Coastal Adaptation Study

For City of Onkaparinga

Main Study Report

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June 2021

Integrated Coasts

Permissions

Documents and Citations

This document is the main report for the coastal adaptation study providing the methodology and key findings and should be cited as:

Western, M, Hesp, P, Bourman, R, Miot Da Silva, G, 2020, Coastal Adaptation Study for City of Onkaparinga, Integrated Coasts, South Australia.

This document is accompanied by 12 standalone cell reports for each of the coastal regions along the Onkaparinga coast. These should be cited as:

Western, M, Hesp, P, Bourman, R, Miot Da Silva, G, 2020, Coastal Adaptation Study for City of Onkaparinga, Integrated Coasts, South Australia, Cell 4, Witton Bluff (example).

Front Cover

City of Onkaparinga coastline, photographed by Coastal Management Branch, Department for Environment and Water in 2014.

Inundation mapping for Saltfleet Road for event 9 May 2016, Integrated Coasts, 2019.

Storm surge at Onkaparinga River, Sue Bennett, 9 May 2016 (used with permission)

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Contents

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- Dr Robert Bourman for his work on the geomorphology of the Onkaparinga coastline and input into the risk assessment process.
- Dr Graziela Miot da Silva (Flinders University) for input into the risk assessment process.
- Mike Hillman and Marcio DaSilva for their work on this project.

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Executive summary

City of Onkaparinga (the Council) engaged Integrated Coasts in March 2018 to produce a coastal adaptation study for the length of its coastline. Integrated Coasts has adopted three broad principles of coastal adaptation:

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 1-2 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 is dependent like no other on the thresholds and tipping points that the geological layout presents at each location. Furthermore, the fabric of the geology, the bathometry 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. In light of this principle, the coastline has been divided into 12 cells according to their geological features and divided into minor cells for more fine-grained analysis as required.

2. **Coastal adaptation is an 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 will 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 digital model created recently with associated imagery creates a digital baseline against which future erosion can be compared (i.e. monitored). Recapturing the data in five or ten years time will enable comparisons to be made against the original capture.
>
> Comparing photographic images of the shoreline position from the 1940s onward will provide a way to form a baseline understanding of 'the state of the system'. Once this baseline understanding of how a beach has been operating over time has been established, projections can be formulated about the possible future impact of sea level rise.

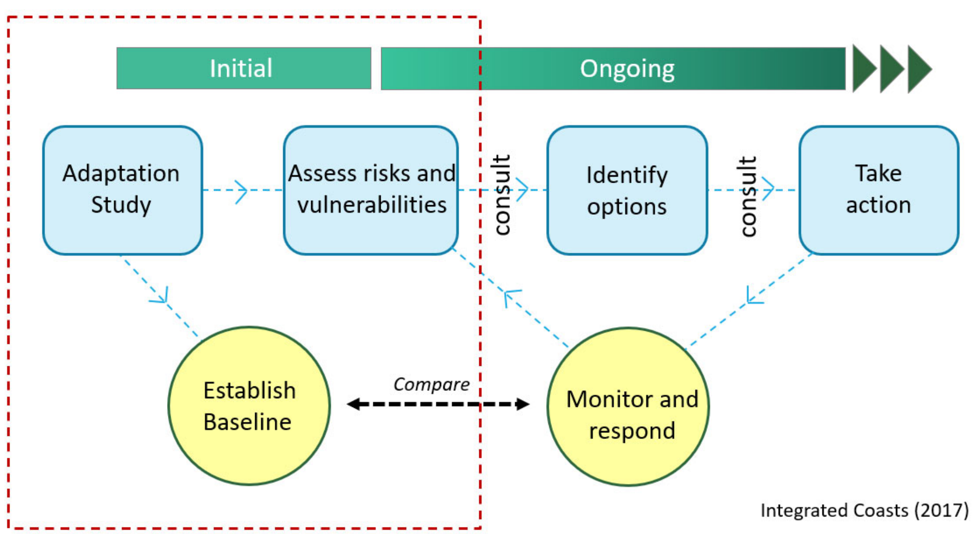
What is known as 'pathways' adaptation methodology is the preferred way to undertake coastal adaptation. This methodology deals with uncertainty using three main ingredients: scenario planning, time, and triggers or thresholds. A 'pathways' approach outlines plausible futures from which to identify key thresholds and triggers, and then considers alternative pathways when these are breached. However, Integrated Coasts holds 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 allocated 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 initially be 'data driven'

Community engagement is best sought once the physical context of adaptation has been established as outlined in (2) above. The first steps of 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. Community views on coastal adaptation matters can vary significantly. On one hand, some community members have an apocalyptic view of climate change and imagine that sea level rise will wreak broadscale havoc on their shores. On the other hand, are those who would maintain that nothing much has changed on their shores over time, and changes in the future are likely to be small. Additionally, sometimes unrealistic expectations exist about what Council can do about the impacts of sea level rise and imagine that whole coastlines can be protected. In summary, by conducting a physical analysis of the coastline and the likely impacts of sea level rise over the course of a century enables the appropriate context for the community to consider the issues. This principle ensures that the community's understanding and 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.

In summary, a coastal adaptation study is the starting point for coastal adaptation that will take place over decades. These principles are encapsulated in Figure 1 and the context of this study is depicted within the dotted red square.

Figure 1: Coastal adaptation model



1. Purposes of the study

Considering the model for coastal adaptation, the purposes of this coastal adaptation study are to:

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

2. Previous study

The foundational study that deals with climate change on coastal lands is *Climate change impacts on the coastal lands of the City of Onkaparinga* by Brian Caton (2007). Using this study as a basis, Council then undertook the following actions and studies:

- Capture of a high-resolution 3D model of the entire coastline in 2015 as a baseline of the coast for future monitoring, and upon which to model the impact of sea level rise (this study).
- Climate change impact studies for Christies Beach[1] and Snapper Point (Aldinga Reef) [2].
- Other studies that referred to Caton's work include flood plain management studies for Pedler Creek and the Washpool Lagoon[3].

The findings of key reports that deal with the vulnerabilities and management of cliff areas have been incorporated into this study. These include:

- URS, 2005, *Detailed Cliff Stability Investigations,*
- URS, 2007, *Clifftop erosion audit,*
- GHD, 2016, *Cliff stability review risk assessment.*

3. Project Scope

The climate change impact under consideration in this project is sea level rise. In this project we focus on the direct impacts of actions of the sea upon backshores along the coast. Other climate change impacts, such as the projection of a drier climate may produce less vegetation in dunes, and further exacerbate erosion, but these impacts are difficult to quantify and are not addressed. In this study the impact of rising sea levels upon backshores can be quantified through sea flood modelling within digital models. Associated with these direct risks are a range of indirect risks. For example, the potential loss of a beach from erosion is a potential social and economic risk (if the beach is

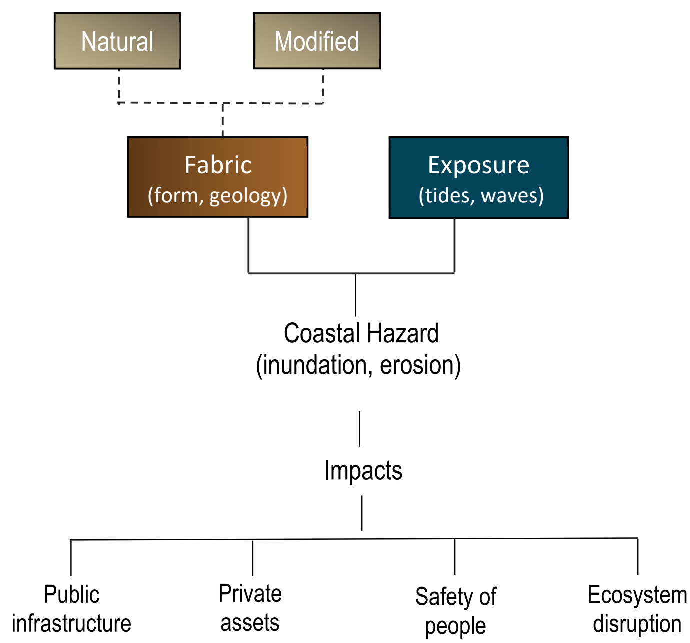
[1] Coastal Engineering Solutions, Climate Change Impact – review Christies Beach (2009), Christies Beach – long term design concept (2011).
[2] Coastal Engineering Solutions, Climate Change Impact – Review Snapper Point, Aldinga.
[3] Tonkin Consulting 2009, Pedler Creek – floodplain mapping study; KBR 2011, Floodplain mapping and climate change modelling for the Silver Sands and Washpool catchment.

related to economic activity such as tourism). A political risk may occur when decision makers act in ways the communities do not support. However, all of these are indirect risks are derived from the direct risks to the coastline from inundation or erosion. In summary, in a bid to increase certainty, this project evaluates the *direct impacts* of inundation and erosion in the context of *rising sea levels*. In a bid to contain focus, this study assesses the *direct risks* to assets, people and ecosystems that are positioned within coastal regions.

4. Conceptual assessment framework (overview)

We adopt a simple and intuitive framework as a context for assessment and to encourage effective communication with all stakeholders. 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 2).

Figure: Conceptual assessment framework



Coastal Hazards

South Australian Coast Protection Board considers three main coastal hazards: inundation, erosion, and sand drift. Due to the nature of the Onkaparinga coastline, only the first two are under consideration in this project. Inundation and erosion hazards experienced along a section of a coastline can be assessed by considering three main coastal features:

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. Conversely, we understand if we are standing on a low sandy dune that erosion may indeed be a factor. It is the geology of the coast upon which our settlements are situated that determines one side of the hazard assessment in terms of elevation (height above sea level), and the nature of the fabric of the coasts (how resistant it is to erosion). We assess coastal geology in four categories of erodibility:

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

2. Coastal modifiers (human intervention)

In some locations there are additional factors that modify this core relationship between fabric and exposure. For example, rock revetment has been placed in front of the soft alluvial coastal cliffs at Christies Beach. Seawalls have been installed at Port Noarlunga and Moana. These installations have modified the fabric of the coast from sand to 'rock'. However, such installations sometimes alter the natural processes of the coast. For example, new erosion problems can emerge either side of the installation, or in the context of rising sea levels, sand levels can decline on the beach. In this study we identify how the coast has been modified and the implications (if any).

3. Coastal exposure (actions of the sea)

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

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

Due to its location within Gulf St Vincent, the whole Onkaparinga coastal region is generally categorised by Nature Maps (SA) as 'moderately exposed'. In this study we also investigate how exposed a section of coast is by modelling routine tidal and storm surge events within a high-resolution 3D model.

Changes in the relationship

In a coastal adaptation study, we are also interested to know how this relationship between ***fabric*** and ***exposure*** may change over time, and what this may mean in the context of our coastal settlements. Our sea levels have been quite stable for several thousand years. However, in the last century sea levels rose on average at ~1.7mm per year. The largest rates of rises have occurred since 1993 (4-5mm in our region), but similar rates of rises also occurred in the time period 1920 to 1950. 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, 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 some coastal locations. In this study, we model routine high-water events and storm surge events that take into account sea level rise projections for 2050 and 2100.

Inherent hazard risk assessment

Each section of the coast is then assessed to determine how inherently at risk it is to the coastal hazards of inundation or erosion. For example, areas of land that are elevated are not at risk from inundation, whereas low lying land is more inherently vulnerable. Landforms that are highly erodible are assigned as higher risk because they are inherently more vulnerable to erosion, and the converse applies. In this project we have employed the expertise of two coastal geologists to make hazard risk determinations for each section of the coastline.

Risk assessment

Taking into all of the above, impacts of erosion and inundation hazards are then considered within four receiving environments:

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

Each of these are assessed for current risk (2020) and future risk (2100). The structure of reporting within each of the cell reports generally follows the flow of the conceptual framework. We use Council's risk assessment framework that utilises a 'likelihood – consequence' matrix to allocate risk. Within cliff environments we adopted the risk assessment of GHD in relation to safety of people.

5. Study outputs

The outputs from this project are:

Summary report

This document provides the overall context of the study and reports the general findings.

Cell reports

Twelve reports where most of the research and investigation is conducted for:

- Lonsdale Region (Cell 1)
- Christies-O'Sullivan Beaches (Cell 2)
- Witton Bluff (Cell 3)
- Port Noarlunga (Cell 4)
- Seaford Cliffs (Cell 5)
- Moana Beach (Cell 6)
- Ochre Point (Cell 7)
- Maslin Beach (Cell 8)
- Port Willunga (Cell 9)
- Aldinga Reef (Cell 10)
- Aldinga Beach (Cell 11)
- Sellicks Beach (Cell 12)

Companion studies

- Extreme event analysis for 9 May 2016,
- Extreme event analysis for 21 November 2018,
- Routine high-water tidal study, July - October 2019 (see Appendix 3),
- Community engagement in the context of coastal adaptation,
- Overview of liability issues in coastal adaptation.

Digital outputs

City of Onkaparinga is developing a digital model within a geographical information systems environment (GIS) to manage its coastal environs. This project has contributed the following digital components:

- Flood mapping (for current and future risks),
- Historical aerial photographs,
- Photographs of each coastal storm water outlet and assessment of impact,
- Shoreline and cliff crest positions – 1979 and 2017 (for shoreline positions),
- Analysis and risk maps for cliff regions adapted from GHD, 2016.

6. Methodology

The study adopts 12 coastal cells and adopts the terms and definitions from CoastAdapt. A standard review process for each of the twelve cells and this summary report was adopted, as follows:

Settlement history

- Provide a brief history of the settlement
- Review archives at Coastal Management Branch
- Review coastal studies

Geomorphology

- Provide a brief overview of how the coast was formed to provide a context from which to understand the coast today

Coastal fabric

- Identify the nature of the coastal fabric
- Analyse changes to the coastal fabric over the last 100 years
- Identify human intervention

Coastal exposure

- Review the impacts of previous storms
- Model the impact of storm surges upon the backshores
- Model the impact of routine high-water events upon the backshores
- Analyse these impacts within time frames: 2020, 2050, and 2100

Storm water runoff

- Photograph each stormwater outlet along the coast
- Analyse storm water impact on beaches and backshores

Hazard risks and impacts

- Assign an inherent hazard rating to each cell (or minor cell, if applicable)
- Describe the likely impact upon the public and private infrastructure, safety of people, and ecosystems.
- Conduct a risk assessment utilising the risk assessment framework of City of Onkaparinga.

Summary and recommendations.

7. General findings - summary of coastal hazards

Specific hazard impacts are recorded within the cell reports. A summary of hazard impacts is also available for immediate review in the Cell Snapshot Summaries in Section 10 of this report.

Inundation

Generally, the coastline of Onkaparinga is set well above sea-flood risk. Exceptions are the Washpool Lagoon at Aldinga Beach, Pedler Creek (where the caravan park is vulnerable), and Onkaparinga River (flood modelling indicates that the current levee system is too low, and ~2070, the township is likely to be extensively flooded. Note some areas are already subject to flooding – Saltfleet Street, and the carpark on the north side of the river).

Erosion

Within locations of soft sediment backshores in low lying areas the recession will be significant (Moana, Aldinga). In locations of soft sediment cliffs, the issue is likely to be serious, especially if infrastructure is located near to the crest of the cliff (Aldinga Reef, Seaford Cliffs).

Some area will be afforded longer term protection (Sellicks- Aldinga where an existing pebble bank will slow erosion).

In locations where humans have placed hold points (seawalls), or nature has placed hold points (harder cliffs) sand levels in these regions are projected to drop with the possibility of the loss of some beaches (Port Willunga, Port Noarlunga, Christies Beach).

It is not known how an area such as Southport will respond to higher sea levels as the sand spit is maintained by various ongoing coastal dynamics.

In places of harder cliffs such as Port Willunga, the undermining of the base of the cliffs is likely to accelerate, with accompanying increases in landslides and rock falls.

8. Implications for coastal adaptation

The implications from the above findings in the context of coastal adaptation include:

Settlement history

1. The practice of laying out urban settlements with an esplanade road between coastal open space and private assets means that a buffer has been created between the coastline and private property. Therefore, the main focus for coastal adaptation will be for Council to manage its own public assets in the context of rising sea levels.

2. Irrespective of (1), there is unlikely to be any legal requirement for Council to protect private assets. Furthermore, it has been the State Government's policy since 1980 not to fund the protection of private property.

3. Councils were only required to consider actions of the sea in planning decision after ~1990. Before this time, the implications of sea level rise were generally unknown and therefore Councils are unlikely to be liable for decision making in the absence of knowledge or policy.

Coastal Fabric

4. The erodibility of the Onkaparinga coastline is generally characterised as *moderate to high erodibility* (with some sections, *very high erodibility)*.

5. The City of Onkaparinga coastline has been largely stable over a 70-year period. An erosion and accretion cycle are observed (~4m) that takes place over decades. The initial recession is often related to storms or a series of storms, and then the beach slowly rebuilds over time. This finding creates a baseline understanding of how the coastline has been operating over a 70-year period.

6. Overall recession since 1949 of the coastline south of Seaford Cliffs is 2-4m. Beaches north of Seaford Cliffs have shown no overall recession. Large amounts of recession have occurred in the Aldinga Reef region (Snapper Point), and to a lesser extent in the vicinity of Aldinga carpark (but this area may rebuild). In harder cliff areas such as limestone, cliff top recession is 0-2m with no discernible trend as this recession is related to sporadic landslides and rock falls. In the Seaford Cliff area, it is likely that actions of the sea have caused the base of the cliff to recede ~2-3m creating vertical scarps at the base, and steeper slopes in the upper cliff areas. Locations where infrastructure is close to tops of cliffs include: Gordon Street, Aldinga and within Seaford Cliff area (Tiller Street to Robertson Road).

7. Generally, it is difficult to identify any impact of sea level rise upon the coast within the 'noise' of natural variability. One possible explanation for increased erosion at Aldinga Reef is that increased sea levels are reducing the protective effect of the reef. Other explanations

include a lowering in the level of the reef and increase intensity of the storm surge, or a combination of two or more of these factors.

Coastal exposure

8. South Australian Coast Protection Board has adopted sea level rise policy standards of 0.30m sea level rise by 2050 and 1.0m sea level rise by 2100 compared to levels in 1990. These policy standards are based on the assessments of the Intergovernmental Panel on Climate Change (IPCC) and are congruent with the IPCC sea level rise projection scenario for RCP 8.5.

9. The storm of 9 May 2016 almost coincided with 1 in 100-year risk level and provides a useful context to consider existing and future vulnerabilities. City of Onkaparinga will generally not be exposed to inundation risk from rising sea levels apart from areas such as Onkaparinga estuary (areas already vulnerable at Saltfleet Street and the carpark on north side of the river. The township of Port Noarlunga likely vulnerable ~2070). Pedler Creek and the Washpool Lagoon become increasingly vulnerable ~2050.

10. Routine high-water events and the rarer storm surge events are likely to have the following impacts on the coastlines by 2050:
    - Soft sediment plains and slopes – recession of the shoreline (measured in metres).
    - Soft sediment cliffs – undermining of the base of the cliff, steepening slopes, increased stability of base and top of cliffs.
    - Harder cliffs (e.g. limestone) – increased rate of undermining, increased landslides and rock falls.
    - Human intervention – where backshores have been changed to hard surfaces (rock and seawalls), sand levels are likely to decline on the beach.

11. Routine high-water events (occurring at much higher rates than current) and storm surges (occurring at higher sea levels) are likely to have the following impact on the coastline by 2100 if seas rise as projected:
    - Soft sediment plains and slopes - recession of the shoreline measured in decametres (at least 2-3).
    - Soft sediment cliffs – significant recession of the cliffs and ongoing instability and collapse.
    - Harder cliffs (e.g. limestone) – increased rate of recession (but rate not known).
    - Human intervention – in many places the current layout of backshores is unlikely to be adequate (for example: Moana, Port Noarlunga, Christies Beach).

12. In general, City of Onkaparinga is managing the stormwater run-off from urban environments so that erosion in backshores is avoided. A few exceptions exist and these locations are either vulnerable to flows from current storm surges or will likely become increasingly vulnerable if seas rise as projected, or left stranded by receding shorelines.

9. Recommendations

The recommendations listed are limited to those that apply to the whole coastline of City of Onkaparinga. For recommendations that relate to individual cell locations refer to the cell reports.

1. Develop a coastal adaptation plan to provide a framework for future decision making that considers the following factors:

- The coastline has been largely stable over a 70-year period,
- The coastline undergoes periods of accretion and erosion which are now better understood,
- Of the four hazard impact categories, the main threat is to public assets,
- In most cases, the threat to these assets is related to sea level rise that occurs in the decades ahead, or even in the latter part of this century,

Therefore, an adaptation plan is recommended to manage the public infrastructure that is positioned behind the shorelines. In the City of Onkaparinga this area is zoned as 'Coastal Conservation' or similar. Locations assessed as 'high' or 'very high' for either the current outlook of the long-term outlook will assist in prioritising the adaptation planning.

This adaptation plan is likely to take the form of upper level master planning that lays out broad options at the beginning, and these are developed further as the need arises.

2. Prepare a community engagement strategy that reports the findings of this study and engages the community to consider adaptation options.

The approach to community engagement could include opportunity for feedback and comment about the findings of this study, and then a process that enables community input into coastal adaptation planning, including the various options identified at (1).

3. Develop a long-term coastal monitoring strategy that improves knowledge about how the coast operates, including the impact of storms, but also to provide warning when the coast may be operating outside of its normal parameters.

Caton (2007) noted that the impacts of sea level rise are likely to be experienced along the Onkaparinga coast in the context of storms (or a series of storms) from which the coastline does not recover. It makes sense then that the impact of storms should be monitored closely. This is likely to serve two purposes. First it will assist Council with repairs and maintenance but will also provide warning when a coastline is coming under increased threat. Early detection is likely to save significant cost rather than waiting until major infrastructure is threatened.

Just as important will be to monitor shoreline position and beach profiles over time (Caton, 2007) and erosion and instability trends in cliff areas (GHD, 2016).

<u>Monitoring methods include:</u>

- Comparison of newly captured aerial photography,
- Analysis newly captured Coast Protection Board profile data,
- Recapturing the 3D digital model and make digital comparisons (especially useful for cliff and slope assessment),

- Photographing the coast after storm events using drone technology and making a desktop assessment of any changes or impacts to the coast,
- Utilise a ‘citizen science’ approach for the capture of photography in storm events from designated monitoring positions,
- Annual site inspection of areas where undermining or gullying are occurring (if applicable).

10. Recognised limitations of this study

1. Due to issues relating to the required resolution for effective reporting, not all areas of the coastline are depicted within the cell reports. However, all of the coast was reviewed as part of the project and all of the data is held within a digital file by Council so that additional review can be undertaken if required.

2. The modelling of sea level rise scenarios for 2050 and 2100, involves the superimposing of future actions of the sea (i.e. that incorporate sea level rise) over the layout of the existing fabric of the coast. It is recognised that changes in the fabric of the coast will occur over long periods of time. However, the modelling is key to assessing the risks and the visual approach will be a benefit in communicating with stakeholders.

3. Erosion modelling has only been conducted at two locations and these do provide a context for assessing erosion risk for this study. We are of the opinion that erosion modelling for the whole coast is not warranted due to the high cost and significant challenges that exist in quantifying erosion until 2100 with the large number of variables involved in the calculation. Erosion modelling is a useful tool at specific locations and for targeted projects.

4. The risk assessment conducted utilising City of Onkaparinga risk assessment framework contains two challenges. First, It is very difficult to assign risk ratings to public safety issues, especially in the context of the potential for a rock fall or landslide of any particular size in the context of the low probability that someone will be standing in the vicinity when it occurs. The second challenge relates to assigning risk to events at 2100. However, the aim of the assessment is to provide an ‘outlook’ and in practice the methodology appears to produce meaningful outcomes.

11. Further research

Areas that may require further research are listed here.

1. One area that has not been reviewed in this project is the implications of increasing residential density in locations that are in close proximity to the coastline in the context of projected coastal hazards.

2. Further data is required to quantify the flood impact at Port Noarlunga upon buildings and roads including floor level heights, and further analysis of flood flow in the vicinity of River Road and the sports ground area.

1. Introduction

City of Onkaparinga (the Council) engaged Integrated Coasts in March 2018 to produce a coastal adaptation study for the length of its coastline from the Lonsdale region in the north to Sellicks Beach in the south.

1.1 Principles of coastal adaptation

Integrated Coasts has adopted three broad principles of coastal adaptation:

- Coastal adaptation takes place in localities,
- Coastal adaptation is an ongoing process,
- Coastal adaptation should initially be 'data-driven'.

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 1-2 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 is dependent like no other on the thresholds and tipping points that the geological layout presents at each location. Furthermore, the fabric of the geology, the bathometry 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. In light of this principle, the coastline has been divided into 12 cells according to their geological features and divided into minor cells for more fine-grained analysis as required[4].

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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 will 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]
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> Information accumulated concerning the state of a system, process, or activity before the initiation of actions that may result in changes.

[4] The division of cells is similar to that employed by Caton, 2007. In this study, Witton Bluff is assigned its own cell, and Aldinga Sands and Aldinga Beach are combined into one cell.

Two basic elements reside in the definition. To illustrate:

> A digital model created recently with associated imagery creates a digital baseline against which future erosion can be compared (i.e. monitored). Recapturing the data in five or ten years time will enable comparisons to be made against the original capture.
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> Comparing photographic images of the shoreline position from the 1940s onward will provide a way to form a baseline understanding of 'the state of the system'. Once this baseline understanding of how a beach has been operating over time has been established, projections can be formulated about the possible future impact of sea level rise.

What is known as 'pathways' adaptation methodology is the preferred way to undertake coastal adaptation. This methodology deals with uncertainty using three main ingredients: scenario planning, time, and triggers or thresholds[5]. A 'pathways' approach outlines plausible futures from which to identify key thresholds and triggers, and then considers alternative pathways when these are breached. However, Integrated Coasts holds 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 allocated 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[6].

3. Coastal adaptation should initially be 'data driven'

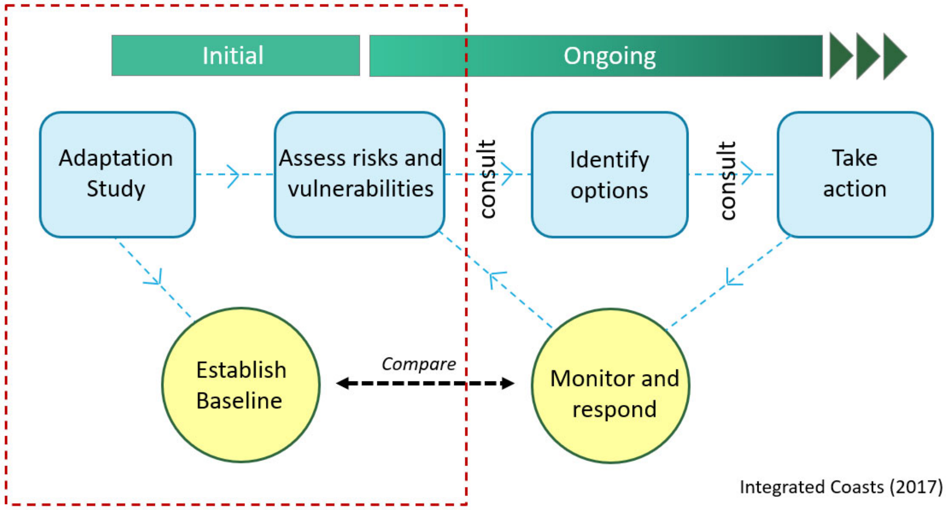
Community engagement is best sought once the physical context of adaptation has been established as outlined in (2) above. The first steps of any coastal adaptation process should be to identify the physical baseline, then to conduct scenario analysis to identify plausible futures, and then to communicate these realities to the community. Community views on coastal adaptation matters can vary significantly. On one hand, some community members have an apocalyptic view of climate change and imagine that sea level rise will wreak broadscale havoc on their shores. On the other hand, are those who would maintain that nothing much has changed on their shores over time, and changes in the future are likely to be small. Additionally, sometimes unrealistic expectations exist about what Council can do about the impacts of sea level rise and imagine that whole coastlines can be protected. In summary, by conducting a physical analysis of the coastline and the likely impacts of sea level rise over the course of a century enables the appropriate context for the community to consider the issues. This principle ensures that the community's understanding and 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.

In summary, a coastal adaptation study is the starting point for coastal adaptation that will take place over decades. These principles are encapsulated in Figure 1 and the context of this study is depicted within the dotted red square.

[5] https://coastadapt.com.au/pathways-approach.

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

Figure 1: Coastal adaptation model



1.2 Purposes of the study

Considering the model for coastal adaptation, the purposes of this coastal adaptation study are to:

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

1.3 Previous study

The foundational study that deals with climate change on coastal lands is *Climate change impacts on the coastal lands of the City of Onkaparinga* by Brian Caton (2007). Using this study as a basis, Council then undertook the following actions and studies:

- Capture of high resolution 3D model of the entire coastline in 2015 as a baseline of the coast, enabling Council to monitor erosion over time (selected locations were recaptured in 2018 for comparison purposes), and to model the impact of sea level rise (this study).
- Climate change impact studies for Christies Beach[7] and Snapper Point (Aldinga Reef)[8].
- Other studies that referred to Caton's work include flood plain management studies for Pedler Creek and the Washpool Lagoon[9].

[7] Coastal Engineering Solutions, Climate Change Impact – review Christies Beach (2009), Christies Beach – long term design concept (2011).
[8] Coastal Engineering Solutions, Climate Change Impact – Review Snapper Point, Aldinga.
[9] Tonkin Consulting 2009, Pedler Creek – floodplain mapping study; KBR 2011, Floodplain mapping and climate change modelling for the Silver Sands and Washpool catchment.

Brian Caton (2007) also endorsed City of Onkaparinga's approach to the management of cliff areas that predated his study. Reports that deal with the management of cliffs include:

- URS, 2005, *Detailed Cliff Stability Investigations,*
- URS, 2007, *Clifftop erosion audit,*
- GHD, 2016, *Cliff stability review risk assessment.*

1.4 Project Scope

Climate Variables

Managing projected climate change impacts involves dealing with 'deep uncertainty'[10]. This uncertainty is primarily related to the nature of long-term projections which are based on climate models. These models are computer-based simulations of the Earth-ocean-atmosphere system, which use equations to describe the behaviour of the system. Models are effective at simulating temperature, but their accuracy is much less for the simulation of rainfall[11]. Overall rainfall is expected to decline in our region over the coming century and the intensity of rainfall events is expected to increase, but these projections are not assigned with as much confidence as for temperature or sea level rise. Furthermore, the climate is a complex system and the variables interdependent. For example, on the one hand we might predict that declining rainfall would produce a more arid climate and therefore less vegetation, but a recent study by NASA has found that over the last 35 years the planet has been greening, and that increased carbon dioxide in the atmosphere is 70% responsible[12]. As we learn more about the climate system and obtain more data over time, observable trends and projections will also become more certain.

Direct and indirect impacts

Some climate change impacts are more direct than others. Rising sea levels will directly impact the landforms adjacent the coast, either through inundation of lower lying areas, or increasing erosion. Other impacts will be less direct. For example, projections for a drier climate are often associated with less vegetation in dunes, and the increased cracking of cliffs[13]. These more indirect impacts may increase the rate of erosion. Increased intensity of rainfall events may increase the gullying of clifftops thereby increasing the potential for increased rates of recession and instability. In the context of a coastal study the impact of rising sea levels can be quantified through sea flood modelling within digital models. The impact of vegetation loss cannot be easily quantified and as noted above, is based upon less certain projections. Attempting to incorporate too many impacts into a coastal study is likely to compound the level of uncertainty and deliver less clear outcomes.

Direct and indirect risks

Direct risks relate to the impact of rising sea levels and associated erosion on the fabric of the coast. Generally, City of Onkaparinga is not vulnerable to inundation risks because it is more elevated, but

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

it does have long sections of cliffs that are likely to be vulnerable to erosion. In this study we evaluate the direct impact of *inundation* and *erosion* in four main receiving environments. These are listed below and explained later in the project:

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

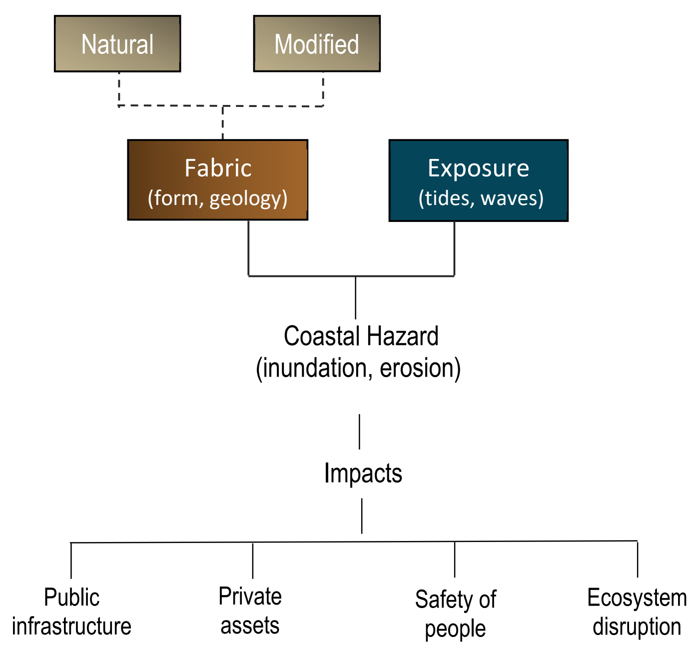
Associated with these direct risks are a range of indirect risks. For example, the potential loss of a beach from erosion is a potential social and economic risk (if the beach is related to economic activity such as tourism). A political risk may occur when decision makers act in ways the communities do not support. A legal risk may occur from not disclosing or responding to risks, or building adaptation structures that fail. However, all of these are indirect risks are derived from the direct risks to the coastline from inundation or erosion.

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

1.5 Conceptual assessment framework (overview)

Integrated Coasts has developed this assessment tool that adopts a simple and intuitive framework. Adopting a conceptual framework ensures that the study is accessible to all stakeholders. 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 2).

Figure 2: Conceptual assessment framework



Coastal Hazards

South Australian Coast Protection Board considers three main coastal hazards: inundation, erosion, and sand drift. Due to the nature of the Onkaparinga coastline, only the first two are under consideration in this project.

Inundation and erosion hazards experienced along a section of a coastline can be assessed by considering three main coastal features:

- **Coastal fabric (geology)**

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

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

Assignment of erodibility classes to each location were completed by experienced coastal geologists[14] taking account of the various geological layouts within the region (See Appendix 1).

- **Coastal modifiers (human intervention)**

In some locations there are additional factors that modify this core relationship between fabric and exposure. For example, rock revetment has been placed in front of the soft alluvial coastal cliffs at Christies Beach. Seawalls have been installed at Port Noarlunga and Moana. These installations have modified the fabric of the coast from sand to 'rock'. However, such installations sometimes alter the natural processes of the coast. For example, new erosion problems can emerge either side of the installation, or in the context of rising sea levels, sand levels can decline on the beach.

In this study we identify how the coast has been modified and the implications (if any).

- **Coastal exposure (actions of the sea)**

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

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

[14] Dr. Robert Bourman and Dr Grazelia Miot de Silva in workshop of December 2019.

Due to its location within Gulf St Vincent, the whole Onkaparinga coastal region is generally categorised by Nature Maps (SA) as 'moderately exposed'[15]. In this study we also investigate how exposed a section of coast is by modelling routine high-water events and storm surge events within a high-resolution 3D model.

Hazard risk assessment

Each section of the coast is then assessed to determine how inherently at risk it is to the coastal hazards of inundation or erosion. For example, areas of land that are elevated are not at risk from inundation, whereas low lying land is more inherently vulnerable to inundation. Landforms that are highly erodible are assigned as higher risk because they are inherently more vulnerable to erosion, and the converse applies. In this project we have employed the expertise of two coastal geologists to make hazard risk determinations for each section of the coastline.

Changes in the relationship

In a coastal adaptation study, we are also interested to know how this relationship between ***fabric*** and ***exposure*** may change over time, and what this may mean in the context of our coastal settlements. Our sea levels have been quite stable for several thousand years. However, in the last century sea levels rose on average at ~1.7mm per year. The largest rates of rises have occurred since 1993 (4-5mm in our region), but similar rates of rises also occurred in the time period 1920 to 1950[16]. 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, 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 some coastal locations.

In this study, we model routine high-water events and storm surge events that take into account sea level rise projections for 2050 and 2100.

Risk assessment

Taking into all of the above, impacts of erosion and inundation hazards are then considered within four receiving environments:

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

Each of these are assessed for current risk (2020) and future risk (2100). The structure of reporting within each of the cell reports generally follows the flow of the conceptual framework. We use Council's risk assessment framework that utilises a 'likelihood – consequence' matrix to allocate risk.

These concepts are explained more fully within this document and within each of the cell reports.

[15] https://data.environment.sa.gov.au/NatureMaps/Pages/default.aspx
[16] CSIRO, 2015, Climate Change in Australia, Technical Report, p.143.

1.6 Study outputs

The outputs from this project are:

Summary report

This document provides the overall context of the study and reports the general findings.

Cell reports

Twelve reports where most of the research and investigation is conducted for:

- Lonsdale Region (Cell 1)
- Christies-O'Sullivan Beaches (Cell 2)
- Witton Bluff (Cell 3)
- Port Noarlunga (Cell 4)
- Seaford Cliffs (Cell 5)
- Moana Beach (Cell 6)
- Ochre Point (Cell 7)
- Maslin Beach (Cell 8)
- Port Willunga (Cell 9)
- Aldinga Reef (Cell 10)
- Aldinga Beach (Cell 11)
- Sellicks Beach (Cell 12)

Companion studies

- Extreme event analysis for 9 May 2016,
- Extreme event analysis for 21 November 2018,
- Routine high-water tidal study, July to October 2019 (see Appendix 3),
- Community engagement in the context of coastal adaptation,
- Overview of liability issues in coastal adaptation.

Digital outputs

City of Onkaparinga is developing a digital model within a geographical information systems environment (GIS) to manage its coastal environs. This project has contributed the following digital components:

- Flood mapping (for current and future risks),
- Historical aerial photographs,
- Photographs of each coastal storm water outlet and assessment of impact,
- Shoreline positions – 1979, 2007 and 2017,
- Cliff crest position – 2017,
- Analysis and risk maps for cliff regions adapted from GHD, 2016,

1.7 Methodology

The study adopts definitions from CoastAdapt[17] and coastal assessment concepts from OzCoasts[18]. The study adopts the national secondary coastal cells from CoastAdapt and utilises 12 tertiary cells that are similar to South Australian Coastal Conservation Cells[19]. A standard review process for each of the twelve cells and this summary report was adopted, as follows:

Settlement history

- Provide a brief history of the settlement
- Review archives at Coastal Management Branch
- Review coastal studies

Geomorphology

- Provide a brief overview of how the coast was formed to provide a context from which to understand the coast today

Coastal fabric

- Identify the nature of the coastal fabric
- Analyse changes to the coastal fabric over the last 100 years
- Identify human intervention

Coastal exposure

- Review the impacts of previous storms
- Model the impact of storm surges upon the backshores
- Model the impact of routine high-water events upon the backshores
- Analyse these impacts within time frames: 2020, 2050, and 2100

Storm water runoff

- Photograph each stormwater outlet along the coast
- Analyse storm water impact on beaches and backshores

Hazard risks and impacts

- Assign an inherent hazard rating to each cell (or minor cell, if applicable)
- Describe the likely impact upon the public and private infrastructure, safety of people, and ecosystems.
- Conduct a risk assessment utilising the risk assessment framework of City of Onkaparinga.

Summary and recommendations.

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[17] https://coastadapt.com.au/sites/default/files/factsheets/CoastAdapt_Glossary_2017-02-06_FINAL.pdf
[18] 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.
[19] https://data.environment.sa.gov.au/NatureMaps/Pages/default.aspx

2. Settlement history

2.1 Establishment of settlements

Early settlement

While the focus in this study is the establishment of urban settlements, it is recognised that the Kaurna Aboriginal people lived in the land called *Ngangkiparringa* long before the arrival of Europeans.

Prior to settlement of South Australia in 1836, whaling operations visited Christies Beach and Aldinga Beach, most likely as places of respite. In the 1840s, land was opened up by the State Government for farming. Ports were established at Port Noarlunga (1855) and Port Willunga (1853) as a means to transport produce to Outer Harbor and settlements were established in these locations. A railway line linking Adelaide to Willunga was established in 1915, which also linked places such as Moana, where sand was being mined and transported to Adelaide for construction works.

Increasing usage of motor vehicles in the 1920s saw the southern beaches become popular tourist destinations. Photographs in the 1920s and 1930s show that the southern beaches were favourite places for tourists on high days such as New Years Day and racing days on Sellicks Beach.

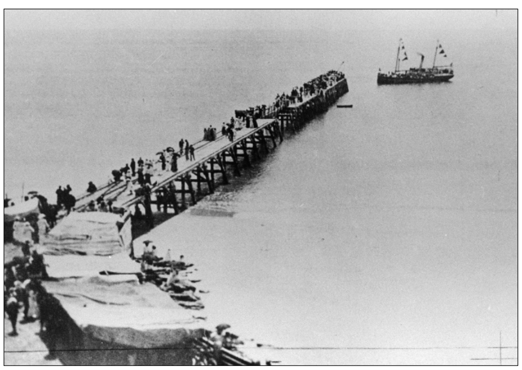

Figure 3: Port Willunga, New Year's Day, 1906 (SA State Library, B55417-9)

Figure 4: Moana Beach, 1920s, (City of Onkaparinga Libaries).

Residential expansion

After World War II, the establishment of holiday homes occurred all along the coast. At this time shack developments also occurred on Crown land within foreshore regions at Aldinga Beach (north of the carpark) and Sellicks Beach.

State Government planning policies of the 1960s and 1970s established Noarlunga as a business district and Lonsdale as an industrial centre. The railway line that had been closed in 1969 was reopened along a different alignment to Noarlunga Centre. These developments resulted in the southern suburbs becoming places for permanent residents and outer suburbs of the Adelaide metropolitan area. By the 1970s, the urban layout along the foreshore as it is observed today was largely established with two exceptions. Moana was expanded laterally to the south in the 1990s with the establishment of Moana Heights, and Sellicks Beach was expanded laterally on the northern side of Sellicks Creek in the early 2000s.

The 1970s was also the time in which the South Australian Coast Protection Board was established which has taken an increasing role in guiding development in coastal areas over the last few decades[20]. The settlement expansions noted above were referred to the Coast Protection Board and both settlements were positioned an appropriate distance from the shoreline. One of the first major roles of the Coast Protection Board was to oversee the removal of shacks sites on Crown land from all around the State, including those at Aldinga and Sellicks Beach.

Urban consolidation

The planning policies that accompanied the Development Act 1993 spawned an era of urban consolidation. These policies were also adopted by City of Onkaparinga which has progressively seen older development on larger allotments replaced with two or more dwellings on smaller allotments. This urban consolidation trend was given further impetus in the context of the production of the *30 Year Plan for Greater Adelaide* in 2010 and updated in 2017. This plan called for higher densities, especially on land located close to open spaces such as coastal areas. Councils were required to respond, and City of Onkaparinga has increased residential density allowances accordingly.

Form of urban layout

Early planners in South Australia tended to configure new urban development with an esplanade road running parallel to the shoreline and then private land holdings behind the esplanade road. This planning methodology has been almost universally adopted throughout City of Onkaparinga. Exceptions include Ochre Point (south of Moana) and Sellicks Beach (north of Sellicks Creek) which ironically have both been areas of later subdivision as noted above.

2.2 Archival review

Archives were reviewed in hardcopy at Coastal Management Branch (Department of Environment and Water) in June 2018. Approximately 250 scans were obtained and the findings from these incorporated into each of the twelve cells as appropriate. The purpose of this review aligns with the project purpose to 'bring everything into one place of reference'. In particular this review bridges between the paper-based era to the digital era.

2.3 Coastal studies

Coastal studies and plans relating to coastal issues can be grouped in the following ways:

Witton Bluff

- Pak-Poy and Kneebone 1983, Witton Bluff Protection Strategy (PER).
- Department of Environment and Planning 1984, Witton Bluff Protection Strategy.
- SA Government 1984, Report of the Parliamentary Standing Committee on Public Works on Witton Bluff Protection.
- PPK Environment and Infrastructure 2000, Witton Bluff Stabilisation.

[20] The Board was established by the Coast Protection Act (SA) 1972.

Cliff stability issues

- Golder Associations 2001, Draft Preliminary Report on Coastline Cliff Stability, Geotechnical Investigation .
- URS 2005, Detailed Cliff Stability Investigations.
- City of Onkaparinga 2006, Cliff Stability Long Term Action Plan 2006-2011.
- URS 2007, Cliff Top Erosion Audit.
- GHD 2016, Cliff Stability Review Risk Assessment.

Climate change focus

- Caton B 2007, The Impact of Climate Change on the Coastal Lands of the City of Onkaparinga.
- Coastal Engineering Solutions 2009, Climate Change Impact – Review Christies Beach.
- Coastal Engineering Solutions 2011, Christies Beach Long-term Concept Design.
- Resilient South 2014, Regional Climate Change Adaptation Plan, prepared by URPS and Seed Consulting Services.

Floodplain modelling (and relationship to sea-flood risk)

- Tonkin Consulting 2009, Pedler Creek Flood Plain Mapping Study.
- Kellogg Brown & Root 2010, Flood Study for the Seaford Rail Extension - Onkaparinga River.
- Kellogg Brown & Root 2011, Floodplain modelling and climate change modelling for the Silver Sands and Washpool catchments.

Other studies and plans

City of Onkaparinga is guided by several management plans and policies such as: Coastal Precinct Guidelines, Coastal Commercial Opportunities, Tjilbruke Dreaming Track, Asset Management Plans, Foreshore Car Park Audit, Disability Access Plan, Coastal Vegetation Survey, Vehicles on Beaches Study, Stormwater Management Scoping Study, Tourist Parks Feasibility Study, Recreational Trails Network Strategy and Action Plan, and Coastal Kiosk project.

2.4 Implications for coastal adaptation

The implications from the above findings in the context of coastal adaptation include:

1. The practice of laying out urban settlements with an esplanade road between coastal open space and private assets means that the main focus for coastal adaptation will be for Council to manage its own public assets in the context of rising sea levels.

2. Due to historical planning decisions, private landowners are afforded a buffer between the coastline and private property and therefore are unlikely to come under direct threat from actions of the sea over the course of this century. The exception to this rule is the five Surf Life Saving Clubs positioned in the foreshore area which are owned by Surf Life Saving South

Australia Incorporated. It should also be considered that if the rate of erosion increased substantially in areas of softer cliffs and backshores that some esplanade roads may come under threat and access to private property may become restricted.

3. While taking into account (2) even if private assets came under threat, there is unlikely to be any legal requirement for Council to protect those assets. Furthermore, it has been the State Government's policy since 1980 not to fund the protection of private property[21].

4. When considering the liability Council may incur from previous decision making, Councils were only required to consider actions of the sea in planning decisions after 1993:
    - The main centres and townships in the City of Onkaparinga region were established over 100 years ago and the current urban street and cadastral layouts along the coastline were established by the 1970s.
    - The two exceptions where lateral expansion has occurred are set well-back from the shoreline and referrals were made to Coast Protection Board for advice.

5. The projects and strategies that have been undertaken to manage the risk to people in relation to cliff areas are likely to be a defence that Council has appropriately performed a 'duty of care'[22].

6. One area that has not been reviewed in this project is the implications of increasing residential density in locations that are in close proximity to the coastline.

Several key principles that provide context to legal liability are listed in Table 1 below from the companion report, *Liability issues relating to coastal adaptation*[23]. Project note: the purpose of this section of report is not to provide legal advice, but to provide a framework from which to consider coastal adaptation issues.

	Table 1: Key legal principles in the context of coastal adaptation
1	The nature of reasonable knowledge at the time a decision is made, or an action taken is a critical aspect in determining any legal decisions. Knowledge that has come to light since the decision or action will carry no weight in determining whether a decision or action was reasonable at the time.
2	Decision made on the best currently available information are likely to be upheld in court. In the case of South Australia, Councils can rely on advice from Coast Protection Board and this is likely to be a defence.
3	Government is not under a legal obligation to provide infrastructure to protect against climate change. Lack of resources to construct such infrastructure forms a legal defence.
4	If a Council does provide protective infrastructure it is obliged to maintain it. Failure to do so may constitute negligence.
5	High level strategic policy tends to be exempt from negligence actions.
6	Local decisions on individual developments that do not take known risks into account may expose councils to legal risk.
7	Litigation must commence within six years of the cause of action accruing.

[21] Coast Protection Board Policy Document: Revised 22 May 2012, p.24.
[22] Norman Waterhouse 2001, advice to Council, scan 1120_20010315.
[23] Integrated Coasts 2019, Liability issues relating to coastal adaptation, p.5.

3. Geomorphology

Geomorphology, in its most basic definition, is the study of the earth's physical features and the processes in which those features are formed. Geomorphology comes from the Ancient Greek words *Ge*, *morphe*, and *logos* which mean "Earth", "change", and "study" respectively[24]. In this project we consider the geomorphology of the coastline to provide an understanding of the changes that have occurred over long periods of time, so as to provide a context from which to consider future changes. In particular, we are interested in the nature of the physical forms and their susceptibility to change in the context of rising sea levels.

3.1 Geological setting

The dominant geological influence on the coastline of Metropolitan Adelaide is a series of curved fault lines, which extend from the hills in the east and culminate at the sea[25] (Figure 5). The two fault lines within City of Onkaparinga coastline are the Willunga Fault which culminates at the sea south of Sellicks Beach and the Clarendon Fault line which culminates at Ochre Point in between Moana and Maslin Beaches. The various faulting of different rock strata along the coast over long periods of time have formed the modern template of the coastline. The uplifted zones are associated with prominent cliffs and headlands, while between these uplifted sections of coasts are the sandy bays of our southern beaches. Although important rivers such as the Onkaparinga and the Torrens have their outlets on this section of coast, they deliver minimal sediment to Gulf St Vincent.

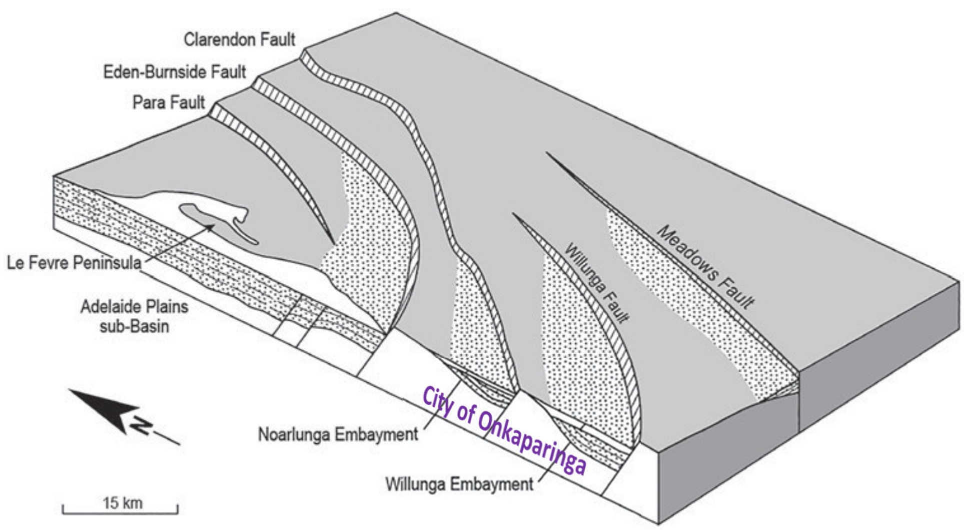

Figure 5. The curved shaped fault scarps trend broadly in a northeasterly direction and lowlands between the uplifted fault blocks have formed, such as the Willunga, Noarlunga and Adelaide-Golden Grove Embayments and the Adelaide Plains Sub-basin. Fault activity has determined the general distribution of bedrock cliffs, sandy bays and beaches (Adapted from Coastal Landscapes of South Australia, p.47)

24 https://www.worldatlas.com/articles/what-is-geomorphology.html
25 Bourman et al 2016, Coastal Landscapes of South Australia p. 45.

3.2 Long-term sea-level changes

Global and regional sea levels

Climate change occurs over long timescales in response to solar variations, changes in the Earth's orbit around the Sun, volcanic eruptions, movement of the continents and natural variability[26]. Sea levels reflect the state of the climate system. During ice ages a large volume of water is stored on land in the form of ice sheets and glaciers, leading to lower sea levels, while during warm interglacial periods, glaciers and ice sheets are reduced and more water is stored in the oceans. These sea level changes are global and are known as eustatic sea levels.

There are two ways in which sea levels are experienced in relation to the land upon which we live. The first is in relation to eustatic or global sea levels. The primary contributors to eustatic sea level change are the expansion of the ocean as it warms and the transfer to the ocean of water from melting ice locked in mountain glaciers and continental ice sheets. The second way that sea levels are experienced in relation to the land upon which we live depends on the vertical movement of the land. One way in which vertical movement can occur is during periods of rapid sea-level rise. Seawater floods onto the continental shelves following the melting of the ice sheets and this depresses the sea floor and the adjacent land along the new coast rises which results in fall in sea level against the rising land[27]. This is known as relative sea level.

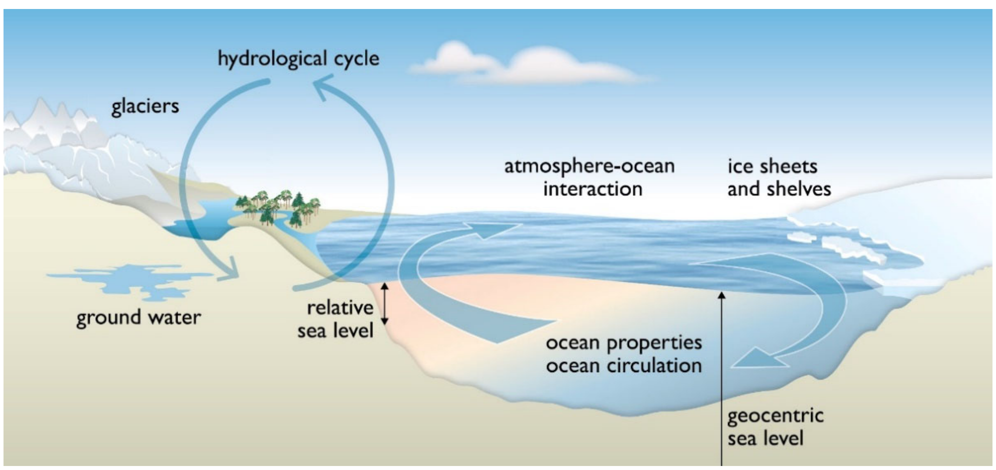

Figure 6. Climate sensitive processes and components that influence global sea level. The term 'ocean properties' refers to ocean temperature, salinity and density, which influence and are dependent on ocean circulation (IPCC, AR5, Chapter 13)

The last time the earth was completely free of ice about 118,000 to 132, 000 years ago, eustatic (global) sea level was 5-9m higher than present[28]. However, studies within the South Australian region place this height at 2-3m above present[29]. On the other hand, at the last time ice was at its fullest extent upon the earth about 21,000 years ago, sea levels were approximately 125m below the

[26] Coast Adapt (2017).

[27] https://coastadapt.com.au/how-climate-and-sea-level-have-changed-over-long-term-past.

[28] J. Curry 2019, Sea level and climate change, Climate Forecast Application Network.

[29] Bourman et al 2016, Coastal Landscapes of South Australia, University of Adelaide Press. See also R.M. Carter 2008 that suggested that the difference may reflect subsidence in South Australia, or the coastline was formed at a slightly younger time period, and at a lower sea-level.

present shoreline. At that time, Gulf St Vincent was a wide and shallow valley with drainage extending from the Adelaide Plains across the continental shelf and Kangaroo Island was joined to the mainland[25].

The warming climate after 21 000 years ago melted the ice and returned the water to the sea. Australian sea levels are thought to have reached their peak about 7000 years ago and then fell by about 1 to 3 m, depending on location, due to *hydro-isostatic* movements. In other words, as the rising waters weighed down the continental shelf, there was a compensating seesaw rise of the land by as much as 1 to 3m resulting in a relative sea-level fall (Figure 7).

It is still uncertain if this fall was smooth and progressive or was interrupted by stages of relative sea-level stability or possibly small sea-level rises. This sea-level fall (relative to the rising of the land) ended approximately 2-3000 years ago[30].

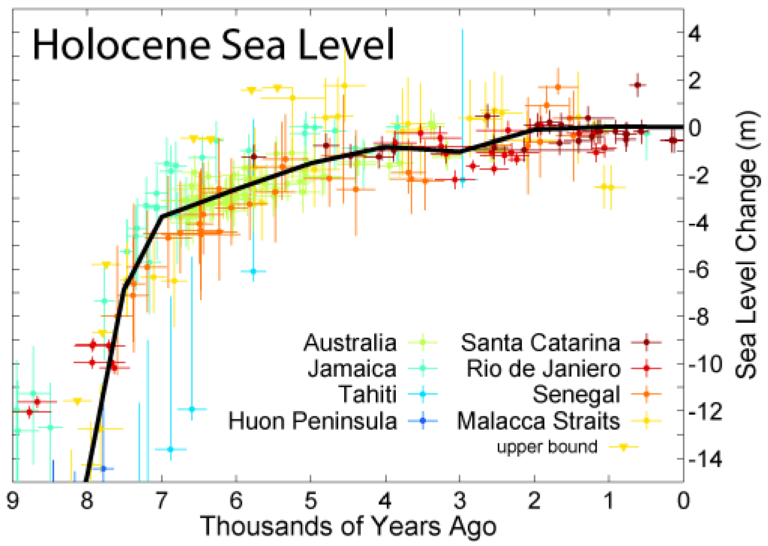

Figure 7. Estimated global sea level changes since 8000 years ago. Note, the sea level rise fall is not shown here because the plot is related to eustatic sea level rise, i.e. the volume of water within ocean basins (Source: CoastAdapt).

The modern metropolitan coast and the lowland embayments between the major fault scarps such as Sellicks, Aldinga, Port Willunga, Moana, Port Noarlunga, Christies Beach and the sandy metropolitan coast north of Kingston Park, were all shaped within this period of rising sea levels called the Holocene. The original dunes along our coast formed over the past 7000 years, after sea level had stabilised to near its present level.

Generally, within South Australia, current rates of land subsidence and land uplift are very small, and Coast Protection Board advises that they can be discounted in the context of evaluating the impact of sea level rise upon landforms. The exceptions are places such as Port Adelaide, which is undergoing subsidence, and within the Upper Spencer Gulf area which is undergoing uplift[31].

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30 https://coastadapt.com.au/how-climate-and-sea-level-have-changed-over-long-term-past.

31 South Australian Coast Protection Board, Coastal erosion, flooding and sea level rise standards and protection, 26 January 1992. See also Harvey et al. 1999 who found that at Port Pirie isostatic uplift was 0.33mm/yr has caused sea level to fall 2.2m since 6700 years ago.

3.3 Long-term stability of landforms

The layout of a coast is usually a reflection of how resistant the rocks and sediments have been to erosion over long periods of time. Differential tectonic movements have brought rocks and sediments of differing degrees of resistance and erodibility into contact with the ocean waters of Gulf St Vincent. Variations of coastal features develop depending on whether the rocks are uniformly soft or hard, or alternating soft and hard.

There are great variations in the rate of coastal erosion along the Onkaparinga coastline. On some very resistant rocks, such as those in Port Stanvac region, virtually no coastal recession may have occurred in the past 7000 years. On the other hand, alluvial cliffs composed of clay or silt can retreat at rates up to 2m per year as has occurred at Snapper Point (Aldinga Reef) since the early 2000s[32].

Instability of landforms are not only caused by actions of the sea but can be caused by other processes such as mass movement or weathering[33]. Mass movement refers to the movement of material downslope under the influence of gravity. These 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 that occurs at coasts are rotational slumps. Slumps occur due to a combination of factors. Marine processes erode and undermine the base of the cliff and remove the support of the cliff. In addition, runoff from rainfall events can infiltrate into the slope through unconsolidated soils and then create a slip plane when it reaches an impermeable material, such as clay. The clay and accumulating water cause the weighted saturated material above to slump. This process can be seen in the diagram below (Figure 8).

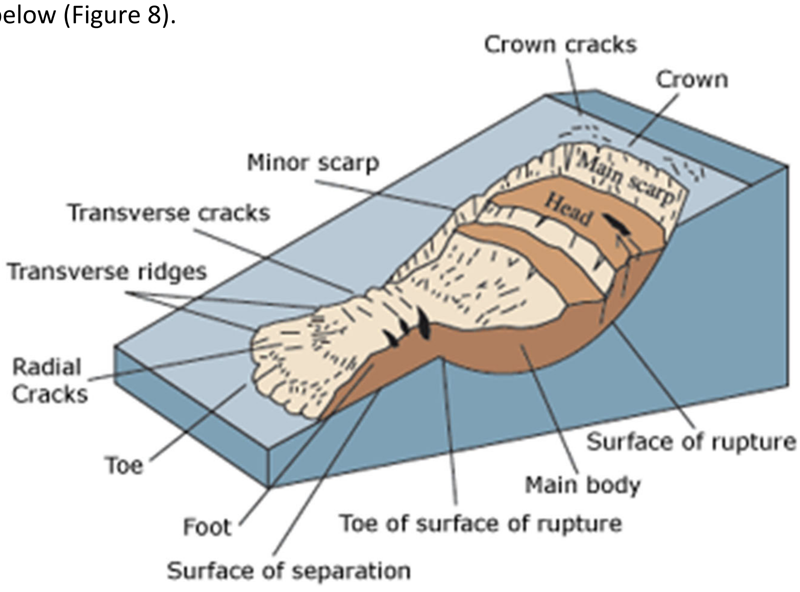

Figure 8. Visual presentation of the impacts of mass movement within coastal slopes and cliffs (Source: www.thebritishgeographer.weebly.com)

[32] A comparison case study exists at Middleton Cliffs where at the turn of 19th century, approximately 100m of alluvial cliffs were eroded from the coast in a matter of decades at a rate of up to 4m per year (Source: R. Bourman).
[33] http://thebritishgeographer.weebly.com/coastal-processes.html

Weathering is the process of breaking down of rock in situ. A common type of mechanical weathering found at coasts is salt crystallization. This occurs as waves deposit salt crystals in cracks and over time the salt applies pressure to the crack, eventually breaking the rock down. Chemical weathering can occur in limestone rocks as a chemical reaction between water and the rock. Biological weathering can occur by the nesting of birds or burrowing of animals. Uncontrolled rainwater runoff down coastal slopes and cliffs can cause gullying in the upper cliff areas and contribute to the breakdown in stability. In summary, weathering weakens coastal slopes and cliffs and this speeds up the rates of coastal erosion or contributes to increases in mass movement.

3.4 Rivers and creeks

The City of Onkaparinga region has six rivers or streams that flow to the coast. Sea-flood modelling for the Onkaparinga River demonstrates that inundation will impact the Port Noarlunga township later in this century (See Cell 4). Similarly, modelling for Pedler Creek at Moana shows that sea-flood modelling will increasingly inundate the caravan park and impact a few private properties (Cell 6). The remaining creeks of Christies Creek (Cell 2), Maslin Creek (Cell 8), Willunga Creek (Cell 9) and Sellicks Creek (Cell 12) are narrow and these incise through surrounding landforms which are more elevated. Sea level rise modelling indicates that impact into these creek beds will be minor.

3.5 Implications for Coastal Adaptation

The implications from the above findings in the context of coastal adaptation include:

1. The geomorphology of the coastline has been largely influenced by sea level. Rising seas after the last ice age brought with them the sand for our modern beaches but also interacted with the older rocks and sediments. Areas that were more erodible became our beaches and bays while slower eroding rocks became our headlands. Furthermore, the weight of larger volumes of sea upon ocean basins caused uplift of the land along the coast. Sea levels have been largely stable for ~2-3000 years, but if they rise as projected then the rate of change on adjacent landforms can be expected to increase.

2. The coastline of City of Onkaparinga is generally elevated and therefore will not be vulnerable to inundation from the sea. The exceptions to this general rule exist at Onkaparinga River and Pedler Creek where sea-flood modelling indicates vulnerability.

3. Instability in cliff regions may relate to the impact of coastal processes at their base or processes of weathering and mass movement in the upper cliff areas, or a combination of these. In summary:
    - The main focus of this project is to evaluate actions of the sea upon cliffs, coastal slopes and beaches.
    - Previous projects by GHD (2016) and URS (2005, 2007) have evaluated the coastline in relation to cliff stability that also includes the impact of mass movement and weathering and the results of their work are incorporated into this project.

4. Coastal Fabric

4.1 Introduction

As we noted in the introduction, it is the geology of the coast upon which our settlements are situated that determines one side of the hazard assessment in terms of form (height above sea level), 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' is adopted from *Smartline* developed by OzCoasts[34]. 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 etc). Using the word 'fabric' also encompasses the study of human interventions in backshores that are not related to natural geology.

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….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.

Why analyse beach changes?

The first reason to analyse beach changes is to identify the normal cycles of accretion and erosion which may occur on a beach over time measured in decades. These cycles can be observed in two main ways: the position of the shoreline changes, and the levels of sand change on the beach. In times of erosion, the shoreline tends to recede, and sand levels become lower. In times of accretion, the opposite is true. The second reason to analyse beach changes is to identify the impact that sea level rise may be having on the coast. Caton (2007) noted that 'all geomorphological models of beach and dune change show recession in response to sea level rise'[35]. Therefore, analysing beach changes provides the opportunity to identify any impact that accelerating sea level rise may be having along the coast.

In summary, the purpose of evaluating the historical changes to the beach is to formulate a baseline understanding of how the coast has been operating in the past. This understanding will assist us to identify if sea level rise is currently having an impact on beaches, and if not, then it will assist us to identify when sea level rise is making a difference in the future.

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[34] Sharples et al 2009, Australian Coastal Smartline Geomorphic and Stability Map Manual, University of TAS. Note that CoastAdapt adopted OzCoast methodology into Shoreline Explorer which classifies each section of beach firstly in relation to 'fabric' (composition, constituency) and secondly on 'form' (topography). However, Shoreline Explorer does not utilise the word 'fabric'.

[35] Caton, 2007, The Impact of Climate Change on the Coastal Lands of City of Onkaparinga, p.3.

4.2 Methodology

To evaluate the nature of the fabric of the coastal cells we utilise the following procedure:

1. Provide an overview of each cell,
2. Analyse changes to the shoreline,
3. Analyse changes to beach profiles,
4. Identify human intervention in backshores.

4.2.1 Overview of each coastal cell

An overview of the fabric of each cell is provided in terms of its form (topography), benthic (nature of the seafloor), and geology (classification of landforms). The benthic map for Ochre Point is provided below as an example (Figure 9). The information from these three map types provide an overview of the characteristics of Ochre Point including:

- The blue lines designate the extent of the cell,
- The dotted black lines indicate the location of minor cells. In this case the division is based upon the existence of a small beach backed by dunes in 7.2 whereas the remainder of the cell is predominantly a rocky beach backed by steep cliffs.
- Ochre Point is dominated by a rock shore platform close to shore and a low-profile reef offshore, interspersed with sand patches, some containing seagrass of medium cover.
- Harder rock is positioned at the base of the cliff (ABC Range Quartzite, Eocene limestone), the cliffs rise to ~40m high which are composed of more recent softer quaternary deposits.

This procedure is undertaken for all of the twelve cells in the study.

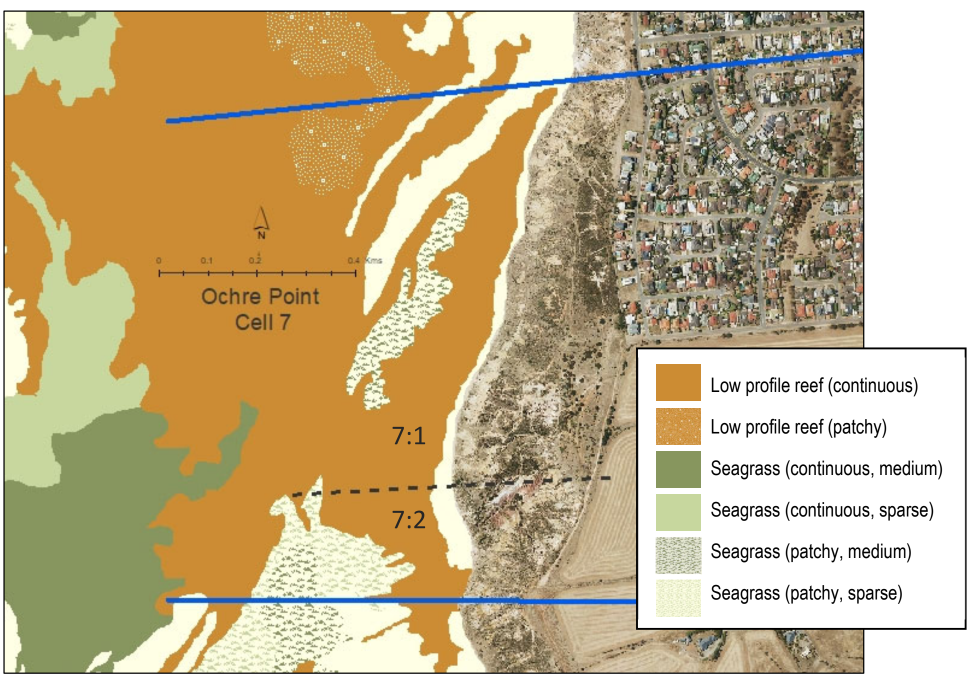

Figure 9. Benthic map for Ochre Point (Cell 7) (Source: Nature Maps, SA).

4.2.2 Analyse changes to the shoreline.

What is the shoreline?

The shoreline is the position of the land-water interface at one instant in time. But in reality, the shoreline position changes continually through time because of the dynamic nature of water levels at the coastal boundary. The best indicator of shoreline position is the location of the vegetation line closest to the area on the beach where waves end their journey. In other circumstances the shoreline may be the base of a cliff, an earthen bank at the toe of a slope, or a seawall in locations where humans have intervened (Figure 10).

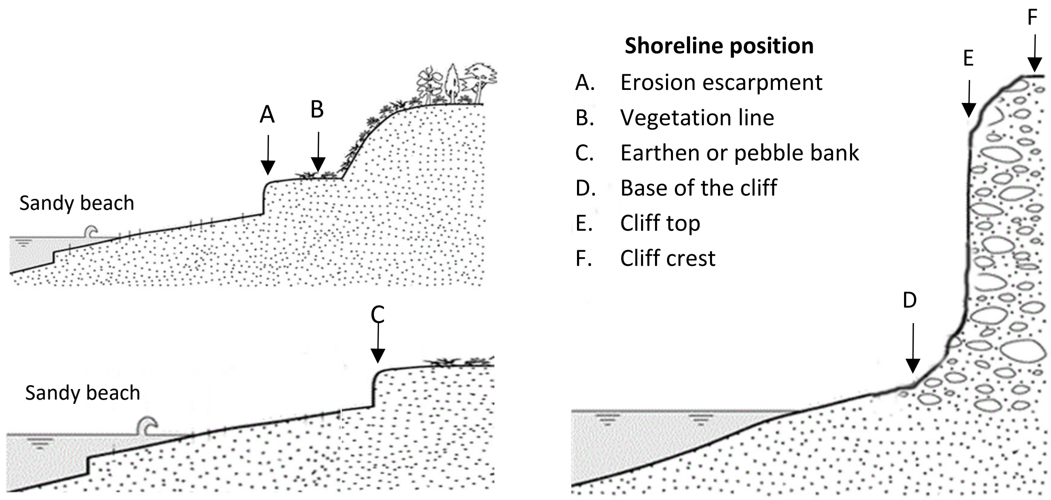

Figure 10. Adapted from Boak and Turner (2005), Shoreline definition and detection.

Evaluating shoreline change

The prime methodology for evaluating shoreline change is to utilise aerial photographs that are georeferenced so that they can be compared within geographic information systems (GIS). This means that they can be accurately aligned within computer software and changes to the shoreline measured. Depending on the clarity of the photograph, measurements should usually be accurate to plus or minus 1m, but this may vary with older photographs. The methodology includes:

- Comparing aerial photography from 1949, 1969, 1979, 1989, 2007 and 2017.
- Referencing all photography to 2017 because the shadows and general clarity of this photograph were optimum for analysing cliff environments.
- Referencing the 1949 photograph into each location of analysis as it was not possible to reference this photograph using broader digital processes.

A secondary method was employed to analyse shoreline changes before the introduction of aerial photography. Where available, comparisons were made using land-based photography. This analysis tended to be more qualitative but provided a bridge between the early 1900s and 1940s to evaluate shoreline changes. In locations such as Christies Beach, Port Noarlunga and Moana, these photographs also provided an insight into the nature of the coast before significant modifications were installed.

Examples of each methodology are provided in Figures 10 and 11.

Example 1: A comparison of shoreline position in 2017 with photography from 1979 reveals a major change to the shoreline which has receded in excess of 25m. Also note the position of the SA Coast Protection Board survey profile line 200054 which we will review in the next section.

Figure 11. Comparison of shoreline position between 2017 and 1979 (M. Western,2020)

Example 2: A comparison of land-based photography of Port Willunga from 1909 to 2020 provides the basis for qualitative analysis of changes over 110 years. In this instance, very little beach change is observed between the photographs.

Figure 12. Comparison of shoreline characteristics between 1909 and 2020 (Source: SA State Library, M. Western)

Fine-grained analysis of the whole coastline was completed within the digital environment, but reporting was contained by the need to include imagery at a high enough resolution to make analysis meaningful. On beach locations the scale of the map could be as high as 1:2000 but within cliff environments the scale was required to be closer to 1:500. Locations for reporting were selected based on the following criteria:

- The proximity of human infrastructure,
- Where a review in the digital environment showed that shoreline changes were significant,
- Where a review showed that changes were uniform samples were selected that were representative of the whole,
- Where photography was available and clear.

4.2.3 Analyse changes to beach profiles

Department for Environment and Water (DEW) has been surveying twenty-two profile lines within the region from the 1970s. These profile lines run perpendicular to the shoreline and represent survey height levels of the backshore, intertidal and subtidal zones. Evaluating changes to these profiles provides a way to identify the erosion and accretion trends over time. Three different types of analysis were performed at each profile line and the profile line from Aldinga Reef is provided below as an example.

Analysis 1 uses profile surveys that correspond to the time of the aerial photography used in 4.2.2. To provide additional context, dotted lines are drawn to indicate highest astronomical tide (HAT) and lowest astronomical tide (LAT). In this case the recession of the shoreline observed in the aerial photography is identified in the profile. The analysis shows that the shoreline remained in a similar position until 2007 whereupon it underwent rapid recession.

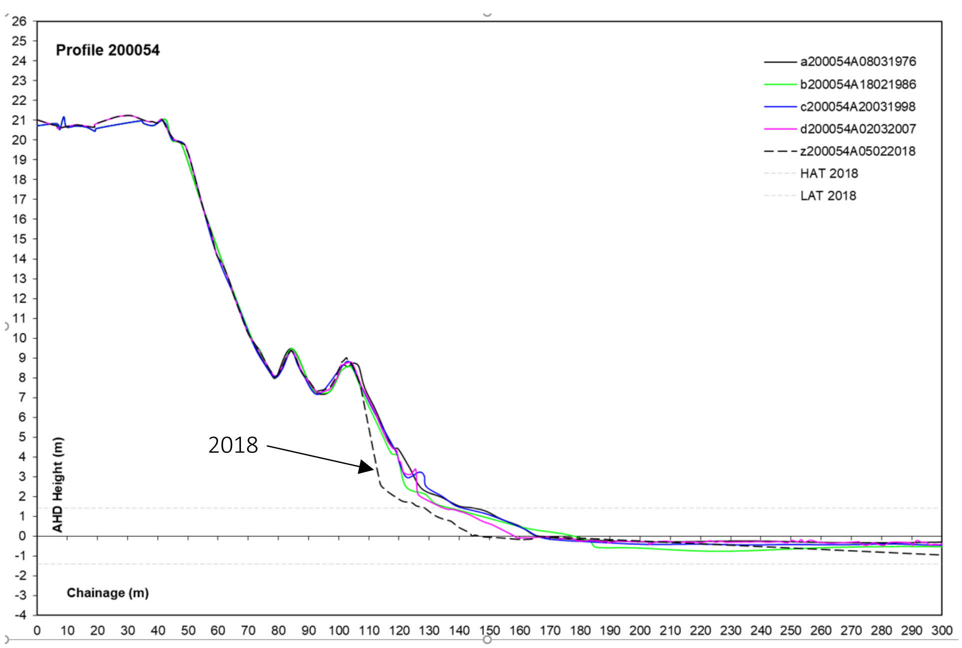

Figure 13. Analysis of profile line 200054 displayed in the context of five surveys from five decades that correlate approximately with the aerial photography (Source: SA Coast Protection Board).

Analysis 2 displays all the profile surveys in grey scale and presents the starting profile in 1976 in a solid line and the final line in 2018 as a dashed line. This analysis provides a view of the range of profiles over 50 years and where the current profile line sits within that range.

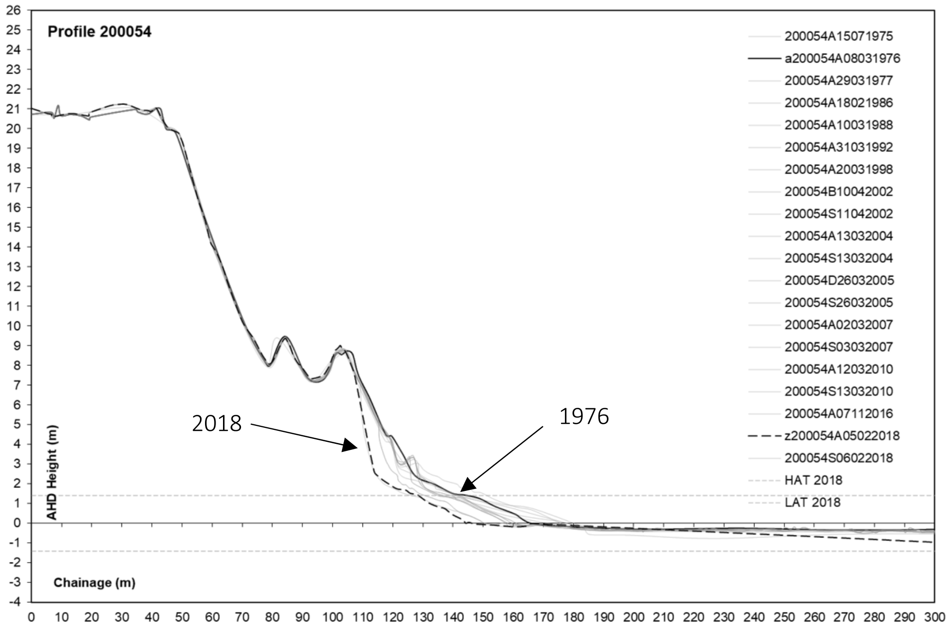

Figure 14. Analysis of profile line 200054 displayed in the context of all profile surveys at this location (Source: SA Coast Protection Board).

Analysis 3 is a trend analysis of all survey profiles to establish if there is a beach widening or beach narrowing trend. In this case, due to the significant amount of erosion there is a statistically meaningful widening trend. Note, in many cases in the analysis there was no meaningful trend.

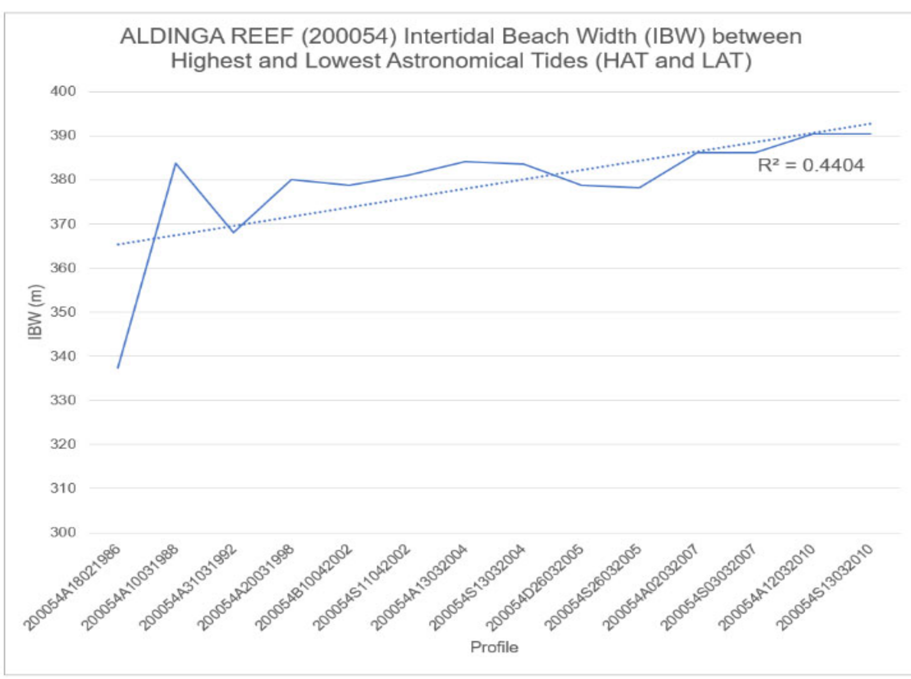

Figure 15. Trend analysis of all the profile surveys from1976 to 2018 (Source: SA Coast Protection Board).

4.2.4 Identify human intervention in backshores

Urban settlements placed too close to shorelines impose rigidity in the backshore, which was formerly flexible and could cope with the natural cycles of accretion and erosion. If sea levels rise as projected, then beach shorelines will recede. Those beaches that have room to recede will tend to maintain their existing profile and sand levels, those that cannot recede will tend to lose sand levels from their beaches. Within cliff locations, sea level rise brings increased action of the sea to the base of the cliff and causes it to be undermined. In natural situations, the slope of the cliff would increase, and then slides and falls would cause the top of the cliff to recede until a new equilibrium was reached. When urban infrastructure is placed too close to the top of cliffs, then cliff tops cannot recede, and the slope of the cliff tends to increase until it becomes unstable.

In some locations, protection items may be installed when backshores come under threat. In other instances, the desire to create urban spaces in close proximity to the beach results in the installation of a seawall to create a promenade. If sea levels rise, the shoreline will be unable to recede and the increased energy of the waves now acting in closer proximity to the seawalls will tend to remove sand from the vicinity of the seawall, and sand levels are likely to decline on the beach.

Example 1: The nature of the backshore at Christies Beach has been altered from silty clay to rock.

Figure 16. Aerial photograph of Christies Beach (Source: SA Coast Protection Board, 2014).

Figure 17. The Esplanade at Seaford in 1979 and 2007 (Aerial Photography, City of Onkaparinga).

Example 2: The esplanade road was widened in early 2000s to be within 1.5m of a backscar of a slump. A piled retaining wall has now been inserted under the footpath to ensure stability.

4.3 General findings

4.3.1 Overview

Each cell has been evaluated in regard to its form (topography), benthic characteristics (nature of the seafloor), and geology (nature of landforms). Understandably, there is great variation between cells in relation to these characteristics. However, in general the coastline of City of Onkaparinga is bordered by much older and harder rocks to the north at Lonsdale (and within Marion Council) and to the south (within Yankalilla Council) (ages ~1000 million years)[36]. Most of the coastline as we know it today was formed recently in the Holocene (last 7000 years) as sediments interrelated with the softer and much younger rocks of the Eocene (~50 million years). The general layout of the Onkaparinga coastline is depicted by Nature Maps (Figure 18) and is characterised by:

- A medium – fine sand beach is present in most locations,
- Offshore is generally dominated by sand but interspersed with low profile reefs and seagrass beds (varying from patchy to continuous),
- Backshores vary from soft rock sloping shores, soft rock cliffs or sedimentary plains.

In summary, the erodibility of the Onkaparinga coastline can be generally characterised as *moderate to high erodibility*. This finding is generally borne out in the individual cell reports apart from Lonsdale which is categorised as *low erodibility*, and locations such as Aldinga Reef, the Lower Esplanade Road at Aldinga, and Seaford Cliffs (south) which are categorised as *very high erodibility*.

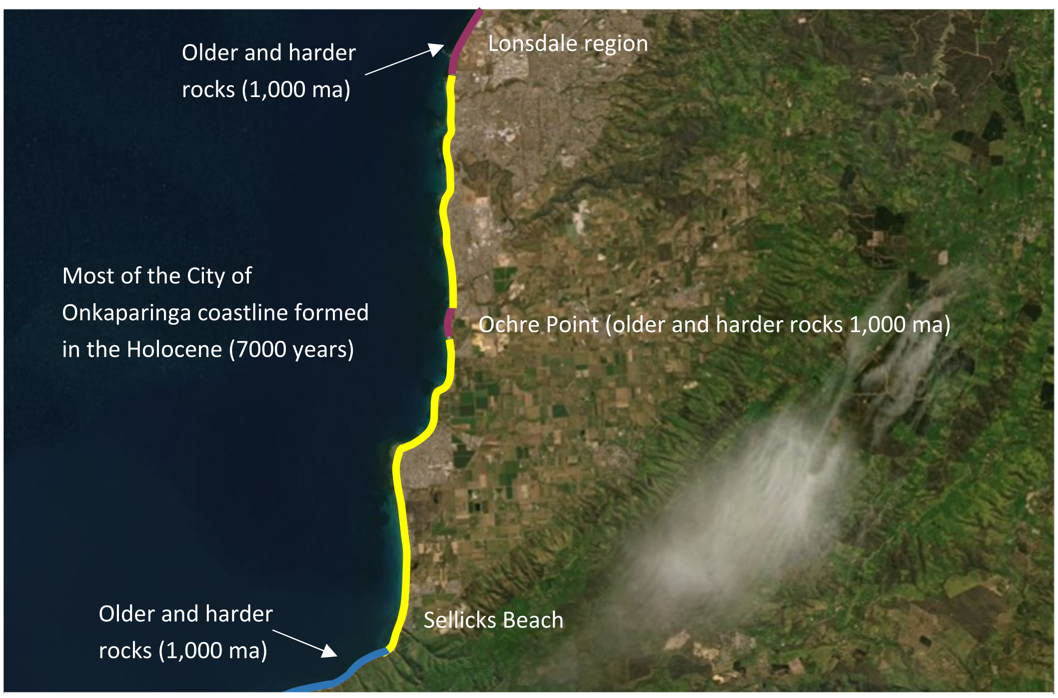

Figure 18. The general layout of the coastline of City of Onkaparinga (Adapted from Nature Maps, Department of Environment and Water).

[36] One exception exists at Ochre Point which is the culmination of the Clarendon fault (see geomorphology section).

4.3.2 Analysis of shoreline and profile line changes

The findings of the shoreline analysis within beach environments revealed:

- A stable coast with overall shoreline recession of 2-4m since 1949 in beach locations.
- Cycles of erosion and accretion were observed which took place over decades with shoreline movements seaward and landward of 4-6m.
- Observed recession often occurred suddenly due to the impact of storms and then a gradual build-up of sand and vegetation moved the coastline seaward again over a period of years.
- The shoreline was at its most seaward position in the late 1970s and generally the survey profile lines also show high levels of sand in this period.

The findings of the profile analysis revealed:

- As a general rule, current sand levels are situated in the mid to upper range of all the profiles since surveys began, although sand levels have also been higher or lower than present.
- The analysis of the profile lines showed a similar pattern of accretion and erosion over decades as observed in the shoreline analysis.

The findings of the beach width analysis revealed (See also Appendix 2):

- The intertidal beach widths along the coast vary considerably from beach to beach. The variation is likely due to their varying exposure differences, the presence or not of reef and its depth and proximity to the shore, to human actions, and in some cases, perhaps, to local trapping of the longshore drift.
- The trends in intertidal beach widths show that of the 15 beaches examined, 4 indicate slight increases in beach width, and 8 beaches indicate slight decreases in width. NONE of these trends are statistically significant with extremely low regression coefficients[37].

The findings of the shoreline analysis within cliff areas revealed[38]:

- In locations of limestone cliffs, such as Port Willunga and Maslin Beach (south), the tops of the cliffs receded 0-2m over a fifty-year period (1979 to 2017).
- In the softer cliffs in the Seaford south area, the base of cliffs receded 1-3m creating a vertical scarp, but the recession was not uniform.
- In selected locations (Port Willunga, Maslin Beach, and Seaford) analysis was conducted of the position of the upper crest line of the cliff. The general finding was that the upper crest lines has made little landward movement over a 50 to 70-year period. This finding tends to suggest that the slopes of cliffs may be growing steeper over time (especially at Seaford).
- Slumping, landslides, and block falls were observed to occur within cliff locations but GHD 2016, and URS, 2005 & 2007 are the prime sources for this review.

[37] The meaning of not being statistically significant relates to the large range of the data within the data set.

[38] Shoreline recession was either undertaken for the top of the cliff or the base of the cliff depending on the location. The analysis of cliff movement is more difficult to achieve with aerial photography due to the slow movement of cliffs, the height differences between top and bottom of the cliff, and the difficulty of dealing with shadows that obscure interpretation.

Exceptions to the above findings include the following locations:

- Aldinga Reef (in the vicinity of Gordon Street) – significant recession (~8m) of the toe of the cliff which is comprised of soft Ngaltinga clays.
- To a lesser extent, the area around the Aldinga beach onramp is a similar story where the impact of storms has caused recession toward the Lower Esplanade Road. The beach has begun to rebuild, but whether erosion continues to move toward the road will depend on how soon the next storm arrives.
- Aldinga Reef (end of Butterworth Road) - significant shoreline recession ranging from 17m to 27m was identified in all three analyses, the majority of which occurred post 2005 and likely related to storm activity of 2007, 2009, 2016.
- Sand levels in front of the seawall at Port Noarlunga show an ongoing trend for decline in level (but no decline in beach width).
- Current sand levels at Christies Beach and O'Sullivan Beach are at their highest, or well into the upper range of all of the profiles but some recession of the toe of the dune is observed at O'Sullivan Beach profile which may relate to the storm of 2016.
- Seaford Beach has shown a decline in beach width generally below median sea level (AHD) for reasons that have not been determined.

4.3.3 Human intervention

Esplanade roads and carparks

In most case esplanade roads are set well back from shorelines. Exceptions exist at:

- Lower Esplanade Road which is set close to an escarpment of soft sediments,
- The Esplanade between Hack Street and Gordon Street where the cliff crest can be as close as 8m from the road,
- The carparks and foreshore infrastructure set close to the beach at Moana,
- Walking paths, carparks and roads set in close proximity to cliff crests in Seaford (south of Seaford Road).

Works and strategies

Council has undertaken the following works and strategies to manage coastal issues including:

- Rock revetment installed to various coastal locations (Sellicks Beach carpark, Seaford Beach pedestrian accessway, base of the cliffs at the mouth of Onkaparinga River, adjacent the river on Weatherald Terrace, the northern side of Witton Bluff, selected locations at Port Willunga, and Christies Beach).
- Seawalls have been installed at Port Noarlunga (sloping seawall) and Moana (vertical seawall).
- Geotextile bags have been installed at Moana at the base of the slope under the upper carpark but these appear to be nearing the end of their life.

- Overhangs and unstable cliffs have been removed at the mouth of the Onkaparinga River (1993, 2008), Maslin Beach (south), and Witton Bluff (south).
- Piled retaining walls have been installed under the footpath on the Esplanade at Gordon Street (Aldinga Reef) and Gulf Street (Seaford Cliffs) to provide stability to the road reserve in the context of nearby erosion and slumping of cliffs.
- Stormwater system upgrades have occurred at Sellicks Beach, Maslin Beach and Port Willunga to reduce the flow of storm water on the beach. Other storm water strategies such as riprap rock are employed at various locations (Note this is not an exhaustive list).
- Slope controls and gully infill have occurred at Witton Bluff (north and south) and Maslin Beach.
- Council employs ongoing management strategies such as revegetation, pedestrian and vehicle control using signage and fencing.

4.4 Implications for coastal adaptation

The implications from the above findings in the context of coastal adaptation include:

1. As an overview, the erodibility of the Onkaparinga coastline can be generally characterised as *moderate to high erodibility* (with some sections, *very high erodibility)*.

2. An erosion and accretion cycle are observed (4m – 6m) that takes place over decades. The initial recession is often related to storms or a series of storms, and then the beach slowly rebuilds over time. This finding creates a baseline understanding of how the coastline has been operating over a 70-year period.

3. Overall recession since 1949 (or 1969) of the coastline south of Seaford Cliffs is 2-4m. This overall recession distance is less than when comparing to 1979 because in that era the vegetation line was ~4m forward of the 1949 line. Beaches north of Seaford Cliffs have shown no overall recession, although in the case of Christies Beach this is primarily related to the installation of rock revetment to the base of the silty clay cliffs.

4. In harder cliff areas such as limestone, cliff top recession is 0-2m with no discernible trend as this recession is likely related to sporadic block and rock falls. In the Seaford Cliff area, it is likely that actions of the sea have caused the base of the cliff to recede ~2-3m creating vertical scarps at the base and steeper slopes in the upper cliff areas.

5. Generally, it is difficult to identify any impact of sea level rise upon the coast within the 'noise' of natural variability. One possible explanation for increased erosion at Aldinga Reef is that increased sea levels are reducing the protective effect of the reef. Other explanations include a lowering in the level of the reef and increase intensity of the storm surge, or a combination of two or more of these factors.

5. Coastal Exposure

As we noted in the introduction, the other side of the hazard assessment is evaluated in terms of exposure. In this study we are primarily concerned with the exposure of coastal landscapes to wave energy and ocean swell. However, coastal landforms can also be vulnerable to exposure from rainfall run-off or from the impact of wind which increase the erosion of coastal landscapes, especially in cliff regions of softer constituency[39]. The degree of vulnerability of a coastline to actions of the sea is related to the degree of exposure of the coast to wind, current, and wave attack, especially during storms. As the position within gulf waters and the orientation is essentially the same for the whole City of Onkaparinga coastline, Nature Maps (SA) allocates a general exposure rating to the coastline as:

- Moderately exposed
- Low wave height

These allocations set the coastline of City of Onkaparinga within the broader context of all South Australian marine waters and provide the broad inputs for the inherent hazard rating undertaken in the next section, along with the erodibility ratings that we have applied in the previous section.

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[40]. 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'. The word 'exposure' is therefore deemed suitable to convey coastal concepts as it has relevant technical meaning but is also readily accessible to all stakeholders.

5.1 Conditions of exposure in the context of Gulf St Vincent.

Wave Energy

Swell waves generated in the Southern Ocean to the southwest of Australia have been recorded as the largest of any in the world's oceans[41]. Swell waves from the Southern Ocean can penetrate Gulf St Vincent from the south-west between Kangaroo Island and Yorke Peninsula. However, after passing through Investigator Strait, and having refracted, diffracted and attenuated due to bottom friction, wave heights are much reduced as they approach the shoreline of the Onkaparinga coastline. Swell waves that propagate on to the Onkaparinga coastline have 12-16 second periods, heights generally below 1m, and arrive from the south-west direction (at close to 260˚).

[39] URS 2005, 2007 and GHD 2016 review these impacts and their findings are included in the cell reports.
[40] Sharples et al 2009, Australian Coastal Smartline Geomorphic and Stability Map Manual, University of TAS, p. 7
[41] Pattiaratchi C. and R. Jones (2005). "Physical and oceanographic studies of Adelaide coastal waters using high resolution modelling, in-situ observations and satellite techniques – PPM 2 Sub Task 4 Draft Final Technical Report"

Sea waves within Gulf St Vincent are generally of short-wave period and quite steep, up to 2.6m high, frequently with white caps and approach the shore from the direction of the wind, predominantly from the south-west to west, but can also roll in from the north-west (250˚ - 310˚). In storm surge conditions, offshore wave heights have been recorded as high as 11m[42].

Orientation and fetch

Orientation refers to the way a segment of land interrelates with the oceanic forces, and *fetch* relates to the distances that wind can blow across open waters. The alignment of the City of Onkaparinga shoreline is broadly orientated north-south, with transition sections at Witton Bluff, Ochre Point, Blanche Point and Aldinga Reef. Kangaroo Island provides significant protection from the Southern Ocean (Figure 19). Winds from the northwest and west travel over the shallower waters of the Gulf for fetch distances of less than 100 km. While winds from this direction do impact the shoreline with raised wave action, they are unable to generate the more elevated waters that are produced when waters are pushed up through Investigator Strait from the Southern Ocean when the winds are from the south-west (see also Storm Surge section below, p. 36).

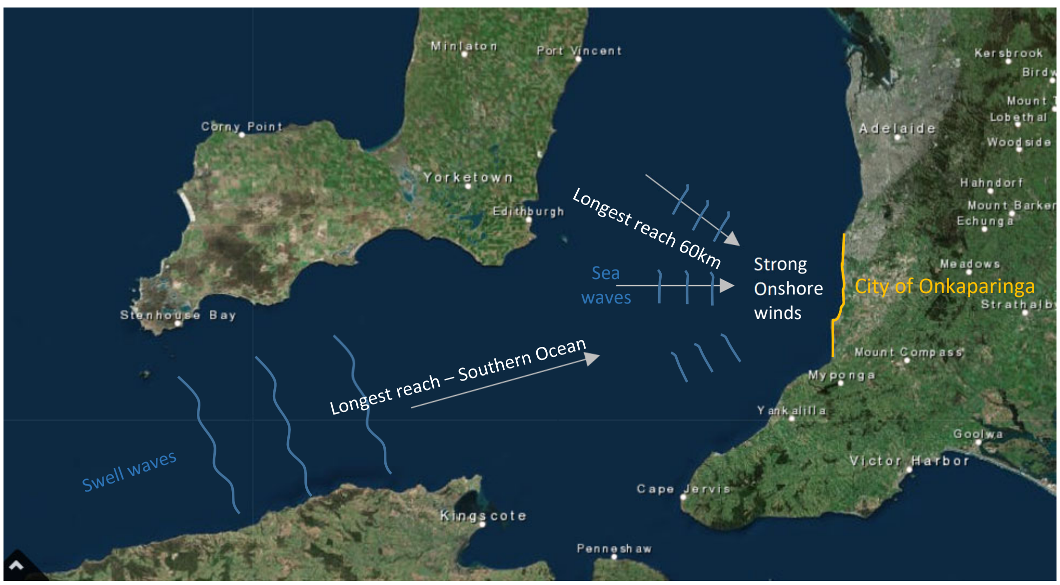

Figure 19. The orientation of the Onkaparinga coastline to wave energy (Adapted from map from location.sa.gov.au)

Tidal Range

The effect of tides pushing up through a narrowing and increasingly shallow gulf increases the tidal range in the northern parts of the Gulf. In other words, the same tidal event produces different levels of water that are lower in the southern portion of the gulf (where the gulf is wider and deeper), and higher levels in the northern parts of the gulf (where the gulf is narrow and shallow).

The ranges between low and high tides are categorised world-wide as micro-tidal (<2m), meso-tidal (2-4m) and macro-tidal (>4m). In the City of Onkaparinga region, the categorisation is borderline

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42 Lord, D (2012), Hallett Cove Coastal Management Study, Coastal Environmental Pty Ltd, p 22

between micro-tidal and meso-tidal, again due to tidal flows being contained within the shallower waters of Gulf St Vincent which increases the tidal range.

Table 2: Tidal range in Adelaide coastal region

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

Source: Lord D. (2012) p. 20

Sediment Balance

The sediment balance is an essential geomorphic parameter and particularly important for coastlines falling into the sedimentary and soft rock categories (i.e. City of Onkaparinga). 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 characteristics and the relative sea level change. The sediment compartment in which the coastline of City of Onkaparinga is located is known as 'Adelaide Coast'[43]. The diagram below illustrates the predominant littoral drift of sediment that occurs from south to north within Gulf St Vincent. However, the City of Onkaparinga coastline is divided again into twelve tertiary sedimentary compartments (cells). Within some of these cells, headlands and breakwaters form sediment compartments where sand tends to remain trapped within the cell (examples include Port Willunga, Maslin Beach, Christies and O'Sullivan Beaches).

The work of Bourman and Harvey showed that over the past 7000 years, since present sea level stabilised, the metropolitan coast has been naturally running out of sand, making the metropolitan coast very vulnerable to the subsequent detrimental impacts of European settlement[44]. Additionally, Gulf St Vincent only has a limited number of rivers, such as the Onkaparinga and the Torrens, but these deliver minimal sediment to Gulf St Vincent.

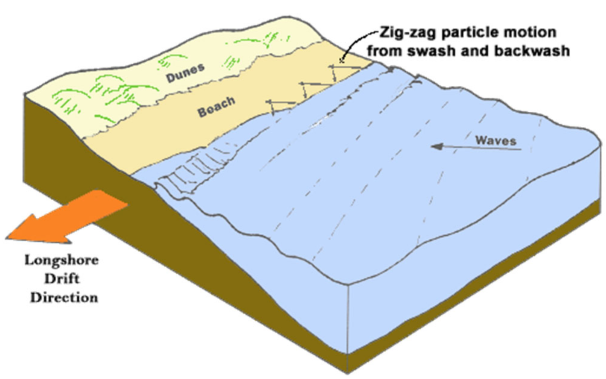

Figure 20. The diagram depicts the actions that cause sand to drift northwards on the Adelaide coast. However, within smaller cell compartments which have headlands or breakwaters, the flow of sand will be 'trapped' or at least the slowed.

[43] See http://docs.coastadapt.com.au/sediment_compartments/SA02.01.04.pdf
[44] Coastal Landscapes of SA, p. 66

Storm surge

Estimates of storm surge at particular locations are based on historical occurrence and calculated from highest astronomical tide, storm surge height, and wave effects (wave setup and wave runup). The concept of storm surge is illustrated at Figure 21 and the components explained below:

- **Storm surge** (storm tide) refers to the combined effect of barometric setup and wind setup. 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 ocean surface and piling water up against the coast. A unique aspect of storm surges within Gulf St Vincent is that the narrowing of the gulfs towards the north tends to increase the height of the storm surge in the upper reaches of both gulfs. In the upper regions of the gulf there is less volume in the ocean basin and therefore water is increasingly piled up against the narrowing coastlines.

- **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** 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.

The meteorological and tidal conditions that produce the largest storm surges in Gulf St Vincent occur with the passage of a deep depression (low) across the Southern Ocean are as follows. With a falling barometer and the onset of northerly winds, the tides are below prediction, but as the wind backs to the north-west an increase in level occurs (waters in the Gulf are backed up against Kangaroo Island). If the strong north-westerly wind backs to the west-south-west at about the time of low water, then a storm surge of maximum amplitude will occur with heights expected from 1m to 2m above prediction (within City of Onkaparinga coastline at ~1.40 to 1.50m). These high levels will continue until the barometer starts to rise, and the wind backs rapidly to the south east within 12 hours, and with a rapidly rising barometer the tides return to normal at about that time[45].

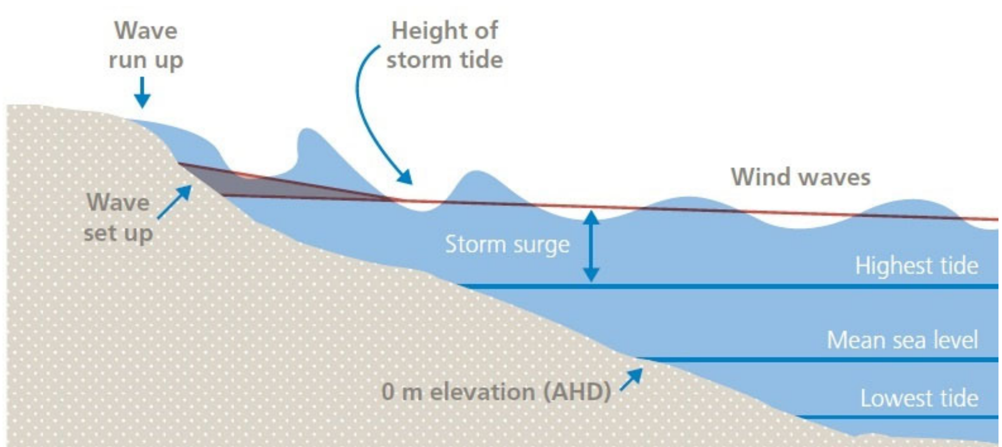

Figure 21. The components of storm surge which use the highest astronomical tide as the starting point for calculating storm surge heights and impacts (Source: CoastAdapt.com.au)

[45] Flinders Ports (ND) Port User Guide – General Information, and Lord 2012, p 22.

5.2 Trends and projections for sea level rise

In the context of a coastal adaptation study, it is recognised that increases in sea level rise will also increase the exposure of the coastal fabric to actions of the sea. The purpose here is not to undertake a full review of matters relating to climate change and sea level rise. Readers requiring further information are encouraged to refer to resources developed by National Climate Change Adaptation Research Facility (NCCARF) at the website https://coastadapt.com.au/.

Global and regional sea levels

Global sea levels reflect the state of the climate system. During ice ages a large volume of water is stored on land in the form of ice sheets and glaciers, leading to lower sea levels, while during warm interglacial periods, glaciers and ice sheets are reduced and more water is stored in the oceans. Regional changes also occur in sea level, but these do not change the overall mass of the ocean. For example, regional sea levels change in accordance with the climate variability associated with El Nino and La Nina cycles. During El Nino years sea level rises in the eastern Pacific and falls in the western Pacific, whereas in La Nina years the opposite is true[46]. Sea levels also change in relationship to the vertical movement of land. If an area of land is falling, then in relative terms, sea levels will rise, and vice versa. In the context of City of Onkaparinga coastline, South Australian Coast Protection Board advises that vertical movement is small enough to be disregarded for the purposes of coastal adaptation[47].

Short-term to medium-term historical sea-level rise

Global sea levels have varied greatly over long time periods but have been largely stable over the last 2-3000 years[48]. One of the outcomes from global warming is sea level rise, caused by thermal expansion and melting of ice caps and glaciers. Over the period 1901 to 2010, global mean sea level rose by around 0.19m, or an average 1.7mm per year (Figure 22).

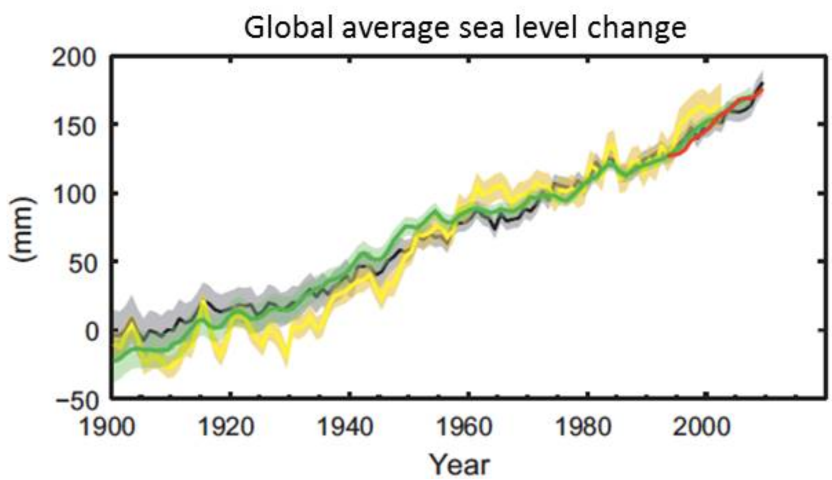

Figure 22. Global mean sea level relative to the 1900–1905 mean of the longest dataset, and with all datasets aligned to have the same value in 1993, the first year of satellite altimetry data. Coloured lines indicate different data sets. Source: IPCC 2013 (Fifth Assessment Report, Working Group 1, Summary for Policy Makers, Figure SPM.3d).

[46] CSRIO (2020) Sea level, waves and coastal extremes.

[47] SA Coast Protection Board, Coastal erosion, flooding and sea level rise standards and protection, 26 January 1992.

[48] https://coastadapt.com.au/how-climate-and-sea-level-have-changed-over-long-term-past.

CoastAdapt states that sea levels have risen at a faster rate around Australia since 1993 (partly due to natural variability), and that the rates of rises are similar to that measured globally. There is some variability in the trend around the Australian coastline with greater increases observed in the north, north-west and south-east than in the southern and mid-eastern regions[49]. In our region the rate of sea level rise since ~1990 has been on average 4.3mm per year based on SEAFRAME gauges at Port Stanvac[50] and at Thevenard[51] and satellite measurements.

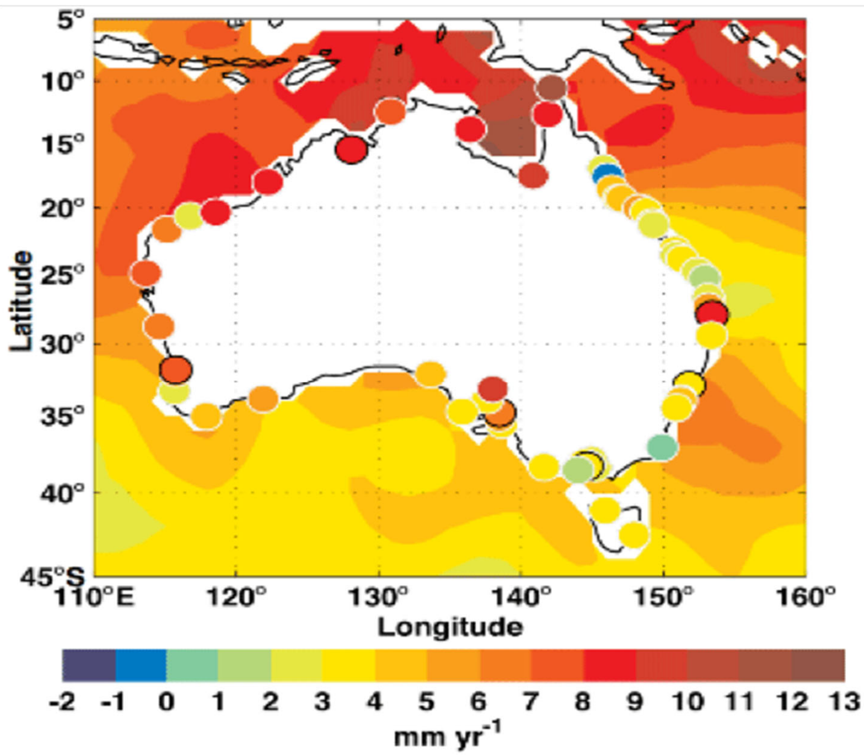

Figure 23. Sea-level trends from January 1993 to December 2010 from satellite altimeters (colour contours) and tide gauges (coloured dots). Source: CSIRO and BoM 2015 © Commonwealth of Australia.

Sea level rise projections

Sea level rise projections for the 21st century are based on computer based simulations of the climate system and the likely impact of increased greenhouse emissions on temperature (and therefore, sea level). The Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) identified four emissions scenarios to frame projected climate futures. These are known as Representative Concentration Pathways (RCPs) and are framed in the following manner:

RCP 8.5 Very high emissions pathway
RCP 6.0 High emissions pathway
RCP 4.5 Moderate emissions pathway
RCP 2.6 Low emissions pathway

[49] https://coastadapt.com.au/how-to-pages/how-to-use-national-mapping-to-understand-recent-climate-trend
[50] This tide gauge decommissioned in 2010.
[51] CSIRO and Bureau of Meteorology 2015, Climate Change in Australia Information for Australia's Natural Resource Management Regions: Technical Report, CSIRO and Bureau of Meteorology, Australia, p. 145

CSIRO and Bureau of Meteorology have utilised the IPCC findings and provided sea level rise projections for locations around Australia, including Port Adelaide (Table 3)[52].

Table 3: Projections of sea level rise for Port Adelaide based upon various RCP scenarios

STATIONS	SCENARIOS	2030	2050	2070	2090
PORT ADELAIDE (INNER)	rcp25	0.13	0.24	0.36	0.50
	RCP4.5	0.13	0.25	0.40	0.59
	RCP6.0	0.13	0.24	0.39	0.60
	RCP8.5	0.14	0.28	0.50	0.81

South Australian Coast Protection Board

In 1991, South Australian Coast Protection Board (CPB) adopted sea level rise policy standards of 0.3m rise by 2050 and 1.0m by 2100 (compared to 1990 levels), and these standards were written into South Australian Development Plans in 1994. These policy standards are based on modelling by the Intergovernmental Panel on Climate Change (IPCC) which has modelled global climate and produced scenarios of accelerated sea level rise that relate to the various rates of projected accumulation of Greenhouse gas emissions in the atmosphere. CPB believes it has taken the best advice available in resolving to base the sea level rise aspects of its hazards policy on the IPCC sea level rise projections[53]. Figure 24 depicts sea level rise projections based on the adoption of scenario RCP 8.5 and how CPB policy levels relate.

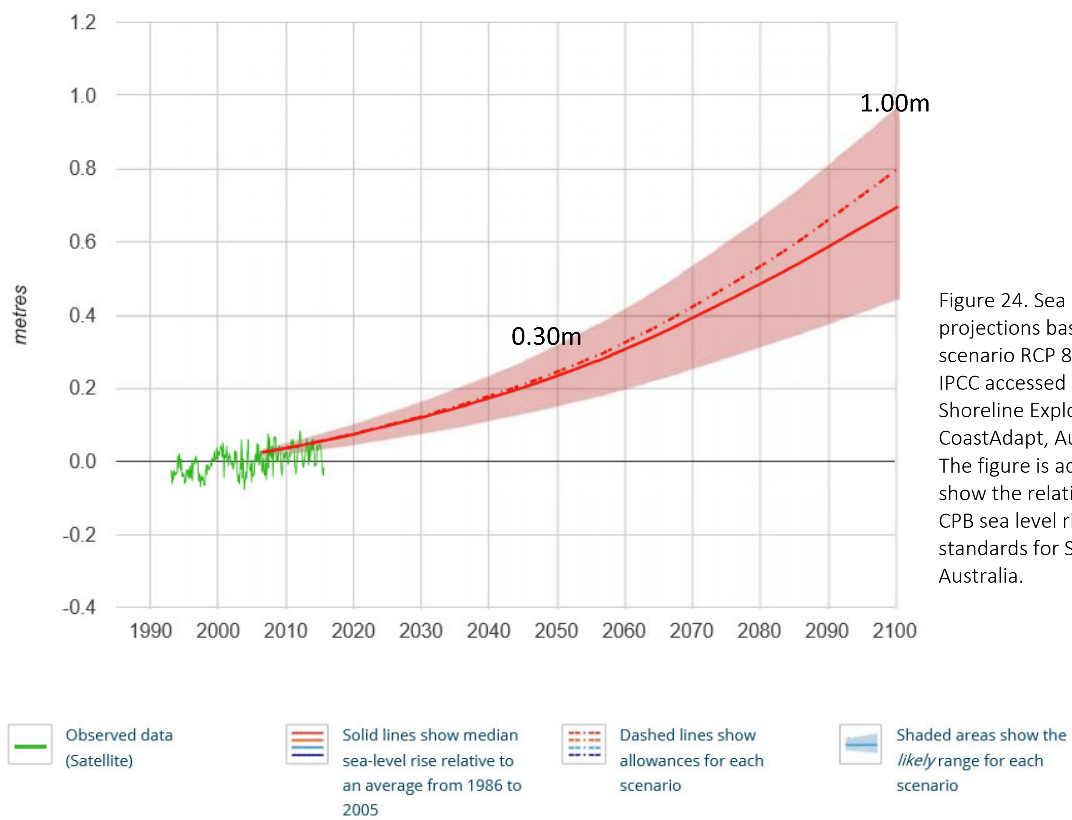

Figure 24. Sea level rise projections based on scenario RCP 8.5 from IPCC accessed from Shoreline Explorer, CoastAdapt, August 2017, The figure is adapted to show the relationship to CPB sea level rise policy standards for South Australia.

[52] CSIRO and Bureau of Meteorology 2015, Climate Change in Australia Information for Australia's Natural Resource Management Regions: Technical Report, CSIRO and Bureau of Meteorology, Australia, p. 156.
[53] Coast Protection Board Policy Document: revised 29 July 2016, p. 16.

5.3 Methodology

To evaluate the nature of the exposure within the coastal cells we utilise the following procedure:

1. Identify the impact of previous storms,
2. Analyse the impact of storm surge events,
3. Analyse the impact of routine high-water events,
4. Assess these impacts in the context of scenarios for 2050 and 2100.

5.3.1 Identify the impact of previous storms

The analysis of previous storms provides a window into the past to assist us to identify where the coast is most vulnerable. In some ways, storms are 'natures' vulnerability assessment of how resilient our coast currently is, and how it may respond in the future. Brian Caton (2007) also encapsulated the importance of studying the impact of storms when he noted, 'recession of the [shoreline] will not be regular over time, but will occur with the failure of the beach and foredune to fully recover from individual storms or a series of storm episodes'[54].

The procedure included:

- Identify significant storm events from the past,
- Locate storm accounts and photographs from the community, Council and Department of Environment and Water (SA).
- Analyse the impact of the storm and where possible, identify sea-flood heights.

5.3.2 Analyse the impact of current 1 in 100-year storm surge scenario.

This project analyses the impact of storm events within a high-resolution 3D model that takes into account: storm surge height, wave setup, and wave runup (See Figure 21 above). The inputs for the modelling came from two main sources.

1. Coast Protection Board

Coast Protection Board has assigned sea-flood risk ratings for the Onkaparinga coastline using three categories of storm dynamics: storm surge height, wave set-up, and wave run-up (Table 4).

Table 4: Coast Protection Board sea-flood risk level for Port Noarlunga, Moana, and Sellicks Beach.

AHD	*Port Noarlunga*	*Moana*	*Sellicks*
Storm surge (1 in 100 ARI)	2.30m	2.20m	2.20m
Wave setup	0.40m	0.40m	0.40m
Wave run-up	1.00m	1.00m	1.50m
Total risk height	3.70m	3.60m	4.10m

Source: Email James Guy, DEWNR, 13th October, 2017.

[54] Caton, B (2007), The impact of climate change on the coastal lands of City of Onkaparinga.

Coast Protection Board uses 1 in 100-year average return interval methodology which means in terms of probability, the event described would only occur one time in every 100 years. However, nature does not read our probability charts and this event could occur in shorter time scales. For example, the fifth and sixth highest events on the all-time record for Outer Harbor occurred within the months of June and July in 1981.

2. Storm event 21 November 2018

To provide a more fine-grained basis for the modelling the *wave run-up* figures in Table 4 were not utilised but wave run-up figures were obtained by surveying the location and height of seaweed strands of the storm on 21 November 2018. This storm occurred when the tidal cycle was in the lower range and therefore had only moderate impact, but the wave effects were significant. The wave effects applied to each coastal cell are recorded in Appendix 3. See also report, *Extreme event analysis: Port Noarlunga to Sellicks Beach for 21 November 2018*, for full explanation of methodology and results. Sea-flood modelling for the current 1 in 100-year event was created within the 3D model for each cell using the inputs described in Appendix 3. Examples for Moana and Port Willunga are provided below (Figure 25).


Figure 25: Current 1 in 100-year sea-flood scenario for Moana Beach and Port Willunga (M. Western).

5.3.3 Identify the impact of routine highwater scenarios

While storm surges can have a significant impact on the coast, these by their very nature are rare events. Routine tidal action is likely to have a greater impact on the general form of the beach and backshore over time, especially in the later part of the century if seas rise as projected. In this project, routine high-water events are currently expected to occur a few times a month from April to September. Any rise in sea levels will increase the frequency of the impact. Inputs are based upon:

- Tide gauge data from Onkaparinga River footbridge (May to October 2019),
- Tidal study utilising mechanical tide gauges and direct observation at Sellicks Beach and Maslin Beach (August to October 2019),
- Seaweed strand analysis from the moderate event of 23rd July 2019 (and observations),
- Mean of monthly high-water at Outer Harbor from 1945 to 2017.

The wave effects applied to each coastal cell are recorded in Appendix 3. See also report, *Routine high-water analysis: City of Onkaparinga Coastline, July to October 2019* for a full explanation of methodology and results.

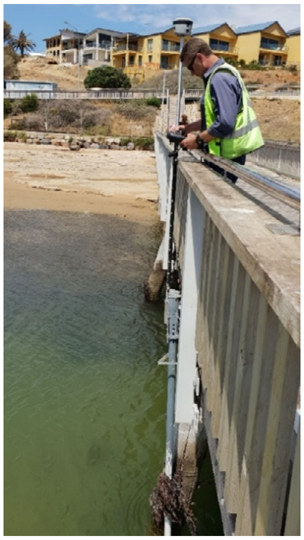

Figure 26: Levelogger tide gauge installed in tube on footbridge at Southport.

Figure 27: The float and tube manual tide gauge was installed prior to each tide data capture on the surveyed base.

Figure 28: Five-minute observations were taken over ~1 hour period at projected high tide on calm days.

5.3.4 Assess these impacts in the context of scenarios for 2050 and 2100.

Using the inputs as described in the previous section, 0.30m for scenario 2050 and 1.00m for scenario 2100 were added to the modelling for storm surge and routine high-water events. Scenario modelling of 1 in 100-year events for Moana and Port Willunga are depicted below as examples.

Figure 29: Modelling for 2100 scenario for 1 in 100-year sea-flood for Moana Beach and Port Willunga (M. Western).

5.4 General findings

5.4.1 Overview of the impact of previous storms

A more detailed review and accompanying pictures are contained within the cell reports and the companion report, *Extreme Event Analysis for City of Onkaparinga Coastline for 9 May 2016.* The three highest events on record at Outer Harbor all occurred within the decade 2007 to 2016. The height of the storm surge for these events was 1.40m to 1.50m above the astronomical tide.

- 4 July 2007 (2)
- 25 April 2009 (3)
- 9 May 2016 (1)

One additional event was identified in 1981 which removed the sand spit at Southport. In reality there were two events that occurred within consecutive months – June and July. These events still stand as the fifth and sixth highest since records began in 1940 at Outer Harbor.

Figure 22. Photograph: Southport sand spit, Dave Manzdorf, 1981. It is unknown as to when this photograph was taken but presumably it is of the second event or after the second event as the sand spit has already been removed at the time of capture. (Photograph supplied by Sue Bennett, Midcoast Surfing Reserve).

<u>4 July 2007</u>

The 4th July 2007 event was the second highest on record at Outer Harbour. The archives at Department of Environment and Water recorded impacts from only two locations – Moana and Seaford Cliffs. At Moana wave runup undermined the slope under the carpark and caused a landslide (Figure 23) and a beach shelter forward of the seawall was destroyed. At Seaford Cliffs (Tiller Drive), the increasing height of the erosion scarp was first noticed in this event (Figure 24).

Figure 23. Increasing height of erosion scarp first noticed in event 4 July 2007 (Department of Environment and Water).

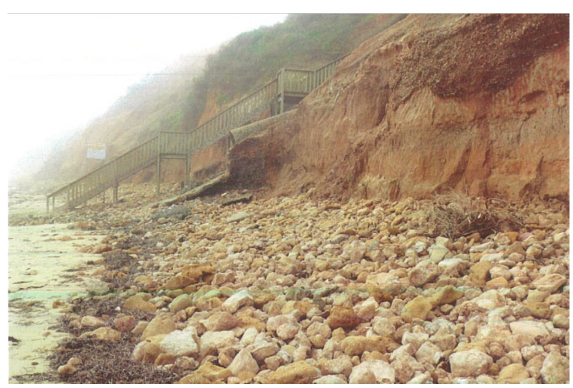

Figure 24. Increasing height of erosion scarp first noticed in event 4 July 2007 (Department of Environment and Water).

Project note: late in the preparation of this report it was found that inundation also occurred within the Moana Tourist Park and that there was general concern at the time regarding low sand levels, and the vulnerability of the foreshore and Surf Life Saving Club (See Cell 6, Moana Beach).

9 May 2016

The findings for this event are recorded within *Extreme Event Analysis for City of Onkaparinga Coastline for 9 May 2016* which analysed the event at four locations: Port Noarlunga, Onkaparinga River, Moana, and Port Willunga. The flood heights determined within the Onkaparinga River and Pedler Creek are used as the basis of modelling for those estuaries.

Port Noarlunga

The height of the flood waters was accurately identified as 2.35m AHD between the footbridge and Saltfleet Street (Figures 25,26).

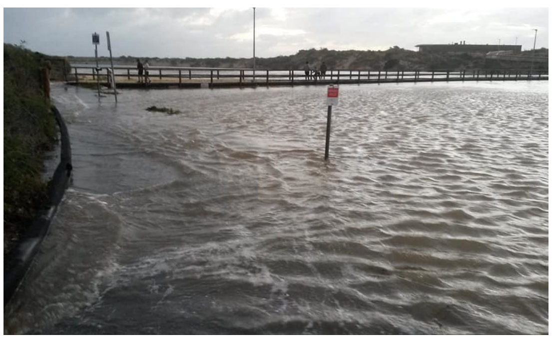

Figure 25. High tide, 17:30, 9 May 2016 Photograph: Sue Kenny (Mid Coast Surfing Reserve).

Figure 26. Tide receding but debris marks the high tide mark Photograph: Darren McPhail (Mid Coast Surfing Reserve).

The characteristics of the storms general impact was observed at Port Noarlunga and the wave height identified as ~2m.

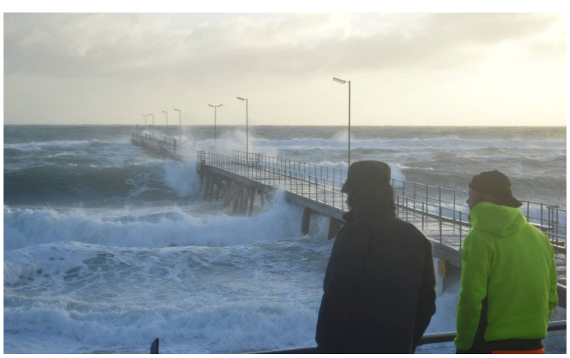

Figure 27. High tide, 17:30, 9 May 2016. Photograph: Ray Palmer (Mid Coast Surfing Reserve).

Figure 28. High tide, 17:30, 9 May 2016. Photograph: Ray Palmer (Mid Coast Surfing Reserve).

The impact on Southport spit. The photograph on the right is from the event of 28 September 2016. Anecdotes from Council report that follow-up events were just as damaging due to earlier erosion.

Figure 27. Event 9 May 2016. Photograph: Sue Kenny (Mid Coast Surfing Reserve).

Figure 28. Event 28 September 2016. Photograph: Ben Tazer (Mid Coast Surfing Reserve).

Moana

The height of the flood was accurately identified in Pedler Creek at 2.50m AHD but this is likely to include an increase height over storm surge level due to narrowing of creek banks. Sandbags were required at the front of the Surf Life Saving Club.

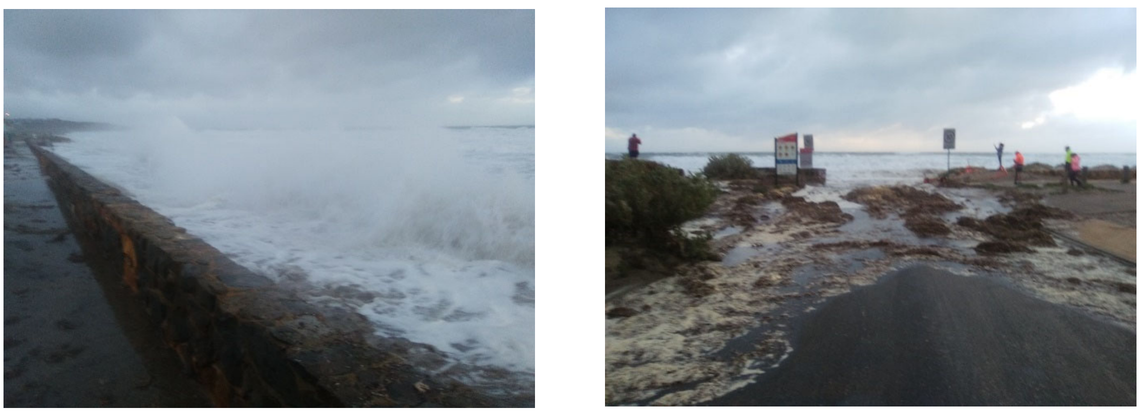

Figure 29. Storm event 9 May 2016, 1730. Photographs by M. Western. Survey height within Pedler Creek was 2.50m AHD

Port Willunga

The impact on the cliffs at Port Willunga was significant. Photographs from the event 25 April 2009 appeared to have a similar impact.

Figure 30. Photograph: Mr Adamson, 9 May 2016, ~17:25

Figure 31. Event 25 April, 2009. Photograph: Diana Motteram.

5.4.2 Analyse the impact of the various storm surge and routine high-water events

The impact of the various scenarios depends largely on the nature of the beach and backshores and this is analysed in a fine-grained manner within the cell reports. It is acknowledged that for scenarios 2050 and 2100 that we have superimposed future exposure upon existing fabric in the 3D model. If seas rise as projected, then the fabric will change more slowly over time. Additionally, fine grained erosion modelling has not been conducted as part of this project. However, we have two case studies from either end of the coastline. At the Washpool Lagoon, P. Hesp estimated erosion by 2100 as between 26m to 43m. D. Fotheringham (DEW) estimated that the sand dunes to the west of the Surf Life Saving Club at Southport would recede 35m by 2100. In summary:

Current scenarios

- The modelling of routine high-water events reveals virtually no impact. This is an expected finding because it is the routine actions of the sea that have formed the current beach and backshores.
- The modelling of the current storm surge events reveals a similar impact to 9 May 2016. The historical analysis showed that for the majority of the coast beaches and backshores reform over time. In cliff areas such as Seaford Cliffs, the recession and steepening of the cliffs will continue to be exacerbated.

2050 scenarios

- The combination of routine high-water events and the rarer storm surge events will cause some recession in softer sediment backshores (likely to be measured in metres, 5-12m).
- This combination will cause undermining and recession of soft sediment cliffs and sloping shores that will contribute to instability in the top regions of the cliff.
- Within backshores that cannot recede due to human intervention or are cliffs of harder constituency (such as limestone), sand levels are also likely to decline.

2100 scenarios

- If seas rise as projected, then the scenarios for 2100 can only be described as catastrophic for many areas of the coastline. Recession in soft sediment backshores are likely to be measured in decametres (at least 2-3 in most locations). It is not possible to identify how some of the harder limestone rock cliffs will react to significant increases to ongoing actions of the sea but increase undermining, landslides and rock falls are likely.

5.5 Implications for coastal adaptation

The implications from the above findings in the context of coastal adaptation include:

1. South Australian Coast Protection Board has adopted sea level rise policy standards of 0.30m sea level rise by 2050 and 1.0m sea level rise by 2100 compared to levels in 1990. These policy standards are based on the assessments of the Intergovernmental Panel on Climate Change (IPCC) and are congruent with IPCC sea level rise projection scenario for RCP 8.5.

2. Nature Maps (SA) assesses the exposure of City of Onkaparinga coastline within the context of South Australian marine waters as: *moderately exposed* with *low wave heights*. This general assessment, and in the context of more fine-grained analysis within the coastal cells, provides the second input for the assignment of the inherent hazard risk rating.

3. The storm of 9 May 2016 almost coincided with 1 in 100-year risk level and provides a useful context to consider existing and future vulnerabilities.

4. City of Onkaparinga will generally not be exposed to inundation risk from rising sea levels apart from areas such as Onkaparinga estuary, Pedler Creek, and the Washpool Lagoon.

5. Routine high-water events and the rarer storm surge events are likely to have the following impacts on the coastlines by 2050:
    - Soft sediment plains and slopes – recession of the shoreline (measured in metres).
    - Soft sediment cliffs – undermining of the base of the cliff, steepening slopes, increased stability of base and top of cliffs.
    - Harder cliffs (e.g. limestone) – increased rate of undermining, increased landslides and rock falls.
    - Human intervention – where backshores have been changed to hard surfaces (rock and seawalls), sand levels are likely to decline on the beach.

6. Routine high-water events (occurring at much higher rates than current) and storm surges (occurring at higher sea levels) are likely to have the following impact on the coastline by 2100 if seas rise as projected:
    - Soft sediment plains and slopes - recession of the shoreline measured in decametres (at least 2-3).
    - Soft sediment cliffs – significant recession of the cliffs and ongoing instability.
    - Harder cliffs (e.g. limestone) – increased rate of recession (but rate not known).
    - Human intervention – in many places the current intervention in backshores will unlikely to be adequate (for example: Moana, Port Noarlunga, Christies Beach).

6. Storm water runoff from urban settlements

The purpose of this study is to evaluate the impact of storm water that flows from urban areas to the coast. Large volumes of rainwater can quickly accumulate and flow from the impervious surfaces of urban settlements. Storm water flowing over softer cliffs can cause gullying and instability at the top of the cliffs. Storm water rushing out to the beach can cause gullying of the dunes or embankments and scouring of the beach. Over time cliffs, embankments and dunes break down and sand levels are likely to drop on the beach.

In the context of sea level rise, the locations where storm water is impacting beach and backshores are likely to be the first points along the coast that become vulnerable. Additionally, as noted by Caton (2007), if shorelines recede, then storm water infrastructure is prone to be left forward of the coastline. This has already occurred in places such as Seaford Cliffs as a result of the storm on 4 July 2007 (end of Tiller Drive) and at Aldinga Reef (in the vicinity of Quinliven Road) where the cliff has receded over time.

6.1 Scope of the assessment

The scope of this assessment is limited to answer three questions. Are storm water flows from urban environments adequately controlled so that:

- Storm water flows do not flow over coastal backshores (dunes, slopes or cliffs) in an uncontrolled manner that is likely to cause gullying and/or erosion?
- Storm water flows do not cause detrimental scouring or lowering of beach levels?
- Outlets are not positioned too low or too close to the shoreline so that rises in sea level will impact these in the future[55]?

The following limitations apply to this study:

- The assessment is concerned only with water flowing from urban environments because this is the responsibility of the Council to control and therefore a liability also exists.
- The project is not concerned with assessing the adequacy of the current storm water system in terms of matters relating to volume, velocity, current sediment and pollution controls, unless observations on beaches and backshores indicate a potential problem.
- The project recognises that in some cases draining storm water to the coast is unavoidable and that some scouring of beaches will occur. The question here is to what degree and how permanent is the scouring.
- In the context of a broad scoping project the assessment tends to be qualitative and based only on direct observations.

[55] Caton, 2007, observed that erosion caused by sea level rise could leave storm water outlets stranded forward of a receding coastline and that it was important to control storm water flows in backshores.

6.2 Methodology

1. An inspection of each outlet was conducted, and photographs captured at the beach level to assess:

- The nature of the outlet,
- The condition of the outlet,
- Evidence of scouring or other effects on backshores.

In relation to the last point, it is recognised that the assessment took place at the end of summer in 2019. However, follow-up inspections of selected locations were undertaken in July 2020, at the time of rainfall episodes and about 2 weeks after. The timing of the inspection is deemed appropriate to analyse how beaches rebuild after rain events. It was assumed from the selected inspection points that the findings would be applicable to other locations.

2. Review the storm water system within Geographic Information System (GIS) software to:

- Identify the approximate catchment and the scheme of the general flow of storm water,
- Identify any areas of low beach levels in the vicinity of storm water outlets that may be caused by storm water outflow, but also may be vulnerable to sea-flooding in storm events.

3. Inspection from the crest of coastal backshores to identify any areas of the coast where storm waters may be flowing from urban environments into backshores. This inspection was relatively easy due to the predominant urban layout of an esplanade road positioned between the coast and urban development.

6.3 General Findings

1. In general, Council is effectively managing the flow of stormwater from urban environments to prevent uncontrolled flows through coastal backshores. Effective measures include:

- Creating stormwater systems that flow away from the coast (where possible), and are collected and managed, and then piped in various directions (sometimes towards the coast, other times into river and creek basins etc).
- Kerb and gutter have been installed to esplanade roads in all parts of the coast apart from the esplanade roads between Aldinga Beach carpark and the Washpool Lagoon.
- In locations where Council has been making improvements, outlets are being placed further up coastal slopes and rip rap rock (and similar methods) utilised to disburse the energy of the water. Without commenting in a technical sense as to the efficiency of the methodology in dealing with storm water, the principle appears valid in the context of the potential for shorelines to recede, and even in the context of natural variability where a range of shoreline positions may occur over a period of decades.
- Detention systems at Sellicks Beach, Port Willunga, Maslin Beach, and the Washpool Lagoon (which separates storm water flows from natural flows) are all improvements to deal with storm water flows to the coast. Upgrades to some end controls were observed.

2. Locations where storm water controls may require attention:

- Aldinga Beach, Lower Esplanade Road (near Quondong Ave)

No kerb and gutters are installed between Aldinga Beach carpark and the Washpool Lagoon. Generally, this area is flat, and water appears to run off in a dispersed pattern that doesn't scour dunes and backshores. However, in steeper sections of Lower Esplanade Road, storm water appears to be running from the road reserve and scouring the coastal scope between the road and the beach. Additionally, just north of the amenities block an outlet is positioned adjacent the road. Stormwater flows have created a gully between the road and the beach which is covered by vegetation. Storm surge modelling for the 2020 scenario indicates that sea water would flow into this gully causing increased erosion and further breakdown of the slope.

- Aldinga Reef (end of Butterworth Road).

Inspection within a rain event revealed that the current sandbag system in the gully appears to be about to fail (or at least inadequate to control storm water flow). Storm surge modelling for 2020 shows that sea water would enter this gully.

- Moana Beach, The Esplanade (end of Fourth Ave)

The difficulty of managing storm water flows in the vicinity of Fourth Ave is recognised. The current strategy for draining storm water is through a spoon drain, and then through a channel under the footpath and seawall to the beach. It was observed that in rain events the area around the spoon drain is flooded on the road and scouring occurs on the beach. In a storm surge event, water flows back under the seawall and floods the road. It is outside the scope of this project to do further than observe that it is likely that a long-term solution will need to be found in the context of rising sea levels. However, it is also important to recognise that the scenario modelling for 2100 indicates that the current layout of Moana would not be viable if seas rise as projected (see Cell 6).

- Moana Beach (Pedler Creek)

Previous projects have focussed attention on Pedler Creek catchment:

  - A detention pond system has been installed on the eastern side of Commercial Road (date unknown),
  - Flood plain modelling completed by Tonkin Consulting (2009),
  - Storm water management design by AWE (2011).

This project has analysed the impact of sea-flood scenarios into Pedler Creek for 2020, 2050, and 2100. Tonkin Consulting analysed rainfall flood scenarios that also took into account the 1 in 100-year sea-flood event but concluded that the impact of storm water flow effectively 'drowned out' the sea-flood event within 100m of the coast. It is also generally acknowledged that the meteorological conditions that produce high rainfall do not coincide with the meteorological conditions that produce storm surges. However, as noted in the review of the storm surge event on 4 July 2007, this event appears to have coincided with some storm water flows which combined to produce flooding within the Moana Tourist Park (See Exposure section, Cell 6). The storm surge modelling for 2020 does not produce flooding within Moana Tourist Park, and therefore the risk of flooding within the park is likely to be higher than modelled.

- Christies Beach (end of Beach Road).

It is acknowledged that at this location is significant storm water infrastructure. The purpose within this report is to inform that storm surge modelling, and future routine highwater modelling indicates that sea water will be able to enter the storm water system.

3. Infrastructure requiring upgrade (in particular end controls).

The main data source for Council to evaluate individual storm water structures at the beach level is the data set of photographs and assessment notes that have been uploaded into the 3D model. Individual cell reports also provide a photograph and assessment where infrastructure may not be operating to optimum levels.

6.4 Implications for coastal adaptation

1. In general, City of Onkaparinga is managing the stormwater run-off from urban environments so that erosion in backshores is avoided. A few exceptions exist and these locations are either vulnerable to flows from current storm surges or will likely become increasingly vulnerable if seas rise as projected.
2. In a few locations, stormwater outlets are set at low elevation and are vulnerable to seawater inundation (Fourth Ave, Moana Beach is the most significant example).
3. In soft sediment backshores, coastal recession will leave some stormwater outlets stranded forward of the shoreline. This point was noted by Caton (2007) and Council appears to be progressively taking this factor into account.

7. Hazard impacts and risks

7.1 Overview

South Australian Coast Protection Board considers three main coastal hazards: inundation, erosion, and sand drift. Due to the nature of the City of Onkaparinga coastline, only the first two are under consideration in this project.

It is the combination of the characteristics of the coastal fabric and the nature of the exposure that determines the degree of hazard risk (Figure 32). This reality is most simply understood when considering inundation risk. Whether a coast is at risk from inundation depends entirely on the topography of the coast. If we explain this another way, a low-lying coast is *inherently* more at risk to flooding whereas an elevated coast is *inherently* not at risk from flooding.

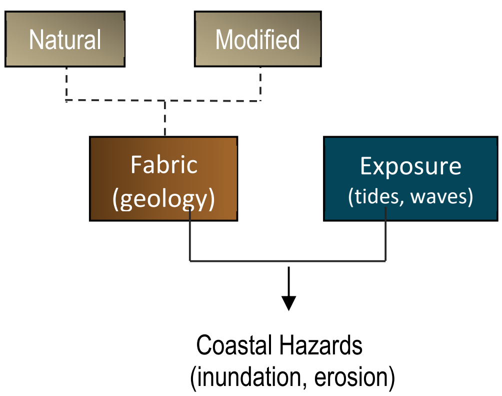

Figure 32. Conceptual framework for assessment (Integrated Coasts)

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

The application of an inherent risk rating does not suggest that areas rated as 'low' are entirely free from vulnerability, nor conversely that areas rated more highly are necessarily vulnerable now. The aim is to assess the underlying inherent vulnerability of the fabric of the coastal location.

The output from the assessment has been designed so that it is easily accessible to all stakeholders.

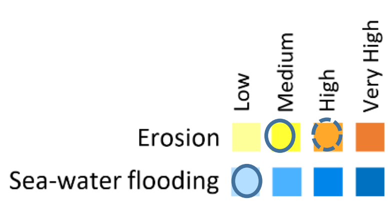

Figure 33. Example output from inherent hazard risk assessment that has meaning within South Australian coastlines.

7.2 Methodology

The assessment of hazard impacts and risks is undertaken in three main steps.

7.2.1 Assign an inherent hazard rating

Erosion

Inherent hazard ratings for erosion were applied in workshops held on 12 and 13 December with two geologists who specialise in coastal geomorphology: Dr Robert Bourman and Dr Graziela Miot da Silva. The assessment was undertaken for each cell (or minor cell if applicable) using a worksheet that followed a set process (refer to the worksheet in Appendix 4):

1. Assign an erodibility rating
2. Is any amendment required due to human intervention?
3. Apply an exposure rating
4. Assess historical impacts on backshores
5. Assess any influence from benthic characteristics
6. Assess the sediment balance
7. Assess any other factors that may warrant a change to the rating.

Inundation

Inherent inundation ratings are much easier to apply as these depend on the topography of the land in the coastal region. The assessment is applied from the chart below which takes into account any historical flooding as well.

Table 5: Inherent hazard rating assessment for inundation

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

The aim of the assessment is to provide an assessment that has meaning within the entire State of South Australia. We therefore expect to see some commonality within the inherent hazard ratings in a particular region. For example, we would expect to generally see higher inundation hazard ratings in the upper regions of the gulfs where land elevations are low, and we would expect to see higher inherent erosion ratings in locations along the Southern Ocean.

7.2.2 Describe hazard impacts upon urban settlements.

In this study we are primarily concerned with the way that coastal hazards may impact urban settlements over the coming century. How inundation and erosion impact human settlement will vary according to location. For example, at Moana Beach, on the northern side of Pedler Creek, public infrastructure is positioned close to the shoreline. However, located just a hundred metres to the south is the Moana Sands Conservation Park which has no infrastructure. While the impact of sea level rise may be somewhat uniform on a coastal region such as Moana, the impact will be felt differently in the context of human settlement. In the first instance, significant public infrastructure may be under threat, whereas in the second instance, ecosystems may be under threat.

To bring appropriate focus, hazard impacts are described within four main receiving environments:

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

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

The aim in this assessment is to use the inherent hazard ratings assigned above and describe the likely impacts in each cell (and minor cell where applicable).

7.2.3. Conduct risk assessment using the risk framework of City of Onkaparinga.

The final step is to conduct a risk assessment using Council's Risk Management Framework which utilises 'likelihood' and 'consequence' methodology in the context of the various risk categories[56]. Risk assessment is completed for current outlook, but also for the future outlook at 2100. It is recognised that values and parameters of risk assessment will have changed by 2100, but the procedure does produce meaningful outputs. In particular, the two risk eras provide a useful context to understand the trend of a coastline. For example, in one area of coast the immediate backshore may be high enough that inundation is not a risk in this current era and all of the risk indicators are assigned as low. However, the scenario modelling may demonstrate that a tipping point is reached sometime in the future and inundation may flow over the immediate backshore and flood lower lying areas behind. Within the City of Onkaparinga, the Onkaparinga River is an example where the existing levee system is likely to protect the majority of the township until ~2070, but after this time period, flood depths are 1m to 1.60m within the township.

The risk assessment can be produced for inundation or erosion. However, due to the elevated nature of Council's backshores, the inundation hazard risk assessment is only completed three times in this project: Port Noarlunga township, Pedler Creek at Moana, and the Washpool Lagoon at Aldinga.

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[56] City of Onkaparinga, 2020, Risk Management Framework.

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.

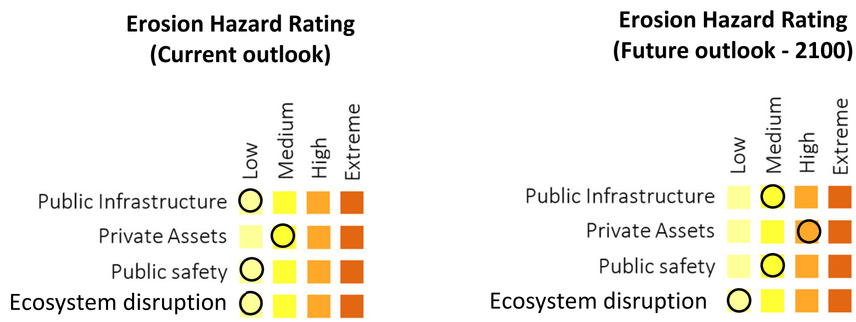


Figure 16: Risk assessment conducted within receiving environments (Example outputs for erosion. Inundation risk assessments are conducted in blue tones)

7.3 General findings - Hazard impacts

Specific hazard impacts are recorded within the cell reports. A summary of hazard impacts is also available for immediate review in the Cell Snapshot Summaries in Section 10 of this report.

Inundation

Generally, the coastline of Onkaparinga is set well above sea-flood risk. Exceptions are the Washpool, Pedler Creek (where the caravan park is vulnerable), and Onkaparinga River (flood modelling indicates that the current levee system is too low, and ~2070, the township is likely to be extensively flooded. Note some areas are already subject to flooding – Saltfleet Street, and the carpark on the north side of the river).

Erosion

Within locations of soft sediment backshores in low lying areas the recession will be significant (Moana, Aldinga). In locations of soft sediment cliffs, the issue is likely to be serious, especially if infrastructure is located near to the crest of the cliff (Aldinga Reef, Seaford Cliffs). Some area will be afforded longer term protection (Sellicks- Aldinga where pebble ridge will slow erosion). In locations where humans have placed hold points (seawalls), or nature has placed hold points (harder cliffs) sand levels in these regions are projected to drop with the possibility of the loss of some beaches (Port Willunga, Port Noarlunga, Christies Beach). It is not known how an area such as Port Noarlunga-Southport will respond to higher sea levels. In places of harder cliffs such as Port Willunga, the undermining of the base of the cliffs could be expected to accelerate, with accompanying increases in landslides and rock falls.

8. Recommendations

The recommendations listed are limited to those that apply to the whole coastline of City of Onkaparinga. For recommendations that relate to individual cell locations refer to the cell reports.

1. Develop a coastal adaptation plan to provide a framework for future decision making that considers the following factors:

- The coastline has been largely stable over a 70-year period,
- The coastline undergoes periods of accretion and erosion which are now better understood,
- Of the four hazard impact categories, the main threat is to public assets,
- In most cases, the threat to these assets is related to sea level rise that occurs in the decades ahead, or even in the latter part of this century,
- Decisions about public assets need to consider long time periods.

<u>Rationale</u>

There are four receiving environments upon which coastal hazards can impact: public assets, private assets, public safety and ecosystems. In City of Onkaparinga:

- Private assets are normally positioned landward of public assets,
- Eco-system disruption is not projected to be a major issue in the context of sea level rise,
- Public safety in coastal regions is predominantly controlled by the location and nature of public assets (ie where roads, carparks, accessways, and fencing are positioned).

Therefore, an adaptation plan is recommended to manage the public infrastructure that is positioned behind the shorelines. In the City of Onkaparinga this area is zoned as 'Coastal Conservation' or similar. Locations assessed as 'high' or 'very high' for either the current outlook of the long-term outlook will assist in prioritising the adaptation planning.

<u>Examples</u>

The following are examples to provide light on the concept, not to be definitive about these assets:

- The proposal for upgrade to footpath, kerb and gutter for Saltfleet Road could have considered a design alternative that would have catered for flooding from the river. To design and construct both in the same project would have been a cost-effective approach.
- Walkways and carparks are often placed close to the crest of the cliffs in the Seaford region. An overarching plan designed to relocate these landward could be implemented over the next 20 years when upgrades to these assets were required. In the context of sea level rise, managed retreat would allow the cliffs to find equilibrium in their slopes and reduce the expenditure required to protect the assets.
- The lower carpark at Maslin Beach is set within sand dunes and 25m from the shoreline. When upgrades are required to the carpark, consideration could be given to removing three banks of carparks and increasing the distance from the shoreline to 50m.

This adaptation plan is likely to take the form of upper level master planning that lays out broad options at the beginning, and these are developed further as the need arises.

2. Prepare a community engagement strategy that reports the findings of this study. The approach to community engagement could include opportunity for feedback and comment about the findings of the study, and then a process that enables community input into coastal adaptation planning, including the various options identified at (1).

3. Develop a long-term coastal monitoring strategy that improves knowledge about how the coast operates, including the impact of storms, but also to provide warning when the coast may be operating outside of its normal parameters.

Rationale

Caton (2007) noted that the impacts of sea level rise are likely to be experienced along the Onkaparinga coast in the context of storms (or a series of storms) from which the coastline does not recover. It makes sense then that the impact of storms should be monitored closely. This is likely to serve two purposes. First it will assist Council with repairs and maintenance but will also provide warning when a coastline is coming under increased threat. Early detection is likely to save significant cost rather than waiting until major infrastructure is threatened.

Just as important will be to monitor shoreline position and beach profiles over time (Caton, 2007) and erosion and instability trends in cliff areas (GHD, 2016).

Monitoring methods include:

- Comparison of newly captured aerial photography,
- Analysis newly captured Coast Protection Board profile data,
- Recapturing the 3D digital model and make digital comparisons (especially useful for cliff and slope assessment),
- Photographing the coast after storm events using drone technology and making a desktop assessment of any changes or impacts to the coast,
- Utilise a 'citizen science' approach for the capture of photography in storm events from designated monitoring positions,
- Annual site inspection of areas where undermining or gullying are occurring (if applicable).

4. Investigate storm water flows from the urban storm water system to further identify what impact this is having on beaches and coastal slopes (Caton, 2007).

Rationale:

This project has inspected storm water outlets and generally found that minimal scouring is occurring on beaches and backshores. The first inspection was undertaken at the end of summer 2019, and a follow up inspection was conducted within most cells in August 2020. It was observed that in most cases beaches recover quite quickly from scouring caused by storm water.

Methods:

A cost-effective way to manage this aspect is likely to be within the coastal monitoring program mentioned at (2).

9. Limitations and further research

9.1 Recognised limitations of this study

1. Due to the need to find a balance between finding an appropriate resolution for reporting of historical analysis and scenario mapping and reviewing as much coast as possible, it was not possible to report on every section of the coast. However, priority has been given to locations where significant infrastructure exists, or where it was observed that changes or impacts were more significant. In some circumstances, the location was dependent on the availability of photographs of reasonable resolution and accuracy. Additionally, the data sets are available within the GIS environment of the Council so that analysis can be undertaken at any location and at any resolution.

2. It is recognised that when we produce scenarios for 2050 and 2100, that we are superimposing future actions of the sea (that incorporate sea level rise) over the layout of the existing fabric of the coast. Changes in the fabric of the coast will occur over long periods of time. However, the scenario mapping does provide a way to visualise and assess the likely impact in the context of the nature of the backshores (ie characteristics and erodibility). This visualisation will be especially useful when communicating risk and outlook with stakeholders and members of the public.

3. Erosion modelling was not part of the general scope of this project. Erosion modelling was produced at the Washpool Lagoon (26-43m) as part of this project and erosion modelling was completed earlier by Department of Environment and Water for the sand dunes west of the Surf Life Saving Club at Southport (35m). The fact that these are on opposite ends of the coast and slightly different in nature provided a context from which to consider the whole coast. However, there are a myriad of backshores with different slopes and constituency. Therefore, rather providing a definitive outlook for the amount of recession, assessments were given more broadly. For example:
    - 2050 – erosion likely to be measured in metres (5-15)
    - 2100 – erosion likely to be measured in decametres (at least 2-3).

    We are of the opinion that erosion modelling for the whole coast is not warranted due to the high cost and significant challenges that exist in quantifying erosion until 2100 with the large number of variables involved in the calculation. Erosion modelling is more effectively utilised in the context of a specific issue at a specific location.

4. The risk assessment conducted utilising City of Onkaparinga risk assessment framework contains two challenges. First, It is very difficult to assign risk ratings to public safety issues, especially in the context of the potential for a rock fall or landslide of any particular size in the context of the low probability that someone will be standing in the vicinity when it occurs. GHD, 2016 recognised this issue in their risk assessment methodology by abandoning the 'consequence' side of the assessment and only reporting how 'likely' a rock fall or landslide might be to impact the public. We are of the opinion that this is a much more

effective way to attribute risk in these circumstances and in future we would adopt the same methodology for public safety issues. In any case, this project defers to GHD, 2016 in cliff locations. The second challenge relates to assigning risk to events at 2100. It is recognised that in practice this involves making assumptions about a large range of variables. However, the aim of the assessment is to provide an 'outlook' and we feel that containing the risk assessment to Council's framework is an advantage for interpretation and context. In practice the methodology appears to produce meaningful outcomes. Additionally, tying assessment to a particular Council means that assessments can be contextualised appropriately to the size and budget for various councils. For example, the cost of one incident at City of Onkaparinga may be judged as minor, whereas in a smaller rural council the cost may in reality be judged a much greater risk within a smaller budget.

9.2 Further research

Areas that may require further research are listed here. These items are in addition to specific recommendations made within the various cell reports.

1. One area that has not been reviewed in this project is the implications of increasing residential density in locations that are in close proximity to the coastline. If rapid erosion should occur which places private dwellings, or access to those dwellings at risk, how would the legal system view the decision to increase density in coastal area.

2. Various data gaps are missing from the flood analysis for Port Noarlunga township (i.e. flooding from Onkaparinga River).
    - Finished floor levels of various buildings and structures on either side of the levee system, and in particular the impact of flooding on Sauebier House which is positioned outside the levee system.
    - Further investigation is required as to whether water can flow through to River Road on the north side of the flood plain (dense undergrowth in the area means that the digital elevation model is less reliable).
    - Further investigation as to possible minor inundation in the sports ground area (River Road) for the current 1 in 100-year flood risk scenario.

10. Cell summaries (snap shots)

The following pages contain summary pages for each minor cell. There are twelve cells within the study, and in all, 30 minor cells.

Cell 1 – Lonsdale Region

Cell description:

The Lonsdale Region cell is characterised by 30m hard rock cliffs with10 – 40m wide shore rock platform at the base, and with sand at rear of platform in small embayments. Sub-tidal reefs exist within the nearshore zone. Slopes, cliff and platform are composed of resistant sedimentary strata and are not easily undermined by shoreline erosion and

Coastal history

As expected with the resilient nature of the fabric in this cell, there is little observable change to the coastline apart from changing levels of sand. The storm of 9 May 2016 damaged the pedestrian path that runs north from the boat ramp.

Scenario modelling

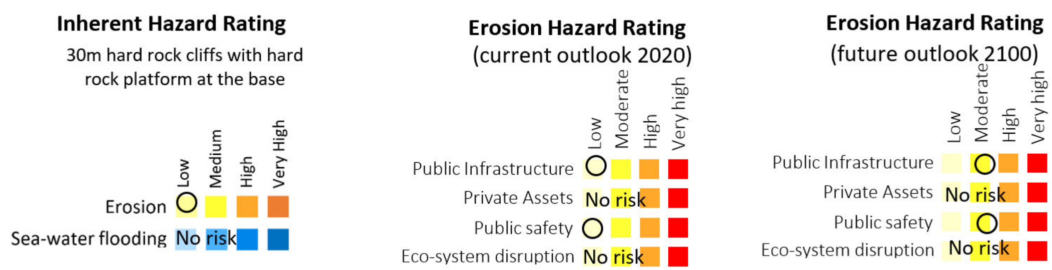
Scenario modelling for 1 in 100-year ARI storm surges for current, 2050 and 2100 demonstrate that there will be little impact in this region on backshores. The pedestrian path will come under increasing impact if seas rise as projected.

Storm water runoff

Storm water appears to flow from a limited catchment area and flows to the ocean over the rock shore platform. The outlets were not inspected as part of this project.

Overview of Impacts

Due to the resilient and elevated nature of the coastline in this cell, there are minimal identifiable impacts expected from sea level rise. GHD rates 'risk to life – individual' as unlikely and 'risk to life – societal' as unlikely.

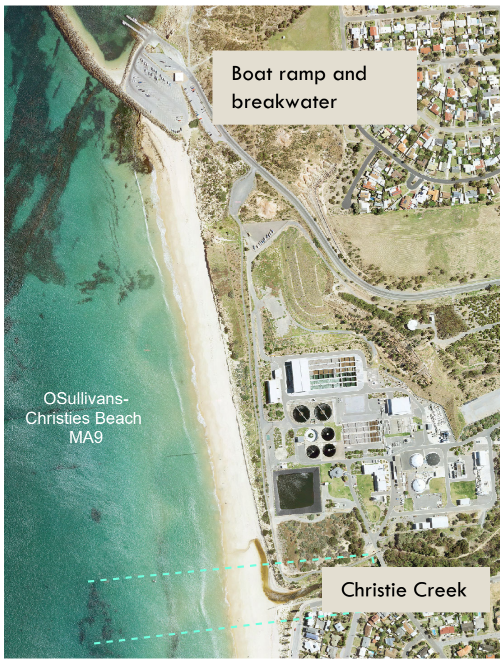


Cell 2.1 Christies-O'Sullivan Beaches

O'Sullivan Beach (2:1)

Coastal description:

O'Sullivan Beach is characterised as a sandy beach backed by dunes and soft sediments. Intertidal and subtidal are dominated by sand. The boat ramp and breakwater installed ~1980s act as a headland to this section of beach and sand is retained on the southern side of this structure.



Coastal history

Historical analysis indicates that the coastline undergoes periods of accretion and erosion. But overall the sand levels have increased in this section of coast due to the installation of boat ramp and breakwater further north. The shoreline is further seaward than in 1949/1969.

Scenario modelling

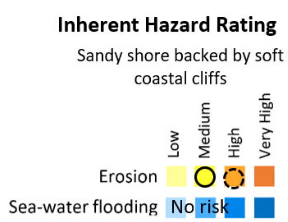
Scenario modelling indicates that wave runup from current large storm events would impact the toe of the dune, but routine tides are not having an impact. In the current era, the dunes are likely to recover and rebuild. However, if sea level rises as projected, later in this century both routine tidal action and storm surges will have high impact on the dunes. Despite higher sand levels, the dunes would be expected to recede.

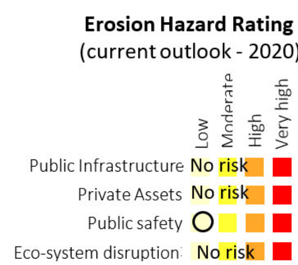
Storm water runoff

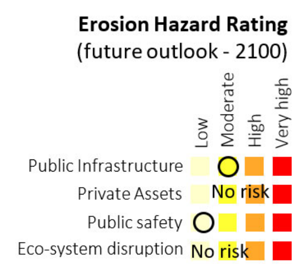
There are no storm water outlets in this location.

Overview of impacts

If seas rise as projected, the dunes can be expected to recede back towards the walking/cycling track and the Christies Beach Wastewater Treatment Plant. However, these are set well back and at higher level than the beach. It is unknown if these dunes will recede enough to impact the infrastructure but in the meantime the beach is stable, and there is an opportunity to monitor changes over time.







Cell 2.2,3 Christies-O'Sullivan Beaches

Christies Beach
(2:2,3)

Coastal description:

Christies Beach is characterised as a sandy beach backed by man-made soft earthen sloping shores with rock placed at the toe of the slopes of varying degree of constituency and height. The 300m of coastline south of Christie Creek is backed by dunes. Horseshoe Reef situated is situated 300m offshore and causes waves to refract and a small sandy cuspate headland has formed.

Coastal history

The beach undergoes a normal accretion and erosion cycle. Overall, sand levels are higher on this beach than in 1975. This may be in response to the construction of the boat ramp and breakwater at O'Sullivan Beach which retaining sand. A comparison of aerial photographs demonstrates that the once vertical cliffs were made into slopes in the 1970s. Rock placed at the toe of the embankment has held the shoreline position in the same place since installation.

Scenario modelling

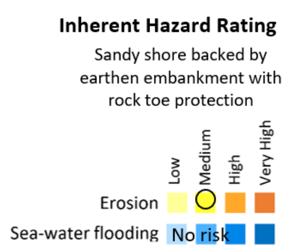
Scenario modelling demonstrates that routine highwater events are interacting with the backshore. If the 1 in 100-year event occurred now, the impact on rock and the embankment above would be significant. If seas rise as projected, then the impact of storm surges and routine high-water events will increasingly erode the embankment which is protected with rock at insufficient heights and not always at an appropriate engineering standard.

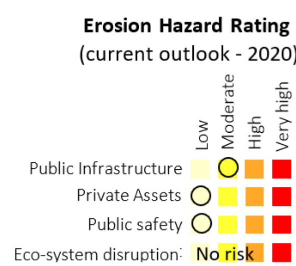
Storm water runoff

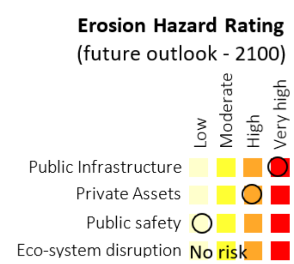
The largest storm water outlet is at the end of Beach Road and caters for a large catchment area. Five other outlets north of Beach Road service much smaller catchments. Storm water from urban settlements appears to be adequately captured and piped away from the top of the embankment and with suitable end controls. At time of inspection scouring and channelling of the beach was observed at the Beach Road outlet.

Overview of Impacts

Without an upgrade to the current rock protection, the embankment can be expected to erode and will eventually fail. Infrastructure such as walking/cycling track, carparking and the Esplanade road will be undermined. With higher sea levels interacting against a seawall, sand levels are likely to be lowered, and perhaps the sandy beach would be lost.







Cell 3.1 – Witton Bluff (north)

Witton Bluff (North)
Cell 3.1

Cell description:

Witton Bluff (north) is characterised as having no beach and the toe of the cliff protected by 760m of rock revetment. Behind the rock revetment are positioned steeply sloping cliffs and slopes. Nearshore and surf-zone is dominated by low profile reef and Port Noarlunga reef is positioned ~300m offshore.

Coastal history

A comparison of aerial photographs from 1949 to 1979 depicts the erosion problem at Witton Bluff and the subsequent installation of rock revetment and upper cliff remedial actions that took place in three main eras: 1970s, 1980s and 2000s. Periodic repairs have been undertaken of the wall and an assessment by Coastal Engineering Solutions (CES) identified where the wall may be deficient. Photographs from the early 1900s show that a rock formation called 'Table Rock' was positioned forward of the point of the bluff but collapsed into the sea in 1912 and was eroded away over a decade or so.

Scenario modelling

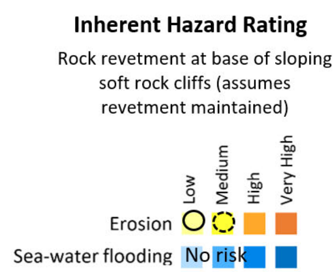
Modelling of routine highwater events demonstrates that the seawall will manage all scenarios until 2100. Two scenarios have been modelled for 1 in 100-year events using Coast Protection Board (CPB) inputs and CES inputs. Modelling using CPB inputs depicts the seawall as managing all 1 in 100-year scenarios, but these inputs do not factor in the impact of wave effects on seawalls. The modelling of CES inputs which factor in wave effects on seawalls demonstrate that the current configuration is unlikely to manage significant storm events after 2050.

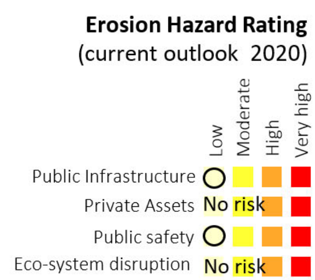
Storm water runoff

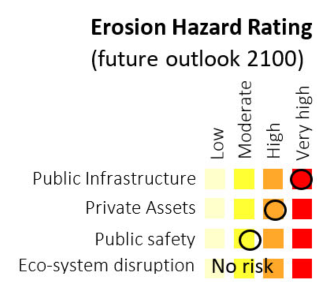
Storm water flow from urban settlement is controlled away from the cliff tops by kerb and gutter.

Overview of impacts

The assigned inherent erosion rating as 'low-medium' is dependent on maintaining the seawall in its current condition. However, if the seawall is not maintained and upgraded over time, then increasingly actions of the sea will overtop the revetment and impact the steeply sloping cliffs of varying constituency, including softer rock and sediments.







Cell 3.2 – Witton Bluff (south)

Witton Bluff (south)
Cell 3.2

Cell description:

Witton Bluff (south) is characterised as a sandy beach backed by limestone ledge overlain sloping cliffs of softer rock and clays. Nearshore and surf-zone is dominated by low profile reef and Port Noarlunga reef is positioned ~300m offshore.

Coastal history

A comparison of aerial photography from 1949 to 2017 depicts the shoreline in a similar position. Some recession of the concave areas of the limestone shelf has occurred. Minor recession (1-2m) has also occurred in the upper ridgeline. The beach undergoes a normal accretion and erosion cycle which is observed in the level of sand adjacent the base of the limestone shelf. Gullying and undermining has been observed in the upper cliff area near the road.

Scenario modelling

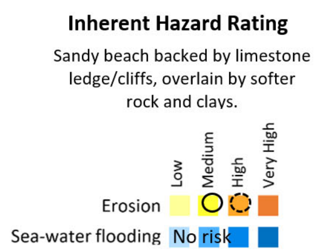
Routine highwater is interacting with the base of the limestone ledge but is unlikely to be impacting the softer cliff behind. Modelling for 1 in 100-year current risk shows that the storm surge would have high impact on the rock ledge and wave runup would flow over the ledge and interact with the cliffs behind. Scenario modelling for 2050 and beyond demonstrates that routine highwater would increasingly interact with the limestone ledge and the rate of erosion would increase. Higher levels of water due to sea level rise will increasingly interact with the softer cliffs behind and these can be expected to suffer undermining and possible slumping.

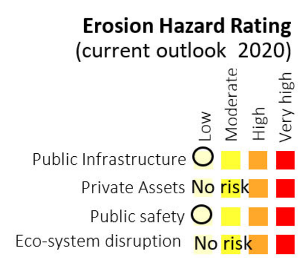
Storm water runoff

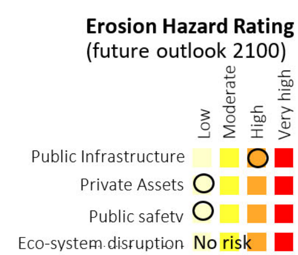
Storm water flow from urban settlement is controlled away from the cliff tops by kerb and gutter.

Overview of Impacts

The main threat that sea level rise will bring is increasing impact of storm and tidal action on the limestone ledge and softer cliffs behind which are likely to increase the potential for undermining and slumping. Infrastructure set at the top of the softer cliffs is likely to become increasingly vulnerable in the second half of this century.







Cell 4.1 – Port Noarlunga (foreshore)

Port Noarlunga (foreshore)

(4:1)

Coastal description:

Fine to medium sand beach backed by seawalls and formal promenade and buildings. Nearshore and surf-zone dominated by sand, with an offshore reef of Bridgewater formation running parallel to the beach.

Coastal history

Historical analysis demonstrates that there was a substantial dune system prior to installation of seawalls which has now resulted in a rigid and inflexible backshore. As a result, beach levels are lower in this area (especially on the northern side of the jetty). The impact of storm 9 May 2016 provides a context to understand how storms currently interact with the backshores.

Scenario modelling

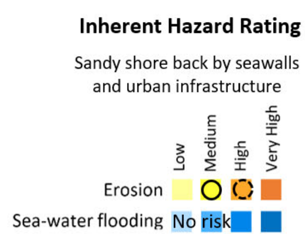
Scenario modelling for current 1 in 100-year ARI storm surge indicates that wave runup would overtop the sea walls but this event is unlikely to cause any major damage. Later in the century the modelling shows that the full energy of wave setup from routine high-water events will impact the seawalls. The impact may be higher as depth of water reduces the sheltering effect of the reef. Beach level would be expected to drop in the vicinity of seawalls and undermining would occur in the backshore area.

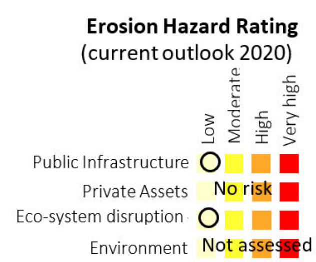
Storm water runoff

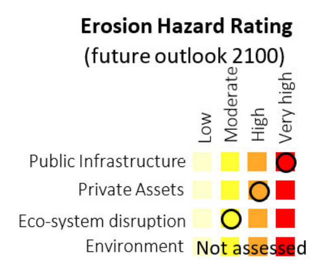
Storm water is collected from the carpark and nearby roads and piped to the top of the sloping seawall. This means that rising sea levels will not impact this outlet.

Overview of Impacts

Modelling for current day events indicates that the current design of seawalls will absorb the impact of storm events. However, as seas rise, the impact from storm surges and routine highwater events 1m higher than present are likely to prove that the current design of seawalls and protection in the area inadequate.







Cell 4.2 – Port Noarlunga (Esplanade Road)

Port Noarlunga (Esplanade Rd)
(4:2)

Coastal description:

Fine to medium sand beach backed by dune field and/or Esplanade Road. Nearshore and surf-zone dominated by sand, with an offshore reef of Bridgewater formation running parallel to the beach (~300m offshore) for much of the cell.

Coastal history

A comparison of aerial photography and beach profile lines demonstrate that the coast undergoes normal cycles of erosion and accretion. But overall, this section of coast has been very stable over a seventy-year period. The storm of 4 July 2007 damaged one beach access point, but the exact location is unknown.

Scenario modelling

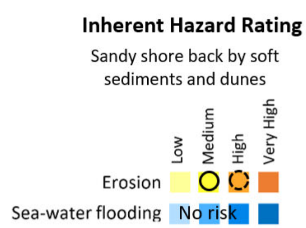
Modelling for the current 1 in 100-year indicates that the dunes under the Esplanade would experience erosion but the beach is likely to rebuild in the current era. Routine highwater events are not currently having any adverse impact on the backshore. Modelling for later in the century demonstrates that storm surges and routine highwater events will impact the base of the dunes and these will undergo recession. (However, in comparison to other places along the coast this area currently has higher levels of sand and the modelling appears to have less impact).

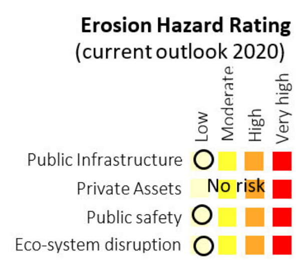
Storm water runoff

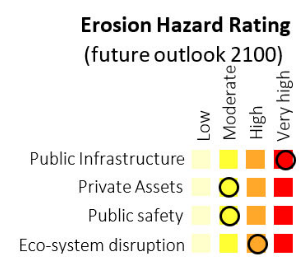
Storm water is managed efficiently with kerb and gutter so that no water from urban settlements is flowing over the embankment. One storm water drain collects water from the road and drains near the top of the embankment over an end control of rip rap rocks.

Overview of impacts

Historical analysis and analysis of current storm and tidal action demonstrates that this area is potentially vulnerable to sea level rise induced erosion. The level of protection offered by the offshore reef is likely to decline and the sediment supply and transport characteristics are difficult to predict.







Cell 4.3a – Southport (beach)

Southport

(4:3a)

Coastal description:

Fine to medium sand beach and spit near the river mouth, backed by dune field becoming more vegetated toward the north. Nearshore and surf-zone dominated by sand, with an offshore reef of Bridgewater formation running parallel to the beach (~300m offshore) for much of the cell.

Coastal history

A comparison of aerial photography and beach profile lines demonstrate that the coast undergoes normal cycles of erosion and accretion. Large storm surges reduce or remove the spit in the south (1982, 2007, 2016) but this reforms over time. This cycle has proved to be very stable for seventy years and relates to a localised sediment 'sink' formed by the interaction of wave action, river flow and bathymetry. This area does not lose as much sediment to longshore (northward) drift as adjacent beaches.

Scenario modelling

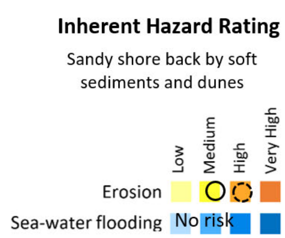
Scenario modelling for current 1 in 100-year ARI storm surge demonstrates that the base of the dunes would be impacted but these are likely to rebuild in this era. Routine highwater will have increased impact post 2050. In the latter part of this century, modelling demonstrates that both routine high water and storm surges would have major impact on the current fabric, and dunes would recede.

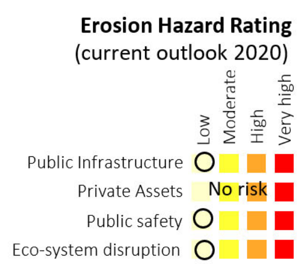
Storm water runoff

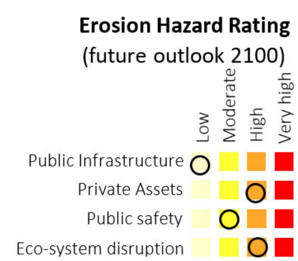
There is no runoff from urban settlements in this region.

Overview of impacts

It is difficult to predict how this system will react to rising sea levels. Increased levels of water over the reef are likely to diminish its sheltering affect. The spit and dune system can expect to recede on the seaward side. Increased aridity may also increase the possibility of dune blowout and sand moving into the Onkaparinga River to the east (refer Caton, Settlement History section). However, in the meantime, the system is stable, and ongoing monitoring will clarify the longer-term projections.







Cell 4.3b – Southport (river mouth)

Onkaparinga River (south of footbridge) (4:3b)

Coastal description:

South of the Onkaparinga River footbridge the river takes its last turn towards the west. The river on the eastern/southern side is bordered by cliffs. On the eastern side Ochre Cove /Ngaltinga Clay formation and closer to the river mouth, limestone base with various formations on top. These cliffs are impacted by riverine flow, tidal flows, and rainwater runoff.

Coastal history

Cliffs south of the Onkaparinga River footbridge are subject to the erosive forces of riverine, tidal estuarine, and surface runoff flows. Close to the footbridge, cliff recession occurred between 1949 and 1979. Further south, a mass slide movement of Pleistocene (soft) material occurred between 1949 and 1979. Rock falls and recession have occurred on the southern portion of cliffs. Unstable sections of cliffs have been collapsed by blasting or mechanical means in 1990s. Rock has been installed to the base of the limestone cliffs, first in the 1980s and then in 2000s.

Scenario modelling

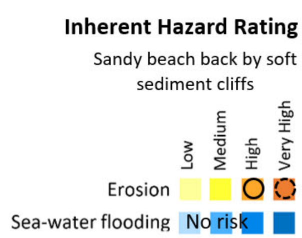
Scenario modelling for current 1 in 100-year ARI storm surge risk demonstrates that significant impact would occur on the base of these cliffs. The modelling for current routine highwater events indicates a lower impact, and wave runup should be ignored in this section. Scenario modelling for post 2050 demonstrates that increasingly both storm surges and routine highwater will have increasing impact due to frequency of flows and additional height of flows.

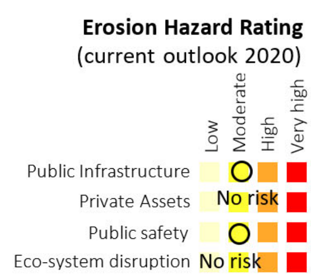
Storm water runoff

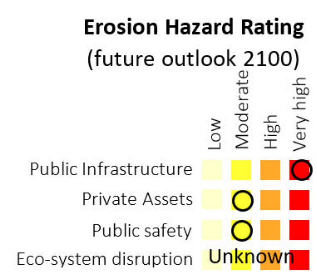
A review of storm water scheme for the area east or south of the river revealed that storm water from urban settlement is adequately controlled and does not flow over cliffs. (This assessment doesn't include water from natural surfaces).

Overview of Impacts

Higher sea levels will increase the rate of erosion of these cliffs. Roads, such as Weatherald Tce, are likely to come under increased threat - GHD assigns risk rating for land slides as 'high' in this location. GHD assigns societal risk as 'almost certain' for the southern portion of cliffs (near the river mouth).







Cell 4.4 – Port Noarlunga (river township)

Port Noarlunga township (4:4)

Coastal description:

North of the Southport footbridge the takes a wide sweeping turn under Saltfleet Street bridge. In higher tides, the flood plain to the west of Saltfleet Street bridge is flooded and water flows into the floodplain on the north of the river (east side of Gray Street).

Coastal history

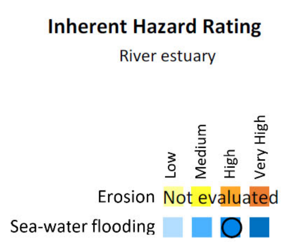
Since settlement, there have been numerous floods of the Noarlunga district. Six since the construction of the Mount Bold Reservoir in 1938, but the heights lower. It has been a belief that flooding of the lower Onkaparinga River only occurs when there is a high tide but 3 floods that have occurred in the absence of a high tide, although it is accepted that a higher tide will exacerbate flooding. A levee system was built in the 1970s and all of the structures removed from the flood plain east of Gray Street. The event of 9 May 2016 was the highest on record at Outer Harbor and the height of this flood was established at 2.35m AHD in the area between the footbridge at Southport and Saltfleet Street Bridge.

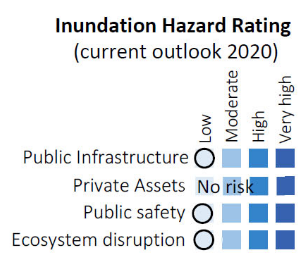
Scenario modelling

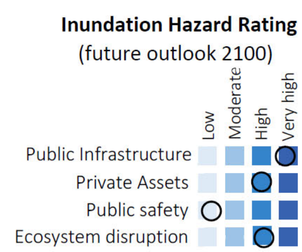
The current levee system is likely to protect most of the Port Noarlunga township from storm surge events from the ocean (without confluence with rainfall events) until 2070 (exceptions noted below). The current risk is the same as the event 9 May 2016. Saltfleet Street was inundated to 0.25m, the playground up to depths of 0.45m, and the carpark on the north side of the bridge, at depths up to 0.55m. The 2050 storm surge risk does not penetrate the levee system, although overtopping would be close (within 0.15m in some locations). The impact is similar to the current storm surge risk, but with depths 0.30m higher and also flows into the grounds of Sauebier House. The 2100 storm surge risk would inundate Port Noarlunga township with water over roads up to 1.10m deep, the deepest point being at the main roundabout on Gawler Street at depth 1.60m.Further investigation is required to ascertain if the flood is able to flow on to River Drive.

- **Overview of Impacts**

Until approximately 2070, the Impacts for current risk and 2050 risk are contained to infrastructure and safety issues in the Saltfleet Steet playground area, and the carpark on the northern side of the river (Sauebier House excepted) The impact post ~2070 is significant with flooding of streets up to depths of 1.60m, and flooding over floor of buildings expected (but not quantified as yet).







Cell 5.1 – Seaford Cliffs (north)

Exmouth Rd to Cliff Ave
(5.1)

Coastal description:

Along this zone Blanche Point Formation limestone occurring at the base of the escarpment forms shore platforms and a low vertical cliff in places up to approximately 2 m high. Overlying materials are deeply dissected with gully/ravine formation and badland terrain.

Coastal history

A comparison of aerial photography from 1949 to 2017 indicates that the base of the cliff is in a similar position. The escarpment in this location is protected by a thin limestone shelf at the base. There has been minimal erosion at the cliff toe over the last seventy years.

Scenario modelling

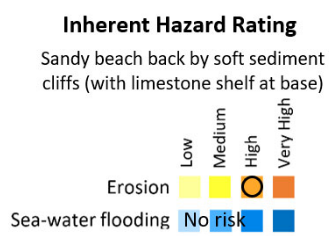
Current modelling demonstrates that 1 in 100-year event impacts the limestone ledge that is situated at the base of the slopes. The modelling for later in this century shows that the full energy of wave setup from routine high-water events will impact the toe of the cliff. Increased undermining and failure of the limestone ledge can be expected, and the softer sediments of the cliff above and behind will be exposed to actions of the sea.

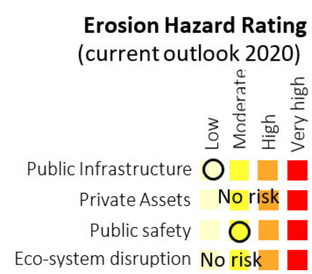
Storm water runoff

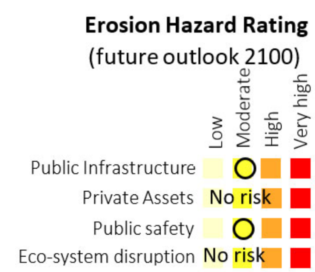
Storm water is managed efficiently so that no runoff from urban settlement flows across cliff tops. Storm water outlets are positioned within the limestone formation and limited scouring was observed.

Overview of impacts

Historical analysis and analysis of current storm and tidal action demonstrates that Seaford Cliffs north of Cliff Avenue have been largely stable and infrastructure is set well back. Future scenarios demonstrate that the limestone shelf and backshore will come under more frequent contact with the sea and an increased rate of erosion and undermining is likely. When the limestone shelf is compromised, the softer sediments above will erode at a rapid rate.







Cell 5.2 – Seaford Cliffs (mid-section)

Cliff Ave to Seaford Road (5.2)

Coastal description:

The limestone dips below the beach level in this area and the coastal slopes become vegetated bluffs, with a limited sub-vertical cliff of clays and sands up to several metres high in places at toe.

Coastal history

A comparison of aerial photography is difficult due to the rapid changes in elevation from cliff top to bottom. However, it is clear that there has been some recession at the toe of the cliff since 1949.

Scenario modelling

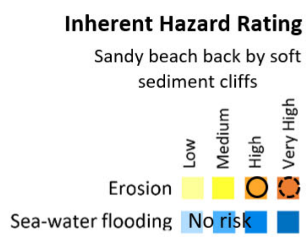
Scenario modelling for current 1 in 100-year ARI storm surge risk demonstrates that significant impact would occur on the base of these cliffs and some recession is likely. The modelling for current routine highwater events indicates a lower impact than observations and seaweed strand analysis. Scenario modelling for post 2050 demonstrates that increasingly routine highwater events will have significant impact on these cliffs. Combined with larger storm surge events, these cliffs will undergo significant and rapid recession if seas rise as projected.

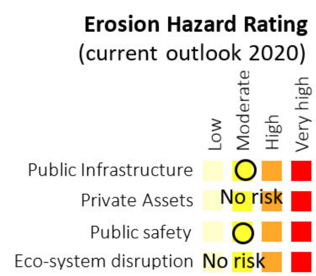
Storm water runoff

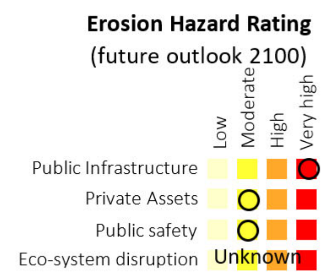
Storm water is managed efficiently so that no runoff from urban settlement flows across cliff tops. Storm water is piped to the beach and outlets have either concrete or rock end controls. Observations of the beach subsequent to rain events in February 2020 revealed significant scouring at Seaford Road storm water outlet.

Overview of impacts

Public infrastructure is set further back from the crest of the cliff than in the previous section (Robertson Road to Seaford Road). Therefore, there will be time to monitor cliff recession and assess more clearly when infrastructure may come under threat.







Cell 5.3 – Seaford Cliffs (south)

Seaford Rd to Robertson Rd
(5.3)

Coastal description:

This area consists of sub-vertical cliffs of Ochre Cove Formation overlying Seaford Formation. Extensively gullied Ngaltinga Formation clay slopes are present above, with an overlying sand and calcrete layer. Coarse sand and rock beach with shingle at the toe of steep soft rock cliffs. Low profile reef in nearshore zone.

Coastal history

A comparison of aerial photographs is difficult due to the changes in elevation but best estimates place recession at 2-3m since 1949 (although this recession is not uniform). Analysis suggest that the upper crest has receded by up to 5m since 1949, principally driven by stormwater runoff and sub-aerial processes.

Scenario modelling

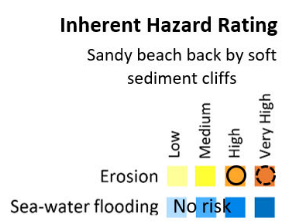
Scenario modelling for current 1 in 100-year ARI storm surge risk demonstrates that significant impact would occur on the base of these cliffs and recession and perhaps some collapse is likely. The modelling for current routine highwater events indicates a lower impact than observations and seaweed strand analysis. Scenario modelling for post 2050 demonstrates that increasingly routine highwater events will have significant impact on these cliffs. Combined with larger storm surge events, these cliffs will undergo significant and rapid recession if seas rise as projected.

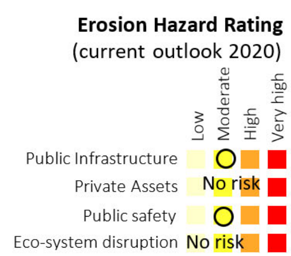
Storm water runoff

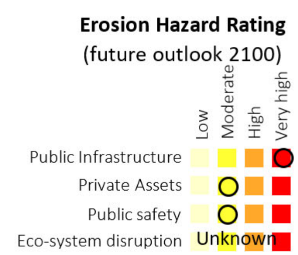
Storm water is piped to the base of cliffs at the end of Starboard Road and Tiller Drive. The storm water outlet at Tiller Drive has been upgraded in response to storm damage. Scouring was significant after rains at Starboard Road. Appropriate schemes are in place that ensure that storm water from urban settlement doesn't flow across cliff tops.

Overview of Impacts

If a current 1 in 100-year event occurred, locations where cliffs are vertical may suffer recession or slumping. Some of these locations are very close to carparking or roads. If seas rise as projected, then these cliffs are likely to recede rapidly, and infrastructure situated at the top would come under immediate threat.







Cell 6.1 - Moana Beach (Foreshore area)

Moana Beach

(Foreshore area 6.1)

Coastal description:

Moana Beach is characterised as a sandy beach backed by seawall and foreshore development. Further north a steep earthen embankment is situated under the upper carpark. The nearshore and surf-zone are dominated by sand, with offshore low-profile reef.

Coastal history

The position of the backshore has been governed by urban development – carparks and seawalls. Profile line and aerial photography indicate recession of the backshore by approximately 2m. The storm on 4th July 2007 impacted the embankment in this location and protection items (sandbags and rock) have been positioned at the base to slow any further erosion. The storms of 2016 have dislodged some of the sandbags.

Scenario modelling

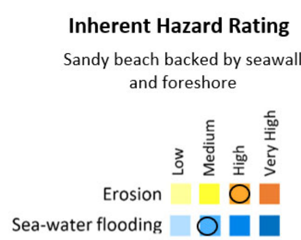
The event of 9 May 2016 is likely to be similar to the current 1 in 100-year event (see photographs in settlement history section). Scenario modelling for 2050 demonstrates impact on the seawall, along with significant overtopping of waves onto the foreshore area and Surf Life Saving Club. Scenario modelling for 2100 indicate that the current layout of Moana foreshore is unlikely to be viable.

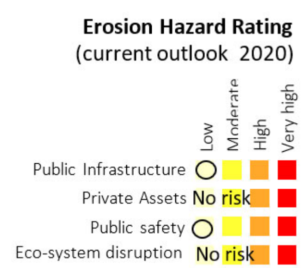
Storm water runoff

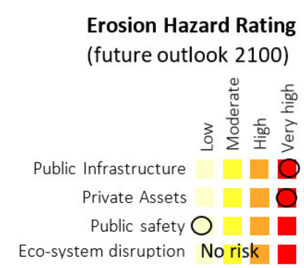
Storm water flows across The Esplanade in an open drain to the beach under the sea wall. While a confluence of rain and seawater flooding is unlikely, significant flooding may be likely if this were to occur. In the longer term, sea water is likely to penetrate this storm water outlet.

Overview of impacts

The main threat that sea level rise will bring is increased storm and routine tidal action on the urban backshores of Moana foreshore area. Post 2050, erosion is likely to remove the sand dunes from the onramp area, undermine the seawall in front of foreshore infrastructure, and undermine / erode the embankment under the upper carpark. It is likely that sand levels on the beach will drop significantly. It is difficult to see how the foreshore would be viable by 2100 in its current layout.







Cell 6.2 - Moana Beach (Pedler Creek)

Moana Beach

(Pedler Creek 6:2)

Coastal description:

Moana Beach is dissected by Pedler Creek just south of Moana Beach foreshore area. A detention pond system has been installed on the eastern side of Commercial Road that effectively controls storm water flows from the upper catchment areas.

Note: The dotted line around Pedler Creek indicates flood modelling for 1 in 100-year ARI event projected for 2100 and thus is the extent of the likely risk. No assessment has been undertaken as to the possibility of confluence of sea-flooding and rain events. Historically, the weather systems that drive extreme seawater events are not accompanied by significant rain systems, and the detention pond system will reduce the impact of flows into lower creek area. See reports by Tonkin, 2009.

Coastal history

A comparison of aerial photographs from 1949 reveals that Pedler Creek has remained largely unchanged. The storm event of 9 May 2016 resulted in seawater flowing up Pedler Creek approximately 500m and height of sea flood was measured at 2.54m AHD on the bank of the creek.

Scenario modelling

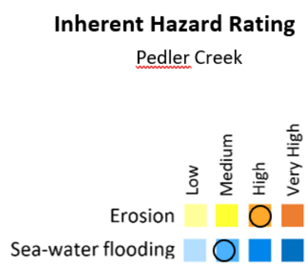
The current 1 in 100-year event does not flood the caravan park or any other urban infrastructure. However, whether storm water and storm surge flows can occur together requires further investigation. The scenario for 2050 does flood the caravan park and inundates Moana Crescent, and is likely to inundate Nashwauk Tce at low heights (0.3m). The scenario for 2100 depicts flooding at depths 0.7m to 1.0m over the caravan park.

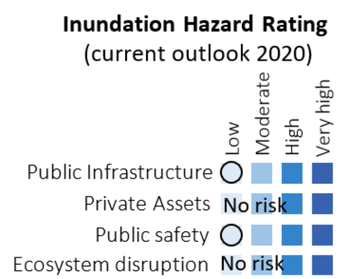
Storm water runoff

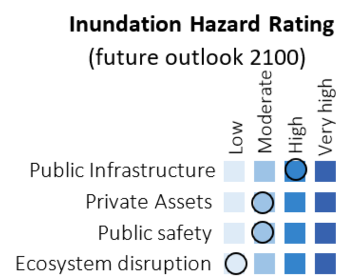
Storm water from the Moana settlement on the western side of Commercial Road flows into Pedler Creek. Assessments by Tonkin Consulting (2009) have identified rainfall flooding hazards for Pedler Creek and Development Plan controls have been implemented for floor and site levels for new development.

Overview of impacts

Pedler Creek is vulnerable to increased level of sea water flooding as sea level rises. The slope of the creek bed and banks tend to contain the flooding within the basin. The caravan park will be vulnerable to 1 in 100-year event flooding by 2050 (<0.3m). Scenario modelling for 2100 indicates that flooding will occur at depths 0.70m to 1.00m in the caravan park, Moana Crescent and Nashwauk Tce. Some private properties will be inundated at levels up to 0.6m.







Cell 6.3 - Moana Beach (Moana Sands)

Moana Beach

(Moana Sands 6.3)

Coastal description:

Moana Beach is characterised as a sandy beach backed by shingle ridge. Behind the ridge is an extensively modified low-lying dune field comprised of large soft sediment. The nearshore and surf-zone are dominated by sand, with offshore low-profile reef most dominant at the southern end near Ochre Point.

Coastal history

A comparison of aerial photographs indicates that overall, the vegetation line south of Moana Creek has receded ~4m. Profile line 200051 shows that current beach sand levels are within the upper range of the total profiles taken. A historical assessment for beach width revealed no trend for narrowing of the beach.

Scenario modelling

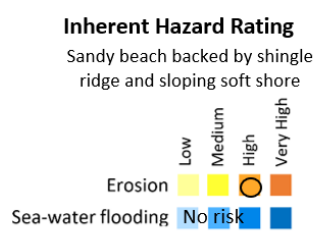
Scenario modelling for current 1 in 100-year ARI storm will impact the rear of the beach causing recession (and in this location the dunes do not tend to rebuild). Modelling for 2050 indicates increased pressure on the backshore with moderate recession likely. Modelling for 2100 indicates that both storm surge action and routine monthly highwater events are likely to cause rapid recession of the soft sediment backshore measured in decametres (at least 2-3).

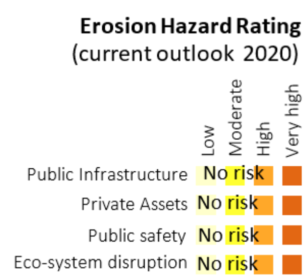
Storm water runoff

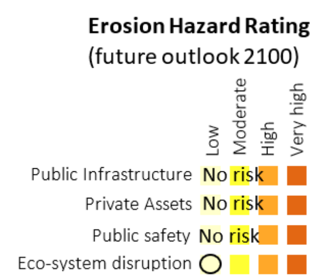
No storm water infrastructure in this section of coast.

Overview of Impacts

Scenario modelling suggests that only extreme events may reach the backshore in this current era. The main threat that sea level rise will bring is the permanent recession of the pebble bank and impact to the area behind. Over the course of this century, recession is expected for the shoreline due to the low-lying backshore and soft sediments at a distance measured in decametres (at least 2). However, the area is not expected to be impacted by inundation.







Cell 6.4 - Moana Beach (Moana Heights)

Moana Beach

(Moana Heights 6:4)

Coastal description:

Moana Beach is characterised as a sandy beach backed by shingle ridge, and sand dunes behind the ridge. The Esplanade is positioned ~100m from the shoreline. The nearshore and surf-zone are dominated by sand, with offshore low-profile reef most dominant near Ochre Point.

Coastal history

The beach undergoes a normal accretion and erosion cycle which is observed in changing sand levels within the profile lines. A comparison of aerial photographs indicates that overall the vegetation line south of Moana Sands CP has receded ~4m. A historical assessment for beach width revealed no trend for narrowing of the beach.

Scenario modelling

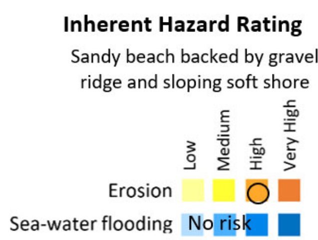
Scenario modelling for current 1 in 100-year ARI storm will impact the back of the beach causing recession (here the dunes do not tend to rebuild). Modelling for 2050 indicates increased pressure on the backshore with recession likely (measured in metres). Modelling for 2100 indicates that both storm surge action and routine monthly highwater events are likely to cause rapid recession of the soft sediment backshore that will be measured in decametres (at least 2-3).

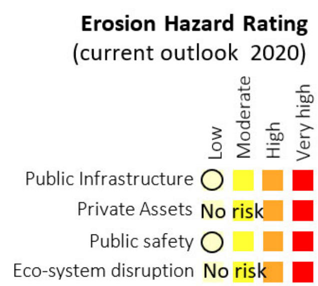
Storm water runoff

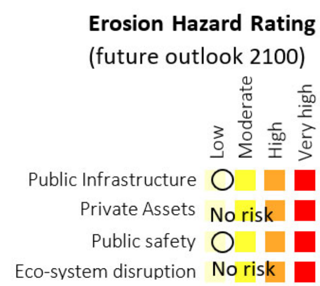
Storm water from urban settlement is being appropriately managed so that none is dispensed over the top of coastal slopes. Storm water outlet at end of Regent St is blocked, some scouring on the beach after rain events.

Overview of Impacts

The main threat that sea level rise will bring is the permanent recession of the pebble bank and toe of the sloping soft backshore. Overall impact is low and limited to impact on beach access points.







Cell 7 - Ochre Point

Ochre Point

Coastal description:

Ochre Point is characterised as a rock shore platform, 50m wide rock rubble and rock flats fronting a narrow coarse sand beach. Harder rock sloping cliffs at the base. Soft rock sloping cliffs higher up the cliffs. Nearshore and surf-zone dominated by offshore low-profile reef.

Coastal history

The beach and backshores have been stable over the last 70 years. A comparison of aerial photographs indicates that overall, the toe of the cliff and vegetation line are in the same position as 1949. Minor accretion and erosion trends are observed in the pocket beach in the southern portion of Ochre Point, with the 1970s being the highest sand levels. The highest storm event on record of 9 May 2016 produced minor scouring at the base of the cliff adjacent Moana.

Scenario modelling

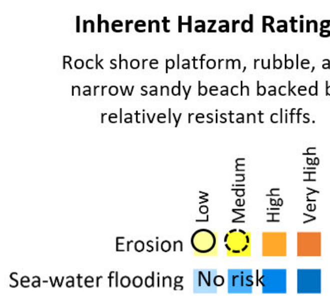
Scenario modelling for current 1 in 100-year ARI storm will impact the back of the beach causing recession (but in this current era, may rebuild depending on sediment supply). Routine high water is unlikely to make an ongoing impact until after 2050. Modelling for 2100 indicates that both storm surge action and routine monthly highwater events are likely to impact the base of the cliffs causing undermining and recession and impact the dunes of the pocket beach in the south. Sediment supply from the cliffs may maintain the beach, or beach levels may lower and the beach lost.

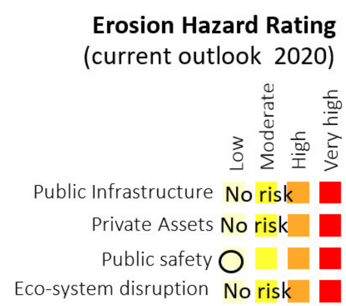
Storm water runoff

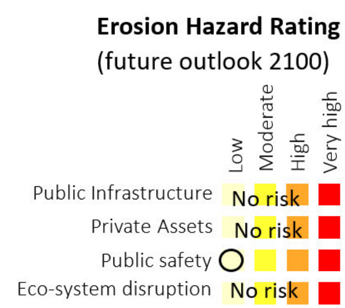
Storm water from urban settlement is being appropriately managed so that none is dispensed into the coastal conservation area.

Overview of Impacts

The main threat that sea level rise will bring is increased impact on the toe of cliffs and dunes. However, no assets or infrastructure are situated within the reserve, and there is no apparent threat to ecosystems on a wide scale.





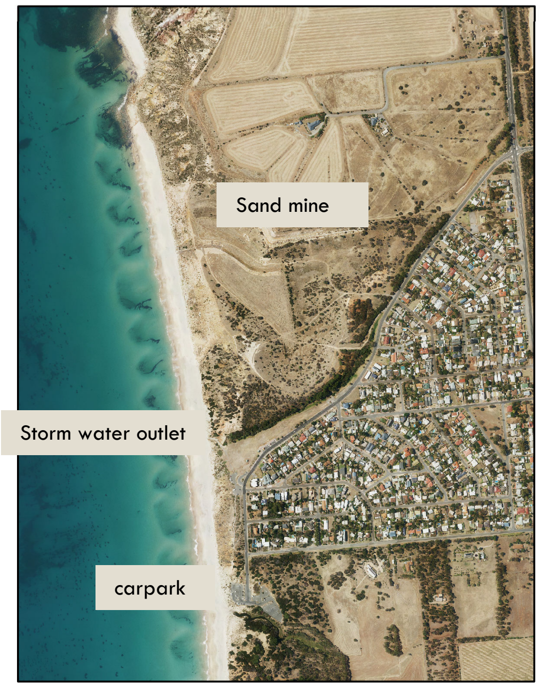


Cell 8.1 – Maslin Beach (north)

North of Maslin Creek (Cell 8.1)

Coastal description:

Maslin Beach is characterised as a sandy beach backed by soft coastal cliffs (harder rock at the base). The cell is dissected by Maslin Creek. Nearshore and surf-zone dominated by sand. Offshore scattered low-profile reef and seagrass.



Coastal history

Historical analysis indicates that the coastline undergoes periods of accretion and erosion. The beach and position of the toe of the embankment in the north have been largely stable but areas of dunes in front of the park at Maslin Beach have recede. A sand mine operated adjacent the coast in the earlier part of the twentieth century. Soft sediments have been deposited in the backshore when the mine was rehabilitated.

Scenario modelling

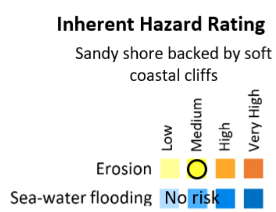
Scenario modelling indicates that wave runup from current large storm events would impact the toe of slopes, but routine tides are not having an impact. If seas rise as projected, later in this century both routine tidal action and storm surges will have high impact on the backshores causing recession (at least 2 decametres). The dunes in front of the lower carpark are likely to erode back to the carpark. The embankment in front of the upper carpark and lawned area are expected to suffer recession and the slope of the embankment increase. Further north, scenario modelling demonstrates that routine tides/ storms will interact with the soft sediments from the former sand mine.

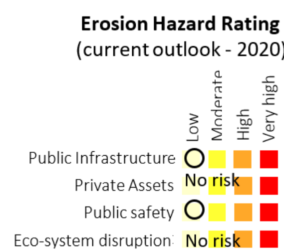
Storm water runoff

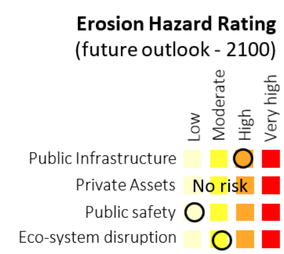
Areas on the northern side drain into the channel that runs adjacent to Gulf Parade. Detention systems have been constructed near to Commercial Road and a gabion basket system acts as end control. These strategies reduce the rate of flow and impact on the beach. Higher rainfall events cause scouring on the beach, but the current sediment supply and coastal morphological regime see these areas rebuild. If coastal recession is accompanied by lower sand levels, these storm water controls may become exposed to actions of the sea.

Overview of impacts

If seas rise as projected, the lower carpark is likely to be impacted first by dune recession. The gabion storm water end control and beach access points are likely to become isolated forward of the retreating shoreline, but this is unlikely until post 2050. Sediments from the mine remediation works may be released into the sea.







Cell 8.2 – Maslin Beach (south)

South of Maslin Creek (Cell 8.2)

Cosatal description:

Maslin Beach is characterised as a sandy beach backed by soft coastal cliffs (harder rock at the base). The cell is dissected by Maslin Creek. Nearshore and surf-zone dominated by sand. Offshore scattered low-profile reef and seagrass.

Coastal history

A comparison of aerial photographs and Coast Protection Board profile lines indicate that the coastline undergoes periods of accretion and erosion. The limestone cliffs in the southern portion have experienced rock and block falls from the vertical cliff and evidence of major collapses/falls within the cliff, some due to probable cave collapse. The beach and position of the toe of the embankment have been largely stable.

Scenario modelling

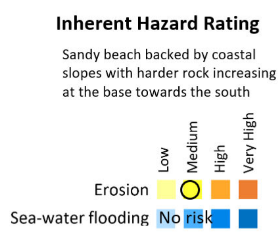
Scenario modelling indicates that wave runup would impact the toe of the coastal slopes, but current routine tides are not having an impact. If seas rise as projected, the cliffs in the south which are relatively resistant to wave erosion, will be eroded and undermined at a faster rate. Later in the century (post 2050) both routine tidal action and storm surges will have high impact on the toe of coastal slopes and the toe can be expected to recede and slopes to become more vertical, and the cliffs in the southern portion undermined and more likely to experience rock falls/ cliff failures.

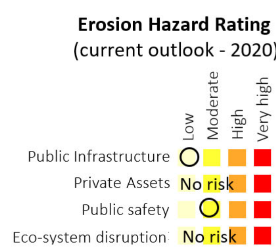
Storm water runoff

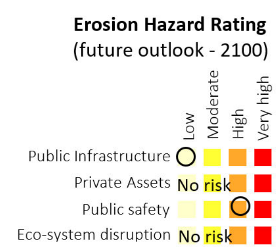
Areas on the southern side of Maslin Beach drain into Maslin Creek. Upstream controls limit the flow of water from higher up in the catchment. Some scouring is observed after heavy rains, but the beach rebuilds quickly with the current sediment supply and coastal morphology regime.

Overview of Impacts

While erosion of the coastal slopes and cliffs is expected to occur at a faster rate, there is very little infrastructure positioned within this part of the coast (beach access point). Increase to the safety of people may be a factor. GHD assigned risk to individual life for someone who lives in the area as 'unlikely' and societal risk as 'likely'.





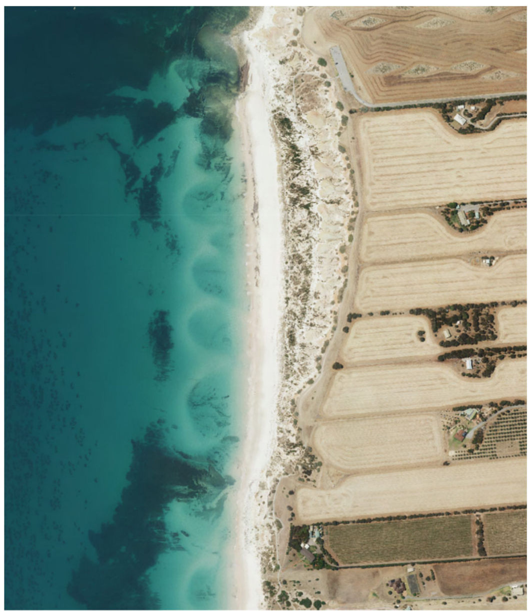


Cell 9.1 – Port Willunga (north)

North of Willunga Creek (9.1)

Cell description:

Port Willunga is characterised as a sandy beach backed by soft coastal cliffs. The cell is dissected by Willunga Creek. Nearshore and surf-zone dominated by sand with low profile reef of varying consistency offshore.



Coastal history

Historical analysis indicates that the coastline undergoes periods of accretion and erosion. A major section of the cliff just north of the creek has slumped some time since 1949. On the north side of the creek the nature of the coast is largely unchanged (overall recession ~4m since 1975). Sea level rise does not appear to have had any major impact on this section of coast as yet.

Scenario modelling

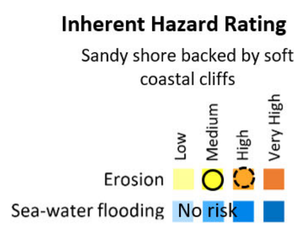
Scenario modelling shows that the cliffs immediately north of Willunga Creek currently receive routine wave action at the base. Further north, routine tidal events do not impact the base of these soft coastal cliffs. However, in areas to the north, these may have capacity to rebuild (dependant on available sediment supply). If seas rise as projected, then the impact upon the backshore will become more routine and these cliffs and backshores will be likely to recede (measured in decametres by year 2100).

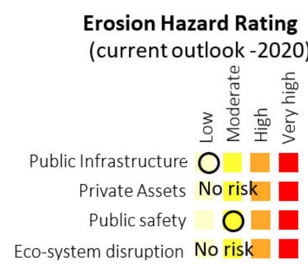
Storm water runoff

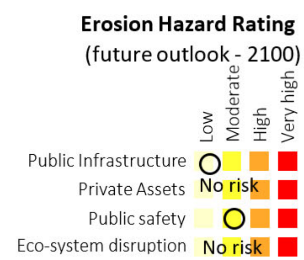
There is no runoff from urban settlements within Port Willunga north.

Overview of impacts

Public assets are limited to walking trails and minor infrastructure. GHD (2016) rates risk to life (individual) as *likely*, and risk to life (societal) as *almost certain*. Integrated Coasts adopts ‘moderate’.







Cell 9.2 – Port Willunga (Willunga Creek)

Willunga Creek (9.2)

Cell description:

Port Willunga (9.2) is characterised as a sandy beach backed by coastal dunes.. Nearshore and surf-zone dominated by sand with low profile reef of varying consistency offshore.

Coastal history

Historical analysis indicates that the coastline undergoes periods of accretion and erosion. The beach and dune area near Willunga Creek appear largely unchanged since 1909, and the dunes have built up since 1975. Sea level rise does not appear to have had any major impact on this section of coast as yet.

Scenario modelling

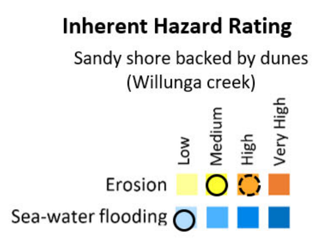
Routine highwater is currently having minimal impact on the dune system which has been large stable for over 100 years. The current 1 in 100-year ARI event would cause erosion beyond the vegetation line but the dunes in this location have shown ability to rebuild. However, these dunes can be expected to recede with sea level rise (dependant on sediment supply). Scenario modelling of sea level rise within Willunga Creek basin indicates that the impact will be limited to flows of 400m inland and contained within the current basin until much later in this century.

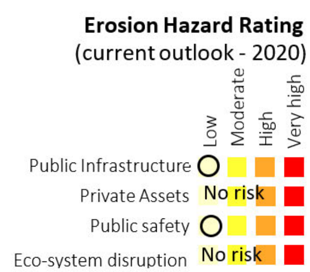
Storm water runoff

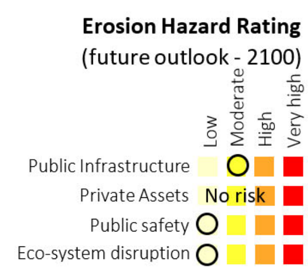
Stormwater from most of Willunga settlement flows into the Willunga Creek basin. Runoff from significant rainfall events do reduce sand levels at the mouth of the creek but within the current coastal morphological regime, the sand levels soon recover.

Overview of impacts

The main threat that sea level rise will bring is increasing impact of storm and tidal action on the dunes causing erosion. There is no significant infrastructure on the land side of the dunes, but the current access way to the beach may become more exposed (with erosion on the north side). Modelling of seawater incursions into the creek indicate limited impact.







Cell 9.3 – Port Willunga (south)

South of Willunga Creek
(9.3)

Cell description:

Port Willunga (9.3) is characterised as a sandy beach backed by limestone cliffs in the south overlain with softer sediments. Nearshore and surf-zone dominated by sand with low profile reef of varying consistency offshore.

Coastal history

Historical analysis indicates that the coastline undergoes periods of accretion and erosion. There appears to be less volume of sand adjacent the cliffs south of the creek than in 1909 which may relate to rises in sea level over a century. Some recession of the cliff has occurred in places as a result of rock falls (overall recession 1-2m). The cliff has become undermined in places, and rock has been placed in one location under the cliff to slow erosion.

Scenario modelling

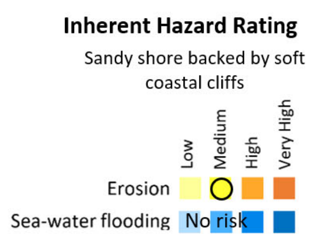
Scenario modelling indicates that wave runup is likely to be currently impacting the base of the cliffs several times a month. If seas rise as projected, the scenario modelling demonstrates that routine tide action would constantly impact the base of these cliffs in the latter part of the century. These cliffs are characterised as relatively resistant to wave erosion, but constant impact will increase the rate of undermining and increase the likelihood of cliff falls/ failure.

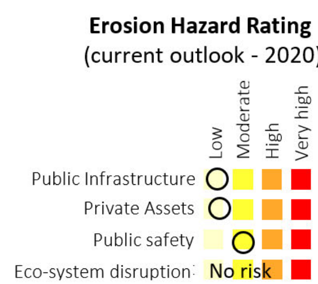
Storm water runoff

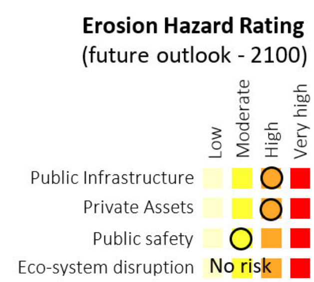
Storm water flow from urban settlement is controlled away from the cliff tops by kerb and gutter into a detention basin to the north of the lower carpark before flowing at a slower rate to the coast adjacent the lower walkway.

Overview of Impacts

Impacts from ongoing storm and tidal action at the base of the cliff (limestone in this location) will increase the rate of undermining and erosion of the base of the cliff. An increase of rock falls and slides which may cause loss of infrastructure or impact to people. GHD rates risk to life (individual) as *likely*, and risk to life (societal) as *almost certain*.







Cell 10.1 – Aldinga Reef (north)

Marlin Road to Chenoweth Street (Cell 10.1)

Coastal description:

Rocky/sandy shore backed by soft coastal cliffs. Ngaltinga formation on the top and Blanche Point formation at the base (which is resistant to erosion). Fronted by reef/rock platform close to the shoreline.

Coastal history

Historical analysis reveals that this coastline undergoes periods of accretion and erosion, the latter relating to larger storm events (2007, 2016). GHD noted evidence of block falls and tension cracks, some up to 10m from the cliff crest. A comparison of aerial photograph estimates recession of cliff top ~2m from 1979.

Scenario modelling

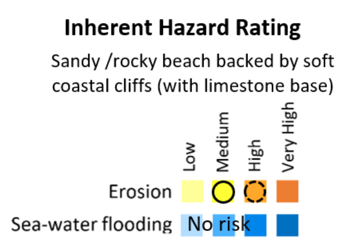
This section of coast has thin layer (~2m) of limestone at the base of the cliffs and the soft Ngaltinga formation on top. The limestone is relatively resistant to wave erosion (historical recession 1-2m). Scenario modelling demonstrates that 1m of sea level rise would result in the base of this cliff coming under high impact from routine tidal action and storm surge action. At the very least it can be expected that the rate of undermining and recession/rock falls are likely to increase.

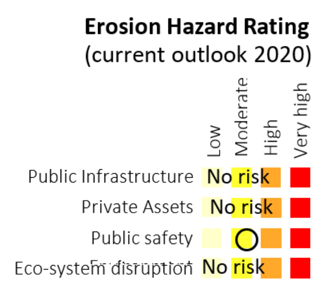
Storm water runoff

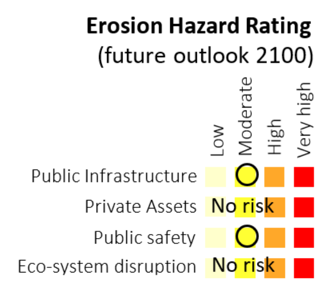
Storm water is piped to the beach level in the vicinity of Hamilton Road. The end control has been left exposed by cliff recession. Stormwater runoff from urban settlement is effectively controlled so that it doesn't flow over the cliff tops.

Overview of impacts

Scenario modelling demonstrates that this area will increasingly be impacted by storm and tidal action at the base of the cliff (limestone in this location). The main threat that sea level rise will bring is to increase the rate of undermining and erosion of the base of the cliff with increase of rock falls and slides. The Esplanade Road is setback ~25m from the cliff edge (at shoreline) and ~10m from the crest of the cliff. GHD assigns risk to life for someone living in the area as 'rare', and societal risk as 'unlikely'.





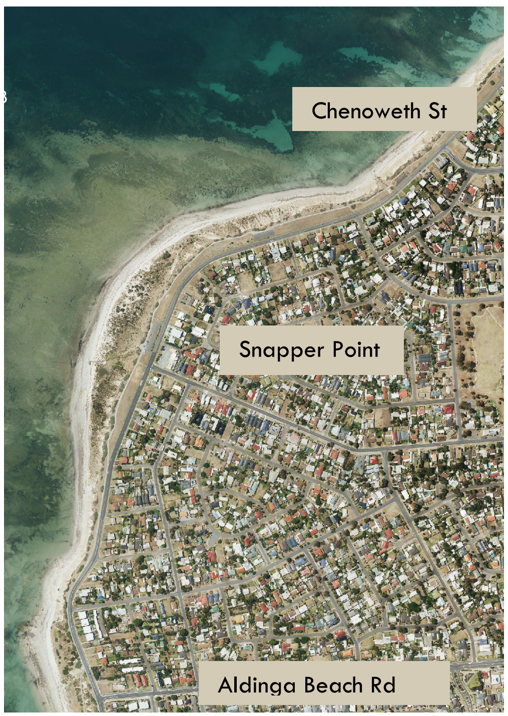


Cell 10.2 – Aldinga Reef (Snapper Point)

Chenoweth Street to Aldinga Bay Road (10.2)

Coastal description:

In the south, sandy shore backed by soft coastal cliffs (highly erodible Ngaltinga formation). In the Snapper Point region, the sloping soft cliffs are set behind a dune system. Nearshore and surf-zone are dominated by a low-profile reef



Coastal history

A comparison of aerial photographs from 1949 to 2006 demonstrated that this coastline was stable. Substantial erosion has occurred since 2006. In the vicinity of Gordon Street, 8-10 metres recession of the cliff toe, but only minor erosion of the cliff crest is likely to have occurred. At Snapper Point, 24-34m recession of the shoreline has occurred between Butterworth Road and Hume Street. Analysis of the beach profile lines is congruent with these findings.

Scenario modelling

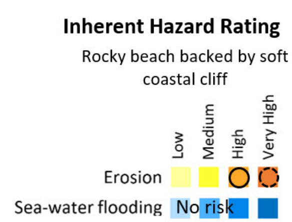
Gordon Street: Scenario modelling for current storm surge indicates significant impact would occur on the soft sediment of the cliffs and cause recession. These cliffs are likely to become more vertical and the risk of failure increases. Modelling for future sea level rises indicates severe impact. Without intervention, major recession of these cliffs is likely. *Snapper Point:* Scenario modelling indicates that if seas rise as projected, then both storm surge action and routine monthly highwater events are likely to cause rapid recession of the soft sediments behind the current shoreline.

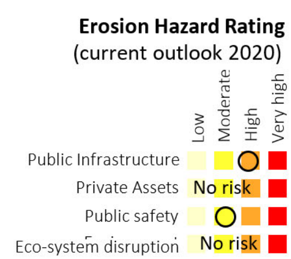
Storm water runoff

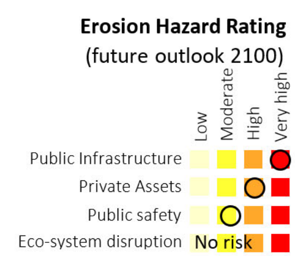
Stormwater is piped to a position lower down the embankment and then flows in the open over rip rap rock end control or in open gully (with sandbag end control). Scouring on the beach is noticeable within this section of coastline. Uncontrolled storm water gullies are locations where storm surge action may rapidly increase recession of the shoreline.

Overview of impacts

Public infrastructure is set close to the top of the cliffs in the vicinity of Gordon Street. Both current and future storm surge and routine tidal action are likely to cause the recession and possible collapse of some sections of cliffs. Without intervention, it is also conceivable that private assets may be impacted by the end of this century. GHD assigns risk to individual life to someone living in the area as 'unlikely' and societal risk as 'likely'.





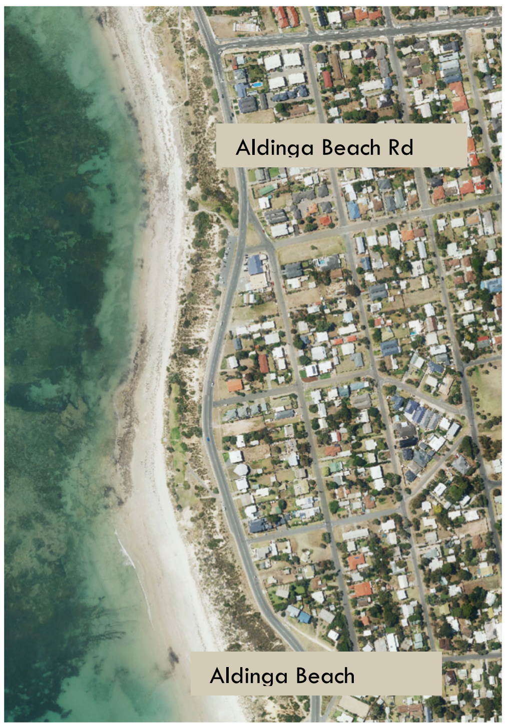


Cell 10.3 – Aldinga Reef (south)

Aldinga Beach Road to Ocean Street (10.3)

Coastal description:

Sandy shore backed by soft coastal cliffs (highly erodible Ngaltinga formation). Artificial platform on bottom edge of cliff, planted with grass. Fronted by reef/rock platform close to the coast.



Coastal history

A comparison of aerial photographs and Coast Protection Board profile lines indicate that the coastline undergoes periods of accretion and erosion, the latter relating to larger storm events (2007, 2016). However, recession of the shoreline is more prevalent in this cell than neighbouring cells, 8-10m of recession has occurred. Any increase in the depth of water over the reef due to future sea level rise may lessen its protective effect and may contribute to increased impact.

Scenario modelling

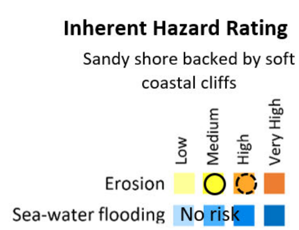
Scenario modelling for current 1 in 100-year ARI storm will impact the rear of the beach causing recession (but in this current era, may rebuild depending on sediment supply). Modelling for 2050 indicates increased pressure on the backshore with recession measured in metres. Modelling for 2100 indicates that both storm surge action and routine monthly highwater events are likely to cause rapid recession of the soft sediment backshore (at least 2-3 decametres).

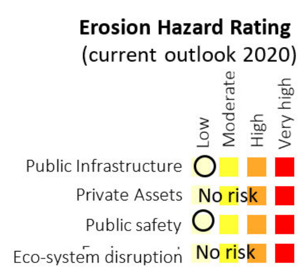
Storm water runoff

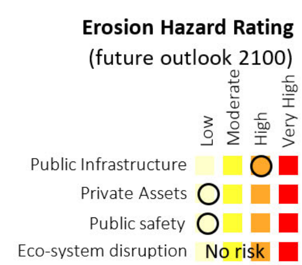
Storm water from urban settlement is being appropriately managed so that none is dispensed over the top of cliffs. Most of the outlets are in the mid to lower range of the coastal slope and most have some type of end control. Stormwater outlet at end of Seaview Rd flows through open channel which is causing gullying into the embankment.

Overview of Impacts

Erosion in the latter part of the century is likely to cause recession of the toe of soft cliff and an increase in the slope, potentially becoming unstable. The carpark on the Esplanade is positioned 40m from the current shoreline. Private assets are set behind the Esplanade and not likely to be at risk over the course of this century







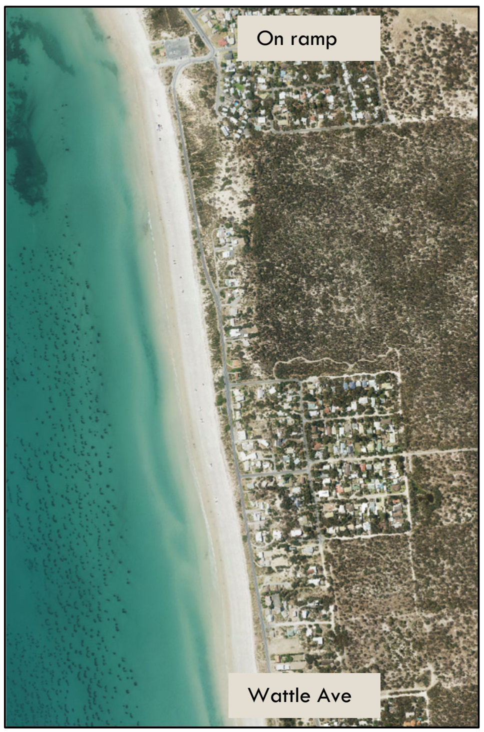
Cell 11.1 – Aldinga Beach (north)

Aldinga Beach onramp to Wattle Ave

(11.1)

Coastal description:

Sandy shore backed by dunes of Semaphore Sand which rise to ~20m inland. The nearshore and surf-zone are dominated by unconsolidated sand, with patchy to medium density seagrass and a low-profile offshore reef. In the immediate backshore is an slope of soft sediments under the Lower Esplanade Road. Highly erodible.



Coastal history

A comparison of aerial photographs and profile lines indicate that the coast undergoes periods of accretion and erosion, the latter relating to storm events (2007, 2016). Overall erosion is greatest in this region at 9-11m. Recent storm events in 2016 have increased erosion toward the road. Given that the highest three events have occurred within a decade, and these events have caused erosion toward the Lower Esplanade Road it is plausible that sea level rise is beginning to make an impact in this area of the coast.

Scenario modelling

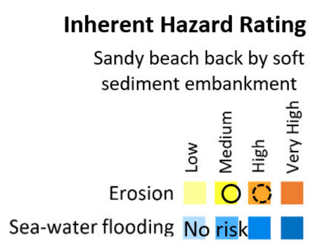
If a large storm surge occurs, wave runup is likely to flow near to the embankment under Lower Esplanade Road. In the context of rising sea levels storm surges and routine tidal action are likely to erode the embankment making it increasingly vertical and unstable. Depending on the number of storms over the next few years will determine whether the beach has time to rebuild, or permanent recession of dune/vegetation line to towards the road occurs.

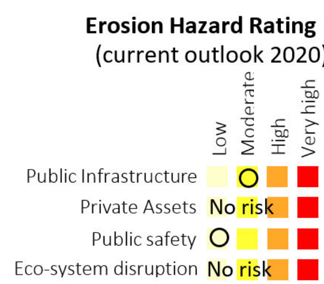
Storm water runoff

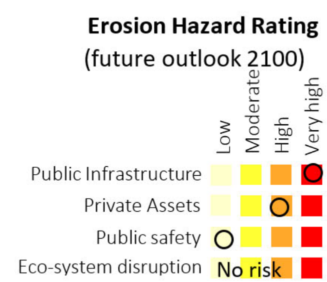
Storm water from road surfaces from the Lower Esplanade drain over the coastal slopes. Some possible scouring of the slope was observed in the Quondong Ave region which require further review. The outlet at Quondong Ave has no end control and a gully has formed to the beach. Other storm water outlets have end controls and impacts appear minor.

Overview of impacts

Public infrastructure in this region relates primarily to the Lower Esplanade Road, onramp and Aldinga Beach carpark. Scenario modelling indicates that the northern section of Lower Esplanade Road may be vulnerable now to a larger storm surge. Modelling of future scenarios indicates that this road would be severely impacted by storm surges and routine tidal events and is therefore unlikely to be viable in the latter part of this century (post 2050).







Cell 11.2 – Aldinga Beach (south)

Wattle Ave to Loongana Road
(Cell 11.2)

Coastal description:

Sandy shore backed by dunes and soft sediments less than 8m AHD but rising to 15-20m AHD north of Norman Road. The nearshore and surf-zone dominated by unconsolidated sand, with patchy to medium density seagrass and a low-profile offshore reef. A pebble ridge is situated in the backshore, but the height of the pebble ridge declines toward the north. Moderately erodible.

Coastal history

A comparison of aerial photographs and profile lines indicate that the coastline undergoes periods of accretion and erosion, the latter relating to storm events (2007, 2016). In the vicinity of the Norman Road on ramp, there has been ~2m recession of the shoreline, but with little evident in the last decade. Further north toward Wattle Road, the impact of erosion increases to 2-4m, with some areas at 6m of erosion.

Scenario modelling

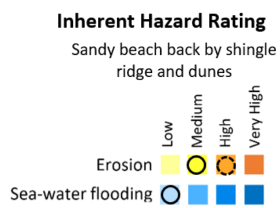
Modelling for current scenarios suggests that the pebble bank will provide protection. Modelling for 2050 indicates increased pressure on the backshore with recession of the shoreline likely (measured in metres). Modelling for 2100 indicates that both storm surge action and routine highwater events would cause recession of shoreline (likely to be at least 2 decametres). South of Norman Road the low height dunes may recede and then also be inundated from the sea.

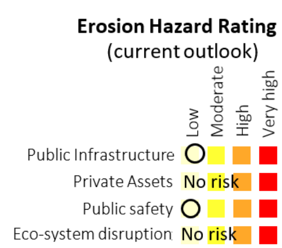
Storm water runoff

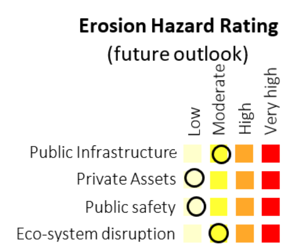
Storm water from urban infrastructure situated close to the coast often drains into dune areas. This is an area of low density and high pervious surfaces. In most places no scouring was observed. Sediment around the outlet south of Norman Road has been lost up to the rear of the concrete headboard, and minor scouring was observed on the beach.

Overview of impacts

Public infrastructure is set well back from the shoreline. Erosion modelling for the Washpool Lagoon area estimates shoreline recession at 26m to 43m and therefore the esplanade road is unlikely to be impacted by erosion in this current century.







Cell 11.3 – Aldinga Beach (Washpool Lagoon)

Washpool region (11.3)

Coastal description:

The coast in this region is characterised as a sandy beach, the nearshore and surf-zone dominated by unconsolidated sand, with patchy to medium density seagrass and a low-profile offshore reef. A pebble bank is situated in the backshore. Behind the ridge a low-lying plain basin called the Washpool Lagoon is located.

Coastal history

A comparison of aerial photographs and beach profile lines indicates that the beach undergoes cycles of accretion and erosion. The pebble bank is in a similar position to 1976. Analysis of beach width from 1976 to 2018 revealed no significant trend for the narrowing of the beach in this location. Levees have been installed in the Washpool Lagoon at height 3.00m AHD which will protect the lagoon from inundation from the sea.

Scenario modelling

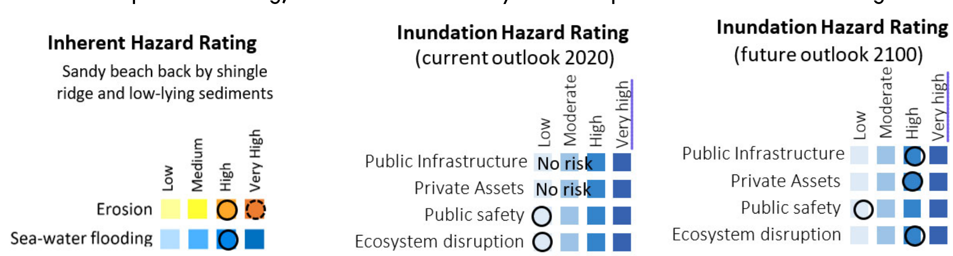
Scenario modelling for 2050 scenario demonstrates that sea-flood impact is low. Post 2070, scenario modelling shows that seawater flooding may occur within the Washpool Lagoon. Erosion modelling estimates that the pebble bank will recede between 23m and 46m by 2100. Whether the pebble bank remains intact and translates to the east or degrades is unknown. The consensus is that a confluence of a rainwater event and a storm surge event is unlikely to occur. Modelling by KBR demonstrate even if it did, the impact will be negligible.

Storm water runoff

Storm water from the hinterland and from urban settlement to the north flows into the Washpool channels before flowing out to sea through a swale in the backshore. An erosion scour is cut in the sand in larger rainfall events, but the beach has shown ability to recover quickly in recent years at this location.

Overview of Impacts

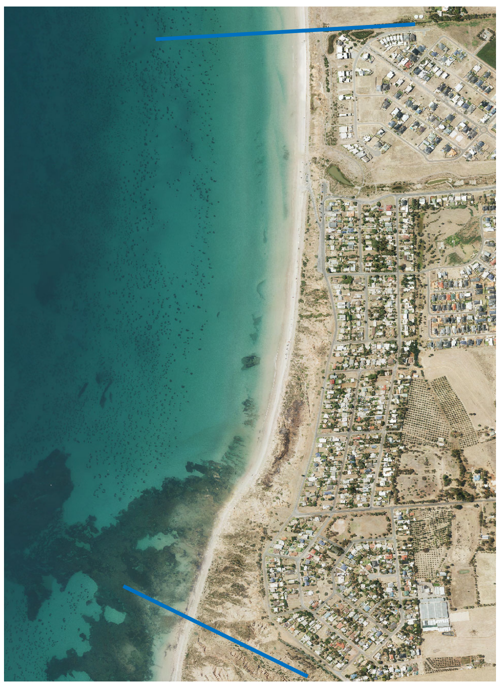
The extent of impacts to the Washpool Lagoon area will depend on whether the pebble bank remains intact and recedes landwards or degrades and breaks down. If the latter occurs, then flooding impact into the Washpool Lagoon will be higher. Irrespective of this factor, sea-flood modelling indicates that post 2070, the Silver Sands residential area will be subject to flooding, and seawater is likely to overtop the levees around the lagoon.



Cell 12 – Sellicks Beach

Coastal description:

Sellicks Beach is characterised as a sandy foreshore with a shingle beach and pebble bank backed by soft alluvial sediment coastal cliffs. Nearshore and surf-zone are dominated by sand and patchy seagrass. A low-profile reef is situated in the south of the cell adjacent limestone cliffs.



Coastal history

Historical analysis indicates that the coastline has been largely stable over the last 70 years. The coastline undergoes periods of accretion and erosion. Overall minor recession 0-3m. The highest recorded event in 70 years at Outer Harbor resulted in damage to backshore adjacent the onramp, but generally the backshores remained intact. Sea level rise does not appear to have had any major impact on this section of coast as yet.

Scenario modelling

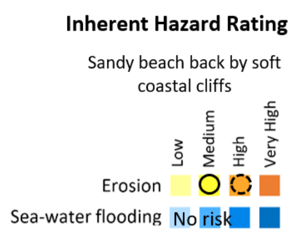
This beach is afforded protection by a pebble bank and therefore current impacts are contained. Modelling for 2050 indicates minor recession of the pebble bank (measured in metres). Modelling for 2100 indicates that both storm surge action and routine high-water events would over top and erode the pebble bank. The soft coastal cliffs would then be vulnerable to rapid erosion with erosion measured in decametres (at least 2).

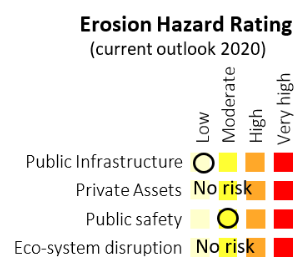
Storm water runoff

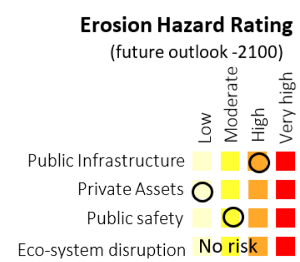
Storm water outlets and flow paths from urban settlement were analysed. The study found that no impact was observed on the beach and storm water flows were draining into detention ponds constructed within Sellicks Creek.

Overview of Impacts

Most public assets are set well back from the shoreline. If the pebble bank erodes away post 2050, then the escarpment under the beach access road is likely to be undermined and become unstable. The existing location of the carpark is unlikely to be viable by 2100. Private assets are not expected to come under threat over the course of this century. Increased undermining and erosion at the base of cliffs may increase the likelihood of rock falls/ slides. GHD (2016) rates 'risk to life – individual' as unlikely and 'risk to life – societal' as likely.







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Appendix 1.

SUMMARY OF SEDIMENTS AT THE ONKAPARINGA COAST AND THEIR VULNERABILITY TO EROSION

Dr. Robert Bourman

Geological description/ category	Erodibility rating
North Maslin Sand, the basal Eocene unit in the Willunga and Noarlunga Embayments, crops out at the coast in 'The Canyon' north of Bennett Creek and overlies Permian glacial sediments in the old ABM Sand Quarry. It was deposited in river channels and lakes and ranges in size from coarse gravel to fine sand, comprised predominantly of quartz.	Very vulnerable
South Maslin Sand, which consists dominantly of fine and coarse quartz sand, is a marginal marine unit, deposited in estuaries. It occurs in coastal cliffs at Maslin Bay from 'The Canyon' towards Blanche Point, and at the coast north of Witton Bluff.	Very vulnerable
Tortachilla Limestone is a thin limestone unit, ~2 m thick, exposed at the coast between Tortachilla Trig and Blanche Point separating the South Maslin Sand from the Blanche Point Formation. It forms a prominent shore platform at Blanche Point.	Resistant to erosion but a very thin unit
Blanche Point Formation is exposed in the coastal cliffs between Tortachilla Trig. In Maslin Bay towards Aldinga Creek in Aldinga Bay (Figure 17), forming the prominent headland of Blanche Point. The formation is up to 40 m thick. It contains the Gull Rock member, which forms Gull Rock and the base of Blanche Point	Particularly resistant to erosion
Chinaman Gully Formation, a marginal marine deposit 2-7 m thick, occurs at the coast either side of Chinaman Gully 300 m north of Willunga Creek on the coast at Port Willunga, and near the mouth of the Onkaparinga River. It is sporadically exposed as a shore platform 1.6 km south of Moana. At its type section it is ~2 m thick, separating the Blanche Point and Port Willunga Formations.	Moderately resistant but a thin unit
Port Willunga Formation is a bryozoal limestone containing marine fossils. Where exposed between Chinaman Gully and Snapper Point it has a maximum thickness of ~33 m. It has been dramatically offset by faulting south of Sellicks Beach.	*Moderately resistant to erosion.*
Seaford Formation. This is the oldest of the Pleistocene alluvial units, which comprises sandy clays green to grey in colour with yellow mottles. In places it is quite strongly ferruginous. Near its base it interfingers with Burnham Limestone, which is probably of Late Pliocene age, so that it straddles the Pliocene/Pleistocene boundary. *This unit is very vulnerable to erosion.*	*Very vulnerable to erosion*
The Ochre Cove Formation is grey sandy clay sediment characterised by strongly hued, red to purple-coloured, hematitic mottles. It contains the Bruhnes/Matuyama geomagnetic reversal of 781,000 years and the Jaramillo Subchron of 990–1071 thousand years.	*very vulnerable to erosion*

Ngaltinga Formation. This is a green/grey stiff plastic sandy clay with red ferruginous mottles, consisting primarily of fine wind deposited clay. The base of the Ngaltinga Formation has been dated at ~ 500, 000 years old. *T*	*extremely vulnerable to erosion*
Taringa Formation. This is a columnar, green-grey clay containing angular clasts with calcium carbonate in the upper part of the succession. In places, it may be a mudflow deposit and is ~160,000 years old.	*This unit is very vulnerable to erosion.*
The *Pooraka Formation* is a red/brown sandy clay alluvial deposit containing gravel lenses and is mantled by a red/brown earth soil profile containing calcium carbonate in the B-horizon. It ranges in age from 125,000 to 85,000 years ago.	*This unit is very vulnerable to erosion.*
A distinctive, grey/black alluvium, the *Waldeila Formation* occupies channels largely cut into the Pooraka Formation, sometimes exceeding 6 m in thickness. It forms low-level, paired river terraces in many streams and is best developed in the study area in the lower Onkaparinga River. It is approximately 4-5,000 years old and was deposited when sea level was ~ 1 m higher than present.	*This unit is very vulnerable to erosion.*
Hallett Cove Sandstone The Hallett Cove Sandstone is a calcareous sandstone and limestone containing marine fossils of Pliocene age ~3-4 million years old.	*It is relatively resistant to erosion but is a thin unit.*

Appendix 2

Summary of findings from beach width study using Coast Protection Board surveyed profile lines from 1975 to 2018.
Dr. Patrick Hesp

The intertidal beach widths along this stretch of coast vary considerably from beach to beach. The largest variations in beach width occur at Aldinga Morgan Beach (72m), Moana Regent (74m), and Moana Sands (69m). The lowest occurs at Port Willunga Snapper Point (22m) (excluding Christies Solarfarm which has limited data). The variation is likely due to their varying exposure differences, the presence or not of reef and its depth and proximity to the shore, to human actions, and in some cases, perhaps, to local trapping of the longshore drift.

The trends in intertidal beach widths show that of the 15 beaches examined, 4 indicate slight increases in beach width, and 8 beaches indicate slight decreases in width. NONE of these trends are statistically significant with extremely low regression coefficients. Three beaches have moderately statistically significant trends (R^2 ~0.4), one of which shows widening (Port Willunga Snapperpoint), and 2 show a decrease in width (Seaford and Christies Solarfarm).

On average the widest beach widths occur in summer months, but there are many occasions when this also occurs in winter months. Some of the narrowest profiles also occur in summer. This variation in seasonal beach widths is likely due to two completely separate causes. Figure 1 illustrates the surfzone near Sellicks Washpool area. There is a wide beach, surfzone trough, and subtidal bar present. If the bar migrates onshore, which commonly occurs during low wave periods, fills in the trough and attaches to the beach, the beach width will nearly double significantly increasing the intertidal beach width. Alternatively, if there is a high wide berm present, and a storm occurs which transports sand down-beach, eroding and flattening the profile, the intertidal beach width will increase. Thus, calm periods and bar accretion or storms and beach erosion will operate at times to produce an increase in intertidal beach width (HAT to LAT) as measured here.

Finally, a cautionary note. In some cases, the data presented in the figures above (e.g. Christies Solarfarm) indicates a narrowing (loss) of beach width over time, whereas, in fact the beach has accreted by forming a high wide berm (Figure 2 below). When a measurement of the distance between Highest Astronomical Tide (HAT) and Lowest Astromonical Tide (LAT) is taken from the 2014 profile shown in Figure 2, the accreted profile at Christies Solarfarm, the calculated intertidal beach width is narrower than the more eroded profile of 2010 (Figure 1) because more sand is higher up on the 2014 profile than is the case in 2010. Thus, beach widths are calculated as 67.8m for the more eroded 2010 profile and 47.7m for the accreted 2014 profile. We recommend that the data presented in the graphs on intertidal beach width changes be carefully interpreted while also looking at the 2D topographic profiles.

Appendix 3

Studies completed to establish inputs for 1 in 100-year storm surge modelling and routine high-water modelling for each coastal cell. M. Western (Integrated Coasts)

Inputs for 1 in 100-year storm surge

To provide a more fine-grained basis for the modelling the *wave run-up* figures allocated by SA Coast Protection Board were not utilised but wave run-up figures were obtained by surveying the location and height of seaweed strands of the extreme event 21 November 2018. In this event, the height of the surge was recorded at 1.52m AHD at Outer Harbor. This storm occurred when the tidal cycle was in the lower range and therefore had only moderate impact, but the wave effects were significant[1]. The wave effects applied to each coastal cell are recorded in the table below. Data was not available at Christies Beach due to wave runup culminating within the rock revetment (i.e. no measurable seaweed strands) and by the time surveying was completed at O'Sullivan Beach, rain had made surveying imprecise. The wave run-up allowances recorded in the right-hand column were added to the storm surge allowance set by CPB of 2.20m AHD from Sellicks to Seaford, and 2.30m from Port Noarlunga to O'Sullivan Beach. Wave setup has been consistently applied at 0.40m to align with the allowance set by CPB. The companion report, Extreme event analysis: *Port Noarlunga to Sellicks Beach for 21 November 2018* provides a full explanation of the methodology and results.

Table: Results from survey of seaweed strands left by event 22 November 2018.

	Height at beach (AHD)	Outer Harbor gauge	Total wave effects	Wave set-up (0.4m)	Wave run-up
Port Noarlunga Beach	**3.30**	1.50	**1.8m**	0.4m	1.4m
Seaford Cliffs	**3.00**	1.50	**1.5m**	0.4m	1.1m
Moana Beach	**3.00**	1.50	**1.5m**	0.4m	1.1m
Maslin Beach (north)	**3.70**	1.50	**2.2m**	0.4m	1.8m
Maslin Beach (south)	**3.40**	1.50	**1.9m**	0.4m	1.5m
Port Willunga (north)	**3.70**	1.50	**2.2m**	0.4m	1.8m
Port Willunga (south)	**3.40**	1.50	**1.9m**	0.4m	1.5m
Aldinga Reef (north)	**2.90**	1.50	**1.4m**	0.4m	1.0m
Aldinga Reef (middle)	**2.60**	1.50	**1.1m**	0.4m	0.7m
Aldinga Reef (south)	**2.90**	1.50	**1.4m**	0.4m	1.0m
Aldinga Beach	**3.00**	1.50	**1.5m**	0.4m	1.1m
Sellicks Beach	**3.00**	1.50	**1.5m**	0.4m	1.1m

[1] See also report, Extreme event analysis: Port Noarlunga to Sellicks Beach for 21 November 2018, Integrated Coasts, December 2018, for full explanation of methodology and results.

Inputs for routine highwater modelling

1. The installation and operation of a tidal gauge on the footbridge over the Onkaparinga River at Southport from July to November 2019 served two purposes:

    - The first was to provide the inputs for a comparison of tidal data between Outer Harbor gauge and the Southport gauge for the month of October 2019. The study found that the average difference between the two gauges was 0.19m (range 0.12 to 0.25m). Note: Previous analysis between Port Stanvac and Outer Harbor established that Port Stanvac was 87% of Outer Harbor data which is congruent with this finding.

    - When conducting the tidal surveys on six occasions between August and November 2019, the data from this tide gauge provided a comparison point with the manual tide gauges at Maslin Beach and Sellicks Beach (see study 2).

2. The tidal study undertaken at Maslin Beach and Sellicks Beach from August to November 2019, in conjunction with the data from the South Port tide gauge, provided a means to evaluate the tidal relationship along the Onkaparinga coastline. A dumbbell weight was located on a reef at Sellicks Beach and within rocks at Maslin Beach and both surveyed to establish a benchmark. Manual tide gauges were constructed, and observations undertaken for six high tides in calm conditions in the months August to November 2019.

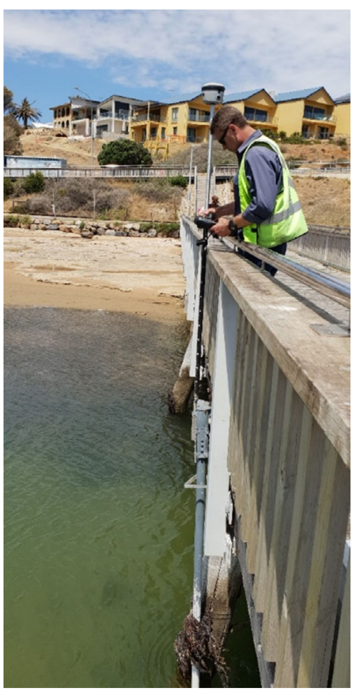


Figure: Levelogger tide gauge installed in tube on footbridge at Southport (Port Noarlunga). Data from a barometric reader was combined with the tidal data.

Figure: Dumbbell surveyed and left on the reef/rocks at Sellicks and Maslin Beaches. The float and tube manual tide gauge was installed prior to each tide data capture.

Figure: Five-minute observations were taken over ~1 hour period at projected high tide on calm days.

Outputs from the tidal study

Table: Outputs from tidal study – Maslin Beach and Sellicks Beach

survey	date	time		OH meas. M (AHD)	Southport	Sellicks	Maslin
A	13-Aug-19	3:37pm			0.50	0.53	no data
B	14-Sep-19	5:05pm		0.87	0.60	0.62	no data
C	4-Oct-19	6:30am		0.81	0.60	0.58	0.66
D	5-Oct-19	6:52am		0.83	0.59	0.59	0.67
E	15-Oct-19	6:20pm		0.69	0.46	0.61	0.50
F	18-Nov-19	7:30am		0.82	0.60	0.59	0.70

Findings from the tidal study:

- The congruence between readings from the tide gauge at Southport and Sellicks was extraordinarily high (range of 3cms over five observations). There was one reading from Sellicks which was an anomaly and possibly due to faulty equipment.
- Maslin Beach's readings were 4cm to 10cm higher than Sellicks/Southport but still a high level of congruence between the three gauges.
- The difference between Outer Harbor and Southport was an average of 23cms. This is 4cm higher difference than the mean of the October comparison (tidal study 1) but also demonstrates strong congruence in the data sets.
- The conclusion from this tidal study is that tide heights are essentially the same along the Onkaparinga coastline and therefore future readings from the Southport tide gauge are valid for the entire coast.

3. The event of 23 July 2019 provided the opportunity to obtain wave effects data for a moderate event by surveying seaweed strands from Sellicks Beach to O'Sullivan Beach. The tide height for this event was calculated at 1.27m AHD by using the mean of all monthly high tides from April to September at Outer Harbor since 1945, less 0.19m to compensate for the difference between the two gauges. The actual Outer Harbor tide height for this event was 1.34m AHD. The height of tide applied to the modelling for the routine highwater was 1.30m AHD. Wave setup was uniformly set at 0.30m for the entire coast. Wave runup figures were based on the seaweed strand analysis and are provided in the table below.

Table: Wave runup allowances for the routine highwater event

Cell	WAVE RUNUP	Wave runup (m)
1	Sellicks Beach	0.70
2	Aldinga Beach	0.70
3	Aldinga reef (south)	0.70
3	Aldinga Reef (middle)	0.50
3	Aldinga Reef (north)	0.50
4	Port Willunga (south)	0.90
4	Port Willunga (north)	1.40
5	Maslin Beach (south)	1.20
5	Maslin Beach (north)	1.40
6	Moana Beach	0.70
7	Seaford cliffs (south)	0.70
7	Seaford Cliffs (north)	0.70
8	South Port	1.40
8	Port Noarlunga Beach	0.90
9	Christies Beach	1.00
9	O'Sullivan Beach	1.40

Modelling of the routine highwater tended to display high congruence with observed winter seaweed patterns throughout the coast.

Figure: Location of seaweed strands after routine highwater events (end of winter)

Photograph: M. Western (2019)

The companion report, Tidal Studies: *Port Noarlunga to Sellicks Beach, July to October, 2019* provides a full explanation of the methodology and results.

Inherent erosion hazard rating - Assessment worksheet

Name of Cell: Port Noarlunga (Cell 4)

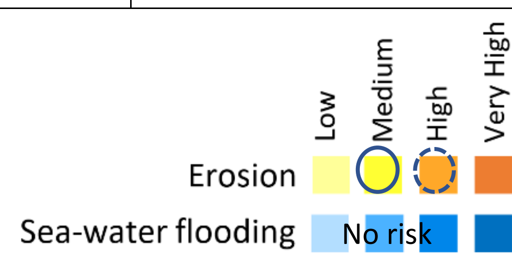
Minor Cell 4.2 End of the Esplanade to the end of the sand spit.

Evaluation Steps	Assessment factors	Inherent hazard risk
Allocate initial erosion hazard rating from geological layout table	Sandy shore backed by soft sediments and dunes, Spit and estuary system.	Moderate (modified from “high” as data shows that beach and dune system is dynamic but overall stable since 1949).
Should this rating be amended due to human intervention such as a protection item? If so, how?	Nil	Moderate
Apply an exposure rating (Nature Maps)	Moderately exposed	Moderate
Assess any impact on Backshore 1	Dynamic, related to beach natural cycle. Blowout on dune system with planting to keep stability.	Moderate
Assess any influence from benthic	Sand and seagrass, Port Noarlunga reef offering some wave protection at the extreme north of the cell.	Moderate
Assess the sediment balance	Expected decline	Moderate
Assess any other factors that may warrant a change to the inherent hazard risk rating.	Notes: Inherent risk is “high” as the system is composed by sand, however although sand is erodible the system seems overall to be stable and changes are associated with common beach dynamics with little overall change, therefore we assign a “moderate” risk, however with SL rise the risk increases to high.	Moderate-high

Assessment completed by:

Dr Robert Bourman
Dr Graziela Miot da Silva (Flinders University)

In workshops held on 12 and 13 December 2019.



Inherent hazard risk assessment – Inundation table

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)