around the turn of the last century. Between 1949 and 2008, a further 10-12 m of cliffs were eroded. Between 2008 and 2018 an incipient dune has built outwards by 10-12 m. This analysis tends to support the view that the Middleton Cliffs area is presently at equilibrium.

Step 6: Assess any other modifiers that may change the assigned erosion rating

This step is a 'catch-all' for any other factors not covered in the above five step.

Summary and conclusion

The purpose of assigning an inherent rating for the coastal hazards of inundation and erosion is to provide an insight into the natural (or modified) characteristics of a coastal tertiary cell (or minor cell if applicable).

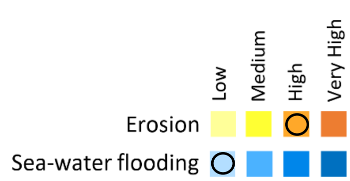
The purpose is not to consider any impact upon human infrastructure or safety. These aspects are dealt with in the following section.

The assessment outlined above could be completed in 'first pass' mode with limited inputs, or in 'second pass' mode with more detailed assessments such as those that can be produced within a digital elevation model. However, it is envisaged that the expertise of a coastal expert would be required to make an appropriate determination.

From a practical purpose, the inherent hazard ratings should serve as a context from which to make future infrastructure decisions. For example, the Middleton to Goolwa Beach has been assigned a 'very high' inherent hazard rating. Whenever Council is contemplating any proposal within this stretch of coastline, a simple check for the inherent rating as a basic input will form the basis upon which the viability of the proposal is to be assessed.

The allocation of inherent hazard ratings also informs whether the specific risk assessment (p. 47) is required for erosion or sea-water flooding, or in some cases both (Ratalang-Basham). In other words and using the example pictured below, the impact of sea-water flooding would receive no further assessment, whereas a specific risk assessment would be conducted for erosion hazard.

Figure 34: Each tertiary cell (or minor cell if applicable) is assigned an inherent hazard risk rating.



2.4.9 Identify hazard impacts upon receiving environments

Background

The Alexandrina coastline has generally developed over time with human infrastructure that is set well-back from the shoreline and areas of impact. Privately owned assets are generally set behind esplanade roads meaning that they are often afforded protection by the Council's responsibility to maintain the road. Furthermore, the context of this study is primarily concerned with Council owned assets, and therefore these assets are the focus of this study.

Purpose

The purpose of producing a coastal adaptation study is to identify ways in which humans need to adapt to current or future coastal change. Therefore, it is desirable that the project should move to assessing these aspects as soon as possible.

Hazard impacts are considered within four receiving environments:

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

Hazard impacts are also considered in two eras: the 'current outlook', and the 'future outlook'. In this study, future outlook means the end of this century.

The term ecosystem disruption is used to describe the situation where increasing inundation or erosion in a coastal region might bring about larger scale changes to the nature of the coastal environment that may threaten to disrupt the entire ecological system. For example, an area of land that is currently ecologically freshwater would become ecologically 'disrupted' if it became inundated by sea water.

The visual output for this assessment process is only produced where the inherent risk assessment has provided the rationale for a second pass assessment. The output is purposefully designed so that it is immediately accessible and meaningful to a wide range of personnel involved in managing the coastal environs including: politicians, elected members, policy makers in all levels of Government, coastal managers, and the general public.

Using four receiving environments is also a way to stream the project. In some areas, no risk to private assets exist, whereas risk to public infrastructure is significant (example, Horseshoe Bay). In other locations there are risks to ecology (example, Ratalang-Basham). In some locations risk exists in all four categories (example, Mundoo Channel).

Methodology

Use a 'first pass, second pass, third pass' approach:

First Pass

Integrated Coasts has adopted a visual style of reporting within each coastal cell and reported in Part 2 of this project. The ability to visually compare the nature and location of infrastructure means that assessing vulnerability of Council assets to coastal hazards in 'first pass' mode is a simple exercise.

- Example: Analysis of the fabric of Mundoo Channel settlement revealed that it is at low elevation and situated in a sand flat. Historical research revealed former cases of flooding (1954).

Second Pass

Where it is apparent from the hazard mapping that Council assets may be at risk, these assets will be duly noted and dealt with in 'second pass' mode.

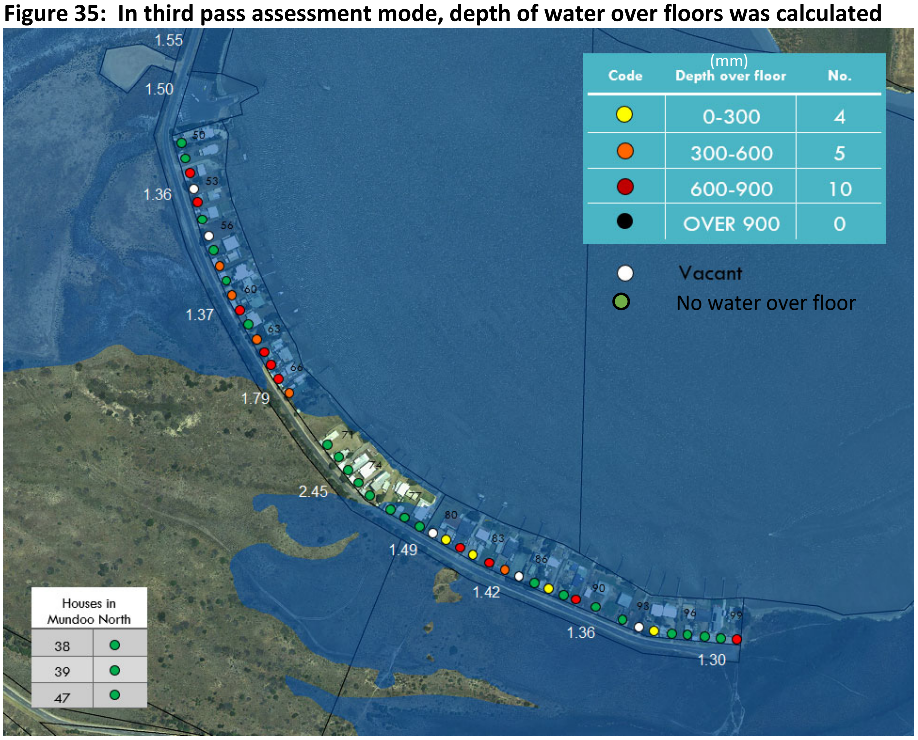
- Example: Scenario flood mapping was conducted for Mundoo Channel which revealed that the settlement appeared to be significantly impacted with flooding.

Third Pass

In the context of this study, some of the more complex assets may require further scrutiny within a 'third pass' assessment.

- Example: Survey work was completed at Mundoo Channel to ascertain accurate heights of sites and floor levels and depth of water over floors and roads calculated for each scenario.

Figure 35: In third pass assessment mode, depth of water over floors was calculated



Source: Integrated Coasts

2.4.10 Conduct risk assessment

Specific Risk Assessment

Each of the cells are assessed more specifically for risk in the context of four receiving environments:

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

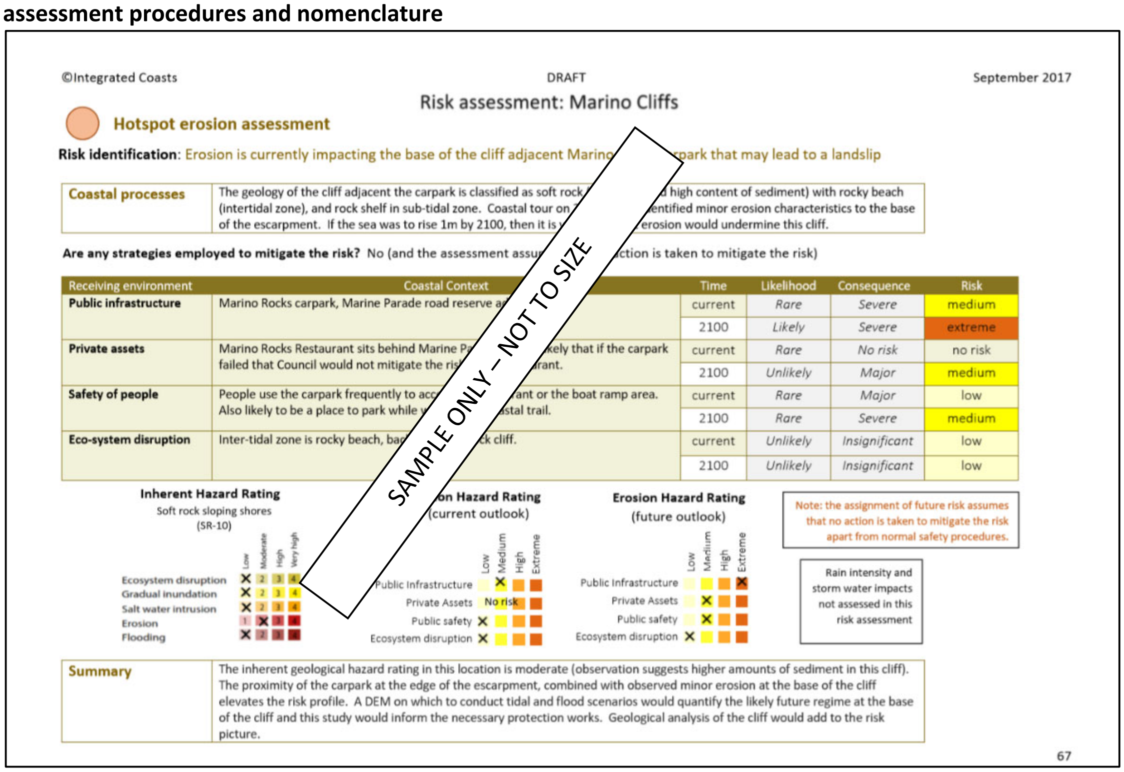
The risk assessment is provided for two eras: the current era, and the 'future outlook'. In this study, future outlook means the end of this current century.

The risk assessment is conducted within a formalised worksheet (Figure 36) and based within Council's formal risk assessment procedures. The pull-down menus can be amended to reflect the Council's specific nomenclature at the start of the project, and the Council's risk 'likelihood and consequence' matrix consulted throughout the assessment process.

The formalised risk assessment is only completed when the inherent risk assessment indicates the relevance of either or both hazards (ie inundation or erosion). In other words, if the inherent risk assessment demonstrates that inundation is 'no risk' or 'low risk' then this specific risk assessment would not be completed.

A formalised risk assessment can be completed for an entire coastal cell or if required for a specific 'hotspot' location (Figure 36).

Figure 36: The risk assessment is conducted within a formalised template but also based on Council's risk assessment procedures and nomenclature


©Integrated Coasts DRAFT September 2017

Risk assessment: Marino Cliffs

Hotspot erosion assessment

Risk identification: Erosion is currently impacting the base of the cliff adjacent Marino [...]rpark that may lead to a landslip

Coastal processes	The geology of the cliff adjacent the carpark is classified as soft rock [...]d high content of sediment) with rocky beach (intertidal zone), and rock shelf in sub-tidal zone. Coastal tour on [...]entified minor erosion characteristics to the base of the escarpment. If the sea was to rise 1m by 2100, then it is [...] erosion would undermine this cliff.

Are any strategies employed to mitigate the risk? No (and the assessment assu[...]ction is taken to mitigate the risk)

Receiving environment	Coastal Context	Time	Likelihood	Consequence	Risk
Public infrastructure	Marino Rocks carpark, Marine Parade road reserve a[...]	current	Rare	Severe	medium
		2100	Likely	Severe	extreme
Private assets	Marino Rocks Restaurant sits behind Marine Pa[...]kely that if the carpark failed that Council would not mitigate the ris[...]rant.	current	Rare	No risk	no risk
		2100	Unlikely	Major	medium
Safety of people	People use the carpark frequently to acc[...]ant or the boat ramp area. Also likely to be a place to park while v[...]astal trail.	current	Rare	Major	low
		2100	Rare	Severe	medium
Eco-system disruption	Inter-tidal zone is rocky beach, bac[...]k cliff.	current	Unlikely	Insignificant	low
		2100	Unlikely	Insignificant	low

Summary	The inherent geological hazard rating in this location is moderate (observation suggests higher amounts of sediment in this cliff). The proximity of the carpark at the edge of the escarpment, combined with observed minor erosion at the base of the cliff elevates the risk profile. A DEM on which to conduct tidal and flood scenarios would quantify the likely future regime at the base of the cliff and this study would inform the necessary protection works. Geological analysis of the cliff would add to the risk picture.

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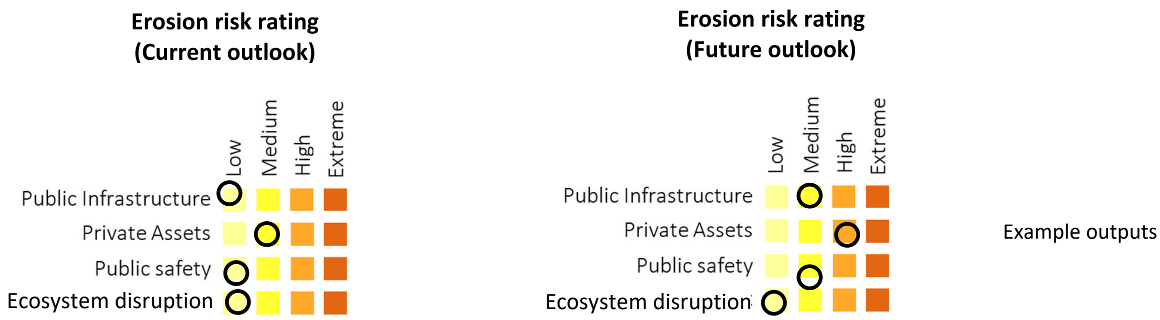
The output is purposefully designed so that it is immediately accessible and meaningful to a wide range of personnel involved in managing the coastal environs including: politicians, elected members, policy makers in all levels of Government, coastal managers, and the general public.

Figure 37: Risk assessment conducted within receiving environments (Example outputs)



Where it is identified that more information is required to further quantify the risks, these localities should be afforded further research, investigation or monitoring.

2.4.11 Assess adaptation options

Background

CoastAdapt provides an excellent resource to understand adaptation planning and the purpose here is not to replicate this resource[44].

Adaptation responses

CoastAdapt notes that there are generally six categories of adaptation responses to climate change in the coastal zone:

- Avoidance
- Hold the line (protect)
- Accommodation (or limited intervention)
- Managed retreat
- Defer and monitor
- Loss acceptance

Adaptation types

Within each of the first four response categories there is a range of potential adaptation options in the areas of[45]:

- Planning
- Engineering
- Environmental management

Planning

These are options that use planning legislation and regulations to reduce vulnerability and increase resilience to climate change and sea-level rise. Thus, land that Is projected to become more prone to flooding in future can be scheduled as suitable only for development such as light industry or warehouses, and unsuitable for housing or critical infrastructure.

Engineering

In the context of climate change adaptation 'engineering' has come to describe adaptation options that make use of capital works strategies such as seawalls and levees. Such projects are 'engineered' to solve a particular challenge such as to protect coastal infrastructure from erosion and inundation damage. These approaches differ from other types of approaches in that they require significant commitments of financial and social resources and create a physical asset.

Environmental management

Environmental management includes habitat restoration and enhancement through activities such as revegetation of coastal dunes or building structures to support continued growth of habitat such as seagrasses or reefs.

It may also include developing artificial reefs to reduce wave erosion of shorelines or engineered solutions to prevent encroachment of saltwater into freshwater systems.

[44] CoastAdapt, 2019, Understand Adaptation, viewed at https://coastadapt.com.au/understand-adaptation

[45] CoastAdapt also includes 'community education'.

Adaptation approaches

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 pathways

Usually adaptation proposals will be a combination of a number of the actions listed above. For example, the adaptation proposal for Knight Beach is summarised as:

- The modelling and assessment indicate that the backshore of Knight Beach is currently not under threat from actions of the sea.
- An **incremental adaptation** approach is recommended.
- To protect private and public infrastructure over time, a **hold the line** methodology is recommended (most likely rock revetment or similar).
- Because there is unlikely to be any immediate threat, the approach should be to **monitor** this beach over time, with special attention to changes/impacts to the back shore.
- Consider amending **planning controls** (ie avoid) to prevent any further densification of sites on Torrens Street.

The way to evaluate how adaptation options may play out over the long term is known as 'adaptation pathways'. Usually, an adaptation pathways approach will also identify trigger points that anticipate that future action will be required.

CoastAdapt acknowledges that there is a shift towards adaptive management frameworks as the most viable means of dealing with uncertainty, especially due to the anticipated responses to sea-level rise. 'This requires a significantly greater incorporation of coastal monitoring into coastal management activities, with decision-making frameworks developed to include monitoring-based triggers for coastal management. A key element of this framework must be the ability to distinguish between cyclic and progressive coastal change, to avoid short-term reactive responses or expensive temporary fixes[46]'.

The Alexandrina coastline provides an appropriate case study to consider in this context as the findings of the study reveal that large sections of the coast have been accreting over the last 10 years. It is relevant then to ask, on what basis should the timing of a trigger be determined? A more appropriate response is to build an understanding of the normal cycles of the coast to be able to identify when climate change is causing the coast to operate outside of its normal parameters. In

[46] CoastAdapt, 2019, viewed at https://coastadapt.com.au/pathways-approach

other words, rather than spending time now identifying hypothetical triggers that are dependent on a very large set of 'unknowns' it will be more effective to establish simple monitoring strategies that will provide an early warning to coastal change caused by climate changes factors. Integrated Coasts concurs with this assessment and in this section of work intends to identify where items should be subject to further monitoring, and where items will require immediate responses.

The exception to this rule is where Council is considering implementing or upgrading infrastructure and an assessment of the timing of thresholds will be crucial to afford expending resources into a location that in the longer term will be vulnerable to coastal processes. Where Council is considering the long-term outlook for an existing asset, an ongoing monitoring approach will provide a more effective decision-making context.

The other assumption within adaptation pathways methodology is that there will be a number of options to consider at any one time. In many instances this is not the case and an effective adaptation study may identify one preferred option (or proposal).

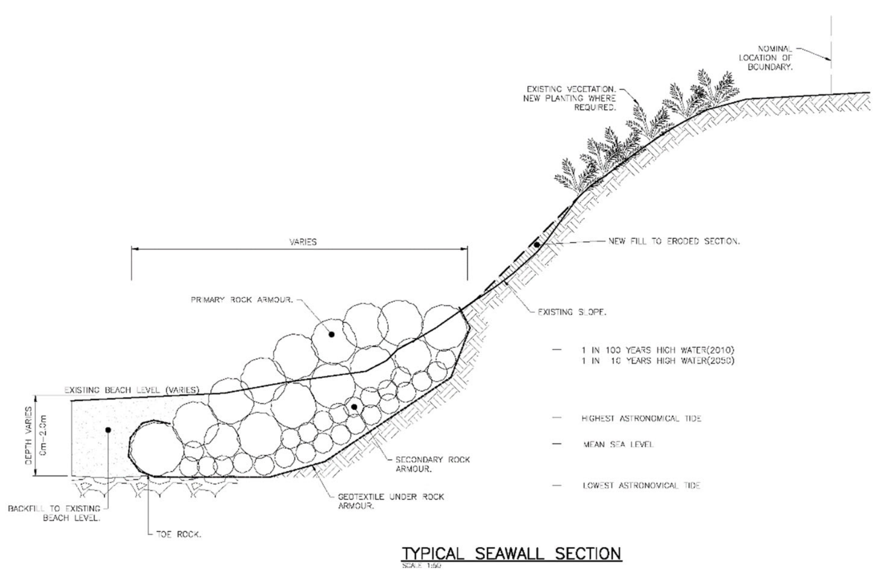
Methodology

Step 1: Identify adaptation options using inputs from the study

- Review all inputs from the project and identify adaptation options (preliminary)
- Workshop with engineer to determine adaptation options, and in relation to protection works, hard or soft options

Step 2: Create preliminary design concepts and estimate costs

Where it is deemed that protection options are required, Magryn Engineering will prepare preliminary design and costing for protection options. The example below is typical of a concept design by Magryn Engineering suitable for environment such as Horseshoe Bay (Figure 38). Note: the level of detail is likely to vary depending on the purpose and location of the item.



2.5 Reporting template

Essential to the methodology outlined above is the use of the coastal adaptation study template developed by Integrated Coasts. The advantages of using a consistently formatted template are as follows:

- The organisation of the template reflects the conceptual framework explained above. A conceptual framework is especially useful in communicating to the various levels of expertise of a range of stakeholders.
- In keeping with the underpinning principle that 'coastal adaptation takes place in localities' (p. 5) a template is an effective way to layer information from each cell in a visual manner.
- Using a template where a significant amount of data can be sourced publicly means that some of the template can be completed by those with less coastal adaptation experience. Geomorphologists and/or coastal engineers can be employed to assess and add to the data as required.
- In keeping with the underpinning principle that 'coastal adaptation takes place over time' (p.6) a template is an appropriate tool on which to add data over time. First, this attribute means that an assessment can be completed in 1st pass assessment mode, and then further data added for 2nd or 3rd pass assessments (see also p. 8,9). Second, this attribute means that data collected in the future can be easily added to the template. For example, changes to the shoreline have been assessed for Alexandrina by comparing aerial photographs from 1949, 2008 and 2018. Future aerial photographs can be easily added to the template for ongoing assessment of coastal change.
- Using a template to which to add data over time also means that previous analysis is not lost within previous linear reports and studies. It is a way to continually bring 'everything into one place' when considering coastal adaptation.
- The coastal adaptation study template provides a familiar and routine way to approach coastal adaptation. Becoming familiar with the rhythm of a template in one coastal location will assist in assessing a new and unfamiliar location. This attribute is especially useful when presenting information in the context of the various levels of stakeholder expertise.

2.6 Stakeholder engagement

Initial stakeholder engagement and review

Initial stakeholder engagement is primarily focussed on Council staff and elected members. The purpose is to communicate the findings of the study to Council so that the next steps of coastal adaptation can be identified, including how to communicate the findings to the public. Presentation and review is also sought from Department for Environment and Water (Coastal Management Branch).

Methodology

- Prepare a preliminary Coastal Assessment report: this report (Part 1) and the locality reports for each coastal cell (Part 2)
- Prepare presentation and conduct Council staff workshop (take relevant feedback into consideration)
- Prepare presentation for Elected Members and first present to Council Executive, and then to Elected Members
- Prepare presentation for Department for Environment and Water, provide reports for review, obtain feedback

Community engagement

Subsequent to the conclusion of this adaptation study, a community engagement program will be designed by URPS to be delivered in 2020.

2.7 Prepare final Coastal Adaptation study

Following community engagement, a final coastal adaptation study report taking into account all inputs and feedback, will be prepared.

The final report will provide an adaptation study for the Council to consider their implementation plan.

3. General Coastal Assessment

This report (Part 1) pertains to the assessment of the coastal issues as they relate to the entire Alexandrina coastline. Part 2 of the report contains more detailed assessments of the smaller tertiary cells. The reports that compile Part 2 are designed as stand-alone documents for easy reference and use by Council and include:

The eight reports that compile Part 2 are:

- The Murray Estuary settlements (Cells SF1-SF2)
- Goolwa Beach (Cells SF3-SF4)
- Middleton Beach (Cell SF5)
- Middleton Creek (Cell SF6)
- Ratalang-Basham (Cell SF7)
- Port Elliot – Horseshoe Bay (Cell SF8)
- Port Elliot – Green Bay and Crockery Bay (Cell SF8)
- Boomer-Knights Beach (Cell SF9)

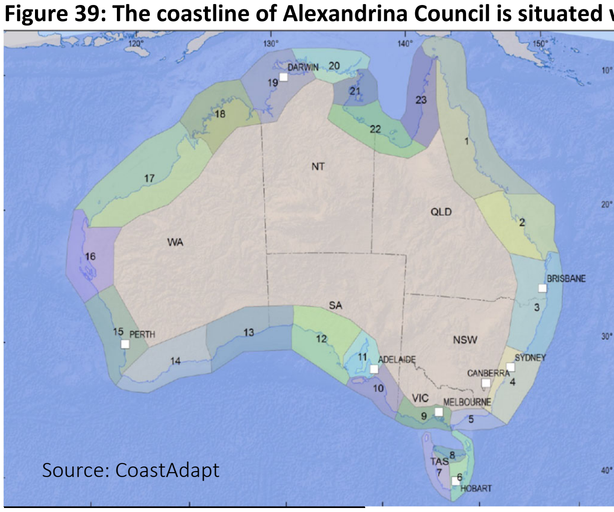
3.1 Partition the coastline into sedimentary cells (compartments)

It is possible to divide the coastline into discrete units within which there are broadly homogeneous features that may include geology, landform types, near-shore currents and sediment availability and movement. A compartment might be, for example, a bay lying between two headlands. The scale of these compartments makes them convenient units at which to consider present-day exposure and vulnerability to erosion from, for example, wave action and storm surge.

Primary and Secondary compartments

A project was carried out around Australia to divide the coastline into realms, regions, divisions, primary and secondary compartments and to gather together information on coastal risk for each compartment[47]. This information has been compiled into a dataset which is available through CoastAdapt[48]. The Alexandrina coastline falls within the Primary Compartment 10, *South-east SA coast*.

Figure 39: The coastline of Alexandrina Council is situated within South-east SA compartment



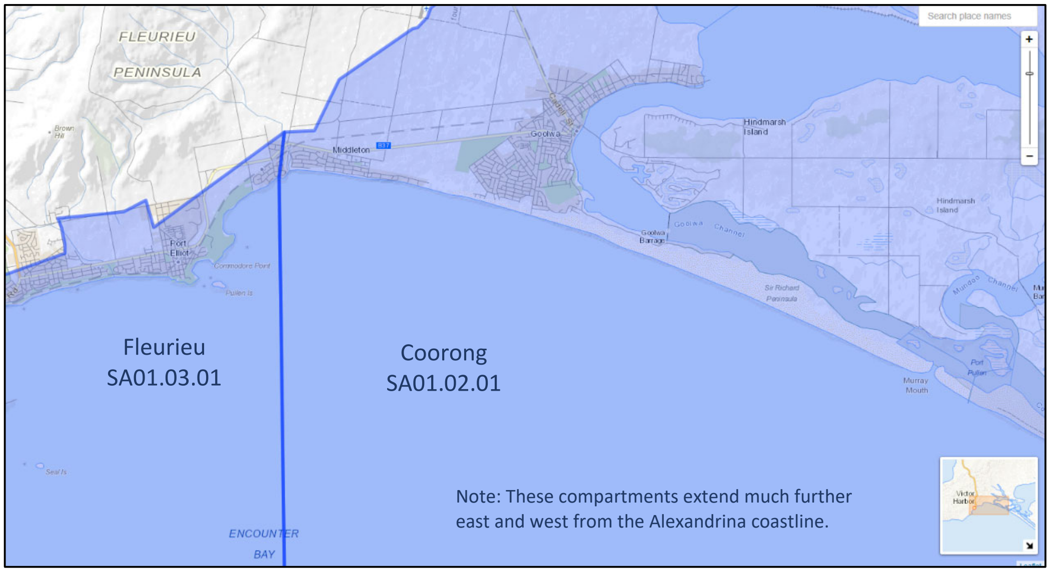
[47] McPherson, A., Hazelwood, M., Moore, D., Owen, K., Nichol, S. & Howard, F. 2015. *The Australian Coastal Sediment Compartments Project: methodology and product development*. Record 2015/25.
[48] http://coastadapt.com.au/coastadapt-interactive-map

Secondary compartments

The coastline of Alexandrina Council falls within two secondary compartments:

- Fleurieu (south east coast) [49]
- The Coorong[50]

Figure 40: The coastline of Alexandrina Council lies within two secondary compartments (cells)



Source: CoastAdapt

Fleurieu Secondary Compartment (south east coast)

The Fleurieu (south east coast) compartment incorporates the section of Alexandrina coastline from Chiton Rocks to Middleton Point. At Middleton Creek the shoreline changes in orientation to approximately east-west after a number of rocky headlands and embayed beaches that make up the Port Elliot and Ratalang Basham conclusion of this cell.

Coorong Secondary Compartment

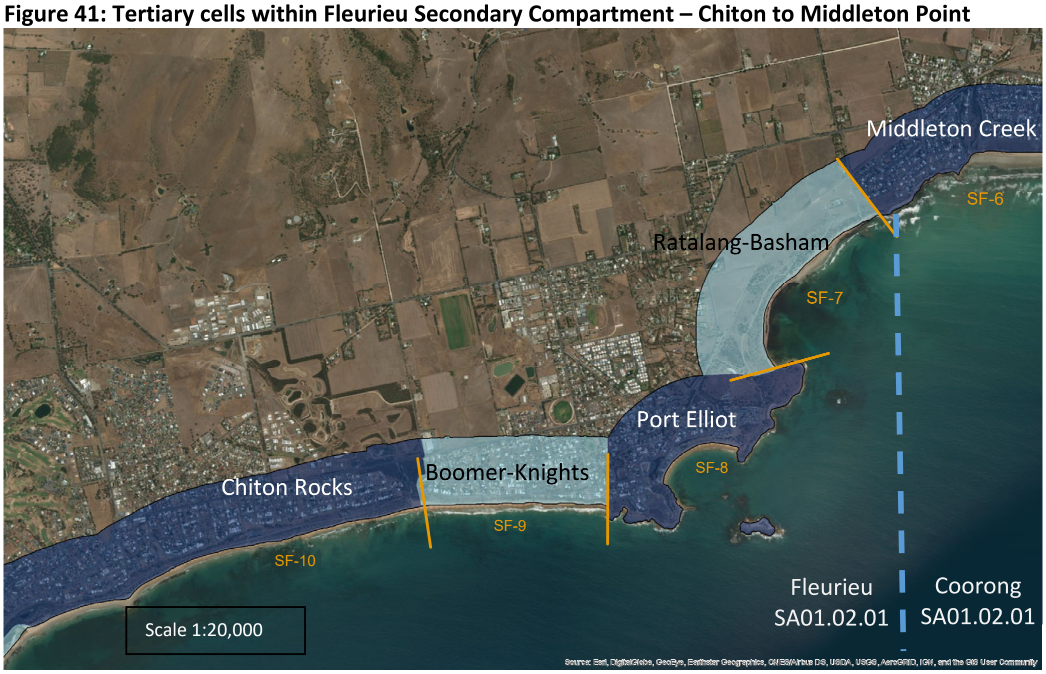
The Coorong compartment incorporates the section of Alexandrina coastline from Middleton Creek to the Alexandrina border. The Coorong cell itself incorporates a much larger area of coast, extending further east to Cape Jaffa.

[49] CoastAdapt http://coastadapt.com.au/coastadapt-interactive-map... SA01.03.01
[50] CoastAdapt http://coastadapt.com.au/coastadapt-interactive-map... SA01.02.01

Tertiary compartments

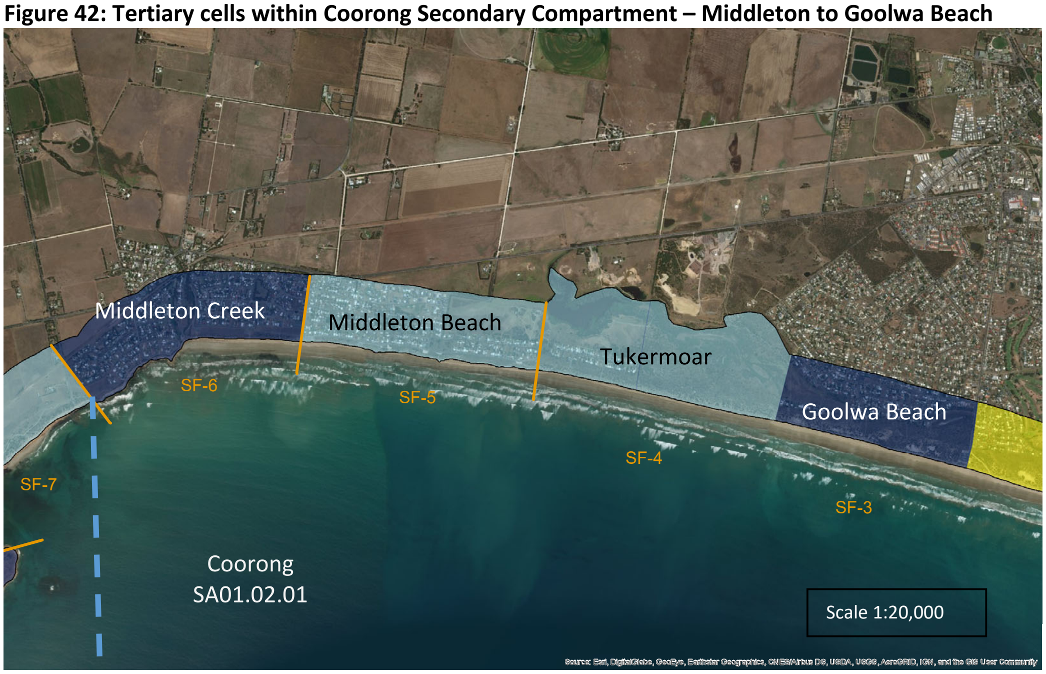
Department for Environment and Water (DEW) has divided the South Australian coastline into *Conservation Cells*[51]. In the context of the secondary cell divisions created around the Australian coastline (see above), these smaller divisions operate as tertiary cells (SF1 to SF9).

Figure 41: Tertiary cells within Fleurieu Secondary Compartment – Chiton to Middleton Point



Source: Rendition from ArcMap using DEW compartments (M.Western)

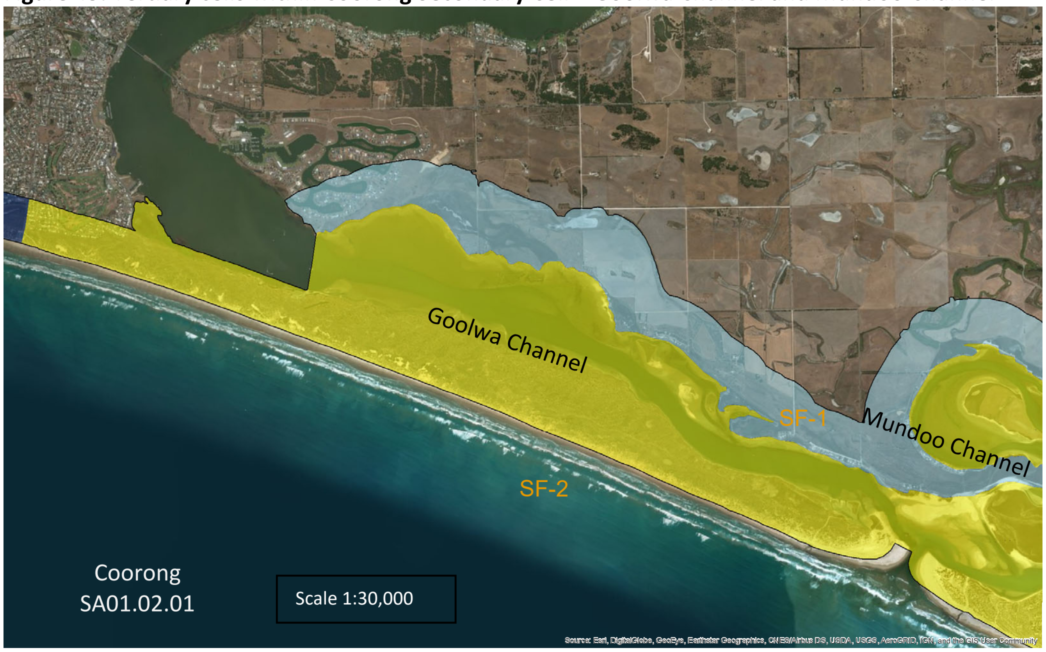
Figure 42: Tertiary cells within Coorong Secondary Compartment – Middleton to Goolwa Beach



Source: Rendition from ArcMap using DEW compartments (M.Western)

[51] Include source. https://data.environment.sa.gov.au/NatureMaps/Pages/default.aspx

Figure 43: Tertiary cells within Coorong Secondary Cell – Goolwa Channel and Mundoo Channel



Source: Rendition from ArcMap using DEW compartments (M.Western)

Refer to Part 2 of this document for assessments within tertiary cells.

3.2 Review settlement history

Dr Bob Bourman reviews the history of the Alexandrina region in Coastal Landscapes of South Australia:

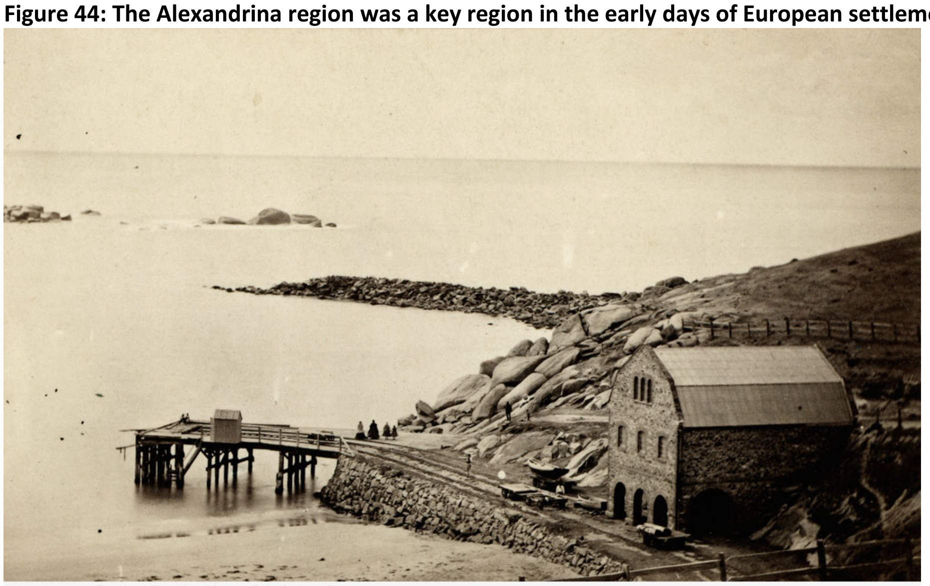
> In 1802, Matthew Flinders and Nicholas Baudin, during their charting of the southern Australian coastline, met offshore from the Murray Mouth in Encounter Bay, the outfall of Australia's largest exoreic river system, although neither navigator recognised it. This is not remarkable; they were many kilometres offshore, the coast is low-lying and there were no large freshwater flows containing sediment. Captain Charles Sturt reached the Murray Estuary in 1830 after an intrepid boat trip down the River Murray and was forced to return the same way after his efforts at accessing the sea were thwarted by sand bars in the Goolwa Channel. Hopes were high that the Lower Murray area would support a thriving port and that Goolwa would become the 'New Orleans of Australia'. However, the mouth could not always be reliably navigated, there was no natural site for a deep-sea port[52].

To resolve the problem of navigation through the Murray Mouth, in 1854, an attempt was made to establish a seaport at Port Elliot and connect the Goolwa river port to Port Elliot by rail.

Thus, the Alexandrina region was important in the early days of European settlement for both the location of Goolwa on the River Murray and its connection with Port Elliot as the region’s first seaport. In the context of this study, these developments also represent early interventions (or coastal modifiers) in the coastal zone of the region.

A vast number of historical photographs are available for review, many of these relating to the coastal environs of the Port Elliot region. Comparing this photographic record dating from 1860 provides an additional way to assess how the coastline has changed over the last 150 years[53].

Figure 44: The Alexandrina region was a key region in the early days of European settlement.



Source: SA State Library

Refer to Part 2 of this document for a historical review within tertiary cells

[52] Bourman, Murray-Wallace, Harvey, 2016, Coastal Landscapes of Sa, p.109

[53] Note: the photographic record is utilised in the geomorphological section (Step 3).

3.3 Analyse Coastal Geomorphology

In this study, coastal geomorphological changes are assessed from the point of view of:

- ancient formation
- recent changes over the last 100 - 150 years.

In this report (Part 1 of the study) a general overview of the ancient formation of the Alexandrina coastline is included. Within the individual tertiary cell reports, short-term coastal change is analysed.

Ancient coastal formation:

Professor Bourman has spent much of his professional life studying the Alexandrina coastal environs and has a significant knowledge regarding how the Alexandrina coastline has developed throughout the Holocene (~last 7,000 years) period. This work provides the broader context from which to understand the current trends operating along the coastline.

Introduction

This section of the Fleurieu Peninsula coastline between Chiton Rocks and Goolwa Beach, covering a distance of approximately 16 km, transects several major geological units, which have had profound influences on the character of the coastline, its age, evolution and management issues related to it. The coast intersects a variety of rocks, sediments, landforms and topographic reliefs presenting different degrees of susceptibility to coastal erosion and/or inundation potential given the predictions of future impending rises in sea level and climatic changes. This coastal sector lies predominantly on the western margin of the Murray Basin with a small section lapping onto the Mount Lofty Range Province.

It is important to note that the present coastline is very young in a geological sense with sea level being at or near its present position for only approximately the past 7,000 years. Before then the coastline stood as much as 125 m below present sea level, rising rapidly from about 17,000 years ago to its present position 7,000 years age at a rapid rate of ~10 mm/yr. As sea level rose, it swept before it unconsolidated sediments previously exposed on the continental shelf. These sediments have contributed to the modern beaches of the area. When the sea reached its present level it came into contact with differing geological materials, some of which are potentially more prone to coastal erosion. Not only is the modern coastline geologically young, but also it is very dynamic, changing with variations in sea level, wind, storm wave and tidal conditions. A prominent feature of this section of coastline has been recent coastal erosion, which has been particularly marked in the softer rocks of the Middleton to Goolwa section of the coastline.

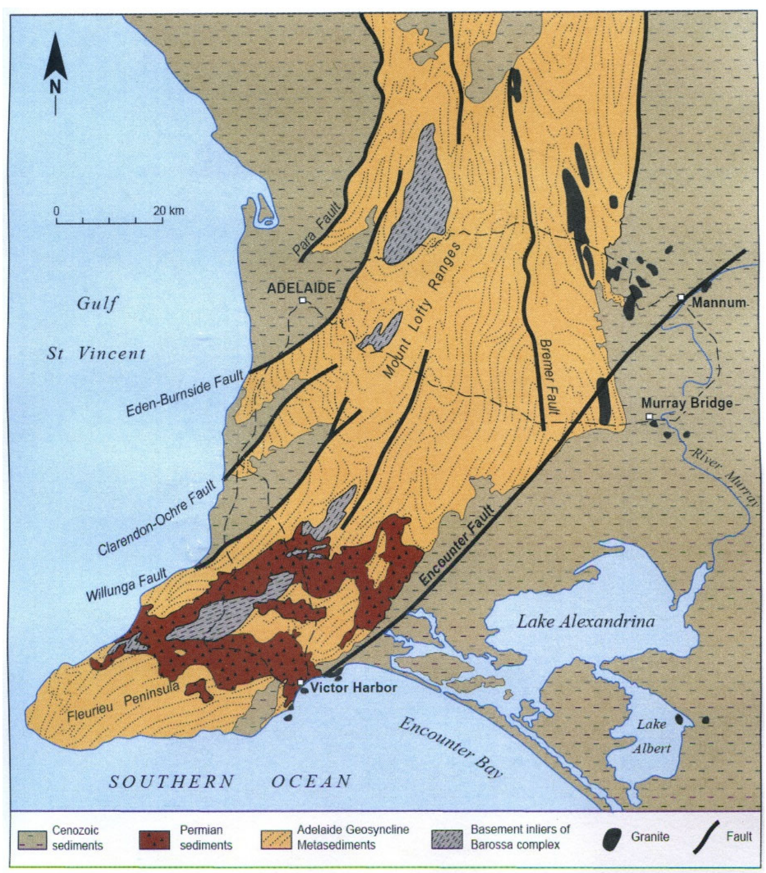
When the sea reached near its present level it came into contact with differing rock units. At Chiton Rocks relatively easily eroded Permian glacial sediments form the coastline, while between Watson Gap and Port Elliot a former old sand dune, now cemented and consolidated, back the shoreline. Granite masses around Port Elliot buttress the shoreline against erosion, forming headlands and islands, while ancient, resistant metamorphic rocks at Basham Beach also provide a buffer to erosion. From Middleton Creek to Surfers Beach, relatively soft Pleistocene alluvial sediments were brought into juxtaposition with the sea; and from Surfers Beach to Goolwa Beach a former coastal sand dune, similar to that at Boomer and Knight beaches is now being eroded at the shoreline. These old sand dunes have been turned into rock by calcium carbonate cement and capped by a hard, resistant layer of a calcium-cemented soil (calcrete). Many of these former coastal sediments are capped by well-developed and resistant calcretes, which are often referred to as limestone. Calcrete is a surface and near surface, white-coloured and very resistant capping of calcium carbonate, typically formed on calcareous sediments after their deposition. Fragments of shelly material within the original sediment were dissolved by soil water and reprecipitated at the surface. Calcium carbonate in solution was drawn upwards by capillarity and evaporative processes into the soil, where plant activity assisted its surface concentration.

Murray River Basin

The majority of the coastline lies within the Murray Basin, which has a long history of ongoing tectonic subsidence. The Murray Basin is separated from the Mount Lofty Ranges by a major fault zone, the Encounter Fault, which broadly runs out to sea to the between Watson Gap and Middleton. The subsidence of the Murray Basin is well illustrated by a borehole on Hindmarsh Island, not far from the Murray Mouth, which penetrated to a depth of 230 m, and ended in Permian glacial sediments, 300 million years old, without reaching the older harder rocks.

Figure 45: The location of the encounter fault

The location of the Encounter Fault, which runs out to sea near Watson Gap. This fault separates the uplifting Mount Lofty Ranges, on which sits the Chiton to Watson Gap coastal sector, from the subsiding Murray Basin, the setting for the remainder of the Alexandrina Coast.



Source: Bourman, Murray-Wallace, Harvey, 2016, Coastal Landscapes of SA.

Mount Lofty Ranges

Mount Lofty Ranges are underlain by ancient rocks varying in age from approximately 2 billion to about 500 million years old. Most of these rocks were originally sediments up to 24 km thick, deposited in subsiding ocean basins underlain by crystalline rocks. Major compressive mountain building, earth movements of the Delamerian Orogeny about 500 to 470 million years ago, folded and metamorphosed these sediments by heat and pressure into hard, resistant rocks, forming a huge mountain range, perhaps of Himalayan proportions, into the base of which a granite mass was intruded at a depth of about 10 km. This mountain range extended from Kangaroo Island to beyond the North Flinders Ranges, and from Yorke Peninsula to the South Australian-Victorian border. The youngest of these ancient rocks of the Kanmantoo Group, the Middleton Sandstone, forms a buttress to coastal erosion on the western side of Middleton Beach. These rocks underlie the coastline at various depths.

Over the ensuing 200 million years (500 to 300 million years ago) this mountain range was so severely eroded that the deeply buried granite masses were exposed at the surface by the time of the passage of a continental ice mass. This occurred during Permian times some 300 million years ago. Glacial erosion is responsible for the general distribution of the granites, which currently form the resistant headlands and islands of Encounter Bay, such as at Port Elliot where glacial striations can be observed. After the Permian ice sheet retreated it left behind huge deposits of sands, pebbles, boulders and clays, which were subsequently reworked by rivers and coastal erosion, providing coastal sediments for the present shoreline. Within deposits related to the Permian glaciation there are many different types of rocks present, having been transported by ice as erratics from distant sources to the southeast of the Alexandrina coast.

Formation of coastline

Following the Permian glaciation the landscape was impacted by at least 200 million years of weathering and erosion, resulting in the formation of a surface of low relief that was intensely weathered to depths up to of 70 m below the ground surface. Throughout this early geological history Australia and Antarctica were co-joined, forming part of the ancient super-continent of Gondwana, not finally separating until about 43 million years ago, thereby forming the embryonic coastline of Encounter Bay. Australia and Antarctica were the last two continents of Gondwana to separate, following which Australia moved rapidly some 3,000 km to the north, a process which is still continuing.

Following continental separation there were vertical tectonic faulting movements producing the beginnings of the Mount Lofty Ranges and the Murray Basin, and allowing incursions of the sea from the early Southern Ocean. The same older, harder rocks that form the Mount Lofty Ranges also underlie the Murray Basin at depth having been considerably down-faulted. These tectonic earth movements are ongoing.

Changes in sea level

As well as ongoing tectonic uplift of the Mount Lofty Ranges and subsidence of the Murray Basin over the past 43 million years there were numerous climatically driven fluctuations in sea level. The oldest of the limestones resulting from the marine inundations are of Eocene age (~40 million years old). Today, these occur at about 70 m above sea level in the Waitpinga area of the Mount Lofty Ranges and at a depth of 100 m to 147 m below present sea level in the Murray Basin, not far from the Murray Mouth, suggesting a tectonic offset between the ranges and the basin of up to 200 m. Subsequently, younger marine limestones were deposited in the Myponga and Hindmarsh Tiers Basins, in the ranges, and the Murray Basin 25 to 16 million years ago during four separate transgressions. During this time there was most likely a seaway across Fleurieu Peninsula linking Gulf St Vincent with the Murray Basin. Faulting has also extensively offset these limestones, which extensively underlie the Murray Basin.

Another major incursion of the sea occurred about 4 to 5 million years ago depositing limestone of the Northwest Bend Formation in an estuarine setting that extended from near Tailem Bend to Overland Corner. Over the past 4 million years or so there have been repeated fluctuations in sea level from near present sea level to as much as 125 m below sea level. Over the past 1 million years sea level fluctuated over this range on roughly a 100,000-year cycle with each former high sea level marked by a coastline similar to the present Sir Richard and Younghusband Peninsulas. A record of these high interglacial sea levels, preserved by the transformation of the coastal dunes into rock, forming calcareous aeolianite, is recorded in the dune ranges of the uplifting Coorong Coastal Plain of the South East.

Causes of sea level change

These rhythmic changes in sea level were driven by astronomical changes in the relationships between the Earth and the Sun; the amount of solar energy reaching the Earth varies due to changes in *eccentricity*, the shape of the orbit of the Earth around the Sun, which changes from near circular to elliptical over a 100,000 year period, *obliquity*, the tilt of the Earth's axis which varies between 21.8^o and 24.4^o oscillating on a 41,000 year period, and *precession*, the wobble of the Earth on its axis (41,000 year oscillation). The combined impacts of these changes is the growth and decay of continental ice masses and associated fluctuations in sea level from near present (interglacials) down to -125 m (glacials) on a 100,000 year cycle. Pauses within these variations are termed interstadials. We are currently in the high sea level phase of the most recent interglacial period.

Subsidence of the Murray Estuary has resulted in the burial of most of these early shorelines along the Alexandrina shoreline, but remnants of one of these high shorelines, which formed about 250,000 years ago during the Penultimate Interglacial, forms Point Sturt Peninsula and the aeolianite dune at Knight Beach. The fossil dune at Surfers Beach formed during a relatively lower stand of the sea ~100,000 years ago, while the extensive former dune in the Goolwa area is of last interglacial age (125,000 years). Erosion of these now fossilised dunes, largely composed of broken shell fragments, provided sand for many of our modern beaches and continues to do so.

About 2.4 million years ago the River Murray was dammed by a tectonic barrier near Swan Reach, forming an extensive freshwater lake, Lake Bungunnia, which covered an area of more than 50,000 km^2 and was at least 60 m deep. The dam was breached about 780,000 years ago with the overflow forming the course of the present River Murray.

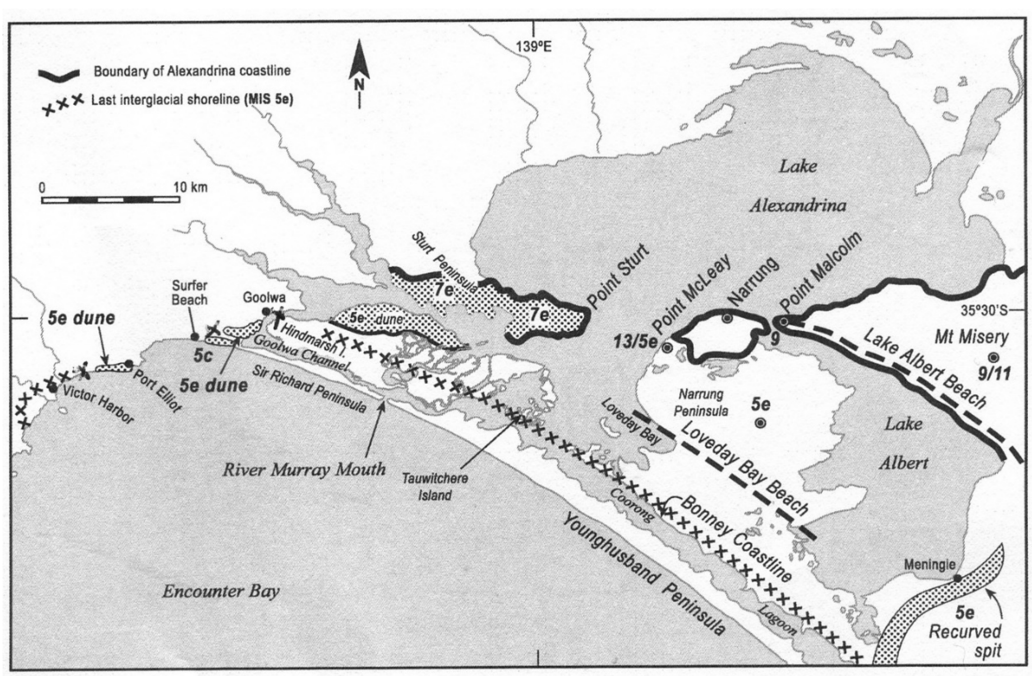
Current interglacial period

Today we are living in an interglacial period, the most equitable time for human beings. The previous equivalent time in Earth history was about 125,000 years ago, during what is called the Last Interglacial (Marine Isotope Stage 5e), when, locally, it was warmer and wetter than at present with sea level being ~2 m higher than now. Remnants of this shoreline remain along the coast from Victor Harbor to Goolwa as well as forming the landward side of the Coorong Lagoon. Dunes of this age form the majority of the northern half of Hindmarsh Island and the higher parts of the Goolwa area. It is possible to map out the approximate location of the last interglacial shoreline when the sea level was 2 m higher than now, which provides a useful indication where sea level may rise to in the future due to naturally occurring changes plus the influence of human impacts.

During the warmer and wetter conditions of the Last Interglacial 125,000 years ago vast quantities of alluvium known as the Pooraka Formation were washed out from the ranges and deposited as alluvial fans grading down to the +2 m high last interglacial sea level. These alluvial deposits currently form the cliffed coastline at Middleton Beach and are very vulnerable to erosion.

Figure 46: The location of the last interglacial shoreline (125,000 years ago)

The location of the last interglacial (125,000 years old) shoreline, marked by crosses) originally at ~ 2 m above present sea level, now uplifted to ~6 m in the Victor Harbor area and depressed to near present sea level in the Goolwa area. The Chiton area is being uplifted while the remainder of the shoreline is sinking tectonically at an average rate of 0.02 mm/yr. We now know that the last interglacial dune (MIS 5e) is now the older MIS 7e dune about 250,0000 years old. The Alexandrina Coastline on this map was a name given to the much older sand dunes landward of the last interglacial shoreline.



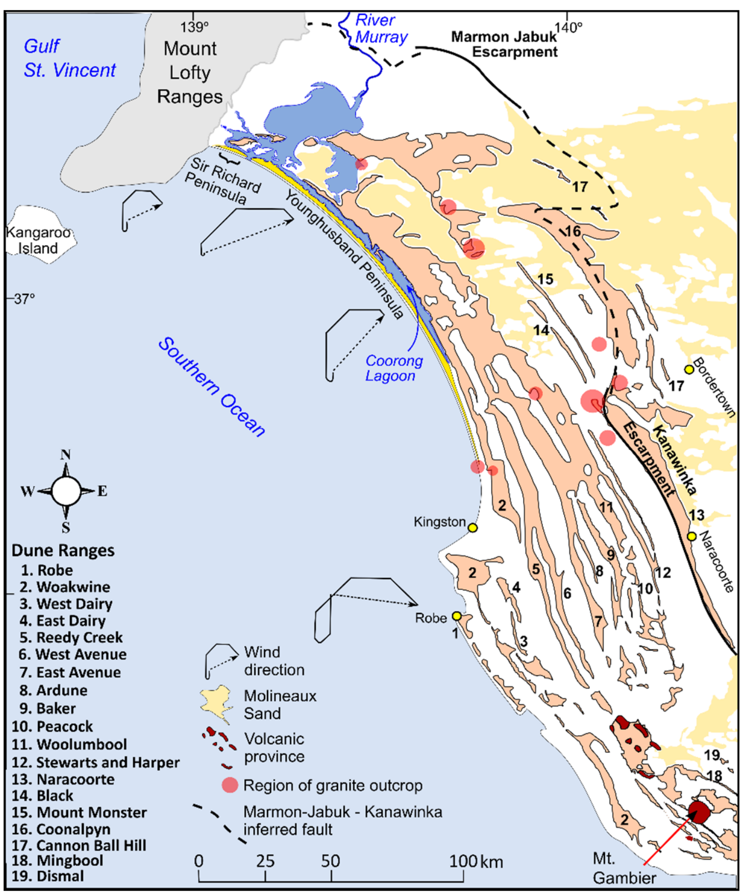
Source: R Bourman

During low sea levels of the glacial periods when much global water was locked up in the ice sheets of the northern hemisphere, sea level dropped to -125 m, exposing the continental shelf across which the River Murray flowed. At this time it would have been possible to walk to Kangaroo Island. Glacial times were marked by cold, dry and windy climates, and desert dunes surrounded the Murray Lakes, extending across the exposed continental shelf. This time was known as the Last Glacial Maximum, which peaked at about 18,000 years ago. The modern coastline developed after sea level rose between 17,000 and 7,000 years ago at a rate of ~10 mm/year at the end of the Last Glacial Maximum. With sea level rise, large reserves of sand, including the last glacial maximum desert dunes on the exposed continental shelf, were carried landward, providing source material for the modern beaches and dunes.

There was a slightly higher sea level about 6,000 to 4,000 years ago resulting in the deposition of sediments around the margins of the Murray Lakes and in the stream valleys of the Fleurieu Peninsula. These grey/black alluvial deposits form low river terraces in Middleton Creek, for example. Relicts of the geological history of the area are preserved in places along the Alexandrina coastline. Ancient metamorphic and granitic rocks at Middleton and Port Elliot bring stability to the shoreline at those locations, Permian glacial sediments and alluvium of last interglacial age back easily-eroded coastlines, while offsets of limestones of various ages record the tectonic behaviour of the area. In particular, offsets of the last interglacial shoreline (125,000 years old), which originally stood at ~2 m above present sea level, confirm the ongoing tectonic uplift of the Mount Lofty Ranges and the South East Coastal Plain, with subsidence occurring in the Murray Estuary. Consequently, most of the study area is undergoing subsidence. Along with a rising sea level, this has found expression in coastal erosion along the shoreline at Middleton, Surfers Beach and along Sir Richard Peninsula in particular. The tide gauge records at Victor Harbor indicate a rising adjusted sea level trend of ~0.67 mm/year, but this value is likely to be higher for most of the Alexandrina coast because of ongoing tectonic subsidence of ~0.02 mm/yr.

Figure 47: The location of the last interglacial shoreline (125,000 years ago)

The general setting of the Alexandrina Coast. Numbers indicate former shorelines similar to the present Younghusband and Sir Richard Peninsulas, uplifting in the south and sinking in the north. Weighted wind resultant diagrams constructed from data derived from the Bureau of Meteorology for localities at Victor Harbor, Meningie, Policeman Point and Robe. These diagrams, which indicate the direction of sand drift, all indicate drift from the southwesterly quarter. The longer the resultant the greater is the propensity for wind driven sand drift to occur.



Source: Bob Bourman

3.4 Current Exposure

The degree of vulnerability of a coastline to the process of erosion is related to the degree of exposure of the coast to wind, currents, and wave attack, especially during storms, which can be exacerbated by tidal influences depending on the nature of the tides in the region.

3.4.1 The Encounter Bay Region

- **Overview**

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). Regional hazards or processes driving large scale rapid coastal changes include: mid-latitude cyclones (depressions), storm surges and shelf waves[54].

- **Tides**

The Encounter Bay coastline is influenced by a microtidal regime of only 0.8 m as displayed in the table below[55].

Table 4: Tide levels for Victor Harbor

Level	Chart Datum (m)	AHD (m)
Lowest astronomical tide	0.021	-0.564
Mean sea level	0.705	0.120
Australian Height Datum	0.585	0.000
Mean high water neaps	1.177	0.592
Highest recorded	2.220	1.635

Source: National Tidal Centre

The highest recorded level of water at the gauge occurred on 9th May 2016 at 14:30. This event is also the highest recorded at Outer Harbor gauge in 80 years of records.

- **Winds**

The study for Victor Harbor region examined the historical wind conditions for the region and concluded that the potential for storm surge and wave action under winds is higher in months May – October[56]. An examination of historical wind roses indicates that for the months of May to September the prevailing wind direction at 9am is from the west and north-west with 20-30% of wind speeds above 40 km/hr. The corresponding prevailing wind and speed at 3pm was from the west and south with 20% of winds above 40 km/hr. The strongest wind speeds from the south occur in September and October.

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54 https://coastadapt.com.au/sites/default/files/docs/sediment_compartments/SA01.03.01.pdf
55 Bourman, Murray-Wallace, Harvey 2016, Coastal landscapes of South Australia, Adelaide University, P 117
56 Australian Water Environments 2013, Victor Harbor Coastal Management Study p. 23

- **Waves**

<u>Swell waves</u> are long period ocean waves, generated in deep water by strong winds often at distances of many hundreds of kilometres from the shoreline where they eventually make landfall. For the shoreline of Encounter Bay, ocean swells are generated in the Southern Ocean.

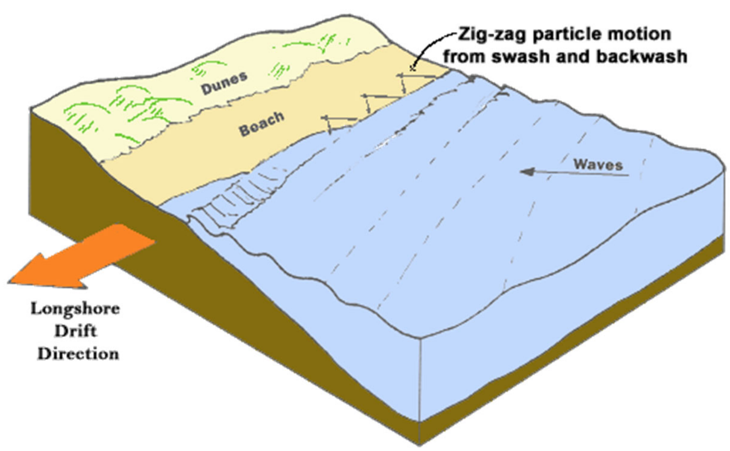
<u>Sea waves</u> are those waves generated by winds associated with local storms, in this case originating close to the coast and at this location with wind directions occurring from south to east. They are generally of short-wave period and quite steep, frequently with white caps as partial breaking occurs. They approach the shoreline generally from the direction of the wind. These sea waves generally contain less energy than the longer ocean swells.

- **Sediment balance**

The sediment balance is an essential geomorphic parameter and particularly important for coastlines falling into the sedimentary/soft rock categories. The sediment balance determines whether there is a net balance, deficit or surplus of sediment at a location over time and is largely determined by the sediment transport/availability and the relative sea level change[57]. Erosion of the shoreline is more likely to take place in locations where sediment is in decline.

Overall the sediment transport within the Alexandrina Council coastal region tends to be from west to east.

Figure 48: Illustration demonstrating longshore drift (but in mirror image to the Alexandrina coastline).



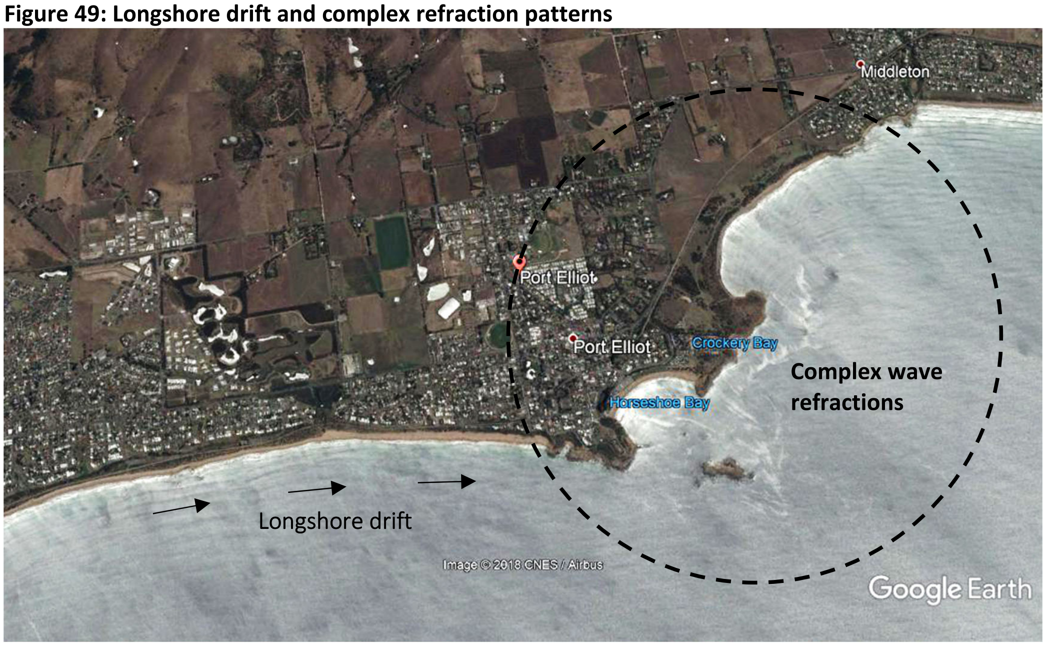
[57] Abridged synopsis from Coastal Hazard Wheel.

3.4.2 Secondary sediment compartments

Fleurieu (southeast)

Longshore drift in Encounter Bay is generally from the Bluff towards Port Elliot, driven by dominant south-westerly winds. However, complex wave refraction patterns result from wave interaction with resistant granite outcrops such as West Island, Rosetta Head, Wright Island, Granite Island, Pullen Island, Commodore Point and Frenchman Rock. These resulting complex wave refraction and diffraction patterns locally affect the direction of longshore transport and mould the shape of the coastline[58].

Figure 49: Longshore drift and complex refraction patterns



Source: Google Earth, accessed 6 December 2018

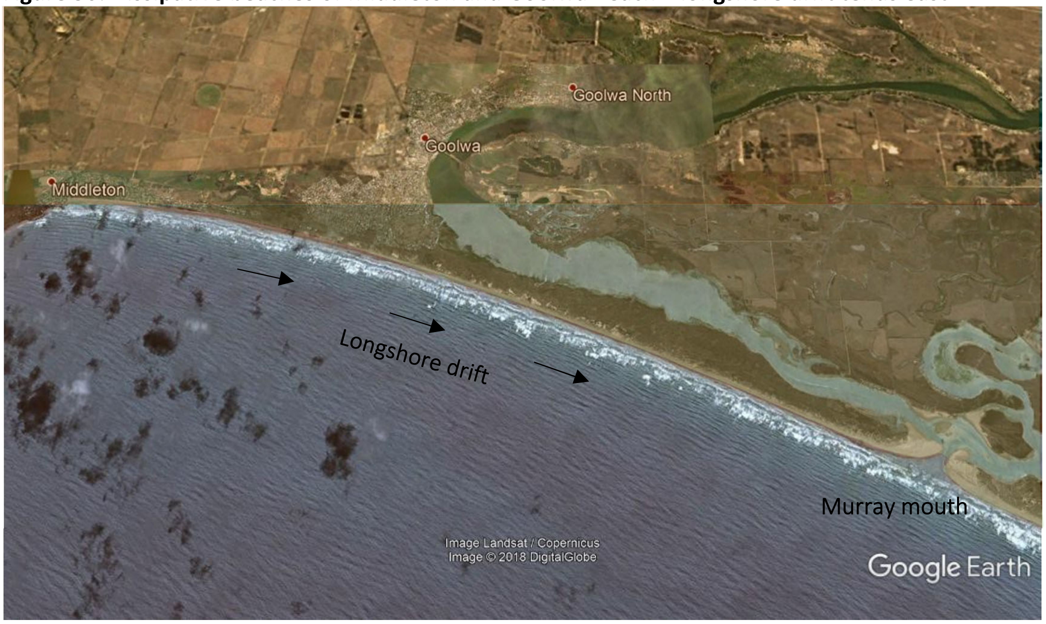
Coorong

The Coorong compartment incorporates the section of Alexandrina coastline from Middleton Point (or Middleton Creek) to the Alexandrina border. The Coorong cell itself incorporates a much larger area of coast, extending down to Cape Jaffa.

Apart from restricted outcrops of aeolianite, no hard rocks front the Murray Estuary on Encounter Bay. Unconsolidated sand dominates the shoreline, so that it is the processes of waves, winds and tides which dictate the morphology or shape of the coastline in plan view and determine the character of the beaches. Two main types of waves influence the shape of the coastline: swell waves and storm waves. Constructive, open ocean swell waves, approaching the curved coast from the southwest, have moulded the regular, curved shape of the Encounter Bay coastline.

[58] Bourman, Murray-Wallace, Harvey, 2016, Coastal Landscapes of South Australia, p 93,94.

Figure 50: Dissipative beaches of Middleton and Goolwa Beach – longshore drift tends east



They impinge on the southern part of the Encounter Bay at an angle that causes longshore drift to the northwest, but causes drift to the east on the northern part of the coast. These opposed sand drift directions help to explain the general position of the Murray Mouth as well as the huge accumulation of sand towards the northern extremity of Younghusband Peninsula.

Storm waves, usually driven by local westerly storm events, have a short wavelength with a wave period of 6 to 8 seconds; they can effect considerable erosion of the shoreline. For example, an overnight storm in March 1984 eroded a 100 m section of Sir Richard Peninsula back by some 14 m, redistributing many thousands of tonnes of sand. Local storm-generated waves tend to move sediment towards the east on Sir Richard Peninsula. Sand-shifting winds also tend to move sand from the beaches into dunes from a south-westerly direction, a direction also indicated by migrating dunes[59].

[59] Bourman, Murray-Wallace, Harvey, 2016, Coastal Landscapes of SA, Adelaide University Press.

3.4.3 Hazard risk terminology explained

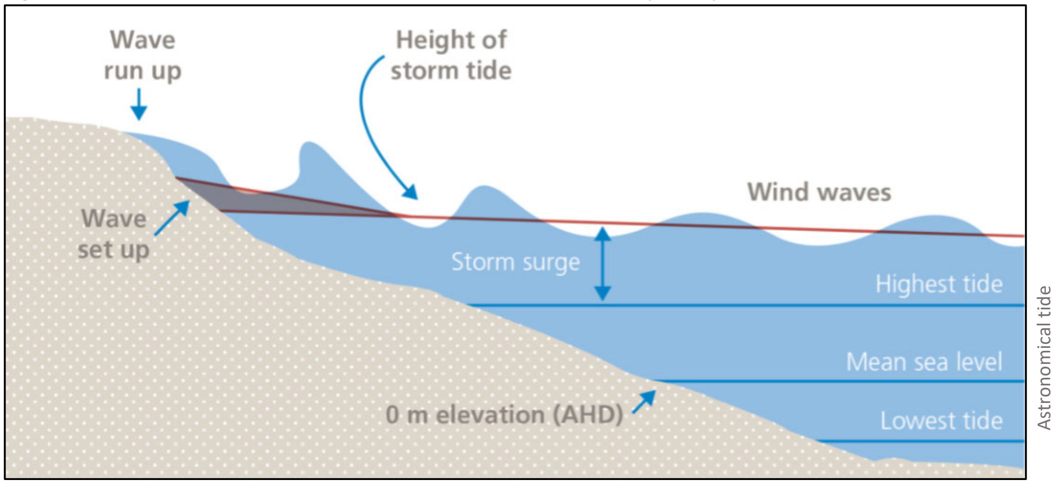
Storm surges explained

The impact of a storm on the coastline depends on a number of factors (Figure 51).

Astronomical tide

Water levels associated with the astronomical tide are highly predictable and can be referenced from a local tide chart. Storm events that coincide with the highest astronomical tides generally cause the greatest hazards.

Figure 51: Illustration of the various contributions to storm impact upon a coastline



Source: CoastAdapt (accessed 14 September 2018)

Storm surge (also called storm tide)

Storm surge refers to the combined effect of barometric setup and wind set-up. Storms are generally associated with low pressure systems. Barometric setup of the coastal water level during storms is commonly in the range of 0.1 to 0.4m. Wind setup is due to the stress of the wind blowing over the the ocean surface and piling water up against the coast.

Wave setup

Wave setup occurs in the surf zone after the breaking of the waves. The water surface inside the surf zone raises up above the still water level and the water encroaches further up the beach than would occur in the absence of waves. Wave setup levels are typically around 20% of the offshore significant wave height.

Wave runup

Wave runup refers to the way waves surge up the beach after breaking. The factors that determine the distance and impact of wave runup include the slope of the beach and the energy of the wave. The point where the energy of the wave is finally dissipated is the height of wave runup. Wave runup can cause erosion to the base of dunes or earthen shorelines[60].

[60] For further explanation refer to https://coastadapt.com.au/sites/default/files/factsheets/T3I4_Coastal_waves.pdf

1 in 100 Average Return Interval events explained

It is important to recognise that these extreme events are very rare. Using 'average return interval' methodology means that, based on historical data and probability, that the 1 in 100 event is likely to occur only once in a century. However, it is important to note, that 'nature' doesn't read our charts and an event of this magnitude could occur within consecutive years, or even consecutive months, although this would be very unlikely. One example to illustrate this point does exist in the tide record of Outer Harbor gauge. In 1981, two extreme events occurred within consecutive months – June and July. These events still stand as the fourth and fifth highest events since records began.

South Australian Coast Protection Board data

South Australian Coast Protection Board adopts a similar approach to defining the various risk components of a storm event. To illustrate, the table below depicts the various components of the storm tide for Horseshoe Bay. For those readers who are more accustomed to reading tidal predictions, the comparative tide chart heights are provided in the parallel column.

Horseshoe Bay (1 in 100 ARI event)	AHD	Victor Harbor (tide gauge reading)
Storm surge	1.75m	2.33
Wave setup	0.50m	0.50
Wave runup	1.00m	1.00
Total Height	**3.25m**	**3.83**

However, it was not apparent at the start of this project that the South Australian Coast Protection Board had no storm surge data for any other region on Alexandrina coastline, apart from within the Goolwa Channel. To resolve this issue, an extreme event analysis project was launched to identify appropriate storm surge parameters for the remainder of the coast (see page 80).

Routine high-water modelling

Extreme events can cause significant damage to a coastline but by their very nature are rare. This project has also modelled a more routine high tide event to provide an indication of areas that may be currently impacted. An average of all the monthly high tides for Victor Harbor from 1966 to 2016 was calculated as a basis for the modelling. Wave effect parameters were applied at a reduced rate from the extreme event of 22 November 2018 based on the nature of the coast in a particular location.

Current erosion exposure

Current erosion exposure is based on the findings from the settlement history and problem areas that are already known to Council. Recent events of 19th July 2018 and 22 November 2018 also provide a context from which to understand the areas of the coast that are most vulnerable to erosion. These are reported within the various tertiary cell locations.

3.4.3 Extreme event analysis – 22 November 2018

A significant storm that occurred in the Alexandrina region in the early morning of 22 November 2018 provided the opportunity to obtain valuable storm surge data for the entire coast. High tide was predicted at ~1.00am and coincided with gale force winds from the south-west with recorded windspeeds of up to 104kmph on Hindmarsh Island. The event occurred with a relatively minor astronomical tide (1.120m) but a height of 2.202 (1.435m AHD) was recorded at 12.45am. This represented ~1.1m of storm surge at the tidal gauge for this event, and was only 0.2m under the highest tide recorded at Victor Harbor on 9 May 2016.

As noted previously, virtually no wave effects data was available for the Alexandrina Council coastline, and therefore no real inundation modelling could be undertaken. This event provided an opportunity to take a 'snap-shot' of the wave effects from Goolwa Beach to Chiton Rocks[61].

Methodology

Two data sets were obtained as illustrated by the photograph below:

- Data set 1: The fresh seaweed strands were pegged at the back of the beach from the previous extreme tide of morning of 22 November 2018, ~01:00
- Data set 2: The receding tide of afternoon of 22 November 2018 was pegged, measured and photographed. The time of the photograph can be coupled with the height of the tide in time, and then compared back to the 1-minute record of the tidal data for the same tide

The pegs at the back of the beach remained in situation overnight and the other pegs removed (due to safety issues). On 23 November 2018, the pegs were reinserted and measured with RTK survey equipment. At most locations, the same holes were visible and reused.

Figure 52: Storm heights were pegged for the extreme event, and for the following high tide

Source: M. Western (2018)

[61] Note: data was only collected as far as Boomer Beach (east) because high winds covered much of the seaweed evidence in sand, and in the Chiton Rocks region, the waves had crashed into the base of the dunes meaning readings were vague.

The findings

For full explanation of the methodology and analysis of this project refer to *Extreme Event Analysis: 22nd November 2018* report to DEW and Alexandrina Council[62]. This event provided a solid data set upon which to model wave effects for most of the Alexandrina coastline. However, no wave effects data was available for the Chiton Rocks region and this area was removed from the study. It is acknowledged here that although the results of the storm study were sound, the findings are predicated on one event. Further events should be analysed in a similar way to provide a more comprehensive data set. The results are displayed in the table below:

Table 5: Estimation of wave effects for event 22 November 2018

	Total wave effects	Wave set-up (30%)	Wave run-up (70%)
Goolwa Beach carpark to Middleton (Chapman Street Carpark)	1.7m	0.5m	1.2m
Chapman Street carpark to The Esplanade carpark (transition)	1.3m (transition)	0.3m	1.0m
Middleton Creek area	0.7m	0.2m	0.5m
Middleton Point (beach region)	1.3m	0.3m	1.0m
Ratalang Basham (east)	1.3m	0.3m	1.0m
Ratalang Basham (west)	0.7m	0.2m	0.5m
Crockery Bay	1.3m	0.3m	1.0m
Horseshoe Bay (east)	1.4m	0.4m	1.0m
Horseshoe Bay (west)	1.0m	0.3m	0.7m
Green Bay	1.2m	0.3m	0.9m
Knights Beach	1.9m	0.6m	1.3m
Boomer Beach	1.7m	0.5m	1.2m

3.5 Future exposure

It is not the purpose of this report to describe the climate change drivers that underpin the projections for sea level rise over the coming century. There are four excellent resources available to Council for review:

- CoastAdapt explains the causes and impacts of climate change in plain English[63].
- Church et al proposed sea-level rise allowances for coastal Councils around Australia, and conveniently included Victor Harbor in the study. When adopting a high emissions scenario (RCP 8.5) the report projects sea level to rise by 0.39m to 0.83m by 2090. This report also warns that if the Antarctic ice sheet melted, then levels could be much higher[64].

[62] Western, M.D. 2018 Extreme Event Analysis: 22nd November 2018 for Alexandrina Coastal region.
[63] http://coastadapt.com.au/learn-about-climate-change
[64] Church et al 2016 Sea-level rise and allowances for coastal Councils around Australia, Guidance Material, CSIRO report.

- A way to locate up-to-date projections is from the Climate Change in Australia website produced by CSIRO and Bureau of Meteorology. These projections are provided in the context of Natural Resource Management regions around Australia. The Alexandrina region falls into the Southern and South Western Flatlands (East) region[65].

- *The Resilient Hills and Coasts Climate Adaptation Plan for Adelaide Hills, Fleurieu Peninsula and Kangaroo Island* provides the appropriate context from which to understand the broader coastal issues associated with climate change as they are predicted to impact the Alexandrina coast[66]. This study utilised the high emissions scenario (RCP 8.5) and an assessment horizon of 2070.

One point of difference between this project and those listed above is noteworthy. Because Alexandrina Council operates in a statutory environment under the *Planning Development and Infrastructure Act 2016* and *Coast Protection Act 1972*, this project adopts the assessment time frame of 0.3m sea level rise indicatively by 2050, and 1.0m sea level rise indicatively by 2100. These sea-level-rise policy levels have been included in South Australian Development Plans since 1992 and still remain valid.

Finally, Church et al (2016) address the potential for climate change to bring about changes to the weather systems that might intensify the storms that produce extreme water levels. While acknowledging that the research is limited, the initial conclusion is that the climate change is unlikely to significantly intensify the storms so that they produce higher extreme sea levels. What this means in the context of this study is that to model a current extreme event (such as 22 November 2018) by adding projected sea level rise, is a valid way to view this future scenario.

On the other hand, within certain localities, storms with current intensity but at a higher mean sea level are likely to be experienced along the shoreline with more impact. For example, a reef that currently provides a degree of protection to a shoreline, may provide less protection if seas were 1m higher over the top of the reef.

Refer to individual cell reports for modelling and assessment of future exposure.

3.6 Sub-aerial processes

The rate of erosion of the fabric of a coastline is also impacted by sub-aerial processes. Sub-aerial processes refer to the processes of weathering and mass movement.

Weathering is the breaking down of rock *in situ*. It can be divided into mechanical and chemical weathering. Mechanical weathering refers to physical processes such as salt crystalization. This occurs as salt water from waves evaporates depositing salt crystals in cracks; as the salt crystals grow they expand and apply pressure to the crevices in which they form. Wetting and drying is common along coastlines. Clay-rich rocks are prone to expansion when they are wet and contraction as they dry. Repeated wetting and drying leads to break up of rocks and makes them more vulnerable to salt crystallisation. Chemical weathering occurs as a result of a weak chemical reaction between water and rock. eg. with limestone. Carbonic acid, formed from rainwater and carbon

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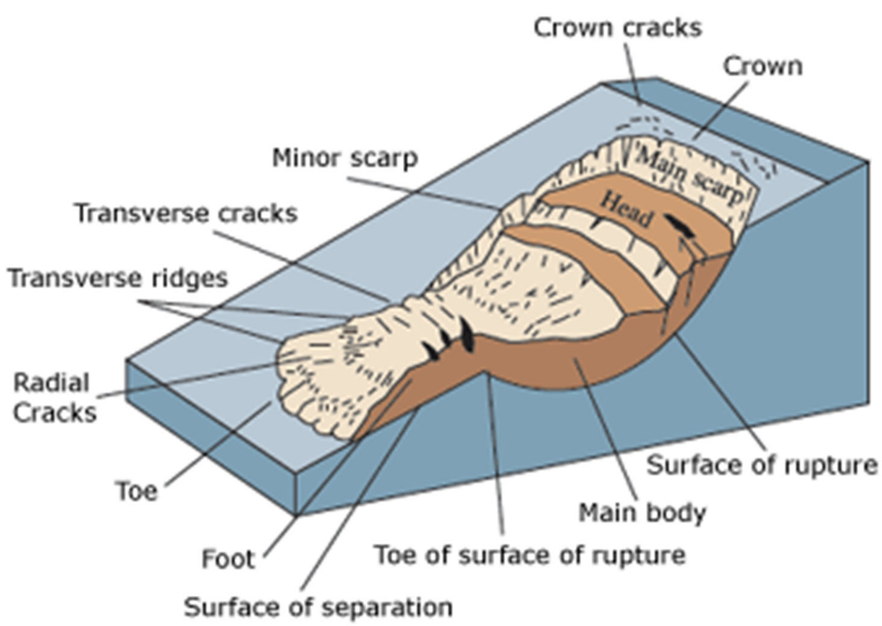
[65] https://www.climatechangeinaustralia.gov.au/en/

[66] Seed Consulting and URPS (2016), ps 44-46

dioxide, will react with calcium carbonate in limestone to form calcium bicarbonate. Since calcium bicarbonate is soluble in water, the limestone effectively gets weathered when carbonation occurs. Physical weathering also occurs by impacts related to the weight of water acting on vulnerable rocks as well as the artillery effect of waves carring pebbles and eroding by attrittion. The role of weathering is to weaken cliffs. This weakening speeds up the rates of erosion.

Another sub-aerial process is mass movement, which refers to the movement of material downslope under the influence of gravity. They can be rapid events, such as landslides and rockfalls or they can be slow processes, such as soil creep. A common type of mass movement at coasts is rotational slumping. Slumps occur due to a combination of factors. Marine processes erode and undermine the base of the cliff, removing support for the cliff. In addition, rainfall infiltrating into the slope through unconsolidated porous material creates slip planes where there are impermeable surfaces, such as clay, causing slope failure. This process can be seen in the Figure 53.

Figure 53: Process of cliff slumping



Source: http://thebritishgeographer.weebly.com/coastal-processes.html

While weathering and mass movement are natural and expected phenoma, uncontrolled storm water flows over cliffs and within dunes can increase the rate of erosion and breakdown of these structures. Storm water is also an area of responsibility of Alexandrina Council and therefore potential liability exists where the impact of storm water was shown to have caused erosion and subsequent loss of assets as a result.

Many storm water outlets drain directly to the sea from City of Alexandrina rainfall catchment areas. Some outlets to the coast are open drains or creeks, while others begin as open drains but are connected to the coast via pipes. A summary audit of storm water outflows is contained within individual cell reports.

Storm water catchment and outflows are assessed within individual cell assessments

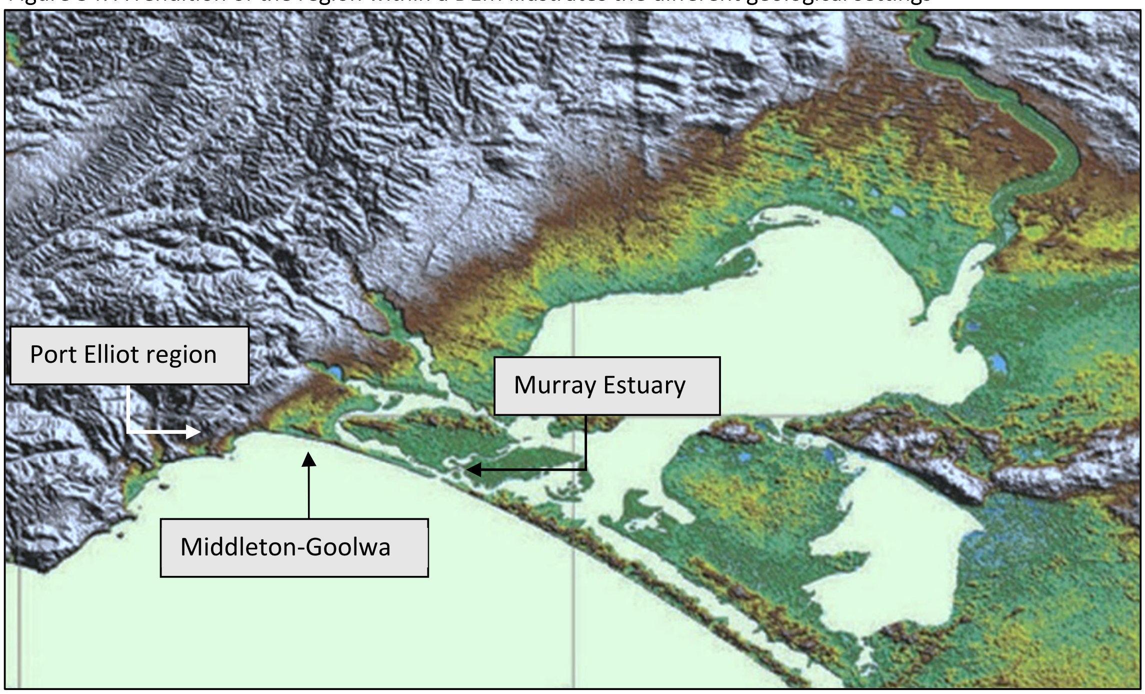
3.7 General Coastal Assessment - overview

In summary, the Alexandrina coastline can be considered in three main geological layouts:

- Chiton Rocks to Ratalang-Basham (Port Elliot region) is situated within the Mount Lofty Ranges and therefore the coastline is elevated, dominated by rocky outcrops and offshore reefs, and interspersed with embayed beaches.
- Middleton Beach and Goolwa Beach are situated within the Murray Basin and are dominated by unconsolidated sand and high energy dissipative beaches.
- Goolwa Channel and Mundoo Channel settlements are situated within the Murray Estuary.

The variation in geological layouts is demonstrated by the digital elevation model in Figure 54.

Figure 54: A rendition of the region within a DEM illustrates the different geological settings



Source: Adapted from Jarvis et al, 2008, depicted in Bourman, Murray-Wallace, Harvey 2016, Coastal Landscapes of South Australia, University of Adelaide Press, p 112

Summary findings

Comparative analysis using historical aerial photographs from 1949, 2009 and 2018 generally revealed that most of the Alexandrina coastline has been stable over a seventy-year period. However, it is likely that the coastline goes through normal periods of erosion and accretion cycles which may need to be measured in decadal terms. For example, comparative analysis of photography from 2009 and 2018 reveals that sections of the coast have been going through an accretion cycle. This is most noticeable in locations such as Boomer Beach, Middleton Beach and Goolwa Beach.

More fine-grained analysis is contained within the individual cell reports.

4. Identify assets and activities at risk

The purpose of this section is to broadly contextualise the nature of assets in the coastal zone and generally identify which of these are likely to be at risk. Part 2 of this reporting will investigate assets within each of the assessment cells.

It is important to also note that the context of this study is primarily concerned with Council owned assets, and not assets owned by others.

4.1 General overview

The Alexandrina coastline has generally developed over time with human infrastructure that is set well-back from the shoreline and possible areas of impact. Early urban planners in the State of South Australia held the view that the coast belonged to 'the people' and thus a coastal reserve backed by a public esplanade road was the standard way to establish a coastal settlement. Community club facilities were usually dealt with in the same manner, and these were not permitted to intrude into what might be considered 'public access' to the beach. The exceptions to the rule included:

- the acceptance that Surf Life Saving Clubs required position in closer proximity to the coast
- caravan parks enjoyed foreshore positions as tourist locations
- early beach shack development at more remote locations (1940s to 1950s)

This early planning principle meant that privately owned assets were generally set behind esplanade roads. Therefore, as long as the Council chooses to protect and maintain the esplanade road free of inundation and erosion, those positioned behind it receive cost-free protection.

4.2 Overview of private assets in coastal regions

A review of the coastline from Chiton to Goolwa Beach demonstrates that for the most part the Alexandrina coastline follows the 'esplanade planning principle' (Figure 55).

Figure 55: The general urban layout of coastal foreshore, esplanade road, and then private assets

Source: M.Western, ArcMap, Council aerial photograph 2016

Exceptions to the 'esplanade planning principle'

Exceptions to this urban layout include locations that are situated a substantial distance landward of substantial coastal dunes.

Figure 56: Private assets set longer distances from substantial dunes sometimes have no esplanade road

Source: M.Western, ArcMap, Council aerial photograph 2016

Another exception is private development within the Goolwa Channel, but the hazard regime is substantially different in this environment (See also history section of Cell SF1 and SF2).

Figure 57: Development on the Murray River is sited on river-front positions

Source: M.Western, ArcMap, Council aerial photograph 2016

As a first pass assessment, only one location on the Alexandrina coastline was identified with private development on the foreshore, and close to any current possible impact from actions of the sea (Figure 58).

Figure 58: Private development situated on the foreshore (cliff) at Boomer Beach (east)

Source: M.Western, ArcMap, Council aerial photograph 2016

The other exception is the location of the Port Elliot bowling club that divides the public space into two sections, albeit now joined by a walking path. While this is not strictly a 'private asset', normally what would be allocated as 'public space' under normal planning conditions, is essentially limited to membership.

Figure 59: Port Elliot bowling club situated on foreshore

Source: M.Western, ArcMap, Council aerial photograph 2016

4.3 Overview of public assets in coastal regions

Nature of Council assets in the coastal zone

The general scope of Council assets in general order of proximity from the coast are:

- Accessways to beaches (the most vulnerable asset in the context of a dynamic coast)
- Fencing (dune and other)
- Shelters and seating
- Carparks
- Toilets and change facilities
- Esplanade roads and associated infrastructure (such storm water and sewer services)

Surf Life Saving Clubs at Chiton Rocks, Horseshoe Bay, and Goolwa Beach all have facilities in the coastal zone, but these appear to be set back at a reasonable distance from the foreshore, or are sufficiently elevated (such as Horseshoe Bay). Scenario modelling in this project will assist in identifying if any of these are at risk when they are assessed within individual coastal cells.

Figure 60: A typical coastal layout of public assets in the coastal zone

Source: M.Western, ArcMap, Council aerial photograph 2016

Overview summary

A first pass review suggests that when considered as a whole, Alexandrina Council's assets are not overly exposed to current risk. The exceptions are: accessways and carparks, and assets within Horseshoe Bay. This general observation also suggests that Alexandrina Council is well-placed to monitor and incorporate decision making over the coming years that will prevent assets being positioned in vulnerable locations.

The location and vulnerability of assets are assessed within individual cell assessments.

5. Adaptation proposals - overview

5.1 Adaptation responses

CoastAdapt notes that there are generally six categories of adaptation responses to climate change in the coastal zone:

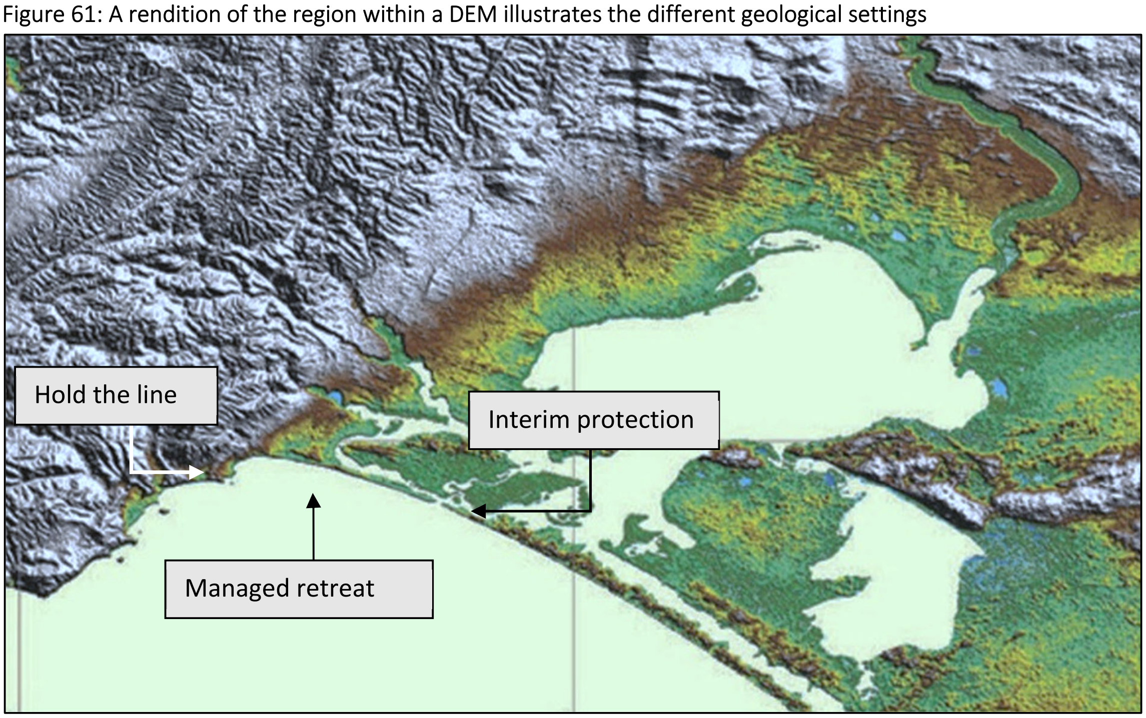
- Avoidance
- Hold the line (protect)
- Accommodation (or limited intervention)
- Managed retreat
- Monitor and respond
- Loss acceptance

General findings

As noted above (p. 74), most of the Alexandrina coastline presents as having been stable over the last seventy-years. However, it is likely that the coast normally progresses through cycles of erosion and accretion. It is unlikely that sea level rise has moved the coastline beyond these normal cycles. Therefore, the almost universal adaptation response is for a 'monitor and respond' approach. If seas rise as projected, then the balance between fabric and exposure will shift, and the fabric can be expected to be impacted. Ongoing monitoring will provide the decision-making basis moving forward.

Furthermore, adaptation response tended to be grouped in accordance with broad geological layouts (Figure 61). There are exceptions to this rule, but this observation does assist in creating an overall adaptation framework that considers the coastline as a whole.

Figure 61: A rendition of the region within a DEM illustrates the different geological settings



Source: Adapted from Jarvis et al, 2008, depicted in Bourman, Murray-Wallace, Harvey 2016, Coastal Landscapes of South Australia, University of Adelaide Press, p 112

Murray Estuary Settlements (Cells SF1 to SF2)

Settlements situated along the Goolwa and Mundoo Channels are positioned on a 'sand-flat' predominantly at elevations below 2m AHD. If seas rise as projected, then this area will increasingly be subject to increased inundation. Erosion is expected to continue along the riverbank, but this factor is expected to be manageable in the short term with various forms of protection (e.g. rock revetment or geotextile sandbags). However, if the terrain becomes increasingly inundated at greater depths and higher frequency, then the unconsolidated sand is likely to be scoured, and the terrain altered over time so that it becomes increasingly unstable. The prime adaptation response for the Murray Estuary is to provide perimeter protection to the region using low height levees (and similar protection strategies) to provide protection to cater for the 1 in 100-year 2050 scenario. The longer-term outlook to 2100 is more uncertain as protection options will become increasingly unviable if seas rise as projected.

Goolwa to Middleton Creek (Cells SF3 to SF6:2)

The section of coast that includes Middleton and Goolwa Beach is dominated by unconsolidated sand within the context of a high energy dissipative beach. Because the current location of the shoreline is determined primarily by the current coastal processes (tides, waves, winds), sea level rise of 1m will cause recession of this coastline by up to 100m by 2100. Therefore, the predominant adaptation response within this region is for managed retreat. Long term protection strategies are deemed unsuitable for this region. It is expected that interim protection will be necessary to protect existing carpark infrastructure, but that in the long term these carparks and associated infrastructure will be required to be reconfigured further away from the coastline. Erosion is the key hazard factor in these cells and not inundation. The exception to this general observation is likely to be Tokuremoar Reserve region where dune fields protecting the swamp behind are low-set and narrow.

Middleton Creek to Boomer Beach (Cells SF6:1 to SF9)

Within the Port Elliot region, which geologically is situated within the Mount Lofty Ranges, adaptation proposals are predominantly 'hold the line'. These are likely to succeed in a geologically stable environment which is resistant to erosion and dominated by rocky outcrops and offshore reefs. The exception to this general observation includes Boomer Beach, and within Horseshoe Bay where it is recognised that some recession is likely to take place in the eastern portion of the bay. Erosion is the prime hazard factor within these cells and inundation is not a key hazard factor.

5.2 Adaptation approaches

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.

General findings

Due to the stable nature of most of the Alexandrina coastline the general adaptation response to 'monitor and respond', and incremental approach to adaptation is preferred. Ongoing monitoring of sea level rise and associated impacts upon the coastline will provide the ongoing decision-making basis over the coming decades. Some erosion has occurred at settlements within the Murray Estuary but this isnot attributable to sea level rise. Ongoing monitoring of the impact of sea level rise within the estuary will assist in determining when inundation and/or erosion is beginning to have an impact on settlements.

The exception to this rule is Horseshoe Bay where a transformative approach is preferred. To provide longevity to the beach, which is an important social icon for Alexandrina Council, the proposed adaptation approach is to increase flexibility in the backshore which will assist in accommodating sea level rises while maintaining a sandy beach. To achieve this end, a new master plan is recommended for Horseshoe Bay (See report Cell SF8: Horseshoe Bay).

5.3 Adaptation types

Within each of the first four response categories there is a range of potential adaptation options in the areas of[67]:

- Planning
- Engineering
- Environmental management

Planning

These are options that use planning legislation and regulations to reduce vulnerability and increase resilience to climate change and sea-level rise. Thus, land that is projected to become more prone to flooding in future can be scheduled as suitable only for development such as light industry or warehouses, and unsuitable for housing or critical infrastructure.

Engineering

In the context of climate change adaptation 'engineering' has come to describe adaptation options that make use of capital works strategies such as seawalls and levees. Such projects are 'engineered' to solve a particular challenge such as to protect coastal infrastructure from erosion and inundation damage. These approaches differ from other types of approaches in that they require significant commitments of financial and social resources and create a physical asset.

Environmental management

Environmental management includes habitat restoration and enhancement through activities such as revegetation of coastal dunes or building structures to support continued growth of habitat such as seagrasses or reefs. It may also include developing artificial reefs to reduce wave erosion of shorelines or engineered solutions to prevent encroachment of saltwater into freshwater systems.

[67] CoastAdapt also includes 'community education'.

General findings

- The general finding of the study is that planning policy appears to be appropriately set so that increased density of expansion of settlements cannot occur in locations that are likely to be impacted by erosion or inundation. The general appeal in this study is to review planning policy to ensure that locations that are identified in this study is appropriately set to cater for future hazards.
- Engineering responses are spread throughout the region. Engineering options could include rock revetment proposals for locations such as Knight Beach, Green Bay, Crockery Bay, Middleton Creek (west), and within some locations of the Murray Estuary.
- Environmental responses are spread throughout the coastal region. Environmental responses could include dune stabilisation at Ratalang-Basham Beach, implementation of dune system at Horseshoe Bay, and sandbag protection within locations of the Murray Estuary.

5.4 Monitoring strategies

The purpose here is not to provide a design for a detailed monitoring program as this will be completed as a separate project. The purpose here is to provide a context for understanding why monitoring is necessary and broadly, what type of monitoring actions are likely to be adopted.

In most areas of Alexandrina coastline, this study has recommended an 'incremental approach' to adaptation (see page above). The main reason to adopt this approach is that most of the coastline is not currently at risk from erosion or inundation. In fact, large sections of the coastline have shown to be accreting over the last ten years.

Prime response – 'monitor and respond'

Therefore, the prime adaptation response would be to 'monitor and respond'. Data will be collected on an ongoing basis and compared to the baseline we have established in this study.

This study has established a baseline in two ways: First, the capturing of the digital elevation model in 2018 provides a point in time baseline of the current form of the coast. In 5 or 10-years' time (depending whether the coast is accreting or eroding), another digital elevation model could be captured, and comparisons made between the two digital models.

The second way in which this study has formed a baseline is by analysing coastal change over time. We have compared the position of the shoreline from 1949 to 2018 and identified areas of erosion and accretion. Overall, the coastline in most places appears to have been stable for 70 years. In some places it has eroded. This understanding of how a coast operates over time also forms part of the baseline understanding. In the future, we can use newly acquired aerial photographs to compare shoreline position in the future. Analysing the impacts of storm activity will also form part of the monitoring strategy and ongoing assessment of Coast Protection Board profile lines will also assist in identifying trends within the coastal region.

Establishing indicators for monitoring

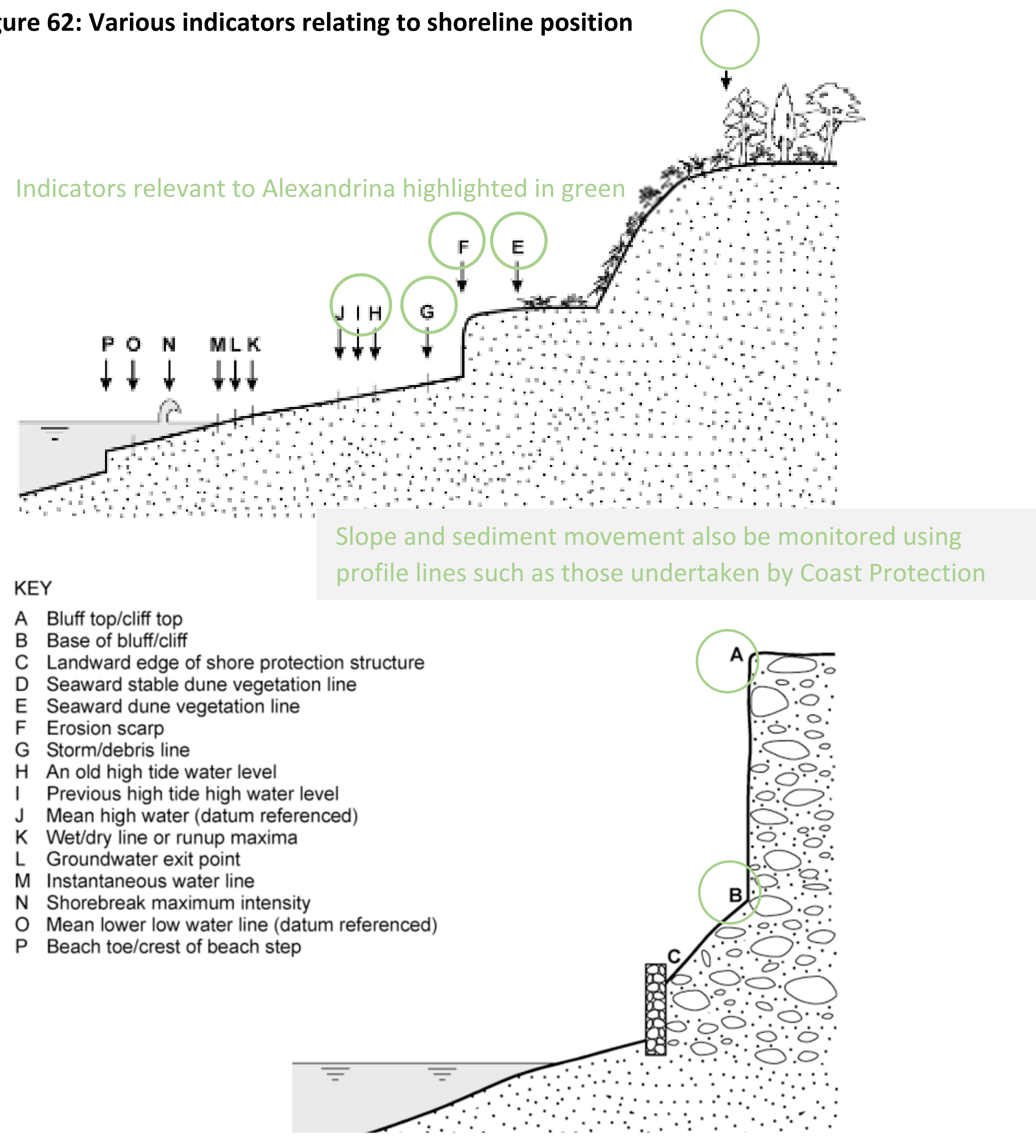
Indicators are things that we can measure. They help to determine whether objectives have been achieved for a specific program or project. Therefore, the monitoring plan should contain measurable objectives together with indicators for each of the objectives. Monitoring programs need to be in place so that they can collect appropriate data on each indicator and assess these against baseline conditions.

The key indicator: the shoreline[68]

Generally, we are most interested in the position of the shoreline over time. Both coastal management and engineering design require information about where the shoreline is, where it has been in the past, and where it is predicted to be in the future.

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 (waves, tides, storm surge, wave setup, wave runup), and because of cross-shore and alongshore sediment movement. The shoreline is a time-dependent phenomenon that may have substantial short-term variability, and this needs to be carefully considered when determining the shoreline position.

Figure 62: Various indicators relating to shoreline position



[68] This section relies on Boak and Turner (2005) Shoreline definition and detection: Journal of Coastal Research.

Typical monitoring activities

The table below lists typical monitoring activities as a means to further understand monitoring techniques rather than as a properly designed monitoring program appropriate to Alexandrina coastline.

Table 6: Typical monitoring activities that may be appropriate for Alexandrina coastline

Item	Rationale	Indicators	Timing
Recapture digital elevation model	Assess shoreline change	Sand volume changes, location of escarpments.	Every 5-10 years
Aerial photography	Assess shoreline change	Position of vegetation lines, dunes, and escarpments. Review coastline for evidence of new erosion trends.	Annually or bi-annually (or when aerial photography is obtained).
Coast Protection Board profile lines	Assess sediment movement	Profile line change indicating accretion or erosion trends	Every 5 years (or when profile line is obtained)
Analyse storm activity	Identifies impacts and trends of storms	Identify erosion and/or inundation impact, and track recovery (or otherwise) in annual review of aerial photography. Where further data is required, survey seaweed strands to identify wave impacts.	When storms occur. Initially, it would be wise to survey seaweed strands from two further storms to more accurately calculate wave effects.

Case Study: Waikato Regional Council

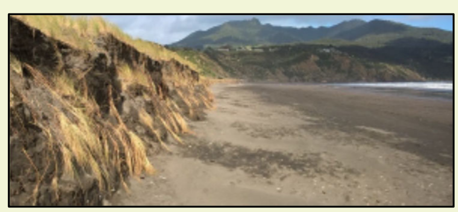
Case Study : Waikato Regional Council (New Zealand)

Waikato Regional Council has been collecting beach profile data for forty years from up to 60 sites along its coastline. The Council also conducts beach video monitoring at selected locations.

The key purpose of the project is to understand shoreline changes over both short and long-time frames. The monitoring **indicators** were 'beach volume' and 'shoreline position'.

Many beaches suffered erosion in the 1970s but these beaches were rebuilt in the 1980s.

The results show that sandy beaches can fluctuate by up to 30m with changes to erosion and accretion occurring over decades.



'Despite sometimes dramatic changes, our records don't show that any of our Coromandel beaches are experiencing a long-term trend for erosion. This may change in the future with projected sea level rise'.

If Waikato Regional Council had not been monitoring coastal change and a rapid increase in erosion occurred as it did in the 1970s, but this time in the context of high awareness of climate change and sensational media reporting, how would it have interpreted the erosion? What actions might the Council have taken that could be very high cost thinking that the rate of erosion was outside the norm, and expected to continue and accelerate?

These questions do not undermine the prevailing view that sea level rise will have an impact upon our coastlines, but rather show that maladaptation, along with high costs, are more likely in the absence of an understanding of how local beaches behave over time. And the only way to understand how they behave is to conduct monitoring of the coastline.

A valid conclusion from case studies such as this one is that cost-effective monitoring is likely to save the Council money over time, and give Council the necessary data to both make hard decisions when these are required, but also resist the political and media pressures that are increasingly prevalent in dealing with climate change.

6. Adaptation study – cell summaries

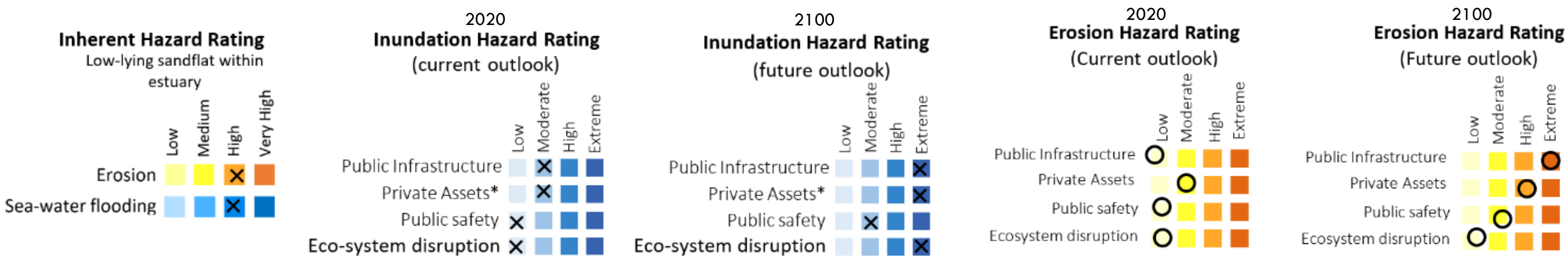
In this section of the report one-page summaries from each cell are provided that give a brief overview of:

- Coastal processes
- Risk assessment
- Adaptation Proposals

Adaptation proposals: Murray Estuary settlements (Cells SF1 - SF2)

Coastal processes	Mundoo Channel and Goolwa Channel settlements are located within Mundoo Channel and Goolwa Channel on the seaside of the barrage. The fabric (geology) of the terrain is described as a 'sand flat' at elevations generally less than 2m AHD. Flows of water in the area relate to the tidal regime at the Murray Mouth. Fresh water flows are controlled by the barrages.

Risk outlook



Adaptation overview:

The overall adaptation proposal for settlements is to 'hold the line' (ie provide protection) to cater for projected sea level rise for 2050. This interim protection will provide a time buffer for further monitoring of sea level rise trends to be identified. The main protection strategy is to install low height levees at the perimeter of Goolwa and Mundoo Channel settlements. In locations where private property (or leasehold property) is situated adjacent to the channels alternative protection strategies are likely to be required, and engagement with the community is required before any firm proposal can be identified. Sugars Beach requires upgrade of existing protection works and installation of sandbag protection to revetment end (east).

Adaptation proposals:

	Adaptation Approach	Short term strategy 2020	Mid-term strategy 2050	Long term strategy 2100	Adaptation Type (when required)	Monitoring strategy
Murray Estuary settlements Cell SF1-2	Incremental (monitor and respond)	Community engagement (then identify preferred adaptation response and develop plan.	Hold the line: provide protection (low height levees) to perimeter of Goolwa and Mundoo settlements.	Unknown: subject to further sea rise monitoring.	Engineering: Low height quarry rubble levees. In front of shacks, other methods are likely to be required. Rock revetment required now at Sugars Beach	Impact of storm events upon settlements. Monitoring of sea level rise (within SA)

Proposed protection items for Sugars Beach

Magryn Engineering provided preliminary design and costing for:

- Rock revetment upgrade (east of boat ramp)
- Sandbag control at revetment end (east end)

Provide perimeter protection

Preliminary feasibility suggests that providing perimeter protection to the Mundoo Channel and Goolwa Channel Settlements is viable to protect the settlements against project sea level rise to 2050.

The table on the right estimates the likely cubic metres of material required to construct levees. The table does not include works required at front of Mundoo private properties.

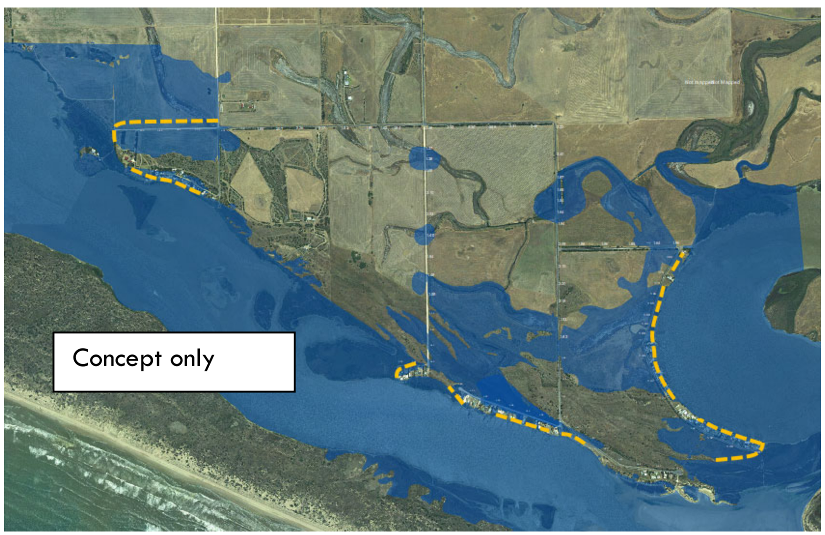


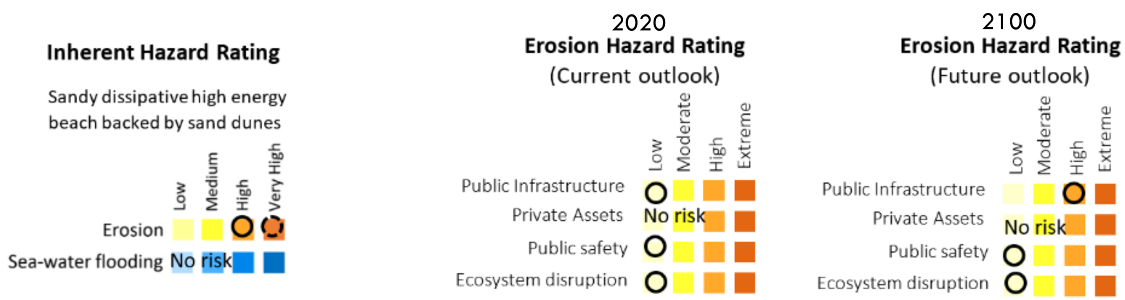
Table: Estimation of cubic metres for installation of low height levees to perimeter of Goolwa and Mundoo Channel settlement

Location	Length (Current)	Length (2050)	Height ~average	Levee m2	Levee m3
Mundoo - South	300m	300m	1.0m	4	1500*
Mundoo - north	220m	270m	1.0m	4	716*
Goolwa Channel Drive (1)	95m	110m	0.9m	3.33	330
Goolwa Channel Drive (2)	46m	65m	0.8m	2.54	132
Goolwa Channel Drive (3)	Nil	115m	0.6m	1.66	115
Mills Road	205	205m	1.0m	4	820
Cooinda Road	225m	470m	0.6m	1.66	468
Chappel Road and Bongalong Road	180m	660m	0.6m	1.66	1095

Adaptation Proposals: Goolwa Beach (Cell SF3)

Coastal processes	Goolwa Beach is situated on a dissipative high energy beach facing the Southern Ocean. Over seventy years the coast has remained relatively stable while going through its natural cycles of accretion and erosion. Over the last ten years the Middleton – Goolwa coastline has been undergoing accretion.

Risk outlook



Adaptation overview:

The over-all long-term strategy for Goolwa Beach is to allow the dunes to retreat. Soft options such as dune fencing, and planting will slow the rate of erosion. For the Goolwa Carpark area, the recommendation is to increase the dune buffer from 20m to 40m and reorientate the access stairs (ie review and amend Master Plan for Goolwa Beach carpark area). If the dunes erode at a later time in this location, then a 'hold the line' strategy is likely to be employed to protect the carpark area or alternatively, accept loss.

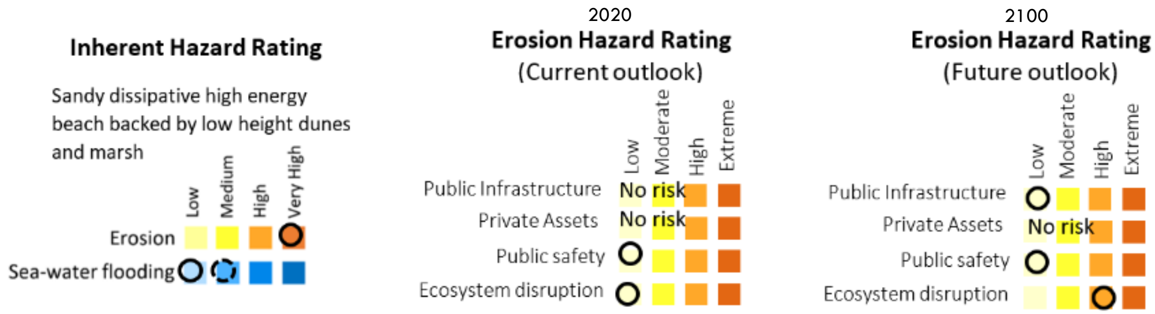
Adaptation proposals:

	Approach	Short term strategy 2020	Mid-term strategy 2050	Long term strategy 2100	Adaptation Type	Monitoring strategy
Goolwa Beach Cell SF3	Incremental (monitor and respond)	Monitor [no immediate works are likely to be required]	Monitor [protection may be required by 2050, or the latter part of this century]	Overall strategy: Allow retreat of dunes. The exception is the carpark area which may need protection later in this century.	Environmental: Increase dune field at the carpark. Continue use of dune fencing and planting. Engineering: Reorientate beach access point.	Shoreline position Sand volumes Storm impacts on backshore

Adaptation Proposals: Tokuremoar Reserve (Cell SF4)

Coastal processes	Tokuremoar Reserve is situated behind low set dunes on Goolwa Beach. Goolwa Beach is situated on a dissipative high energy beach facing the Southern Ocean. Over seventy years the coast has remained relatively stable while going through its natural cycles of accretion and erosion. Over the last ten years the Middleton – Goolwa coastline has been undergoing accretion.

Risk outlook



Adaptation overview:

Initially, the main strategy for Tokuremoar Reserve is to monitor the dunes and provide soft engineering options to maintain dune width and height. However, as seas rises as projected, then this strategy may not succeed in the longer term, but how the coast will actually react to sea level rise is not clear. If protection was required to infrastructure and ecology behind the current dunes, low height levees could be employed further back from the coastline to prevent seawater from flowing inland.

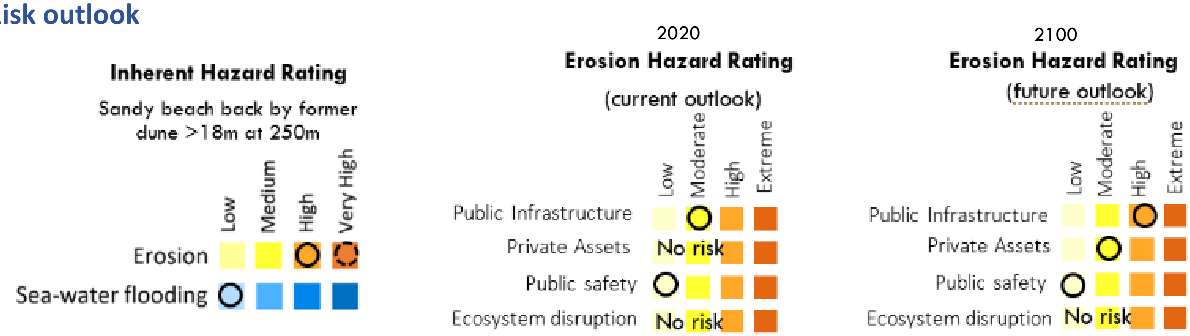
Adaptation proposals:

	Approach	Short term strategy 2020	Mid-term strategy 2050	Long term strategy 2100	Adaptation Type	Monitoring strategy
Tokuremoar Reserve Cell SF4	Incremental (monitor and respond)	Monitor [hold the line: remediate dunes at points they become vulnerable]	Monitor [hold the line: remediate dunes at points they become vulnerable]	Managed Retreat: if hold the line becomes unviable, provide low height levees inland to prevent the inland flow of seawater.	Environmental: Use soft options such as dune fill, sandbags, fencing and planting. Engineering: Longer term may require low height levees set inland.	Shoreline position Sand volumes (dunes) Storm impacts on backshore

Adaptation proposals: Middleton Beach (Cell SF5)

Coastal processes	Middleton Beach marks the beginning of the long dissipative beach that stretches eastward to Cape Jaffa. This is a high energy beach with backshores varying from low-height dunes, to soft rock cliffs. The inherent hazard risk rating is categorised as 'high' to 'very high'. Historical comparisons showed that between 1949 and 2006 the shoreline has retreated 10-12m in places, but since 2006 the shoreline has showed signs of accretion. Most of the shoreline is in a similar position as that of 1949.

Risk outlook



Note: the erosion hazard rating here is typical of most locations along Middleton Beach. Check individual locations for exact risk ratings.

Adaptation overview:

The long-term strategy for Middleton Beach is 'managed retreat' if seas rise as projected. Erosion assessment in neighbouring cells suggest erosion of ~100m by 2100 but in this cell, this rate will depend on the nature of the backshore (which varies in this cell). Carparks and associated infrastructure are currently set at varying distances from the shoreline. The overarching aim is that these should be repositioned / reconfigured so that they are further away from the shoreline. On occasion, **short term protection** options may be required to protect carparks, but these should be cost-effective and only used as **an interim measure** while longer term relocation of infrastructure can be achieved. A proposal to reengineer storm water that flows on to the beach at Chapman Road is included.

Adaptation proposals:

	Approach	Short term strategy 2020	Mid-term strategy 2050	Long term strategy 2100	Adaptation Type	Monitoring strategy
Middleton Beach Cell SF5	Incremental (monitor and respond)	Monitor [Also upgrade storm water infrastructure at Chapman Rd]	Monitor [relocate carparks as upgrades are required, interim protection may be required]	Managed retreat [carparks and associated infrastructure relocated/ reconfigured]	Engineering: Storm water, relocate or reconfigure carparks. Environmental: Interim protection works as required (ie sandbags)	Shoreline position, Storm impacts on backshore, sand volumes

Engineering works for Middleton Beach

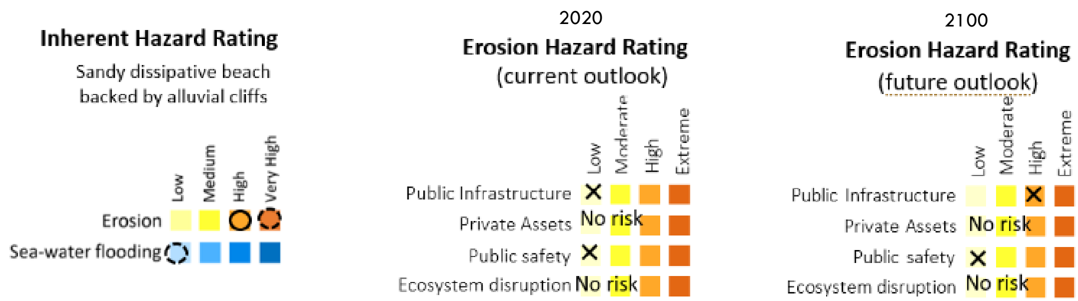
Magryn Engineering provided preliminary design and costing for:

- Reconfiguration of storm water outflow to beach at Chapman Road (including detention pond)
- Collapse overhanging section of cliff and install protection to carpark at Skye Ave carpark (not pictured)

Adaptation proposals: Middleton Creek (East) (Cell SF6-2)

Coastal processes	Middleton Beach (cliff section) marks the beginning of the long dissipative beach that stretches eastward to Cape Jaffa. The beach is backed by a small dune system that has formed over the last ten years. Behind the dunes are alluvial cliffs. Exposure is categorised as 'moderate', and wave energy moderate at ~1m. Historical research found that this area underwent large scale erosion at the turn of the 19th century. Since 1949, the cliffs have receded 12-15m, but the rate of erosion appears to have almost ceased.

Risk outlook



Adaptation overview:

The long-term strategy for Middleton Creek (east) is managed retreat if seas rise as projected. Erosion assessment indicates coastline could recede ~97m to 114m. The carparks on top of the cliff are likely to be positioned far enough back that these will not come under attack until the second half of the century. However, if any upgrades were envisaged, the carparks could be reconfigured to allow a greater distance between the carparks and the cliff tops. Beach access stairs are set well back from current shoreline, but any upgrade of these should consider erosion outlook (ongoing monitoring will provide decision context).

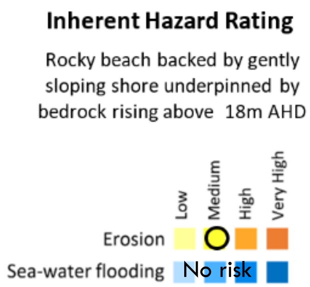
Adaptation proposals:

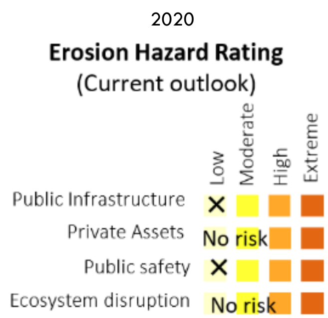
	Approach	Long term strategy 2020	Mid-term strategy 2050	Short-term strategy 2100	Adaptation Type (when required)	Monitoring strategy
Middleton Creek (East) Cell SF6-2	Incremental (monitor and respond)	Monitor [no immediate works are likely to be required]	Monitor [It is unlikely that erosion will impact carpark in this time frame]	Managed retreat [Carpark is set well back – reconfigure further away from shoreline at time of upgrade]	Engineering: Construct carpark further away from shoreline.	Shoreline position Storm impacts on backshore Sand volumes

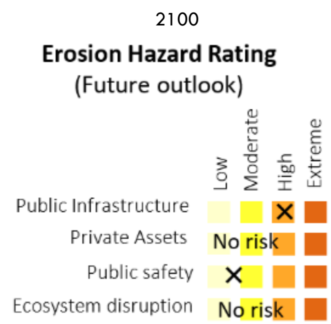
Adaptation Proposals – Middleton Creek (West) (Cell SF6-1)

Coastal processes	Middleton Point (beach) is underpinned by reef, and bordered by sandstone outcrops which dissipate wave energy. The beach is backed by a small dune system in the east and an embankment in front of the carpark. Exposure is categorised as 'moderate', and wave energy moderate at ~1m. Historical analysis indicates that the back-shore of the beach is impacted by larger events and has eroded 2-4m since 1949. Analysis of future regimes suggests that the backshore will come under increasing impacts from the sea if seas rise as projected.

Risk outlook







Adaptation overview:

The long-term strategy for Middleton Creek (west) is to hold the line and protect the backshore (carpark, dune system). This strategy is likely to be effective in the geological setting in which Middleton Creek (west) is located (although the dune width is likely to narrow). An incremental approach to adaptation is recommended. Monitoring of beach processes, sand volumes, and impact to backshore will provide the decision-making context for when protection is required. Storm water outflows should be assessed, and alternative flow path provided to the sea (see proposed works on following pages).

Adaptation proposals:

	Approach	Short term strategy 2020	Mid-term strategy 2050	Long term strategy 2100	Adaptation Type	Monitoring strategy
Middleton Creek (West) Cell SF6-1	Incremental (monitor and respond)	Monitor [storm water infrastructure required to provide alternative flow path]	Monitor [protection may be required by 2050, or the latter part of this century]	Hold the line: protect backshore [Car park and walking track behind beach]	Engineering: Storm water diversion Protection to carpark	Shoreline position (dunes) Storm impacts on backshore

Engineering items for Surf Street, Middleton

Concept plan: storm water diversion away from beach to outlet to rocky outcrop

SURF STREET – MIDDLETON
SCALE 1:1000

CONCEPT ONLY
THE ARRANGEMENT SHOWN IS FOR DISCUSSION PURPOSES ONLY.
IT MUST NOT BE USED FOR CONSTRUCTION.

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ALEXANDRINA COUNCIL
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PROJECT:
COASTAL ADAPTION STRATEGY

PROJECT ADDRESS:
GOOLWA TO CHITON ROCKS

TITLE:
PLAN

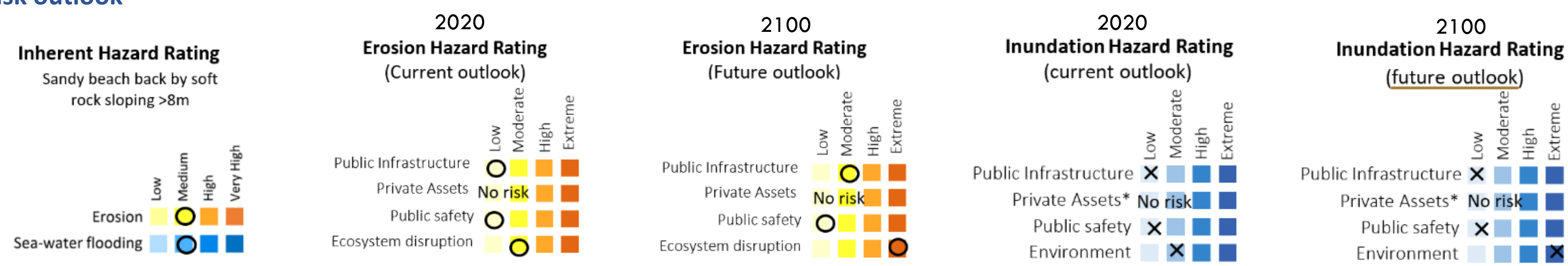
CONTRACTORS MUST VERIFY ALL DIMENSIONS PRIOR TO ANY OFF SITE FABRICATION.

DESIGN: WS	SCALE: AS SHOWN	DATE: FEB. 2019
SHEET SIZE: A3	DRAWING NUMBER: 18084–18	REVISION: A

Adaptation proposals: Ratalang-Basham (Cell SF7)

Coastal processes	Ratalang-Basham is categorised as a sandy shore, backed by dunes. The shoreline is backed by soft sediment rising to elevation of 12-18m at ~500m inland. Ocean waves refract around Commodore Point and Frenchman Rock producing a radial and parallel wave pattern. Ratalang-Basham is protected from south-west swells by Commodore Point. Wave action is 0.5 to 1m and categorised as 'moderate' exposure. Historical analysis demonstrates that Ratalang-Basham beach has been stable over a seventy-year period

Risk outlook



Adaptation overview:

The long-term strategy for Ratalang-Basham is to hold the line as long as feasible. As seas rise, the dune system is likely to either break-down or recede (or a combination of both). To provide the optimum conditions to allow recession to take place, the adaptation proposal is to raise the dune system where there are gaps to prevent sea water from flowing through the dunes. See concept plan on following page.

Adaptation proposals:

	Approach	Short term strategy 2020	Mid-term strategy 2050	Long term strategy 2100	Adaptation Type	Monitoring strategy
Ratalang-Basham Cell SF7	Incremental (monitor and respond)	Monitor [raise height and width of dunes to prevent sea water incursion]	Monitor [protection may be required by 2050, or the latter part of this century]	Hold the line: maintain the dune system [Freshwater ecology is situated behind the dune system]	Environmental: Sandbags, dune fencing, planting.	Shoreline position Storm impacts on backshore Sand volumes

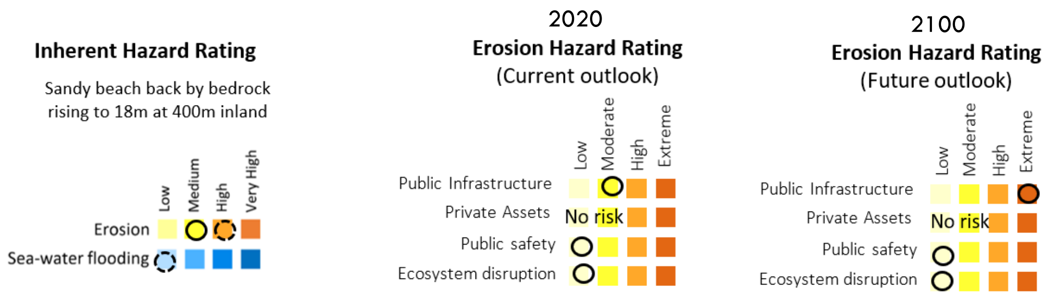
Dune stabilisation and associated works

Install geotextile sandbags to dune gaps, install dune fencing, and raise dune height with sand scraped from the beach.

Adaptation Proposals: Horseshoe Bay (Cell SF8)

Coastal processes	Horseshoe Bay is categorised as a reflective coarse sand beach bordered by granite headlands. The shoreline is backed by seawalls on western end, embankment in the centre, and dunes on eastern end. The bay is 'bedrock backed' with backshore rising above 10m at 100m inland from the shore. Exposure is categorised as 'sheltered', and wave energy low at 0.5m to 1m. Historical analysis reveals a significant change to the nature of the beach where in times past (100 years) dunes were more significant (mid-section to eastern end).

Risk outlook:



Adaptation overview:

The long-term strategy for Horseshoe Bay is to 'hold the line' and the geological layout suggest this is feasible. However, to prevent the likely loss of the beach, in the short to mid-term, increased flexibility in the backshore is proposed for eastern sections of the bay by implementing natural dune system. Protection works are proposed for the western side of the bay that will be designed to absorb the impact of actions of the sea. These strategies are proposed to provide longevity to the beach, while allowing some recession of the shoreline as sea levels rise.

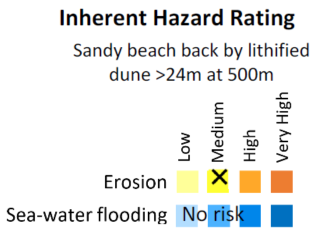
Adaptation proposals:

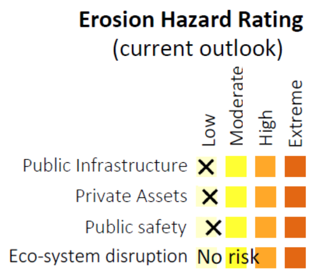
	Approach	Short term strategy 2020	Mid-term strategy 2050	Long term strategy 2100	Adaptation Type	Monitoring strategy
Horseshoe Bay Cell SF8-1	Transformational (new Master Plan for the Bay)	Implement increased flexibility in the backshore (allowing some natural retreat if required)	Maintain sand nourished dune system.	Hold the line [The geological layout of the bay suggests this strategy is feasible]	Planning: New Master Plan Environmental (subject to plan): Implement dune system on eastern end. Engineering: Implement protection system to absorb impact from actions of the sea.	Initial monitoring required to quantify sand movement / volumes in the bay.

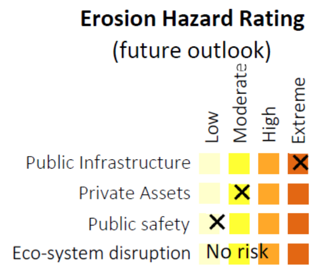
Adaptation Proposals: Boomer Beach (Cell SF9-1)

Coastal processes	Boomer Beach is categorised as a reflective medium sandy beach, tends to be a closed cell as it is bordered by granite headlands on the east. The beach is backed by sand dunes varying in height from 10m AHD (in west) to 18m AHD (in east). Exposure is categorised as 'moderate', and wave energy moderate at ~1m. Historical analysis suggests that the backshore of the beach undergoes periodic accretion and recession over periods of decades. Currently the beach has been in an accretion cycle for ~10 years. Analysis of future regimes suggests that this may change.

Risk outlook







Adaptation overview:

If seas rise as projected, then it is unlikely that the base of the dune at Boomer Beach can be protected. The dune may recede by 18-23m and the slope become increasingly unstable. This is likely to place the trainline at risk in the latter part of the century. It is less likely that private property will be at risk. The overall strategy is to monitor the beach, initially hold the line utilising soft options, and then consider retreat.

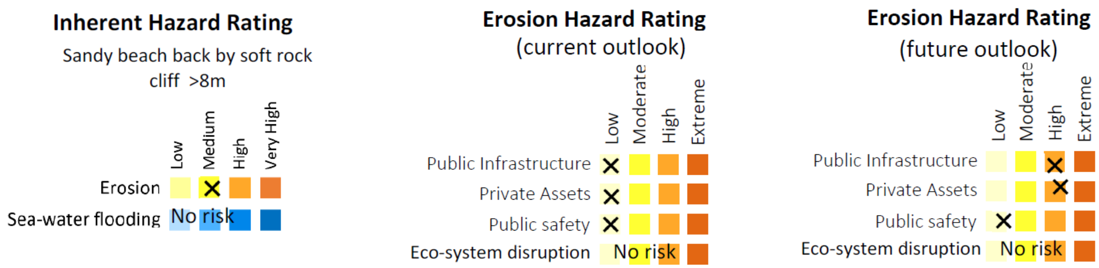
Adaptation proposals:

	Approach	Long term strategy 2020	Mid-term strategy 2050	Short-term strategy 2020	Adaptation Type	Monitoring strategy
Boomer Beach Cell SF9-1	Incremental (monitor and respond)	Monitor [no immediate works are likely to be required]	Monitor [hold the line using soft-protection options]	Managed retreat [Recession of dune projected at 18-23m by 2100 will destabilise the dune and position of trainline at top]	Environmental: Use soft options to hold the line as long as possible	Shoreline position Storm impacts on backshore Sand volumes – identify the normal range of the beach

Adaptation Proposals: Knight Beach (Cell SF9-2)

Coastal processes	Knight Beach is categorised as a reflective medium sandy beach, tends to be a closed cell as it is bordered by granite headlands on the east. The beach is backed by cliffs 5-10m high of Pleistocene aeolianite or calcarenite. The bay is bedrock backed, a former sand dune now hardened, rising above 30m at 500m inland. Exposure is categorised as 'moderate', and wave energy moderate at ~1m. Historical analysis suggests that the backshore of the beach has not and is currently not being impacted by actions of the sea. Analysis of future regimes suggests that this may change.

Risk outlook



Adaptation overview:

The long-term strategy for Knight Beach is to protect the base of the cliff. This strategy is likely to be effective in the geological setting in which Knight Beach is located. An incremental approach to adaptation is recommended. Monitoring of beach processes, sand volumes, and impact to backshore will provide the decision-making context for when protection is required. Review of planning policy for private allotments on Barbara Street is recommended.

Adaptation proposals:

	Approach	Short term strategy 2020	Mid-term strategy 2050	Long term strategy 2100	Adaptation Type	Monitoring strategy
Knight Beach Cell SF9-2	Incremental (monitor and respond)	Monitor [no immediate works are likely to be required]	Monitor [protection may be required by 2050]	Protect backshore [Private and public infrastructure is positioned behind Knight Beach]	Engineering: rock revetment or similar at base of cliff Planning: review and amend planning policy for allotments on Barbara St.	Shoreline position Storm impacts on backshore Sand volumes – identify the normal range of the beach

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