Kangaroo Island Coastal Hazard Strategy

November 2018

Prepared for Kangaroo Island Council by

Seed Consulting Services and Water Technology

seed consulting services

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prepared for Kangaroo Island Council

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Contents

Tables

Figures

Executive summary

Background

Kangaroo Island is valued for its natural assets, which include a range of sand and rocky shorelines that support a unique coastal ecology that has economic, community and conservation significance.

Many coastal settlements on Kangaroo Island have traditionally been vulnerable to the impacts of coastal inundation and flooding, and beach erosion. At some locations, these impacts will be exacerbated in the future due to sea level rise as a result of our changing climate.

The impacts of coastal hazards such as erosion and inundation are already evident on the Island with anecdotal reports of past flooding and some settlements already having levees in place to provide protection against the impacts of large storm surge events.

Kangaroo Island Council is one of six local government partners in the Resilient Hills & Coasts (RH&C) climate change adaptation project covering the Adelaide Hills, Fleurieu Peninsula and Kangaroo Island region. In 2016, RH&C completed a climate change adaptation plan for the region. One of the priorities areas for action identified in the plan was to identify ways to better manage coastal assets at risk from future sea level rise.

Kangaroo Island Council obtained funding via the National Disaster Resilient Program to undertake a further study, but this time addressing coastal hazards associated with current & projected sea level rise.

Objective of this Strategy

The objective of this Strategy is to describe the potential impacts of coastal hazards now and under future conditions for a selection of priority settlements on the Island, and to identify potential response options. Hazards consider the combined impacts of existing conditions, such as storm surge events and underlying erosion trends, with the potential future impact of sea level rise.

The Strategy was developed by combining technical analysis with a community engagement process. The technical analysis was undertaken by Water Technology, and was based on an erosion and inundation hazard risk assessment. The engagement process occurred via an online survey, two series of workshops, and direct engagement with community groups.

The impacts described in this Strategy assume that no action is taken beyond a business as usual approach in the future to protect or manage the impacts of erosion and flooding, which is unlikely in practice. Furthermore, it should not be assumed that all impacts require an immediate response; while this may be the case for some settlements for others it may be more appropriate to sequence response options over a period of decades as part of an adaptation pathways approach.

Coastal hazard risk assessment

The development of this Strategy has been informed by a coastal hazard assessment of the impacts of erosion and inundation on settlements identified by Kangaroo Island Council. The Technical Report summarising this assessment and the link to the online erosion and inundation maps is provided on the Kangaroo Island Council website:

www.kangarooisland.sa.gov.au/coastalhazardmapping

The analysis was underpinned by an understanding of the elevation of each settlement and oceanographic and coastal processes relevant to Kangaroo Island. The elevation was determined using LiDAR data collected in 2015.The main oceanographic processes considered are:

- mean sea level;
- astronomical tide;
- storm tide; and
- wind and waves.

The mean sea level will be influenced by climate change and sea level rise over time. The Coast Protection Board recommends that development allow for 30 cm of sea level rise by 2050 and 1 m by 2100 and as such these figures have been used for the hazard risk assessment conducted for this project.

Storm tide levels are based on the 100-year Average Recurrence Interval (ARI) water level for the Kangaroo Island coastline as provided by the Coast Protection Board.

The general coastal geomorphology for Kangaroo Island which influences susceptibility to coastal erosion, is :

- sandy shorelines, most readily eroded of all sediment types;
- soft rock shores, generally cohesive clayey material which are more resistant to erosion than sandy shorelines, but not as resistant as hard rock;
- hard rock shorelines most resistant to noticeable erosion on decadal time-scales; and
- estuaries, lagoons and tidal flats.

The assessment of erosion differs depending on the underlying geomorphology. For sandy shorelines the assessment accounts for:

- long term recession caused by a net loss or build-up of sediment at a beach;
- short-term erosion as a consequence of storm surge events; and
- recession due to sea level rise, calculated using the “Bruun” factor.

On open coasts, the Bruun factor “rule of thumb” is typically in the range of 50 to 100. That is, coastal recession will be 50 to 100 times the predicted sea level rise magnitude. This means, for example, that 30 cm of sea level rise could be expected to result in 15 m to 30 m of sandy shoreline erosion.

For predominantly soft rock shorelines the assessment accounts for:

- long term recession; and
- recession due to sea level rise.

For predominantly hard rock shorelines the assessment accounts for:

- inherent properties of the rock type;
- wave climate (magnitude and exposure);
- accumulation and retention of slope-foot materials such as rocks at the base of a cliff; and
- presence of engineering structures such as seawalls.

Coastal inundation was assessed by considering:

- Long term inundation as a result of increasing tidal elevations with sea level rise; and
- Short term inundation based on storm tide parameters for the 100-year Average Recurrence Interval (ARI) water level, wave setup and wave run-up for Kangaroo Island.

Potential impacts and response options

The Strategy describes potential impacts and response options of coastal hazards for each settlement. The impacts of future erosion and inundation differ widely across the Island depending on the location, with land height and the underlying shoreline geomorphology determining the amount of erosion and inundation risk under current and future conditions. At least four impact categories of towns and settlements can be identified:

- At risk from erosion and inundation – Antechamber Bay, Bay of Shoals, Brownlow, Island Beach, Nepean Bay and Sapphiretown face risk from both erosion and inundation due to the combination of sandy shorelines and low lying land which is prone to inundation;

- At risk from primarily inundation – American River is at risk primarily from inundation, even under a current 1 in 100 year storm surge event, with its mostly rocky shoreline affording protection from erosion;

- At risk from primarily erosion – Brown Beach, Emu Bay and Penneshaw have sand beaches that are highly erodible, with the majority of assets at higher elevations protected from inundation; and

- Low erosion and inundation risk - Baudin Beach and D'Estrees Bay face some erosion risks to soft rock sections of shoreline, and Kingscote faces limited erosion risk at Reeves Point, but the height of most built assets means that impacts from inundation are limited.

The settlements at greatest risk now and in the future from coastal hazards are American River due to inundation risk, and Brownlow and Nepean Bay, due to the combined impacts of erosion and inundation risk. These settlements should therefore be the focus of immediate action.

Aside from identifying impacts on specific settlements, the results also suggest that:

- sections of Hog Bay Road will become inundated periodically, especially as a result of extreme storm surge events toward the end of the century;
- Western Cove as a broader area faces risks from both inundation and erosion; and
- some critical infrastructure will be exposed to increasing risk from erosion and/or inundation such as the Kingscote Community Wastewater Management Scheme.

Analysis was undertaken to identify the number and value of public and private assets at risk. This found that:

- public assets are at high risk at one settlement by 2050 (American River) and at extreme risk at four settlements by 2100 (American River, Brownlow, Nepean Bay, Penneshaw);

- five roads are at extreme risk by 2050 and nine roads are at extreme risk by 2100;

- 115 properties are at high risk of being impacted by erosion and/or inundation by 2050, and by 2100 there are 244 at extreme risk spread across the settlements as follows:

Under current conditions, approximately $23 million of assets are already at risk, primarily from flooding. By mid-century, the risk is still primarily from inundation, with over $60 million in assets projected to be impacted, again mostly as a result of inundation. However, by the end of the century the impact from erosion and inundation is similar at over $76 and $87 million, respectively. While substantial, the monetary values of assets at risk are considered to be conservative because of a number of issues including an incomplete data available for public assets, no account for the combined impacts of overland flow and storm surge, and

there is no consideration given to an increase in the frequency of events that have an ARI of less than 1 in 100 years but that can still cause damage

Response options were identified based on review of the coastal hazard response literature and with input from the community at a series of workshops held in American River, Kingscote and Penneshaw. Coastal hazard response options include managed retreat, accommodating impacts, protecting assets or accepting losses.

A range of priority actions are identified in this Strategy for different settlements. However, there are a number that are common immediate priorities for Council to consider, which are as follows

- Raise community awareness about potential impacts;
- Further modelling of overland flow and storm surge flooding interaction;
- Review the Development Plan to determine how it can be strengthened to either avoid constructing buildings in high risk areas, or ensure that new buildings can accommodate inundation;
- Developing a community emergency management plan for priority settlements such as American River, Brownlow and Nepean Bay;
- Provide all weather roads to ensure that settlements can be accessed by people wanting to move into or leave an area during a storm surge event;
- Protecting coastal vegetation, which helps to protect dunes from erosion; and
- Monitoring changes in sea level and of observed erosion and inundation impacts in order to build confidence in the community about the need for action and also to inform the timing of future decision making.
- 2D hydrodynamic modelling for American River, Brownlow and Nepean Bay to better understand how water will move across the landscape during a storm surge event.

Over the coming decade Council will need to make decisions regarding the future maintenance, upgrade or establishment of levees to protect businesses and homes. In doing this Council will need to determine the balance between its responsibility to protect existing properties versus the responsibility of individual landholders to either protect their own property, construct buildings that can accommodate inundation risks or move assets to lower risk locations.

The timing of key decisions about response options, especially those involving significant financial investment, should be informed by whether “triggers” are met at different locations across the Island. It is likely that specific triggers that will be important for the Island include:

- inundation of the land at American River on the landward side of Tangara Drive;
- breaches to the levee at Brownlow;
- frequency and extent of inundation at Nepean Bay and surrounding low lying land;
- damage or disruption to traffic movement at various locations on Hog Bay Road; and
- erosion to the extent that Frenchmans Terrace at Penneshaw is impacted.

1 Introduction

1.1 Background

Kangaroo Island is located 13.5 km south of mainland South Australia at its closest point. It encompasses an area of 4,400 square kilometres and has a resident population of approximately 4,500 people, with an additional 200,000 visitors each year. These visitor numbers are steadily increasing. The Island is valued for its natural assets, which include a range of sand and rocky shorelines that support a unique coastal ecology that has economic, community and conservation and significance.

Coastal communities such as those on Kangaroo Island are vulnerable to sea level rise, coastal inundation and flooding and dune recession in our changing climate. The impacts of coastal hazards such as erosion and inundation are already evident on the Island with anecdotal reports of past flooding and some settlements already having protection levees in place around settlements.

In responding to coastal hazard risks, local councils must actively collect data that informs practical decision making, and provides the opportunity for capacity building amongst staff, community and other stakeholders in developing and delivering adaptation responses.

The urgent need for a proactive approach on Kangaroo Island was demonstrated in a 2013 land-based flood event, which impacted on the MacGillivray/Haines district on the south of the island. The Council subsequently deemed hazard mapping and analysis a priority for those areas at risk of land-based flooding to enable informed decision-making and future policy development. In conjunction with Department for Environment and Water (DEW), LiDAR[1] data was captured for the eastern end of Kangaroo Island.
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Kangaroo Island Council is also one of six local government partners in the Resilient Hills & Coasts (RH&C) climate change adaptation project covering the Adelaide Hills, Fleurieu Peninsula and Kangaroo Island region. In 2016, RH&C completed a climate change adaptation plan for the region. One of the priorities areas for action identified in the plan was to identify ways to better manage coastal assets at risk from future sea level rise.

Kangaroo Island Council obtained funding via the National Disaster Resilient Program to undertake a further study, but this time addressing coastal hazards associated with current & projected sea level rise.

[1] LiDAR Light Detection and Ranging: a contemporary method of high resolution topographic mapping using laser reflections off ground and other surfaces.

1.2 Objective

The objective of this Strategy is to describe the potential impacts of coastal hazards now and under future conditions and to identify response options. Hazards consider the combined impacts of existing conditions, such as storm surge events and underlying erosion trends, with the potential future impact of sea level rise.

The focus of the Strategy is on the following coastal settlements:

- American River
- Antechamber Bay
- Baudin Beach
- Brown Beach
- Brownlow
- D'Estrees Bay
- Emu Bay
- Island Beach
- Kingscote
- Nepean Bay
- Penneshaw
- Sapphiretown

The location of these settlements across Kangaroo Island in relation to available LiDAR data, which has been used to determine elevations for the modelling, is provided in Figure 1.

This Strategy does not specifically consider impacts on natural assets and a separate assessment of this issue is warranted, especially given that one of the immediate priority response options is coastal vegetation management to protect dunes and reduce erosion.

1.3 How was this strategy developed?

This Strategy was developed by combining technical analysis with a community engagement process. The technical analysis was undertaken by Water Technology, and was based on an erosion and inundation hazard risk assessment. This generated maps of potential future erosion and inundation for each of the priority settlements. A more detailed description of the technical analysis methods is provided in Section 2.

The community engagement process was designed to build capacity and raise awareness about how erosion and inundation risk is assessed and to seek input into understanding potential impacts and response options for the target settlements. Engagement occurred via an online survey, two series of workshops, and direct engagement with community groups. The first workshop was held in Kingscote and was designed to present the erosion and inundation maps and explore potential impacts on public and private assets, while the

second series of workshops were held in Kingscote, American River and Penneshaw and focused more so on current and future response options.

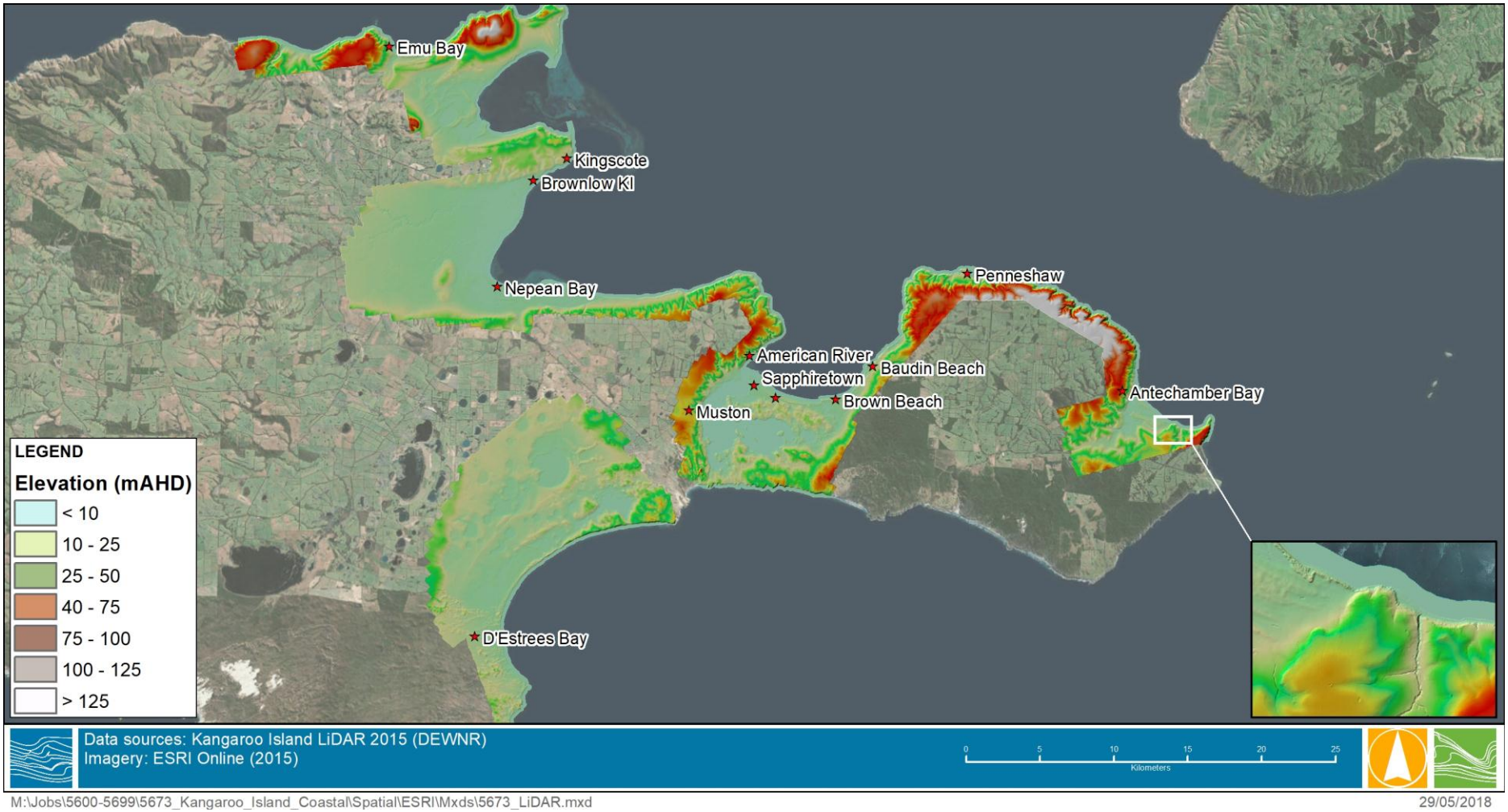

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Figure 1. LIDAR data coverage for Kangaroo Island in relation to a selection of the target settlements for this Strategy.

2 Coastal hazard risk assessment

The development of this Strategy has been informed by a coastal hazard assessment of the impacts of erosion and inundation on settlements identified by Kangaroo Island Council. The Technical Report summarising this assessment and the link to the online erosion and inundation maps is provided on the Kangaroo Island Council website:

www.kangarooisland.sa.gov.au/coastalhazardmapping

Sections 2.1 to 2.4 provide a broad summary of the approach to undertaking the erosion and inundation hazard assessments. For further detail on the methods and results, refer to the Technical Report.

2.1 Oceanographic and coastal processes

The analysis was underpinned by an understanding of the oceanographic and coastal processes relevant to Kangaroo Island.

The main oceanographic processes considered in the analysis are:

- mean sea level;
- astronomical tide;
- storm tide; and
- wind and waves.

The mean sea level will be influenced by climate change and sea level rise over time. The Coast Protection Board recommends that development allow for 30 cm of sea level rise by 2050 and 1 m by 2100 and as such these figures have been used for the hazard risk assessment conducted for this project. A broader discussion on climate change and its impact on sea level rise and other aspects of climate in the region is provided in the Resilient Hills and Coasts Regional Climate Change Adaptation Plan (available on Council's website).

Storm tide levels are also important for determining future potential inundation risk. The Coast Protection Board establishes the 100-year Average Recurrence Interval (ARI) water level for the entire South Australian coastline and provided this data for the areas of interest within the Kangaroo Island coastline.

The main coastal processes are influenced by the geology and geomorphology of the target settlements. The generalised coastal geomorphology is informed by the SMARTLINE dataset[2] and describes susceptibility to coastal erosion, namely:

[2] SMARTLINE data is available from https://ozcoasts.org.au/

- Predominantly sandy – typically sandy types of shorelines, most readily eroded but also very mobile and capable of accretion (growth) as well as erosion;
- Predominantly soft rock – generally cohesive clayey material which are more resistant to erosion than sandy shorelines, but not as resistant as well-lithified rock. These may erode slowly but significantly over time, and do not rebuild as sandy shores may; and
- Predominantly hard rock – most resistant to noticeable erosion on human time-scales although steeper hard rock shores may be notably unstable. Moderately sloping hard rock shorelines are considered to have negligible erosion hazard based on the lack of historical-observed instability in this shoreline type.

A further category considered in the analysis was estuaries, lagoons and tidal flats.

2.2 Erosion assessment

2.2.1 Sandy shorelines

The assessment of erosion differs depending on the underlying geomorphology. For predominantly sandy shorelines the assessment accounts for:

- long term recession caused by a net loss or build-up of sediment at a beach;
- short-term erosion as a consequence of storm surge events; and
- recession due to sea level rise, calculated using the “Bruun” factor.

Long term erosion can be assessed for a number of sites on Kangaroo Island using prolife analysis. Cross sections were provided by the South Australian Coastal Protection Board for the sandy beaches of Emu Bay, Brownlow, Island Beach, Penneshaw and Antechamber. The majority of these cross sections were first surveyed in 1985 and have been regular surveyed ever since.

On open coasts, the Bruun factor “rule of thumb” is typically in the range of 50 to 100 (Mariani, et al. 2012). That is, coastal recession will be 50 to 100 times the predicted sea level rise magnitude. This “rule of thumb” provides a conservative approach to identifying areas potentially at risk. By using the recommended extent of sea level rise advised by the Coast Protection Board, the estimated shoreline recession rates in response to sea level rise ca be calculated.

Table 1. Estimated shoreline recession rates in response to sea level rise.

SLR Scenario	**Bruun Factor = 50**	**Bruun Factor = 100**
2050 (0.3m)	15 m	30 m
2100 (1.0m)	50 m	100 m

2.2.2 Estuaries, lagoons and tidal flats

The primary driver of erosion for estuaries, lagoons and tidal flats is expected to be sea level rise. Elevated water levels in estuaries and coastal lagoons will lead to increasingly saline water and an increase in wave action along the shoreline. Increasing salinity will likely result in dieback of more freshwater dependent fringing vegetation, which then exposes the softer estuarine sediments to waves. A more energetic wave climate in turn increases the rate of erosion of the soft shoreline material. There may be little or no recovery between erosion events, compared to episodic recovery that occurs on open sandy coasts.

2.2.3 Soft rock

For predominantly soft rock shorelines the assessment accounts for:

- long term recession; and
- recession due to sea level rise.

Although there have been studies of long term coastal soft rock erosion and recession processes (e.g. Trenhaile 2011) there are no widely accepted or used methods for generating generic (widely-applicable) soft rock coastal erosion susceptibility zones. Historical rates of soft rock shoreline recession are the best available indicators of potential future rates. As such, comparison of historic aerial imagery was used to estimate historic recession rates for this study.

Individual storm bites as recorded and used for sandy shorelines are not as useful for soft rock shores. Soft rock erodes less in a given storm than soft sediments may, however it does not recover from erosion and so tends to show recession rates over longer periods, representing the cumulative effect of repeated small storm bites. Therefore, the long-term recession rate is more useful to define coastal erosion hazards for soft rock coasts.

Trenhaile (2011) provides evidence that soft rock shores tend to progressively erode and recede landwards at slow to moderate but fairly continuous rates under stable sea-levels. However, soft rock shoreline retreat rates are expected to increase with a rising sea-level, primarily because of reduced wave attenuation as water deepens over the near shore profile, allowing stronger wave attack. Modelling of soft rock recession processes suggests that with continuation of the sea-level rise acceleration now being observed, cliff recession rates in cohesive clay soft rock shores may be 1.5 to 2 times greater over the next century than they were in the last 100 years (Trenhaile 2011). In order to allow for expected acceleration of shoreline retreat rates with sea-level rise, a conservative allowance of 2 x historical recession rates has been applied.

2.2.4 Hard rock shoreline

The rate of recession of rocky shorelines is determined by:

- inherent properties of the rock type;
- wave climate (magnitude and exposure);
- accumulation and retention of slope-foot materials such as rocks at the base of a cliff; and
- presence of engineering structures such as seawalls.

Hard rock shores are the least susceptible to erosion of the different types of shoreline. The rate of recession of hard rock shorelines is very low, however, the risk associated with a collapse can be high as significant portions break off. Steeply sloping hard rock shorelines, such as hard bedrock cliffs, while highly erosion resistant, can be subject to block falls and slumping.

For this study, shorelines of steep to cliffed hard rock (i.e. with a slope of greater than 45º) have been categorized as having potential for rock falls and slumping hazards, although the risk rating is low. More gradual sloped hard rock shorelines are not considered to represent an erosion hazard within existing coastal management time scales.

2.3 Inundation assessment

Coastal inundation describes the process of water from the sea coming over land as opposed to rainfall driven flooding that comes from land based catchments. Coastal inundation has been assessed by considering two factors:

- Long term inundation: Existing and future tidal levels have been mapped as an indication of potential long-term inundation as a result of increasing tidal elevations with sea level rise. The extent of sea level rise allowed for is the same as applied for the erosion assessment i.e. 30 cm by 2050 and 1 m by 2100.

- Short term inundation: Coast Protection Board policy stipulates that the 100-year Average Recurrence Interval (ARI) water level should be applied to assess the predicted coastal inundation. The Coast Protection Board has provided storm tide parameters for the 100-year Average Recurrence Interval (ARI) water level, wave setup and wave run-up for Kangaroo Island. The maximum water level, including wave setup and runup, has been mapped to provide a conservative assessment of inundation extents.

Both the tidal plane and peak 100-year ARI water level has been mapped across the study area using a “static” or “bathtub” water level approach but accounting for local features such as levees or banks which may provide some protection in particularly areas to a low-lying backshore. This uses a digital elevation model that was developed based on LiDAR data collected in 2015.

There are limitations to the bathtub approach because it assumes that any elevation on the land that is at or below future sea level will become inundated. In practice, the way water moves across the land surface may be somewhat different, however, for the purpose of providing a first pass assessment of areas at risk from extreme coastal water levels, this is considered appropriate.

2.4 Risk assessment definitions

Risk was assessed for public, road and private assets by considering the likelihood of impacts from erosion and inundation and the consequence. This was assessed for current conditions, which includes allowance for a 1 in 100 year ARI storm surge event, by mid-century (i.e. 30 cm sea level rise) and the end of the century (i.e. 1 m sea level rise). The result of this was a determination as to which of the following risk categories applied to different assets:

- Low - Tolerable risk. A level of risk that is low and manageable without intervention;
- Medium - A level to frisk that may require intervention to mitigate;
- High - A level of risk requiring significant intervention to mitigate; and
- Extreme - Immediate action required.

Note that for the purpose of this assessment, roads are separated from other public assets for clarity of communication.

3 Potential impacts and response options

3.1 Overview

This section of the report provides a synthesis of the potential impacts and response options for each of the target settlements. The potential impacts are drawn from the Technical Report and outline what may occur if no action is taken to address the changing risk from erosion and inundation. The monetary value of assets impacted combines both the erosion and inundation costs. Separate values for these costs are presented in the Technical Report. The erosion and inundation maps presented in this section can be further explored through the online mapping tool which can be accessed from the Kangaroo Island council website.

Response options were identified based on review of the coastal hazard response literature and with input from the community at a series of workshops held in American River, Kingscote and Penneshaw. In general, coastal hazard response options fall broadly into one of the following categories (NCCARF 2016):

- Managed retreat – Priority assets are moved to locations that will not be impacted by erosion and/or inundation;
- Accommodate - Priority assets are managed, retrofitted or designed in a way that they can withstand the impacts of periodic inundation and erosion;
- Protect - Priority assets are defended using a range of “hard” (e.g. sea walls, rockwalls) or soft (e.g. dune restoration) response options;
- Loss acceptance – Priority assets are not moved, retrofitted or protected and impacts and losses are accepted.

Within each of the first four response categories there is a range of potential adaptation options in the areas of planning, engineering, environmental management and community awareness and education.

None of the response options identified above is necessarily right or wrong. However, the different options will have different environmental, cultural, social and economic costs and benefits associated with them both at an individual, community and societal level and the trade-offs will need to be thoroughly considered as part of the decision making process on how to respond. The purpose of this Strategy is therefore to present a way forward for the community and Council to work together to address current and future coastal hazard risks.

Furthermore, not all response are required immediately. Instead it is essential that the sequence of options be identified, with some being appropriate now (e.g. avoiding construction in high risk areas), while others are delayed until the projected erosion and inundation impacts are observed or at least better understood.

For high resolution versions of the projected erosion and inundation maps please refer to the online version of the maps at: www.kangarooisland.sa.gov.au/coastalhazardmapping

www.kangarooisland.sa.gov.au/coastalhazardmapping

3.2 American River

American River is located at the mouth of Pelican Lagoon on the north coast of Kangaroo Island. The town has a population of approximately 200 people and consists of a lower lying area between Tangara Drive and the southern end of Buick Drive, and a higher elevation area heading north along Scenic Drive.

In addition to residential dwellings, American River has a number of shops, accommodation providers, and recreational facilities (e.g. foreshore tennis courts). The wharf is a base for aquaculture, recreational boating, fishing and tourism activities, and the boat ramp allows for launching of commercial and recreational boats. Critical infrastructure in the town includes the network of roads, wastewater pumps and the CFS, which is located on Tangara Drive.

3.2.1 Potential impacts

Natural and built assets face impacts from inundation under current and future conditions. In contrast, the low erodibility of the hard rock shoreline means that erosion is not likely to be a major concern in the coming decades.

Erosion

The American River foreshore north of the wharf consists of hard rock that has very low erodibility. Given that the town faces a low energy section of coast, erosion along this part of the coast is unlikely to be a concern over the coming century. South of the wharf are softer sediments in the mouth of Pelican Lagoon. These are more susceptible to erosion and projections suggest that by the end of the century erosion in these areas could occur up to American River Road and Tangara Drive.

Inundation

Under current conditions, modelling suggests that a 1 in 100 year ARI storm surge event will push water to Tangara Drive on the southern edge of town and fully inundate the road from its intersection with Moreana Drive toward the intersection with Scenic Drive. Evidence of the potential for inundation in this area came in May 2016, when the newly installed tennis courts were flooded during a storm surge event. Anecdotal reports also suggest flooding of Tangara Drive has occurred in the past although no information is available on how frequently this occurs.

Figure 2. Projected extent of tidal erosion at American River for 2050 and 2100. Light green – current conditions; medium green – 2050; dark green – 2100.

Figure 3. Projected extent of inundation at American River for 2050 and 2100. Light blue – current conditions; medium blue – 2050; dark blue – 2100.

By mid-century, it is projected that a 1 in 100 year ARI storm surge event will have the ability to push water up into the area of open space that lies to the west of the oval. By the end of the century a similar event would result in the inundation of most of the land between Buick and Tangara Drive. Storm surge events of this size will also inundate parts of American River Road that is owned by Department of Planning, Transport and Infrastructure (DPTI).

By the end of the century, the annual high water mark will also cause regular inundation of much of the land on the seaward side of the southern end of Tanagra Drive along with the foreshore areas north of the tennis courts on Tangara Drive.

It is anticipated that inundation would be exacerbated by any overland flow occurring from rainfall driven storm events in the catchments that feed into the drainage lines along Redbanks Road. Modelling to understand this potential impact has not been incorporated into this study, however it is recommended that it be undertaken in the near future (see Section 4.3). Noting that this modelling has not been undertaken at this stage, the extent of inundation described in this study during a 1 in 100 year ARI storm surge event should be considered conservative until this modelling is completed.

Assets

In American River there is limited projected impact of erosion on public and private assets given that erosion is restricted to land alongside the estuary with the exception of Council's campground. This poses the greatest future risk to the integrity of the road base on American River Road and Tangara Drive.

One quarter of the wastewater pumping stations are currently at risk from a 1 in 100 year ARI storm surge event, along with an estimated 8% of the pipes and drains and 11 other public assets (e.g. tennis courts). By mid-century over one third of wastewater pumping stations are expected to be at risk from such storm surge events and by the end of the century, half of the pumping stations will be at extreme risk. By the end of the century it is also projected that 16 other assets will be at a high risk level, such as the tennis courts, car parks and American River CFS.

The projected monetary impact of erosion and inundation on public assets is:

- $2,204,900 if a 1% ARI storm surge event was to occur under current conditions;
- $2,488,750 by 2050; and
- $2,869,700 by 2100.

Several roads in American River are exposed to inundation under current 1 in 100 year ARI storm surge events, however, the extent of inundation will increase through time. For example, under current conditions approximately one third of Bimberta and Moreanda Avenues would be inundated in a 1 in 100 year storm surge event, whereas by the end of the century all of these roads would be fully inundated. Similarly, one third of Tangara Drive

would be inundated currently in a 1 in 100 year event, whereas by the end of the century 89% is projected to be inundated. Such conditions wold create challenges for community members to move out of heir properties and for emergency services vehicles to gain access.

The projected monetary impact of erosion and inundation on roads is:

- $2,379,553 if a 1% ARI storm surge event was to occur under current conditions;
- $2,806,140 by 2050; and
- $3,313,651 by 2100.

While not relevant to direct impacts on American River, potential erosion and inundation at the southern end of Pelican Lagoon where it meets the Hog Bay Road could impact vehicle movement across the Island. At present this is the only road that connects the east and west of the island. Anecdotal reports have already indicated inundation issues at this location, specially YMCA Corner, in previous storm surge events.

With respect to private assets and homes, 31 at low to medium risk in a 1 in 100 year event under current conditions. These are properties located along Tangara Drive, Bimberta and Moreanda Avenues, and Old Schoolhouse Street. By mid-century, there are 50 homes at risk, 12 of which are at high risk, and by the end of the century there are 92 properties at risk, 42 of which are high risk and 38 at extreme risk.

The projected monetary impact of erosion and inundation on private assets is:

- $3,897,690 if a 1% ARI storm surge event was to occur under current conditions;
- $7,255,620 by 2050; and
- $18,050,820 by 2100.

3.2.2 Response options

The aim of response options at American River is primarily to address the potential inundation risk, especially from storm surge events. The projected impact of a 1 in 100 year ARI storm event means that action is already required now to help further protect or avoid damage to key public and private assets.

Given the inundation risks under existing conditions, immediate priority responses should consider:

- Further modelling of overland flow - A concurrent event where significant rainfall in nearby catchments coincide with a storm surge event would create more significant inundation than has been projected in this study, which focusses only on storm surge and sea level rise. Further modelling is required to better inform the extent of flooding under such a scenario and therefore the timing of future actions;

- Review the Development Plan - Amendments to the development plan to ensure that all future dwellings have floor heights that are sufficiently high to protect homes from projected flooding. This can be done through the use of stilts or by raising the height of the pad on which house foundations are laid;

- Developing a community emergency management plan - Such a plan has been developed for other coastal settlements in South Australia (e.g. Webb Beach north of Adelaide), and would provide consistent information on how the community can respond during short duration storm surge events;

- All weather roads - Ensuring that primary roads in and out of American River are all weather roads, that is they are trafficable in all weather conditions; and

- Levee bank upgrade options analysis - A levee bank already exists along parts of the shoreline next to Tangara Drive, and Tangara Drive itself being slightly higher than the surrounding land provides protection from storm surge in some areas. A review of options for increasing the height of the existing levee bank is required, which may consider how to incorporate aspects of passive recreation (e.g. walking trial) into the design.

Within the next decade further work will be required to determine how best to manage assets between Buick and Tangara Drive. This will include balancing options between protecting assets through a levee structure or whether an accommodate approach may be more suitable involving raising the floor heights of existing priorities, now or at the point at which they are redeveloped over the coming decades. With respect to the levee, any such structural work will need to consider the Coast Protection Board's requirement for allowance of 30 cm by 2050 and 1 m sea level rise by 2100.

Other considerations in the short term will be:

- the location of land zoned as Town Centre, which is currently in the area projected to be impacted by future inundation. Other options may need to be explored such as moving the area zoned as Town Centre further up Burden Drive; and

- to assess the potential to reintroduce natural oyster reefs, which were once prolific at American River, as a way of mitigating the impact of wave energy during storm surge events. This option was favoured for further exploration by the community at the response option assessment workshop.

In the longer term, and subject to decisions about the ability to protect key assets in the affected areas, some critical infrastructure may need to be retrofitted or relocated to higher areas such as the water pumping stations and CFS.

The timing of response options should consider when triggers are met for decision making. Based on discussions with the community and information obtained during the background analysis for this Strategy, potential triggers for American River may include:

- impacts on foreshore infrastructure;
- experiencing more frequent high impact weather events;
- extent of flooding on Tangara Drive; and
- impact on Town Centre properties.

As the response options for American River are further scoped and developed, the triggers can be further quantified. Once this is done, monitoring of indicators that relate to the triggers will help to inform whether any of the proposed response options need to be brought forward or deferred where impacts are less than projected.

3.3 Antechamber Bay

Antechamber Bay is an important environmental asset on the eastern end of Kangaroo Island. It features a stretch of sandy shoreline approximately 4 km in length that faces Backstairs Passage, the area of sea between Kangaroo Island and the Australian mainland.

A key feature of the site is the Chapman River which runs into the sea by cutting through the beach at Antechamber Bay. The River forms an estuary, which during dry periods is blocked at its mouth by a sand berm causing water levels in the estuary to increase. The land at the northern end of the beach forms part of Lashmar Conservation Park. In this area, council is responsible for management of Willoughby Road, while the State Government is responsible for Creek Bay Road and Lashmar Road.

3.3.1 Potential impacts

Primarily natural assets along this stretch of coast face impacts from erosion and inundation under current and future conditions.

Erosion

Antechamber Bay is comprised of highly erodible sandy shorelines between the rocky cliffs roughly 700m north of the Chapman River mouth and rocky headland separating Antechamber Bay with Red House Bay in the south. By mid-century, erosion will cause the loss of much of the dune, and by the end of the century erosion will have reached what is currently the landward side of the dune (
Figure 4).

Erosion will also occur along the Champan River estuary and into Lashmar Lagoon. By mid-century erosion will expand around the section of the estuary near Willoughby Road, and by the end of the century erosion can be expected to occur broadly out from the estuary and the lagoon, across larger areas of Willoughby Road and Creek Bay Road.

Inundation

Under current conditions, and when the river mouth is open, the annual high water mark results in water levels largely remaining in the River channel. However, if the mouth of the river is closed over with a sand berm, water levels can build up inside the estuary and Lashmar Lagoon causing inundation of Willoughby Road. Therefore, the way that inundation occurs in the future will be influenced by whether the mouth of the River is open or closed at the time of storm surge events.

Figure 4. Projected extent of erosion at Antechamber Bay for 2050 and 2100. Beach: dark grey – current; medium grey – 2050; light grey – 2100. Estuary: light green – current conditions; medium green – 2050; dark green – 2100.

Figure 5. Projected extent of inundation at Antechamber Bay for 2050 and 2100. Light blue – current conditions; medium blue – 2050; dark blue – 2100.

If the mouth of the River is open, the annual high water mark will result in increasing amounts of flooding of Willoughby Road. By the end of the century this could be a section of some 700 to 800 m of road, which is the primary access point for Lashmar Conservation Park and Cape Willoughby Lighthouse. If the mouth of the River is open during a 1 in 100 year storm surge event large areas of land become inundated along with multiple sections of Willoughby Road, however, much of this is already possible under current conditions and the impact of additional sea level rise is relatively small (
Figure 5).

In general, on sandy shorelines an increase in sea levels is expected to lead to general beach recession. For a site like the Chapman River, this could be accompanied by landward and upward movement of the entrance berm. This will in turn increase the typical water depth in the estuary and cause water levels to back up further. To understand the extent of further inundation under this scenario would require modelling with a range of berm heights.

Assets

Although the extent of inundation and erosion at Antechamber Bay increases through time, the impact on roads is considered minimal under current conditions. The main concern will be whether the roads are passable to through traffic at the time of storm surge events, which is relevant to residents, emergency services personnel and tourists being able to access or leave the area.

There are up to nine properties that could be at risk from erosion and inundation at Antechamber Bay. Three of these properties are considered to be at high risk by the end of the century due to partial but not complete flooding of their properties.

With respect to private assets, the projected impact of erosion and inundation is:
$757,740 if a 1% ARI storm surge event was to occur under current conditions;
$757,740 by 2050; and
$781,095 by 2100.

These values indicate that with the exception of higher water levels that could occur if the berm height increases in the future, most of the financial risks are already present under current conditions due to a 1 in 100 year storm event.

3.3.2 Response options

Although there is potential for enhanced erosion and inundation in the future at Antechamber Bay, there is limited direct projected impact on public and private assets. The absence of dwellings behind the dunes means that the beach and dune system can be allowed to migrate landward without the need for significant protective works.

The main issues confronting Antechamber Bay will be accessibility and or damage to Willoughby Road. Developing responses options is somewhat complicated by the impact that the sand berm at the mouth of the River has on water levels. In the short term, the Department for Environment and Water will need to continue to assess the backing up of water levels along the River and periodically clear the River mouth. In the longer term, the Department for Environment and Water and Council may need to work together to develop strategies to ensure that residents, emergency services vehicles and tourists can safely move in and out of the area during storm surge events, which could involve:

- Ensuring that primary roads in and out of Antechamber Bay are all weather roads that are trafficable in all weather conditions; and

- Developing a community emergency management plan similar to that developed for other coastal settlements in South Australia (e.g. Webb Beach north of Adelaide). This would provide consistent information on how residents and tourists can respond during periods of short duration peak inundation, such as storm surge events.

A potential trigger for additional action at Antechamber Bay is more regular inundation and damage to Willoughby Road. Determining the extent of this could be monitored during individual storm surge events, by directly assessing road damage, or with the use of remote sensing information on the extent of the intertidal zone in this area.

3.4 Baudin Beach

Baudin Beach is a small settlement with approximately 97 properties on the north coast of Kangaroo Island at the eastern edge of Eastern Cove. The shoreline in front of the settlement consists of soft rock. Deep Creek travels under the Hog Bay Road and along the eastern edge of Baudin Beach, draining into Eastern Cove. Aside from a series of mostly unsealed roads through Baudin Beach, the key infrastructure is a boat ramp that supports launching of recreational boats.

3.4.1 Potential impacts

Natural and built assets are at low risk from future erosion and inundation because of the low erodibility of the soft rock shoreline and the height of public and private

Erosion

The potential erodibility of the shoreline is low because of the presence of the soft rock (

Figure 6). Furthermore, although the rate of soft rock erosion is expected to increase as a consequence of sea level rise, the extent of projected erosion is still limited at Baudin Beach.

Inundation

The extent of inundation does not differ greatly at Baudin Beach as a consequence of projected future sea level rise compared with a 1 in 100 year ARI storm surge event (Figure

7). The major change is additional inundation further back up Deep Creek. There are only small areas with additional inundation elsewhere on this stretch of coast.

Assets

Due to the soft rock shoreline and elevation of the settlement there are no buildings projected to be at risk under future sea level scenarios. As for other boat ramp facilities, high seas during storm surge events could impact infrastructure, especially noting that the existing coastal protection structures around the jetty/ boat ramp at Baudin Beach were removed in 2016. The only other potential impact on assets could be as a result of water backing up through Deep Creek during a storm surge event combined with overland flow from nearby catchments, however, the potential extent of this inundation has not been modelled at this point.

3.4.2 Response options

Due to the limited potential impacts at Baudin Beach, there are no immediate priorities relevant to projected erosion and inundation. However, monitoring should occur in the future into the impact of storm surge events on the boat ramp and modelling could be warranted at some stage into the combined effects of storm surge events and overland flow on inundation around Deep Creek.

Figure 6. Projected extent of erosion on the shoreline at Baudin Beach for 2050 and 2100. Dark brown – 2050 existing erosion, orange – 2050 erosion accelerated by SLR, yellow – 2100 existing erosion, fawn - 2100 erosion accelerated by SLR.

Figure 7. Projected extent of inundation at Baudin Beach for 2050 and 2100. Light blue – current conditions; medium blue – 2050; dark blue – 2100.

3.5 Bay of Shoals

The Bay of Shoals is located to the north of Kingscote. Its 21 km of shoreline is dominated by the east facing U shaped bay and associated 20km of sandy shoals. The shoals now effectively block the Bay from Gulf waves, resulting in a very low energy and stable coastline. The Bay has a range of substrate types ranging from sandy shoreline to sections of soft and hard rock. The Bay of Shoals has a number of private priorities that lead to the water's edge. A number of roads lead in and out of properties, however, only North Cape Road runs parallel to the shoreline in the northern section of the Bay.

3.5.1 Potential impacts

Natural and built assets face impacts from inundation under current and future conditions. Erosion may also be of future concern, but this is restricted mostly to areas where the shoreline is sandy, such as in the northern section of the Bay.

Erosion

The Bay is susceptible to erosion of sandy shorelines and of lower lying intertidal areas (

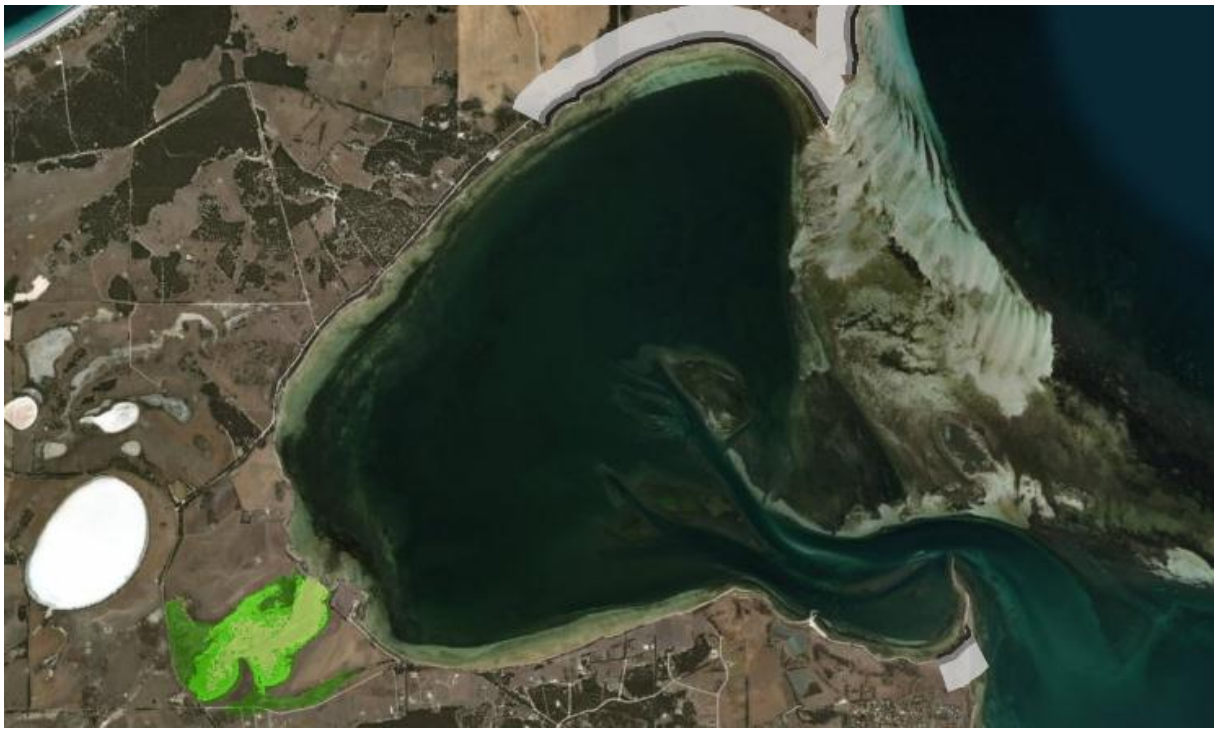

Figure 8). The primary impact from erosion of sand occurs toward the middle and end of the century when erosion is projected to reach and potentially travel further landward over North Cape Road in the northern section of the Bay. Erosion of the intertidal area near the intersection of North Coast Road and Bellmore Road is projected to gradually increase over the coming century, ultimately impacting both roads.

Inundation

The Bay of Shoals shoreline will become increasingly impacted by sea level rise. A representative indicator of the location of future shorelines in these locations is the Mean High-Water Springs tidal plane. This is the level to which the existing fringing vegetation is likely to migrate to and defines the upper limit of the intertidal zone.

By mid-century, the future Mean High-Water Springs level remains close to where it is under current conditions, however, by the end of the century the shoreline moves further inland toward the intersection of North Coast Road and Bellmore Road, and up to and over sections of North Cape Road.

Under a 1 in 100 year ARI storm surge event, short duration inundation will move further landward, again over the intersection of North Coast Road and Bellmore Road and across sections of North Coast Road (
Figure 9). Notably, the low lying lagoons along North Cape Road (e.g. Salt Lagoon) would fill with sea water under such conditions.

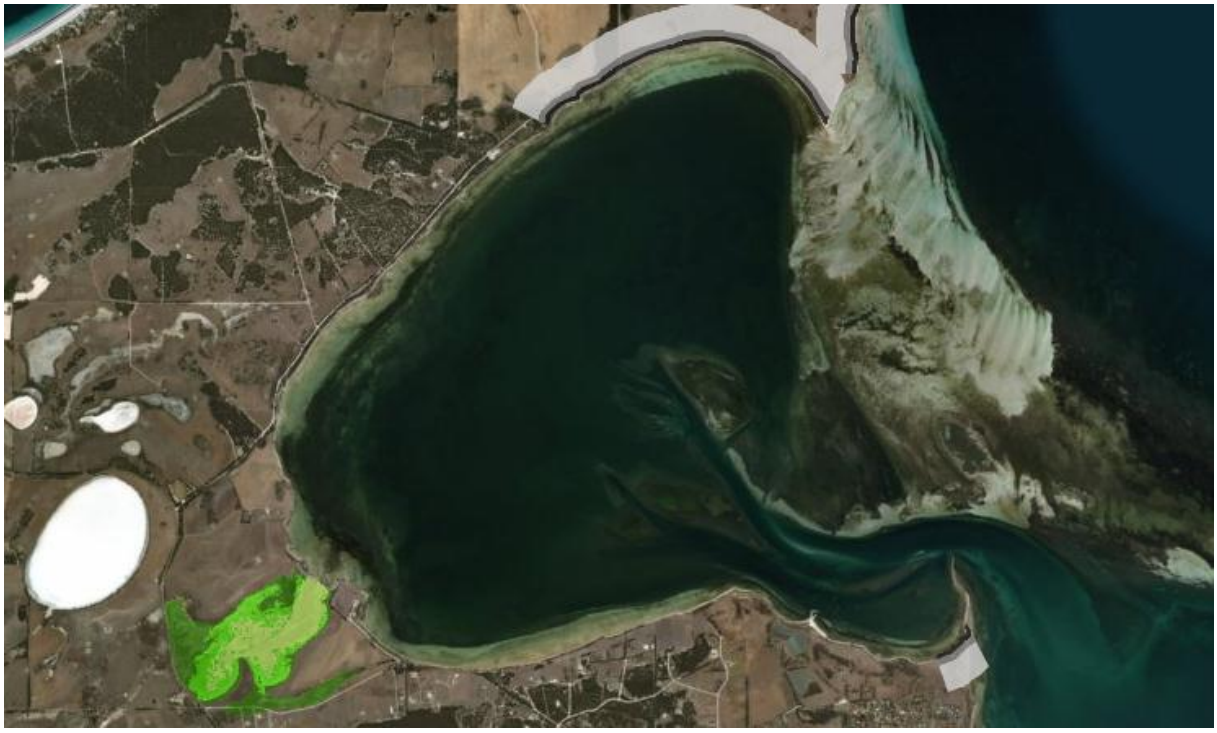

Figure 8. Projected extent of erosion on the beach and in the estuary at Bay of Shoals for 2050 and 2100. Beach: dark grey – current; medium grey – 2050; light grey – 2100. Estuary: light green – current conditions; medium green – 2050; dark green – 2100.

Figure 9. Projected extent of inundation at Bay of Shoals for 2050 and 2100. Light blue – current conditions; medium blue – 2050; dark blue – 2100.

Assets

The impact of erosion on public and private assets in Bay of Shoals is projected to be limited based on currently available information. Inundation of the low-lying land within the Bay of Shoals is shown under both existing and future conditions. This is likely to impact a number of road/access ways, including Bellmore Road, Dover Court and North Cape Road[3]. The boat ramp and breakwater at Bay of Shoal will also be impacted, as well as a number of coastal properties.

3.5.2 Response options

The impacts of erosion and to a greater extent inundation are focused on two main areas: near the North Coast Road and Bellmore Road, and along North Cape Road. In the immediate future, the focus of response options should be on ensuring that all weather roads are maintained around the Bay of Shoals.

In the coming decade, further analysis should be considered to assess how projected inundation may affect the use of the roads and whether they will require upgrade to include protective works or realignment.

While various response options exist in the Bay of Shoals area, it is noted that it is a marine sanctuary zone that is fringed by a threatened salt marsh ecological community. Response options will need to ensure that the integrity of these important marine and coastal ecosystems is maintained.

The timing of response options should consider when triggers are met for decision making. Based on discussions with the community and information obtained during the background analysis for this Strategy, potential triggers for the Bay of Shoals will need to focus on the impact of erosion and inundation on roads in the area. This can be readily monitored as part of routine road maintenance.

[3] The impact on Governor Wallen Drive is described in Section 4.9.

3.6 Brownlow

Brownlow is a settlement located on the south western edge of Kingscote. The majority of houses are located on low lying land along North West Terrace, Third Street and the Parade, which run parallel to the coast. The shoreline consists of highly erodible sand. The settlement is surrounded by a levee which was constructed to provide protection from storm surge inundation.

Further to the south west of Brownlow is the Kingscote Golf Club, Community Waste Water Management Scheme and a large expanse of intertidal land at the mouth of the Cygnet River.

3.6.1 Potential impacts

Natural and built assets face impacts from erosion and inundation under current and future conditions. Impacts on houses are largely reduced by the current levee bank, however, its size and extent will need to be reviewed to provide protection

Erosion

Modelling conducted for this project indicates that Brownlow is already highly susceptible to storm induced erosion because of the small amount of sand within the beach system that provides a limited buffer against storm events. As such, erosion up to The Parade is already possible if overtopping of the levee occurred in a 1 in 100 year storm surge event. If the levee was to be removed, or damaged and not repaired, erosion could progress through to the landward side of North West Terrace. In the land outside of the levee, such as around the Kingscote Golf Club, erosion could extend up to 150 m from the current coastline by mid-century and up to 400 m by the end of the century (
Figure 10).

The erosion potential for estuary, lagoon and tidal flat areas relates to increased permanent or more frequent inundation that occurs as a result of sea level rise. More frequent higher inundation effectively creates a new 'shoreline'. The most significant impacts occur immediately south of Brownlow, where the new shoreline could impact the effluent treatment plant by 2100.

Inundation

The levee at Brownlow is sufficient to prevent extensive inundation in a 1 in 100 year ARI storm surge event under existing conditions (Figure 11). Anecdotal reports indicate that there were multiple breaches of the levee during the May 2016 storm surge event, however, property and infrastructure inundation was avoided due to the 2008/09 upgrades. Outside of the levee inundation in a 1 in 100 year event could occur up to Burdon Drive, then Playford Highway to its intersection with Hog Bay Road.

Figure 10. Projected extent of erosion on the shoreline at Brownlow. Sandy beach: Dark grey – current conditions; Medium grey – 2050; Light grey – 2100. Estuary: Light green – current conditions; medium green – 2050; dark green – 2100.

Figure 11. Projected extent of inundation at Brownlow for 2050 and 2100. Light blue – current conditions; medium blue – 2050; dark blue – 2100.

By mid-century, and without increasing the height of the levee, inundation could be expected to overtop the levee and occur throughout Brownlow, reaching Burdon Drive and Juniper Road. Under these conditions the CWMS would also be overtopped. By the end of the century inundation extends further out and to a greater depth.

Even without storm surge events, the golf course and land south of Brownlow near the CWMS are likely to experience regular inundation in the future due to an increase in the height of the annual high water mark. This may also impact properties located at the southern end of The Parade and Links Road.

Assets

By mid-century public assets are considered to be at moderate risk from inundation and erosion, however, by the end of the century one third of all pipes, drains and pumping stations are considered at extreme risk. The estimated impact of inundation is $1.5 million under current conditions, but increases to nearly $3 million by mid-century and by 2100 is expected to exceed $4 million.

With respect to road infrastructure, The Parade is at extreme risk in the 2050 erosion scenario and Samphire Road is at extreme risk in the 2050 erosion and inundation scenarios. All the other roads in the 2050 inundation scenario are at medium to high risk. All of the roads in Brownlow are at risk in the 2100 erosion and inundation scenarios, with 6 being at extreme risk from erosion, and 7 from inundation.

The impact on roads under current conditions due to inundation is about $5,000, however, by mid-century, it is $331,000 due to both erosion and inundation, and by the end of the century it is over $383,464.

There is low to moderate risk to private assets in the existing and 2050 inundation and erosion scenarios, due largely to the protection afforded by the levee. By 2100, private assets are significantly impacted in Brownlow, with 114 properties at extreme risk from erosion and 118 properties from inundation.

Under current conditions a 1 in 100 year ARI storm surge event could cause nearly $1 million in damage. However, by mid-century the impact of inundation could reach $29 million and by the end of the century could exceed $32 million.

3.6.2 Response options

Brownlow is one of the most at risk settlements on Kangaroo Island from the combined impacts of future erosion and inundation. However, this risk is well understood and led to the construction of the levee in the 1980s which was later extended and upgraded in 2008/09.

Despite this, the projected overtopping of the levee in future extreme events means that its maintenance is a high priority.

Immediate priority responses for Brownlow should consider:

- Levee bank review - Assessment of the integrity of the levee and identification of any low points that could allow the passage of storm surge waters. This assessment should be repeated on a regular basis. Identifying options for re-enforcing the levee with rock or other material which could reduce the ability for it to erode should also be considered;

- Community emergency management plan - Ensuring that the community is aware of the risks of inundation as a consequence of large storm surge events. This could be assisted by developing a community emergency management plan, which outlines how residents can respond during short duration storm surge events;

- Coastal vegetation - Continue to maintain the condition of coastal vegetation, which provides a natural erosion buffer, and where possible increase plantings. Anecdotal reports suggest that rising sea levels are already impacting coastal vegetation due to salinity and therefore suitable species should be identified for planting in this area;

- Seagrass - Seagrass has an important role to play in mitigating the impact of wave energy during storm surge events. It is therefore important to maintain the health and extent of seagrass cover in the Bay through various means, including ensuring that surface water runoff and ground water seepage into the Bay are of a suitable water quality;

- Monitoring - Monitoring of erosion and inundation to the south west of Links Road where the movement of water is not impeded by the levee bank. This will provide an early indication of the potential broader impacts of more extensive impacts in this area; and

- Beach profile analysis - Working with DEW to ensure that regular profile analysis for long term recession and accretion trends along the Brownlow Beach shoreline continue. Making this information available to the community will help inform further discussion about the type and timing of response options.

In the coming decade, long term maintenance and upgrade plans need to be assessed for the levee. This should consider options to provide ongoing protection of the levee, increase its height and extend the levee to prevent water moving up through the golf course and over Links Road from the south of the settlement. However, the ability to maintain and upgrade the levee will also need to be balanced with the potential impact of future erosion. As such, it is likely that regular monitoring of the levee will be required especially following major storm events.

Following a decision on the levee, the Development Plan will need to be reviewed to ensure that homes are designed in such a way so as to suitably accommodate potential future erosion and inundation risk.

Outside of the levee the major concern will be maintaining the operation of the CWMS and providing for road access during inundation from storm surge events. In the coming decade, the focus for the CWMS will need to be on ensuring that plans are in place to manage overtopping.

In the longer term, a decision will need to be made about the viability of some critical infrastructure in its current location, including the CWMS, pipes, drains and pump stations. It is possible that as part of this assessment, the CWMS may be identified for relocation to ensure that wastewater management services can continue to be provided and to reduce the environmental impacts of overtopping and discharge of wastewater into the local environment. Such action would require a long planning lead time because of the need to identify a new location, construct new facilities and build a pipeline.

The timing of response options should consider when triggers are met for decision making. Based on discussions with the community and information obtained during the background analysis for this Strategy, potential triggers for Brownlow may include:

- height of water levels on the levee during storm surge events;
- breaches of the levee wall;
- extent of damage to the CWMS; and
- extent of erosion and inundation impact on properties outside of the levee.

As the response options for Brownlow are further scoped and developed, the triggers can be further quantified. Once this is done, monitoring of indicators that relate to the triggers will help to inform whether any of the proposed response options need to be brought forward or deferred where impacts are less than projected.

3.7 D'Estrees Bay

D'Estrees Bay is located on the south side of Kangaroo Island on a high wave energy stretch of coast. This coastline is mainly comprised of soft rocky shorelines with a moderate erodibility. There is also a small area of hard rocky shoreline with very low erodibility.

The primary roads used to access this area are D'Estrees Bay Road and Osmanli Road. While the majority of residential buildings are located on the landward side of D'Estrees Bay Road, there are a small number of buildings on the seaward side of the Road at elevations closer to the current high water mark.

3.7.1 Potential impacts

There are minimal impacts on this stretch of coast due to the predominant soft and hard rock shoreline. Longer term, soft rock erosion may impact some parts of Osmanli Road.

Erosion

The majority of soft rock shoreline is located along Osmanli Road, winding north from the intersection with D'Estrees Bay Road. Although this shoreline will erode more slowly than sand beaches elsewhere on the Island, the moderate erosion potential means that the shoreline could move up to 50 m inland at some locations by the end of the century (Figure 12).

There are also some small areas of hard rock that are susceptible to erosion because of their slope, however, the projected erosion at these sites is likely to be low over the coming century.

Inundation

D'Estrees Bay is surrounded by rocky cliffs that are at least 5 m above the annual high water mark in most locations. However, there are some lower lying parts of the road that are inundated under a current 1 in 100 year ARI storm surge event (
Figure 13). Toward the end of the century the extent of inundation along D'Estrees Bay Road expands.

Assets

There is a low to medium risk to public assets in D'Estrees Bay, with 6 assets being affected by the 2100 inundation scenario, such as car parks. There is no erosional risk to public assets, although erosion of the soft rock areas does come into close proximity to Osmanli Road at a number of sites.

Figure 12. Projected extent of erosion on the shoreline at D'Estrees Bay. Dark brown – 2050 existing erosion, orange – 2050 erosion accelerated by SLR, yellow – 2100 existing erosion, fawn - 2100 erosion accelerated by SLR.

Figure 13. Projected extent of inundation at D'Estrees Bay for 2050 and 2100. Light blue – current conditions; medium blue – 2050; dark blue – 2100.

There is no risk to private assets located on the landward side of D'Estrees Bay Road and Osmanli Road from any erosion scenario. However, there is a moderate to high risk to private property in the 2100 inundation scenario. The projected extent of inundation also means that some properties may not be accessible during a 1 in 100 year ARI storm surge event towards the end of the century.

The monetary value of private assets that may be under risk as a result of a 1 in 100 year ARI storm surge event increases from about $600,000 under current conditions to $750,000 by the end of the century.

3.7.2 Response options

D'Estrees Bay faces relatively low risks from projected erosion and inundation, however, individual property owners may need to take some risk mitigation actions, especially those with properties on the seaward side of D'Estrees Bay Road.

An immediate priority will be to ensure that D'Estrees Bay Road is an all weather road and can therefore be used during storm surge events by residents and emergency service providers needing to access or leave the area.

In the coming decade, monitoring should be established along the soft rock cliff edges to determine the rate at which erosion occurs. Accelerating erosion may provide a trigger for future protection or realignment works should these sections of road that provide property access be significantly damaged.

3.8 Emu Bay

Emu Bay is located on the north coast of Kangaroo Island to the west of Kingscote. The majority of residential dwellings in the settlement are located atop a hard rock section of shoreline, with a sandy beach stretching for approximately 5 km to the east which is backed by a large sand dune. The dune is well vegetated and mostly continuous, with only a small break out at the western end of the beach where Emu Bay Creek flows to the sea. A small number of properties are located on the landward side of the dune.

There are several roads that lead into the settlement, including Emu Bay Road and Gap Road. Other important infrastructure includes the jetty and boat ramp, which is located along the hard rock section of coast, and a car park located behind the dune at its western end. The beach is the only one on Kangaroo Island that can be driven on with a car without the need for a permit and so is an important recreational asset for the community.

3.8.1 Potential impacts

Erosion of the beach and dune is the primary impact of concern at Emu Bay. In contrast, the higher elevation of the headland, which has a hard rock shoreline, means that buildings located in this area are at low risk from future erosion and

Erosion

The hard rock shoreline in front of the majority of residential dwellings in Emu Bay has low erodibility potential. Furthermore, the low angle of the shoreline means that any wave energy in this area is easily dispersed, meaning that erosion impacts are unlikely by the end of the century.

The sandy beach to the east of the settlement has high potential erodibility (Figure 14). Anecdotal reports suggest that one foredune has already been lost from the beach in recent decades. Despite the high erodibility, the extent of erosion is likely to be limited in most areas by the bedrock at the back of the beach. The exception to this is the roughly 500m stretch of coastline south of Buick St, which does not have a rock backing.

By mid-century, erosion along the sandy beach at Emu Bay could see erosion occur to at least the base of the current dune. By the end of the century erosion will have progressed potentially to the landward side of the dune, equivalent to the entrance to the car park off Hamilton Drive.

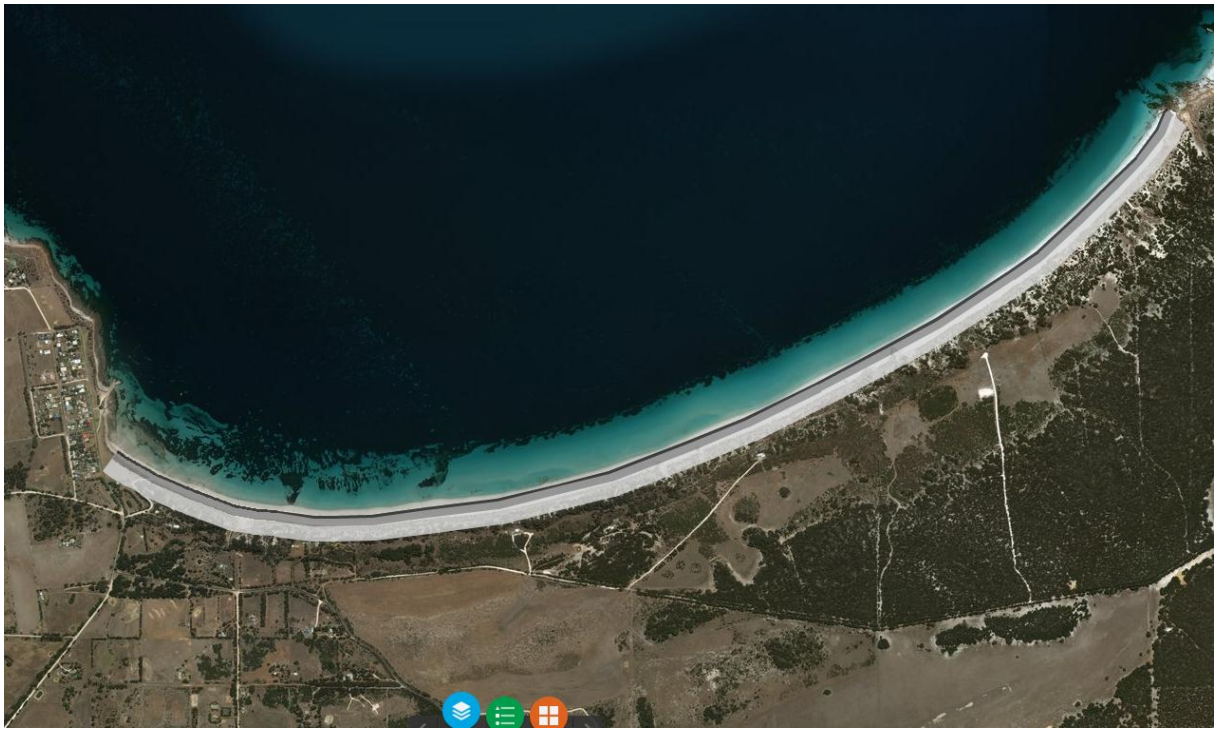

Figure 14. Projected extent of shoreline and tidal (estuarine) erosion at Emu Bay for 2050 and 2100 with a Bruun Factor of 100. Dark grey – current conditions; medium grey – 2050; light grey – 2100.

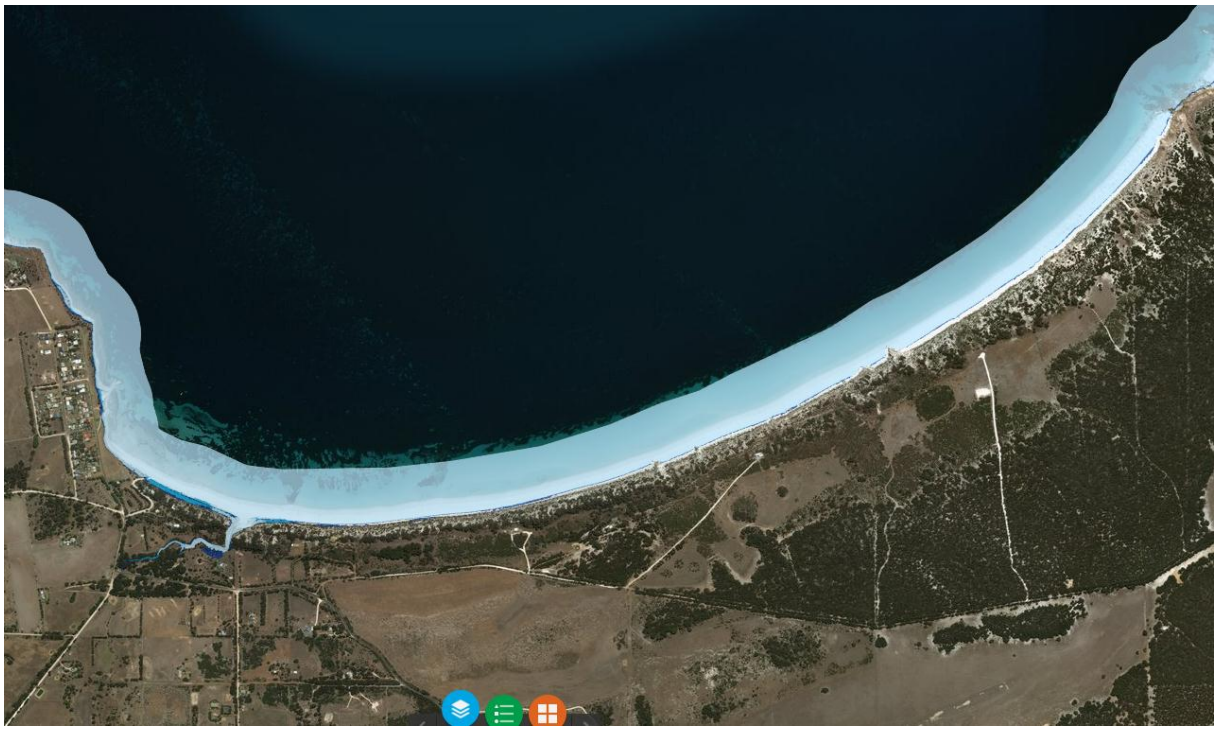

Figure 15. Projected extent of inundation at Emu Bay for 2050 and 2100. Light blue – current conditions; medium blue – 2050; dark blue – 2100.

Inundation

The angle of the hard rock shoreline and the dune backing the sandy beach means that projected inundation at the mid and end of the century even with sea level rise is limited (Figure 15). The most notable area is in the immediate vicinity of the Emu Bay Creek estuary where there is some additional inundation by 2050 projected through nearby dunes and potential higher water levels back up through the creek, however, by the end of the century this extends only as far back as Emu Bay Road.

Assets

In Emu Bay there is no erosion impact to major public assets before the 2100 scenario. By the end of the century one historic asset (Emu Bay Shack Site) is considered to be highly at risk along with a BBQ shelter, playground and public toilet near the foreshore off Emu Bay Road at the western end of the beach.

The current Emu Bay jetty is at risk of inundation in all sea level rise scenarios, as well as the car park and an outflow. However, the upgraded boat ramp will account for higher storm tide levels. This is likely to make the jetty and boat ramp unusable under such conditions, although this is already possible under an existing 1 in 100 year ARI event. The projected monetary impact of inundation is $383,135 relating to existing jetty and boat ramp infrastructure. This remains unchanged for current through to 2100 conditions because a 1 in 100 year ARI event can already impact the boat ramp and jetty.

There is no major erosion or inundation risks projected to occur for roads in Emu Bay and therefore community safety concerns in terms of being able to access the settlement during extreme storm surge events are low.

There are a number of private assets at risk from erosion and inundation. Under current and mid mid-century conditions, one property is partially at risk from erosion. However, by the end of the century this increases to 10, of which have four have an extreme risk. Inundation is also important for 10 properties, with the potential impacts increasing as sea level rise occurs by the ed of the century.

The estimated monetary impact of erosion and inundation on private assets is:

- $448,935,780 under current conditions;
- $448,935 by 2050; and
- $1,598,520 by 2100.

3.8.2 Response options

The primary impact along the hard rock shoreline is the potential inundation of the jetty and boat ramp, which can already occur in a 1 in 100 year ARI event and therefore could become more frequent and extensive with sea level rise factored in. As such, a protection

structure (e.g. sea wall) on the ramp side of the structure may be warranted at some stage, although how this impacts sand accretion will need to be considered.

Along the sandy beach, projected erosion impacts by mid-century mean that immediate priority responses should consider:

- Protecting the dune – The sand dune backing the sandy beach provides natural protection against the impact of waves and storm surge events. Maintaining the vegetation in good condition along this stretch of coast will help to stabilise the dune and make it less susceptible to future erosion. Protection of the dune could involve further coastal vegetation planting programs, fencing and reassessing access points to the beach trough the dune.

- Review car access – Emu Bay beach is the only beach on Kangaroo Island that can be legally driven on. If the width of beach reduces in the future, continued driving on the beach could impact vegetation at the base of the dune. While restrictions to car access may not be require immediately, a review to understand under what conditions access may need to be limited is warranted. Any proposal to restrict vehicle access will need to be balanced by the strong desire amongst parts of the community and from tourists to continue to have beach access;

- Development plan – Determine whether amendments to the development plan are required to ensure that all future dwellings are located in areas with low potential erosion risk or constructed in a manner that can accommodate potential erosion impacts.

- Monitoring - Working with DEW to ensure that regular profile analysis for long term recession and accretion trends along the Emu Bay beach shoreline continue. Making this information available to the community will help inform further discussion about the type and timing of response options.

Modelling at this site of sand movement could help develop more refined projections of erosion for the future, however, whether this occurs will need to be balanced with the need for such studies at other settlements with greater potential erosion risk.

By mid-century the extent of erosion impacts will become clearer. At this point, Council will need to consider options for protecting or most likely relocating the carpark, playground, public toilet and BBQ to a less exposed site.

At the same time private landholders may need to consider what options are available to provide additional protection for homes that are located on the landward side of the dune. By later in the century more extensive protection works may be required given the projected extent of erosion and some buildings may need to be relocated further inland.

It should be noted that Emu Bay is an important beach for nesting Hooded Plovers, which are a threatened species. This needs to be taken into account when considering any of the above response options, particularly with respect to vehicle access on a narrowing beach.

The timing of response options should consider when triggers are met for decision making. Based on discussions with the community and information obtained during the background analysis for this Strategy, potential triggers for Emu Bay may include:

- extent of erosion and impacts on the car park off of Hamilton Drive; and
- extent of erosion and impacts on residential priorities.

As the response options for Emu Bay are further scoped and developed, the triggers can be further quantified. Once this is done, monitoring of indicators that relate to the triggers will help to inform whether any of the proposed response options need to be brought forward or deferred where impacts are less than projected.

3.9 Kingscote

Kingscote is the largest town on Kangaroo Island and is the centre of commerce for business and the primary location for delivery of government services. It is located on the north of the Island and has a predominantly rocky shoreline, or small sections of sandy beaches backed by hard rock. Most of the buildings in Kingscote are on land well elevated above the shoreline. The primary low lying area is on the northern edge of town at Reeves Point, which is the entrance to the Bay of Shoals. Aside from roads, water, wastewater and energy infrastructure spread throughout the town, the town jetty is also critical infrastructure given its use for both commercial and recreational boats.

3.9.1 Potential impacts

Kingscote sits atop a rocky shoreline and so future erosion and inundation impacts are low. The main area of concern is Reeves Point on the north edge of town, which is susceptible to future erosion.

Erosion

The majority of the shoreline around Kingscote is hard rock and has very low susceptibility to erosion. There are small areas of sandy beaches, such as in front of the Yacht Club on Cygnet Road and to the south west of the Jetty on Chapman Terrace, however, these are backed by hard rock and so the landward movement of the shoreline is projected to be minimal.

The primary erosion risk is at Reeves Point on the northern edge of town (Figure 16). Under current conditions with a 1 in 100 year storm surge event, a 100 m stretch of Governor Wallen Drive is at risk. However, toward the end of the century erosion could impact both Governor Wallen Drive and Seaview Road, resulting in erosion of the point back toward McLaren St.

Inundation

The elevated height of the majority of the shoreline around Kingscote means that future projected inundation is similar to what already occurs under a 1 in 100 year ARI storm surge event (Figure 20). The only exception are the lower lying parts of Reeves Point and Governor Wallen Drive, which could be inundated for short periods in storm surge conditions toward the end of the century.

Figure 16. Projected extent of shoreline and tidal (estuarine) erosion at Kingscote for 2050 and 2100 with a Bruun Factor of 100. Dark grey – current conditions; medium grey – 2050; light grey – 2100.

Figure 17. Projected extent of inundation at Kingscote for 2050 and 2100. Light blue – current conditions; medium blue – 2050; dark blue – 2100.

Assets

The primary public asset at risk from erosion in Kingscote is the Reeves Point Historical Site. In contrast, a small number of pipes/drains are impacted by the inundation scenarios. Jetties are also impacted by the inundation scenarios, however, they are currently at a low risk and progress only to a medium risk with future sea level rise. A number of 'other assets' are at low to medium risk from future sea level rise scenarios, including several car parks, piers, boat ramps and Kingscote Tidal Pool. The monetary value of the impacts to public assets in Kingscote are primarily from inundation, with $1,800,000 already possible under current conditions from a 1 in 100 year ARI storm surge event.

The primary road at risk is Governor Wallen Drive. The monetary value of impacts are estimated at less than $5,000 from an extreme event under current conditions, to over $30,000 by the end of the century, mostly due to inundation. Kingscote has one property at extreme risk and 2 properties at a high level risk in the 2100 erosion scenario. There are also 16 properties at high level risk and 2 properties at the extreme risk level in the 2100 inundation scenario. The estimated monetary impact of erosion and inundation under current conditions is $1,318,260, however, this increases to nearly $5,000,000 by the end of the century.

It is important to note that there are some assets of historical and cultural significance that do not have a monetary value, but hold high significance to the community such as Reeves Point in Kingscote. Additionally damage to some assets will not result in complete loss of value, but rather the need for repairs, such as the Kingscote Tidal Pool, CWMS pump stations and roads.

3.9.2 Response options

The impacts for erosion and inundation at Kingscote are low compared with other towns and settlements on Kangaroo Island. This is due mainly to almost all buildings and assets being located on higher ground and the low erodibility of the rocky shoreline. The immediate priority is to monitor erosion at Reeves Point and encourage shoreline stability at the site by planting with appropriately selected coastal vegetation, noting that new plantings may take at least a decade to establish. Monitoring of erosion on the lower lying land where the Yacht Club is located is also warranted.

Within a decade consideration will need to be given to whether Reeves Point will be actively defended through the use of infrastructure options like rock walls or geotextile bags. If erosion is allowed to occur as projected at this site, it may require relocation of sections of Governor Wallen Drive.

While the Kingscote foreshore is largely constituted of hard rock, anecdotal reports indicate visible erosion and backwards retreat of the shore in recent years, which can be viewed to the east of the yacht club. Monitoring of erosion rates along the shoreline is therefore warranted.

The timing of response options should consider when triggers are met for decision making. Based on discussions with the community and information obtained during the background analysis for this Strategy, potential triggers for Kingscote may include:

- extent of erosion at Reeves Point; and
- frequency of inundation and extent of erosion along Governor Wallen Drive.

Both of these triggers can be readily monitored by periodically assessing erosion at the site.

3.10 Nepean Bay

Nepean Bay settlement is located on the north coast of Kangaroo Island on the shores of Western Cove. The settlement has approximately 44 residential dwellings and 25 currently vacant blocks of which a large number are located on two streets that run parallel with the shoreline. It has a well vegetated coastal zone, which supports environmental values, as well as a protected beach which provides amenity and recreation benefits for residents.

Western Cove Road is the primary critical infrastructure for Nepean Bay, providing the only route into and out of the settlement. Ensuring that this remains accessible during periods of short term flooding is important for the safety of the local community. While there are no formal boat launching facilities, the beach is used to launch some water craft such as kayaks and small boats.

3.10.1 Potential impacts

Natural and built assets in Nepean Bay face potential impacts from both erosion and inundation under current and future conditions.

Erosion

The shoreline in the immediate vicinity of Nepean Bay is predominantly sand with high potential erodibility. Moving further east, Western Cove has a greater amount of less erodible hard and soft rock. Anecdotal evidence suggests that erosion is already clearly evident at the north western end of Nepean Bay township heading toward the mouth of the Cygnet River and can be actively observed during and following storm surge events.

By mid-century, Nepean Bay could be impacted by a combination of erosion of the sandy shoreline and in the tidal flat zone (
Figure 18). Erosion under current conditions is expected to lead to retreat of the shoreline to at least the Nepean Esplanade, however, when the impact of sea level rise is added to this, erosion could extend further inland to approximately midway between Nepean Esplanade and, for example, Ocean View Drive. By mid-century, erosion in the nearby tidal flats is projected to reach the edge of Western Cove and Hog Bay Roads.

Toward the end of the century, and without action being taken, shoreline erosion could extend inland beyond Ocean View Drive, Marina Crescent and Sea Vista Road (
Figure 18). It is also projected that erosion in the tidal flats will become much more widespread extending inland beyond Western Cove Road and Hog Bay Road. In the absence of significant swell or exposure to swell, such as in an estuary setting, there may be little or no recovery between erosion events, compared to episodic recovery that occurs on open sandy coasts. This is likely to be the case with Nepean Bay.

Figure 18. Projected extent of shoreline and tidal (estuarine) erosion at Nepean Bay for 2050 and 2100 with a Bruun Factor of 100. Dark grey – current conditions; medium grey – 2050; light grey – 2100.

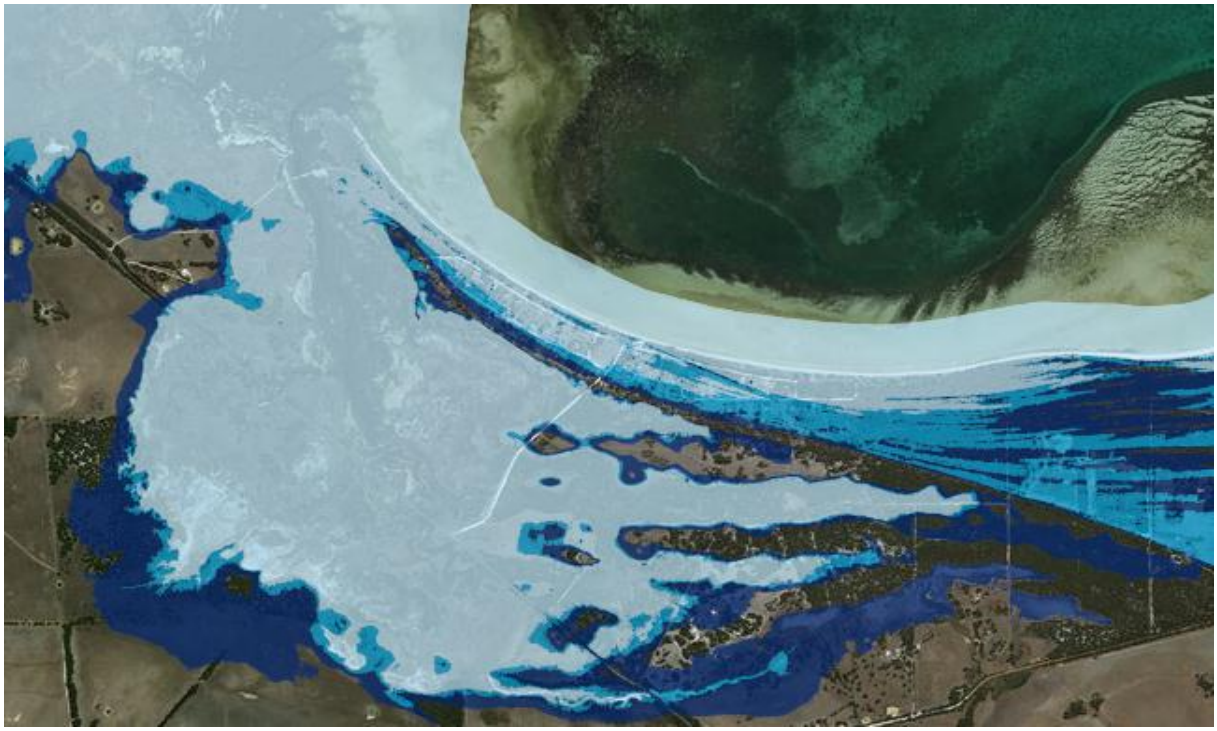

Figure 19. Projected extent of inundation at Nepean Bay for 2050 and 2100. Light blue – current conditions; medium blue – 2050; dark blue – 2100.

Inundation

The Nepean Bay settlement is located on an area of low lying land. It has experienced inundation in the past such as in May 2016, when sea water during a storm surge event reached sections of the Nepean Esplanade and Sea Vista Road. This is to be expected given that under a 1 in 100 year ARI storm surge event, sea water already has the potential to inundate large parts of the Nepean Bay settlement. Under such conditions sea water moves directly over the coastal fringe and back up through the tidal flats, which can lead to inundation of both the Western Cove and Hog Bay Roads.

By 2050 and 2100, the annual high water mark does not extend much further inland over the coastal fringe than it does currently, however, water is projected to reach the Western Cove and Hog Bay Roads by moving through the tidal flats. Inundation is far more extensive when a 1 in 100 year ARI storm surge event is considered, which will result in deeper inundation at the settlement and far more extensive impacts on road access (Figure 19).

Overland flow as a result of rainfall in the Cygnet River catchment could also increase the depth and extent of inundation in this area if it were to coincide with a storm surge event. Modelling this effect was not undertaken as part of this project and needs to be considered as part of future studies.

Assets

Without action to mitigate the impacts of erosion and inundation, a range of public and private assets could be impacted in the coming decades. By 2100, 8 public assets will be at extreme risk levels from erosion, including car parks, the Nepean Bay Conservation Park and Cygnet Estuary Conservation Park.

Most of the affected roads in Nepean Bay are at extreme risk from both erosion and inundation under the 2100 scenario. Western Cove Road is at a high risk under all inundation scenarios and the 2100 erosion scenario. The roads are more at risk from inundation than erosion in existing scenarios.

The projected monetary impact of erosion and inundation on roads is:

- $57,063 if a 1% ARI storm surge event was to occur under current conditions;
- $116,685 by 2050; and
- $161,138 by 2100.

The private assets in Nepean Bay are at a moderate to extreme risk in both the erosion and inundation 2100 scenario. Sixty one properties are at extreme risk of being 100% impacted by the 2100 erosion scenario, with 51 at extreme risk in the inundation 2100 scenario. The projected monetary impact of erosion and inundation on private assets is:

- $6,259,140 if a 1% ARI storm surge event was to occur under current conditions;
- $10,860,075 by 2050; and

- $15,829,500 by 2100.

3.10.2 Response options

The aim of the response options identified are to ensure accessibility in and out of the settlement during periods of extreme flooding, and to protect public and private assets where feasible and appropriate. Response options need to be considered for both erosion and inundation impacts, noting that inundation from 1% ARI events are rare, short term events that recede with the tide.

Given the erosion and 1% ARI inundation risks under existing conditions, immediate priority responses should consider:

- All weather roads - Ensuring that primary roads in and out of Nepean Bay are all weather roads, that is they are trafficable in all weather conditions. This will involve work with DPTI who owns and pays for the maintenance of the Hog Bay Road;

- Community emergency management plan - Such a plan has been developed for other coastal settlements in South Australia (e.g. Webb Beach north of Adelaide), and would provide consistent information on how the community can respond during periods of short duration peak inundation, such as storm surge events;

- Review the Development Plan - Amendments to the Development Plan may be required to ensure that all future dwellings have floor heights that are sufficient to protect homes from projected flooding. This can be done through the use of stilts or by raising the height of the pad on which house foundations are laid;

- Protecting the foreshore - Exploring options to stabilise current erosion of the sandy shoreline, which could include the use of appropriate plants in the coastal zone. This would have the added benefit of providing local environmental and amenity outcomes. Consideration also needs to be given to how to stabilise the shell grit along much of the shoreline which has a different erodibility than purse sand shorelines;

- Overland flow - Modelling to better understand the interaction between overland flow and storm surge events in relation to the depth and extent of flooding. This would also provide an opportunity to explore the impacts of drainage from the catchment surrounding the Airport; which drains to the north west of the Nepean Bay settlement;

- Sand movement - Modelling to better understand how water and sand moves through the bay. This would help inform the scoping of any future protection works that may be constructed at the settlement; and

- Monitoring - Working with DEW to establish regular profile analysis for long term recession and accretion trends along the Nepean Bay shoreline.

At present, Nepean Bay does not have a major levee protecting houses, although the raised height of some of the roads does afford limited protection from rising waters during storm surge events, as observed during May 2016. As such, a priority in the next decade should be to determine whether a levee could be an appropriate response to reduce future inundation risk. Depending on the construction material, a levee could also provide protection from future erosion during storm surge events in particular.

New housing developments may need to consider the requirement for greater short-term retention of stormwater in order to reduce localised flood risk, and alternate measures for treatment of sewage. Another response option for the coming decade for the coming decade will be to consider requirements for drainage pipes and sea gates to limit the impact of flooding when storm surge events do occur.

In the longer term, and most likely after 2050, the response options may need to include greater amounts of protection works, especially in response to projected erosion impacts, and in some areas, movement of some public and private assets further inland to higher elevations.

The timing of response options should consider when triggers are met for decision making. Based on discussions with the community and information obtained during the background analysis for this Strategy, potential triggers for Nepean Bay may include:

- extent of erosion of the coastal fringe along Nepean Esplanade;
- extent and depth of inundation around houses during storm surge events; and
- frequency and severity of flooding on Western Cove and Hog Bay Roads.

As the response options for Nepean Bay are further scoped and developed, the triggers can be further quantified. Once this is done, monitoring of indicators that relate to the triggers will help to inform whether any of the proposed response options need to be brought forward or deferred where impacts are less than projected.

3.11 Penneshaw

Penneshaw is one of the largest towns on Kangaroo Island with a population of approximately 580. The coastline faces a moderate wave energy environment, featuring hard rock along Hog Point, and a sandy, highly erodible shore along Hog Bay Beach.

The Penneshaw Ferry Terminal provides the main access point for people, vehicles and produce to move on and off the Island. Aside from the Ferry Terminal, Penneshaw has a boat ramp and marina in Christmas Cove, and an extensive network of private and public assets across the town, including water, waste water, energy and road infrastructure.

3.11.1 Potential impacts

Natural and built assets face impacts primarily from erosion along Hog Bay Beach. Erosion impacts elsewhere at Penneshaw are mitigated by the rocky shoreline. The

Erosion

Erosion is primarily an issue of concern for the sandy Hog Bay Beach, between the Ferry Terminal and Frenchmans Rock (Figure 20). Historical analysis suggest that the northern end of the beach has been accreting sand in recent decades, while the southern end shows recession. Continued erosion under current conditions suggest that erosion could remove the foredune in time. By mid-century erosion could extend to at least the southern end of Frenchmans Terrace, and by the end of the century all of Frenchmans Terrace could be impacted along with parts of Flinders Terrace.

Inundation

The majority of Penneshaw is protected from inundation in a 1 in 100 year ARI storm surge event because of the elevation of the headland (Figure 21). Under current conditions, such as storm surge event would already lead to inundation of low lying areas amongst the foredune. By 2050 and 2100 the extent of inundation only increases to a small extent across the existing dune system, with no impact on Frenchmans Terrace.

Assets

Erosion at Penneshaw is generally limited to areas seaward of Frenchman's Terrace and hence impacts to public and private infrastructure are focused in this area. In the coming decades the public assets at Penneshaw have a relatively low risk rating, however, under the 2100 erosion scenario, there is an extreme risk to the pipe/drain network. Frenchmans Terrace is at a low risk from the existing and 2050 erosion scenario, but this jumps to a high risk in the 2100 erosion scenario.

Figure 20. Projected extent of shoreline and tidal (estuarine) erosion at Penneshaw for 2050 and 2100 with a Bruun Factor of 100. Dark grey – current conditions; medium grey – 2050; light grey – 2100. The red line indicates areas of hard rock that may be susceptible to erosion.

Figure 21. Projected extent of inundation at Penneshaw for 2050 and 2100. Light blue – current conditions; medium blue – 2050; dark blue – 2100.

Penneshaw has a significant extreme risk to private property, with 17 properties at risk in the 2100 erosion scenario and 1 in the 2100 inundation scenario, with the latter being the jetty and wharf. There is also one property that is at risk of 100% inundation in the existing inundation scenario.

The monetary value of public assets at risk is $1,108,000 under current conditions increasing to $1,111,300 by 2100, which is related to jetty and wharf infrastructure (Christmas Cove). The majority of this impact is due to inundation caused by a 1 in 100 year storm surge event which can already occur under current conditions. Road damage as a consequence of erosion, primarily to Frenchmans Terrace, is estimated to increase from $20,419 under current conditions to $228,083 by the end of the century.

By far the greatest potential monetary impact at Penneshaw is on private assets, especially those located at the southern end of Hog Bay Beach. Until mid-century the greatest risk is still from inundation of properties, which could cause over $700,000 in damage. However, by the end of the century the erosion impacts on private property are projected to increase, with the monetary value of assets impacted exceeding $6 million.

3.11.2 Response options

The major impact to address at Penneshaw is erosion. Based on current projections for erosion, immediate priority responses should consider:

- Protection of the dune on Hog Bay Beach – The dune provides natural protection against the impact of waves and storm surge events. Maintaining the vegetation in good condition along this stretch of coast will help to stabilise the dune and make it less susceptible to future erosion. Protection of the dune could involve further coastal vegetation planting programs, fencing and reassessing access points to the beach trough the dune;

- Development plan – Determine whether amendments to the development plan are required to ensure that all future dwellings are located in areas with low potential erosion risk or constructed in a manner that can accommodate potential erosion impacts; and

- Working with DEW to ensure that regular profile analysis for long term recession and accretion trends along Hog Bay Beach continue. Making this information available to the community will help inform further discussion about the type and timing of response options.

In the coming decade, the focus of work at Penneshaw should be on how to continue to maintain the dune system and to explore what other protective works can assist reduce erosion. The aim should be to maintain road access along Frenchmans Terrace.

In the longer term, and especially after 2050, further consideration will need to be given to whether public and private can be protected from advancing erosion or whether some assets will need to be relocated to higher ground. This includes roads, buildings, water and energy infrastructure. Protection infrastructure will also need to be considered for major assets like the Ferry Terminal and surrounding infrastructure. Although these already have protection from the breakwater, whether this continues to be suitable will need to be reviewed.

As for other locations on Kangaroo Island, Hog Bay Beach hosts nesting, threatened Hooded Plovers, and therefore response options should take this into account when being developed and implemented.

The timing of response options should consider when triggers are met for decision making. Based on discussions with the community and information obtained during the background analysis for this Strategy, potential triggers for Penneshaw focus mostly on the extent of future erosion of the dune on seaward side of Frenchmans Road, and in time, erosion on the landward side of Frenchmans Road. Monitoring of erosion extent will help to inform whether any of the proposed response options need to be brought forward or deferred where impacts are less than projected.

3.12 Sapphiretown, Island Beach and Brown Beach

Sapphiretown, Island Beach and Brown Beach are located on sandy shorelines in Eastern Cove. They feature residential dwellings, many of which are holiday homes, located on low lying land behind the beach. This area is highly valued as a tourism destination and for access for recreational pursuits including boating and fishing. Critical infrastructure in the region is primarily a series of unsealed roads that provide access to houses that are within about 300 to 400 m of the current high-water mark.

3.12.1 Potential impacts

Natural and built assets face impacts from inundation and erosion under current and future conditions, however, this is mostly focused on Strawbridge Point near Sapphiretown.

Erosion

Future projected erosion at Sapphiretown, Island Beach and Brown Beach by 2050 is generally limited to areas forward of access ways which run along the foreshore. However, the analysis suggests that by the end of the century, erosion could occur on the landward side of DeCouedie Drive and Nepean Drive. Furthermore, active erosion of the spit back to the boat ramp road at Sapphiretown is also projected.

Inundation

Inundation at Island Beach and Brown Beach under a current 1 in 100 year ARI event is generally restricted to the foreshore by the existing dune system. At Sapphiretown, inundation extends further inland over the spit and back toward Strawbridge Point Road.

By mid-century, inundation extends further inland at Sapphire Town and Island Beach, and by the end of the century much of Strawbridge Point is impacted. In contrast, Brown Beach remains relatively unimpacted by inundation in the future due to the steep shoreline.

Assets

No public assets are considered to be at risk from current future erosion or inundation. While no roads are at high risk from inundation damage, erosion is likely to impact sections of road at Sapphiretown and Island Beach, as well as private access roads at Brown Beach.

There is a future risk to properties at all locations, for example:

- At Sapphiretown there are 3 properties at extreme risk of being 100% affected by the 2100 inundation scenario. There is also a moderate to high risk of private property being affected by the 2100 erosion scenario;

- Island Beach has a moderate to extreme risk to private property in the 2100 erosion scenario, with 44 properties at high risk and 3 at extreme risk. In the 2100 inundation scenario, there are 4 properties at high risk; and

- Brown Beach has mostly low to moderate risk, but 6 properties are at a high risk in the 2100 erosion scenario.

Across the three settlements, the monetary value of private assets at risk under current conditions is $519,000. This increases to over $1 million by 2050 and $12 million by 2100. Under current conditions and toward 2050, most of this risk is due to inundation, however in the latter half of the century most of the risk is due to erosion impacts on properties at Island Beach.

3.12.2 Response options

Sapphiretown, Island Beach and Brown Beach collectively face erosion risks, while Sapphiretown and Island Beach are also potentially impacted by inundation. This means that a combination of response options needs to be considered. Immediate priority responses should consider:

- All weather roads - Ensuring that primary roads in and out of these settlements are all weather roads, that is they are trafficable in all weather conditions.

- Community emergency management plan - Such a plan has been developed for other coastal settlements in South Australia (e.g. Webb Beach north of Adelaide), and would provide consistent information on how the community can respond during periods of short duration peak inundation, such as storm surge events. It is especially relevant to Sapphiretown where flooding back up through Pelican Lagoon may impact a larger area of roads;

- Review the Development Plan - Amendments to the Development Plan may be required to ensure that all future dwellings have floor heights that are sufficient to protect homes from projected flooding. Consideration will also need to be given as to whether erosion can be accommodated in some locations;

- Protecting the foreshore - Exploring options to stabilise current erosion of the sandy shoreline, which could include the use of appropriate plants in the coastal zone. This would have the added benefit of providing local environmental and amenity outcomes. Consideration also needs to be given to how to stabilise the shell grit along much of the shoreline which has a different erodibility than purse sand shorelines;

- Access to Strawbridge Point – There remains evidence that vehicles continue to drive around Strawbridge Point. Anecdotal reports suggest that this is causing damage to

vegetation and potentially enhancing erosion. Measures to further protect this area require further investigation.

- Monitoring - Working with DEW to continue profile analysis at Island Beach and to encourage it to be expanded to Sapphiretown and Brown Beach.

In the coming decade, consideration will need to be given as to whether Strawbridge Point should be further protected to reduce erosion impacts, or whether it should be allowed to migrate landward. This has consequences for surrounding assets which would need to be relocated if the latter option is pursued. Also relevant in the coming cade is to work with property owners in Sapphiretown and Island Beach to ensure that properties are able to withstand projected inundation impacts by mi-century.

In the longer term the primary focus will be on how to manage the erosion impacts in private property. This will either require expansive coastal protection works or the repositioning of buildings to higher elevations and realignment of selected roads.

The timing of response options should consider when triggers are met for decision making. Based on discussions with the community and information obtained during the background analysis for this Strategy, potential triggers for Sapphiretown, Island Beach and Brown Beach may include:

- extent of erosion of the coastal fringe and around Strawbridge Point;
- inundation of low-lying land around Sapphiretown;
- extent of erosion damage to roads, especially Nepean Drive and De Couedie Drive; and
- direct damage to privately owned buildings.

As the response options for these settlements are further scoped and developed, the triggers can be further quantified. Once this is done, monitoring of indicators that relate to the triggers will help to inform whether any of the proposed response options need to be brought forward or deferred where impacts are less than projected.

4 Discussion

4.1 Future impacts

The impacts of future erosion and inundation differ widely across the Island depending on the location, with land height and the underlying shoreline geomorphology determining the amount of erosion and inundation risk under current and future conditions. At least four impact categories of towns and settlements can be identified:

- **At risk from erosion and inundation** – Antechamber Bay, Bay of Shoals, Brownlow, Island Beach, Nepean Bay and Sapphiretown face risk from both erosion and inundation due to the combination of sandy shorelines and low lying land which is prone to inundation. For most of these sites, the impacts under current extreme events are already significant, but this is exacerbated further with sea level rise in the future;

- **At risk from primarily inundation** – American River is at risk primarily from inundation, even under a current 1 in 100 year storm surge event, with its mostly rocky shoreline affording protection from erosion;

- **At risk from primarily erosion** – Brown Beach, Emu Bay and Penneshaw have sand beaches that are highly erodible, with the majority of assets at higher elevations that are protected from inundation; and

- **Low erosion and inundation risk** - Baudin Beach and D'Estrees Bay face some erosion risks to soft rock sections of shoreline, and Kingscote faces limited erosion risk at Reeves Point, but the height of most built assets means that impacts from inundation are limited.

The extent of risk and impact though is not the same within each category, with the number of public, road and private assets exposed to erosion and inundation differing greatly.

The settlements at greatest risk now and in the future from coastal hazards are American River due to inundation risk, and Brownlow and Nepean Bay, due to the combined impacts of erosion and inundation risk. These settlements should therefore be the focus of immediate action. The extent of impacts at these locations are described further in Section 5.2.

Aside from identifying impacts on specific settlements, the results also suggest that:

- Sections of Hog Bay Road will become inundated periodically, especially as a result of extreme storm surge events. This will create both issues for accessing specific

settlements (e.g. Nepean Bay) as well as general flow through traffic across the Island if restrictions develop at locations such as YMCA corner near Pelican Lagoon;

- Western Cove as a broader area faces risks from both inundation and erosion. Although this is evident from the results of the analysis at Brownlow and Nepean Bay, the entire section of low lying intertidal land to the east of the airport is at risk, with the flood risk potentially being significantly exacerbated as a result of overland flow occurring at the same time as storm surge; and

- Some critical infrastructure will be exposed to increasing risk from erosion and/or inundation. This includes electricity, water and wastewater management infrastructure. Perhaps of greatest concern is the potential impact of erosion and inundation on the Kingscote Community Wastewater Management Scheme.

4.2 Assets at risk

The development of this Strategy has been informed by hazard assessments that identified the public, road and private assets at risk at each settlement and the monetary value of the impacts. Risks are rated from low to extreme, where extreme risks are identified for impacts that are almost certain with a catastrophic impact such as a permanent loss or damage to property, plant and equipment. At a broad level the hazard assessments revealed that:

- Public assets are at high risk at one settlement by 2050 (American River) and at extreme risk at four settlements by 2100 (American River, Brownlow, Nepean Bay, Penneshaw);

- Five roads are at extreme risk by 2050 and nine roads are at extreme risk by 2100, the latter of which are:
    - Brownlow: Third Street, First Street, North West Terrace, Samphire Road, High Street, Links Road, The Parade;
    - Nepean Bay: Marina Crescent, Nepean Esplanade, Ocean View Drive;
    - American River: Bimberta Avenue, Moreanda Avenue;

- 115 properties are at high risk of being impacted by erosion and/or inundation by 2050, and by 2100 there are 244 at extreme risk spread across the settlements as follows:
    - American River = 38 properties at extreme risk by 2100;
    - Brownlow = 118 properties ;
    - Emu Bay = 4 properties;
    - Island Beach = 3 properties;
    - Nepean Bay = 61 properties;
    - Penneshaw = 17 properties; and
    - Sapphiretown = 3 properties.

The combined total monetary value of assets at risk is summarised in Table 2. Across all asset classes, by the end of the century, nearly $90 million in assets is at risk from projected erosion and inundation.

Under current conditions, approximately $23 million of assets are already under risk. The majority of these assets are private buildings that could be damaged in a 1 in 100 year ARI storm surge event as a result of inundation. It is anticipated that many residents would be unaware that standard flood insurance for their home does not cover the impacts of storm surge and hence this may potentially be an unfunded liability, regardless of future climate change and sea level rise impacts.

By mid-century, the risk is still primarily from inundation, with over $60 million in assets projected to be impacted, again mostly as a result of inundation. However, by the end of the century the impact from erosion and inundation is similar at over $76 and 87 million, respectively.

Table 2. Combined total monetary value of assets at risk from erosion and inundation.

Asset	Estimated Value of Assets Affected by Coastal Hazards					
	Erosion			Inundation		
	Existing	2050	2100	Existing	2050	2100
Public assets	$0	$427,650	$4,851,900	$7,057,735	$9,754,185	$10,325,635
Roads	$31,556	$98,838	$679,905	$231,542	$727,424	$911,060
Private assets	$620,205	$6,946,815	$70,677,420	$15,832,095	$53,482,950	$76,669,275
Total	$651,761	$7,473,303	$76,209,225	$23,121,372	$63,964,559	$87,905,970

While substantial, the monetary values of assets at risk for Kangaroo Island presented here are considered to be conservative because:

- there is incomplete data available for public assets (i.e. DPTI roads, power supply, water supply and street lighting) meaning that the impacts for this asset class are likely to be higher;
- assets will be impacted outside of the settlements that were the focus of this study;
- disruptions to commerce due to flooded roads has not been accounted for, such as could occur if sections of Hog Bay Road are flooded;
- the costs do no account for the combined impacts of overland flow and storm surge; and
- there is no consideration given to an increase in the frequency of events that have an ARI of less than 1 in 100 years but that can still cause damage; and
- the projected inundation assumes that the elevation of the shoreline remains as it is currently, however, this is highly unlikely for sandy shorelines as demonstrated by the erosion mapping. This means that in areas where erosion is extensive, inundation could be expected to occur further inland.

4.3 Priority actions

A range of priority actions are identified in this Strategy for different settlements. However, there are a number that are common immediate priorities for Council to consider, which are as follows

- Raise community awareness about potential impacts – The engagement processes used to develop this Strategy have provided an opportunity for some community members to learn about the potential future impacts of erosion and inundation. However, this needs to continue to assist homeowners and businesses learn about potential risks to their own properties, the timing of such risks, and how these can be addressed. As part of this it is important that the community understands the insurance coverage provided for storm surge events, which is normally only part of bespoke insurance products;

- Further modelling of overland flow - A concurrent event where significant rainfall in nearby catchments coincides with a storm surge event would create more significant inundation than has been projected in this study. This is especially the case at American River, Nepean Bay and Brownlow, as well as more broadly across Western Cove. Further modelling is required to better inform the extent of flooding under such a scenario and therefore the timing of future actions;

- Review the Development Plan – While in the short term the focus for ensuring appropriate buildings are constructed in higher risk areas should be on American River, Brownlow and Nepean Bay, in the longer term this is relevant at 7 settlements. As such, the Development Plan should be reviewed to determine how it can be strengthened to either avoid constructing buildings in high risk areas, or ensure that new buildings can accommodate inundation, noting that accommodation of erosion is much more challenging and may not be possible in some locations;

- Developing a community emergency management plan – American River, Brownlow and Nepean Bay would benefit from building a greater community awareness of the risk of inundation in lower lying areas and a common understanding of how the community can best respond. This can be facilitated by the development of a community emergency management plan;

- Provide all weather roads – Maintaining all weather roads will become increasingly important to ensure that settlements can be accessed by people wanting to move into or leave an area during a storm surge event. A register of important roads for all weather access can be developed and included in Council's Road Hierarchy, Levels of Service, budget process and maintenance programmes;

- Protecting coastal vegetation – All sandy shores with backing dunes will benefit from protecting coastal vegetation, which helps to protect the sand from erosion. Although coastal vegetation does not prevent sand from erosion, it can reduce the rate of erosion and the impact of storm events. This action is a "win-win" and can also deliver conservation and amenity outcomes relevant to natural resource management; and

- Monitoring – Monitoring is required of changes in sea level and of observed erosion and inundation impacts in order to build confidence in the community about the need for action and also to inform the timing of future decision making. As part of this, regular reporting on sea level rise based on the Victor Harbor tide gauge should be undertaken, including the discussion on the transferability of these results to Kangaroo Island.

A further response option that could be considered for American River, Brownlow and Nepean Bay is to use 2D modelling to better understand how water will move across the landscape during a storm surge event. Although this is considered to be a more accurate approach than the bath tub modelling method used for the coastal hazard assessment, it is also much more expensive to undertake and hence should be undertaken only for high priority sites.

Over the coming decade Council will need to make decisions regarding the future maintenance, upgrade or establishment of levees to protect businesses and homes. In doing this Council will need to determine the balance between its responsibility to protect existing properties versus the responsibility of individual landholders to either protect their own property, construct buildings that can accommodate inundation risks or move assets to lower risk locations.

Where assets need to be relocated, significant planning will be required in advance. For example, moving the CWMS to a higher location will require initial protection works in the current location. Design of a new scheme, acquisition of land, construction of new pumping facilities, and connection of the new site. This process could take at least 10 years and hence will require significant forward planning.

In addition to asset management issues, there are a number of impacts and response options (e.g. approach to managing coastal conservation zones and threatened ecological communities and species), that require further exploration with organisations other than Council.

The focus of this report is on describing the projected impacts of erosion and inundation on priority settlements across Kangaroo Island. It in no way presents advice for individual property owners on what decisions they may choose to make with respect to future management of their property or related matters such as insurance. Further information on a range of issues related to coastal adaptation, including insurance related considerations, can be found at CoastAdapt (https://coastadapt.com.au), which is an information delivery and decision support framework developed by the National Climate Change Adaptation Research Facility.

4.4 Adaptation pathways

Adaptation pathways provide a way of considering and visualising adaptation response options. Rather than being limited to identifying the best single set of adaptation options for a limited set of climate change scenarios, they enable decision makers and communities to explore what combination of options are most suitable for adapting to future climate change and how they can be sequenced over time (i.e. what should be done now, versus what can be delayed). Furthermore, where the rate of change in climate and related factors like sea level rise are greater than predicted, implementation of actions on the pathway can be sped up; alternately if the rate of change is slower than projected, then actions can be delayed or may not be required at all.

An adaptation pathways map for the combined target settlements assessed for this study is presented in Figure 22. This provides a broad indication of the possible sequencing of response options through time. The horizontal axis of the pathway shows expected changes as a result of climate change (i.e. sea level rise). The range of adaptation options identified for the key area of decision making is listed on the vertical axis of the pathways map.

How to interpret the pathways map

- A horizontal dark green line indicates an option that contributes to the adaptation response.
- A horizontal light green line indicates the time before an option is implemented.
- The length of the horizontal lines shows how long the option can be expected to effectively address the key area of decision making.
- A vertical line through ‘decision point’ circles identifies a point in time at which a decision needs to be made between different response options.
- The timing of the decision is indicative relative to the x-axis. This is based on the premise that as climate changes some options will become less suitable as adaptation measures and so new ones may be required.

A further description of how to interpret the pathways map is provided in (Siebentritt and Stafford Smith 2016).

Instead of being linked to timeframes, it is recommended that the timing of key decisions should be informed by whether triggers are met at different locations across the Island. Triggers can relate to social, economic, environmental, physical and other factors. Based on the process used to inform this strategy, triggers should consider at least:

- extent of erosion of dunes on sandy stretches of coast;
- extent of erosion impacts on public, road and private assets; and
- extent of inundation impacts on public, road and private assets.

It is likely that specific triggers that will be important for the Island include:

- inundation of the land at American River on the landward side of Tangara Drive;
- breaches to the levee at Brownlow;
- frequency and extent of inundation at Nepean Bay and surrounding low lying land;
- damage or disruption to traffic movement at various locations on Hog Bay Road; and
- erosion to the extent that Frenchmans Terrace at Penneshaw is impacted.

The Island scale adaptation pathways map presented here can be further refined and quantified for each settlement, with an initial focus on the settlements at greatest risk from erosion and inundation.

Key area of decision making

How do we maintain and protect public and private assets at settlements across the Kangaroo Island coast given projected increases in inundation and erosion?.

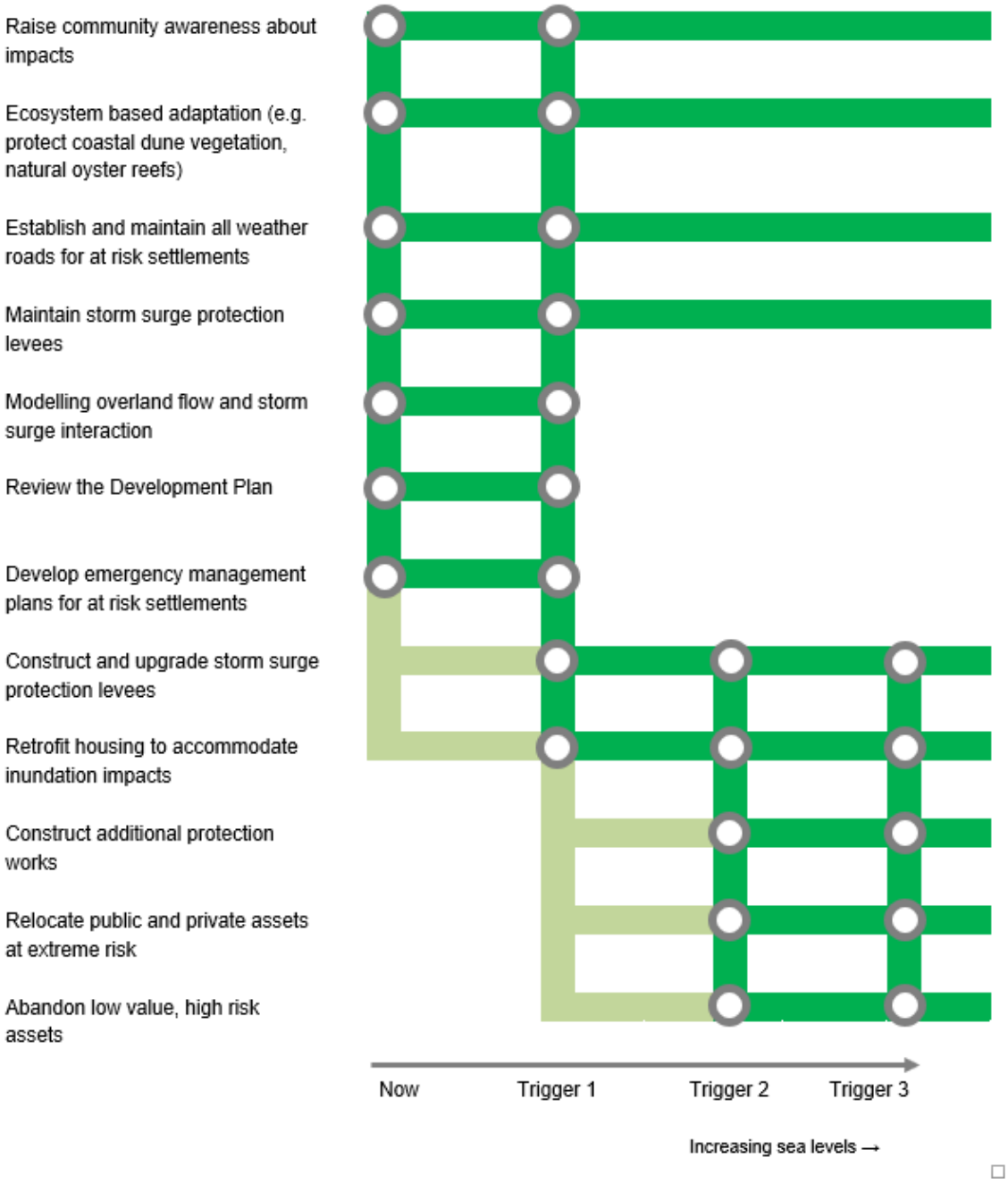

Figure 22. Adaptation pathway for target settlements of response options to increasing erosion and inundation risk as a consequence of sea level rise.

Glossary and definitions

Term	Definition
Accretion	Deposition and accumulation of sediment, either horizontally or vertically
AHD	Australian Height Datum. 0m AHD approximately corresponds to mean sea level
ARI	Average Recurrence Interval. A measure of the average frequency at which a storm of a given magnitude recurs (ideally based on statistical analysis of recorded historical storm data). Thus a 100 year ARI storm is one of a magnitude that statistically occurs every 100 years on average. Note however that this is a statistical average and not a measure of actual recurrence intervals. Thus it is entirely possible that two 100 year ARI storms could occur in the same year.
AEP	Annual Exceedance Probability: The measure of the likelihood (expressed as a probability) of an event equalling or exceeding a given magnitude in any given year.
Astronomical tide	Water level variations due to the combined effects of the Earth's rotation, the Moon's orbit around the Earth and the Earth's orbit around the Sun.
Brunn Factor	A multiplier used to define the amount of horizontal shoreline recession that results from a given sea-level rise. For example, a Bruun Factor of 100 means a shoreline recedes horizontally by 100 times the vertical rise in mean sea-level. The use of Bruun Factors is a highly simplified application of the Bruun Rule of erosion by sea-level rise.
DEM	Digital elevation model. A widely used GIS format which represents surfaces (e.g., of land) as a grid, each cell of which has a defined location and elevation.
Calcarenite	Sand-grade lithified sedimentary rock composed of cemented calcium carbonate grains (i.e., a type of limestone). On the Australian coast, many prominent calcarenite deposits are Holocene or Pleistocene coastal dunes of carbonate dominated sand cemented by groundwater processes. Calcarenites vary from very hard tough rocks to soft friable sandy rocks.
Erosion	Removal of material (e.g., from a sediment body or landform) by natural processes (e.g., wave action). Coastal erosion typically results in landwards recession of the shoreline, but in theory need not do so; e.g., wind erosion of coastal dunes need not necessarily lead to shoreline recession.
Exceedance Probability	The probability of an extreme event occurring at least once during a prescribed period of assessment is given by the exceedance probability. The probability of a 1 in 100 year event (1% AEP) occurring during the first 25 years is 22%, during the first 50 years the probability is 39% and over a 100 year asset life the probability is 63%.
Geomorphology	The study of landforms, their forms, genesis, development and processes.
HAT	Highest Astronomical Tide: the highest water level that can occur due to the effects of the astronomical tide in isolation from meteorological effects.
Holocene	Geological epoch beginning approximately 12,000 years ago. It is characterised by warming of the climate following the last glacial period and rapid increase in global sea levels to approximately present day levels.
Hydro-isostasy	Impact of addition or loss of water on the earth surface elevation.
Lacustrine	Geological term to describe sediments which are derived from a lake environment.

Term	Definition
LAT	Lowest Astronomical Tide. Defined as the lowest tide level which can be predicted to occur under average meteorological conditions and under any combination of astronomical conditions.
LiDAR	Light Detection and Ranging; a contemporary method of high resolution topographic mapping using laser reflections off ground and other surfaces.
Lithified	Indurated, consolidated, cemented or rocky materials (generally hard, albeit some may be relatively soft by reason of being weathered or only semi-lithified).
MHHW	Mean Higher High Water: the mean of the higher of the two daily high waters over a long period of time. When only one high water occurs on a day this is taken as the higher high water.
MHWN	The average height of the high waters of neap tides
MHWS	Mean High Water Springs: the height of MHWS is the average, throughout a year when the average maximum declination of the moon is 23.5°, of the heights of two successive high waters during those periods of 24 hours when the range of the tide is greatest. Used when semi-diurnal tides are present.
MLWN	The average height of the low waters of neap tides
MLWS	The average height of all low waters of spring tides
Neap tides	The tides of decreased range occurring near the times of first and third quarter phases of the moon. The gravitational forces of the moon and the sun counteract each other. Since the combined tidal force is decreased the high tides are lower and the low tides are higher than average.
MSL	Mean Sea Level: the long-term average level of the sea surface.
Pleistocene	Geological epoch from 2.5 million to 12,000 years before present that spans the earth's recent period of repeated glaciations and large fluctuations in global sea levels.
Quaternary	Geological period beginning approximately 2.6 million years ago and continuing today. The Quaternary Period is sub-divided into the Pleistocene (older) and Holocene (recent) stages.
Recession	Landwards retreat of a shoreline resulting from repeated erosion events over a prolonged period of time
Significant Wave Height	The average of the highest one third of all waves.
SMARTLINE	A coastal data mapping format based on attributing a GIS polyline representing the coastline with multiple attributes describing a range of coastal characteristics which describe not just the physical location of the line itself, but also features and processes characterising the coastal area to landwards, seawards and beneath the line, and segmenting (dividing) the line where-ever any one of the attributes change in the alongshore direction.
Spring tide	The tides of increased range occurring near the times of full moon and new moon. The gravitational forces of the moon and the sun act to reinforce each other. Since the combined tidal force is increased the high tides are higher and the low tides are lower than average. Spring tides is a term which implies a welling up of the water and bears no relationship to the season of the year.
Storm bite	The amount of erosion that occurs during a single (usually storm) event.
Storm surge	The meteorological component of the coastal water level variations associated with atmospheric pressure fluctuations and wind setup.

Term	Definition
Storm tide	Coastal water level produced by the combination of astronomical and meteorological (storm surge) ocean water level forcing.
Substrate	An underlying stratum or layer of sedimentary rock / soil
Wave climate	The mix of swell and/or locally-generated wind waves received at a particular coastal location, including average wave heights and directions, and the degree of variability in these that is characteristic of the given coastal location.

References

Mariani, A, T D Shand, J T Carley, I D Goodwin, K Splinter, E K Davey, F Flocard, and I L Turner. 2012. *Generic Design Coastal Erosion Volumes and Setbacks for Australia.* Technical Report for Antarctic Climate and Ecosystems Co-operative Research Centre, Hobart, by Water Research Laboratory, University of New South Wales, Sydney, 99 pp.

NCCARF. 2016. *CoastAdapt.* Accessed November 1, 2018. https://coastadapt.com.au.

Siebentritt, M.A., and M Stafford Smith. 2016. *A User Guide for Applied Adaptation Pathways.* Version 1.0. Adelaide: Seed Consulting Services and CSIRO.

Trenhaile, A S. 2011. “Predicting the response of hard and soft rock coasts to changes in sea level and wave height.” *Climate Change* 109: 599-615.