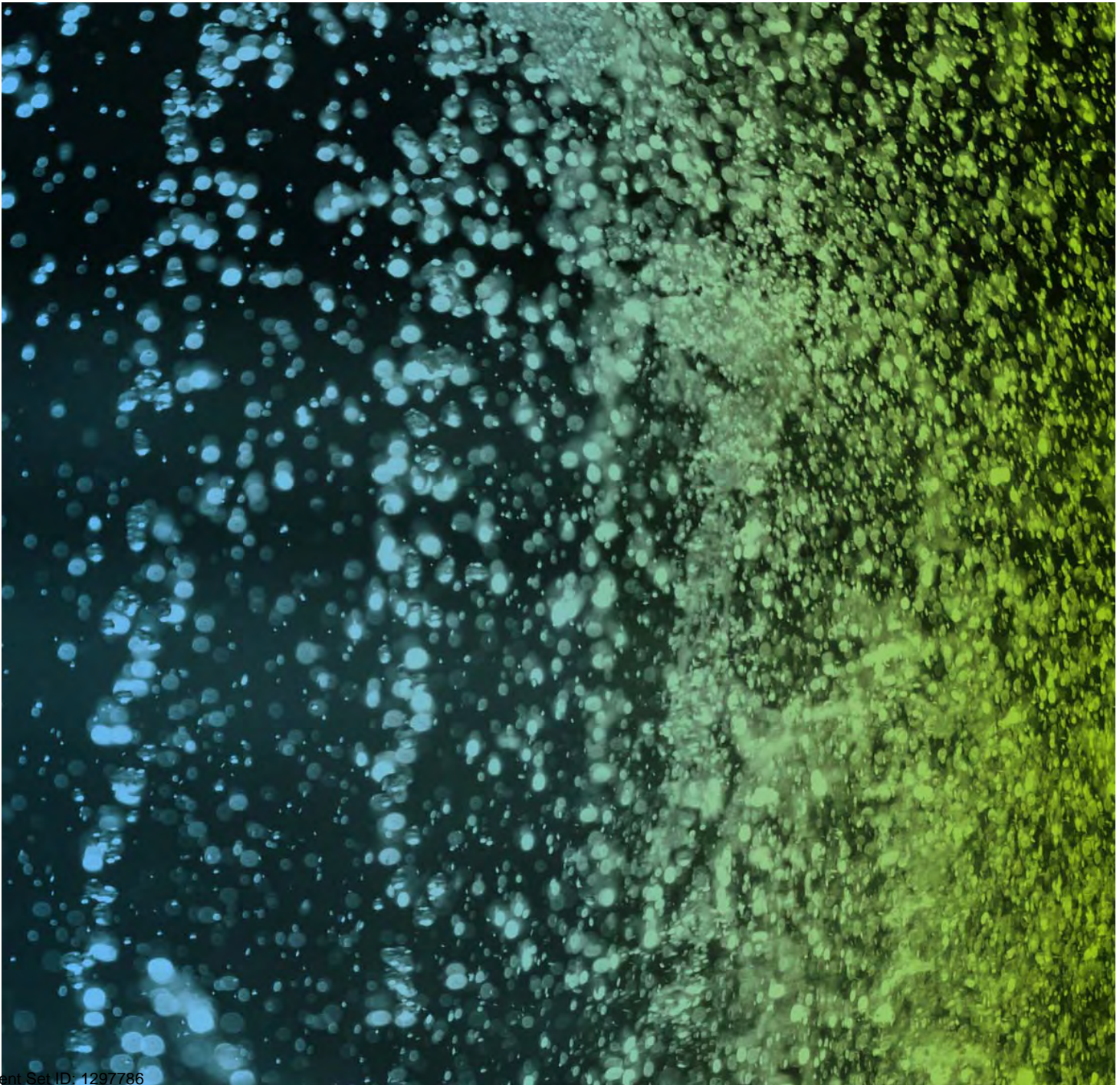


Coastal Spaces- Inundation and Erosion- Coastal Engineering Study



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Prepared for
Glenelg Shire Council

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7 July 2010

60148113

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Quality Information

Document Coastal Spaces- Inundation and Erosion- Coastal Engineering Study
 Ref 60148113
 Date 7 July 2010
 Prepared by Britta Jensen
 Reviewed by Peter Meyers

Revision History

Revision	Revision Date	Details	Authorised	
			Name/Position	Signature
A	09-Mar-2010	For Draft Review	Melanie Collett Principal Engineer- Water	
1	17-May-2010	FINAL REPORT	Tim Jerram Associate Director- Water	
2	07-Jul-2010	FINAL REPORT ISSUE 2	Melanie Collett Principal Engineer - Water	

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Executive Summary

There are low lying areas between Portland and Narrawong that are particularly vulnerable to climate change, especially with respect to sea-level rise, shoreline erosion, increased storm intensity, changes in rainfall and related flooding. These areas are currently impacted by natural coastal processes which lead to coastal erosion, particularly along Dutton Way. Other impacts may occur due to exposure to acid sulphate soil, which alone has many related impacts to the environment and the community.

Preparing for these impacts has been termed “adaptation” by the coastal research and climate change community. As state and local governments consider future climate change policies and strategies, coastal zone management programs will play an important role in identifying vulnerabilities and fostering adaptation to climate change.

AECOM has prepared this report on behalf of the Glenelg Shire Council to explore the current and future roles of Council within the study area, in addressing climate change. This report aims to

- Identify the existing coastal processes active in the study area;
- Quantify the potential impacts of climate change with respect to:
 - Sea-level rise;
 - The impact of storms on coastal erosion; and
 - Increased rainfall intensity.
- Identify potential adaptation options available to Council.

The AECOM team included specialists with the following areas of expertise:

- Climate change;
- Coastal engineering;
- Flood modelling;
- Ground water;
- Geology; and
- Land Use Planning.

Table 1 shows the results of this investigation in terms of the predicted recession in coast line (from 2010). From the specialist investigations undertaken, it was determined that coastal erosion and sea-level rise would have the biggest impact on the study area in the future.

Table 1 Summary of impact of climate change on coastal recession (m) and associated costs (2010 dollars).

Location	Coastal recession predicted by 2030 (m)	Coastal recession predicted by 2070 (m)	Coastal recession predicted by 2100 (m)
1	63	146	211
2	54	134	196
3	47	127	189
4	48	124	183
5	53	133	195
6	47	127	191
7	62	143	207
8	53	134	197
9	46	130	197
10	43	125	189
Direct + indirect costs (excluding sea-wall)	\$101M	\$158M	\$168M

The adaptation options that could be considered for this site include:

- Adaptation Option A – Do Nothing
- Adaptation Option B – Rebuild Existing Sea Wall (Construction cost \$67M)
- Adaptation Option C – Extend Sea Wall (Construction cost \$100M)
- Adaptation Option D – Extend Sea Wall and Build New Groynes (Construction cost \$125M)

A preliminary review has identified the following planning responses that could be considered for the study area:

- Planning Response Option A – Do Nothing
- Planning Response Option B – Prohibit Further Development
- Planning Response Option C – Provide for Limited Further Development
- Planning Response Option D – Facilitate Further Development

It is recommended that the results of this investigation be communicated with all stakeholders including landowners, residents and authorities, to gain their input into the preferred adaptation option. A rigorous risk assessment process could assist in identifying a preferred adaptation option.

The next phase of this investigation should include a detailed investigation into possible planning controls that could be implemented to the local planning scheme to assist Council and residents in preparing for the impacts of climate change.

1.0 Introduction

The residential community of approximately 500 residences is located along a coastal strip of low lying land connecting Portland and Narrawong between Dutton Way and the Princess Highway. These areas are subjected to natural coastal erosion processes, which makes them especially vulnerable to climate change impacts such as sea-level rise, shoreline erosion, increased storm intensity and changes in rainfall and related flooding. Other associated impacts include exposure of acid sulphate soil and ground water intrusion which would have an adverse impact on the environment and residents.

Preparing for and coping with the impacts of climate change has been termed “adaptation” by the coastal and climate change management community. Many of the climate change impacts will require adaptation solutions that cross federal, State, regional and local agencies, policies and political jurisdictions. A number of federal programs have begun to explore options at a federal level, but it has been identified that local government and State government stakeholders have immediate responsibilities for managing the resources and communities likely to be impacted by climate change.

1.1 Background

The Glenelg Shire Council recently completed the Glenelg Strategic Futures Plan (AECOM Australia 2009). This strategy identifies as a high priority the need to undertake a coastal engineering study to gain a thorough understanding of coastal and climate change processes in the vicinity of Dutton Way and Narrawong.

The Glenelg Planning Scheme first came into operation in December 1998. At the time this planning scheme was introduced the Special Use Zone was applied (Special Use Zone 3 – Dutton Way) to land most at risk of marine erosion in the vicinity of Dutton Way. This Special Use Zone prohibits future residential development and restricts land subdivision due to erosion risks.

In 2007 the Glenelg Planning Scheme was amended to apply a Development Plan Overlay (Schedule 7) to land along the coast in the localities of Dutton Way, Allestree and Narrawong. This overlay was introduced to ensure that development applications for land located below the 10 metre contour line considered the impacts of coastal erosion, sea-level rise, inundation and storm surge. There were 27 houses that had planning permits granted at this time.

The restrictions placed on the owners of land affected by these planning scheme controls are significant and there is a need for Council to provide certainty regarding future land use and development within this area. This coastal engineering study will enable Council (in conjunction with relevant State Government stakeholders) to make an informed decision regarding the capability and suitability of this land for a range of potential uses.

The Portland Bay Dynamic Rock Wall has a length of approximately 4.5 kilometres and was originally constructed in 1995, in response to the coastal erosion which had resulted in a number of lots in the locality of Dutton Way being eroded into the ocean. There are many houses in the Dutton Way area that are located on low lying land in close proximity to the rock wall. Past studies have indicated an estimated 50,000 cu.m of sand per year (Peter Reidel of Coastal Engineering Solutions, 2002) is required to be pumped from the Port of Portland and deposited on the seaward side of the rock wall to replenish areas affected by erosion. However, we understand indicated that this has not happened for some years and that the Port of Portland is currently seeking approval for construction of a new pipeline.

1.2 Study Area

The study area is located approximately 360 km south-west of Melbourne in the south of Victoria, between the Portland and Narrawong. The catchment is bounded by the Surry River and its estuary to the north-west, the Princess Highway to the north and Portland to the south west. The study section covers a length of approximately 10 km from Dutton Way in the west to Narrawong in the east.

The area includes sites of significant European and aboriginal archaeology (Glenelg Shire, November 2009) and potentially areas of acid sulphate soils (Acid Sulphate Soil Hazard Maps, 2003).

Figure 1 shows the study area. This area has been defined based on the extent of Development Plan Overlay (Schedule 7).



Figure 1 Study Area

1.3 Study Methodology

A detailed literature review was conducted to investigate the most significant known variables and impacts of climate change on coastal, hydrological, hydraulic, geological, and groundwater processes within the study area.

Section 10 of this report includes a list of all documents and data that were reviewed through this process.

Climate change projections for sea-level rise and extreme rainfall intensities are used for both the coastal (see Section 2.0) and hydrologic and hydraulic modelling (see Section 3.0). The modelling produces predicted outcomes for coastal erosion rates, coastal inundation and flood extents.

A geological evaluation was undertaken to assess the current conditions which may affect the coast line between Portland and Narrawong and provide an investigation into the regional geology, a review of the geomorphologic processes affecting the study area and a summary of the significant geological formations present (see Section 4.0).

The groundwater assessment was undertaken to assess the potential impact of coastal erosion and sea-level rise on groundwater intrusion (see Section 5.0) and acid sulphate soils (see Section 6.0).

The results of all these findings are discussed in Section 7.0 and have been plotted on maps found in Appendix F. Measures to adapt to climate change have been investigated (see Section 8.0).

The outcome of the study provides clear recommendations to the Glenelg Shire Council with regards to the adaptation options available and the impacts of climate change on the study area. This report provides a sound basis for Council to consider policy options and ultimately responses to manage the issue of coastal erosion and inundation within the study area (see Section 10.0).

1.4 Climate Change Variables

Average temperatures in Australia are expected to rise this Century due to anthropogenic activities elevating atmospheric concentrations of greenhouse gases. This change in temperature is expected to affect a range of other climate variables.

The key climate variables that are likely to affect the risk of flooding between Portland and Narrawong include increases in rainfall intensity, changes in wave climate, sea-level rise and increases in the frequency and intensity of storm surge. Secondary effects of changes to climate variables, such as local erosion occurring as a result of sea-level rise, could also significantly change the inundation characteristics of coastal regions.

For this investigation, the 'hazard' for the area has been estimated based on projected increases in sea-level rise and extreme rainfall intensity.

The approach taken to estimate future sea-level rise and extreme rainfall is robust although subject to various limitations. Further details on the approach and limitations can be found in Appendix A.

Sea-level rise

The Victorian Coastal Strategy recommends implementing a policy of planning for sea-level rise of not less than 0.8 metres by 2100. This allowance is approximately consistent with Hunter's (2009) upper limit of 82 cm for the A1FI scenario by 2100, which has been used as a basis for the Portland Coastal Engineering Study. Hunter's sea-level rise projections for the 2030, 2070 and 2100 timeframes for the A1FI scenario are shown in Table 2.

Table 2 Adjusted projections of sea-level rise, based on the A1FI scenario (Hunter, 2009)

Climate Variable	Baseline (1990)	2030	2070	2100
Sea-level rise	0	+0.05 to 0.15 m	0.17 to 0.47 m	0.27 to 0.82 m

In order to be consistent with the approach taken for selecting sea-level rise values for 2100, the upper limits of Hunter's (2009) projections have also been adopted for other timeframes. This study has therefore used the following sea-level rise projections:

- 2030 – increase of 0.15 m (from 2010 levels)
- 2070 – increase of 0.47 m (from 2010 levels)
- 2100 – increase of 0.82 m (from 2010 levels).

Extreme rainfall

AECOM used the 100 year Average Recurrence Interval (ARI), 24 hour duration flood event, as this was found to be the critical storm in a previous study of the Surry River (Water Technology, 2008).

Changes in the 100 year ARI storm event by 2100 have not been published for Victoria. CSIRO have therefore undertaken an extreme value analysis (EVA) of Global Climate Models (GCMs). This used 24 hour rainfall data over the south-western Victorian region, specifically showing the 100 year ARI event for 2046-2095 ("2055") and 2081-2100 ("2090"). Projections were forced using the A2 emission scenario using 11 GCMs for 2055 and 12 GCMs for 2090.

Using this approach, a 15.8% increase in 24 hour accumulation rainfall return levels is projected by 2055, with a 43.2% increase by 2090.

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2.0 Coastal Modelling

Figure 2 shows the methodology used for the Coastal Modelling phase of this investigation.

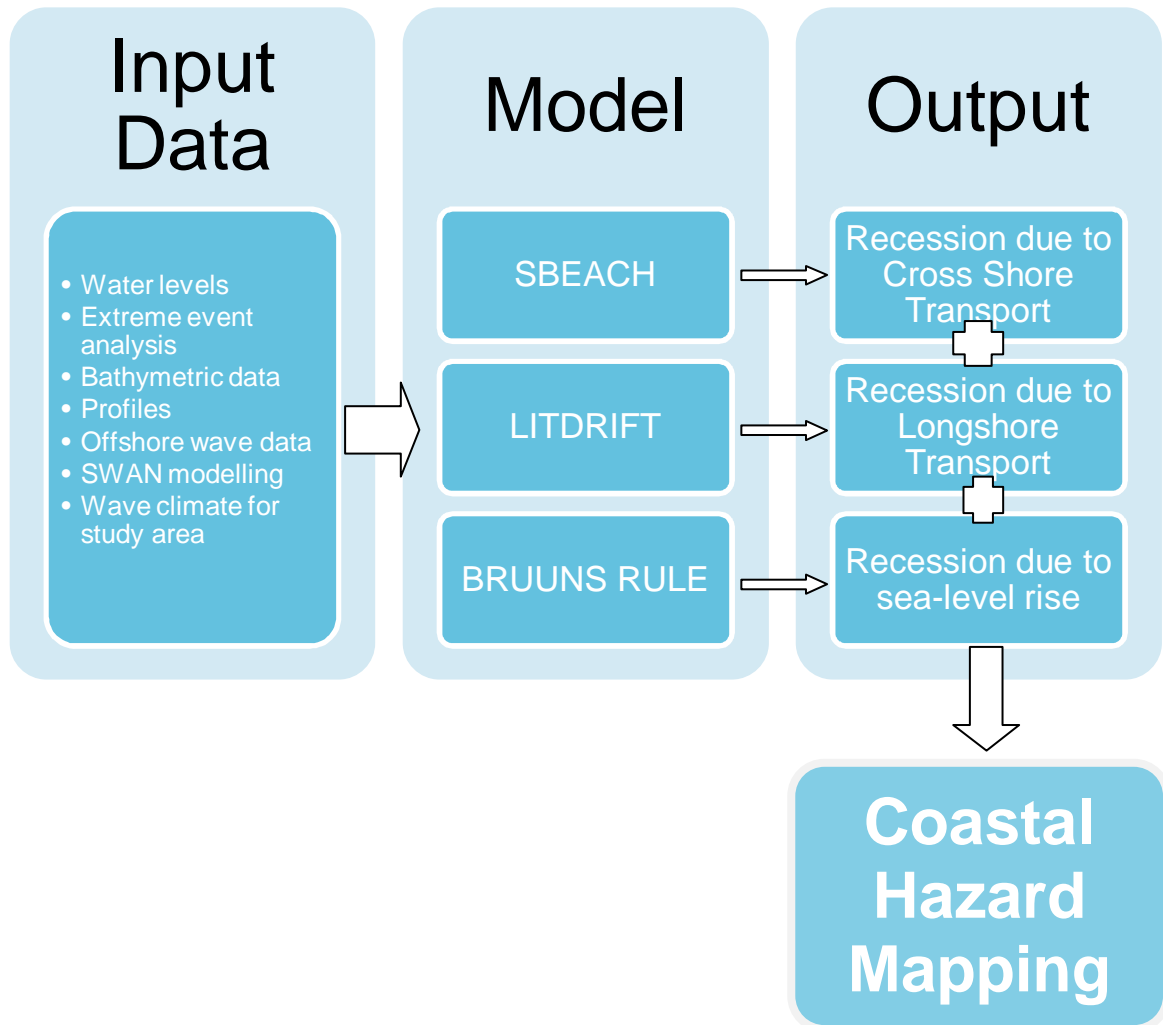


Figure 2 Coastal Engineering Study Methodology

2.1 Input Data

2.1.1 Water-levels

The extreme water-level events were extrapolated to determine the various annual return periods using the Gumble Method (Method of moments). The results are presented in Table 3. For comparison, results from previous studies are also provided.

Table 3 Extreme sea-levels (combined tide and storm surge)

ARI (years)	Sea Level (m AHD) Current Study	Sea Level (m AHD) McInnes, 2009	Sea Level (m AHD) Tawn and Mitchell (1990)
10	1.05	0.83	
50	1.13	1.02	
100	1.17	1.07	1.18

2.1.2 Wave Data

Extreme waves for offshore Portland were calculated using the both Gumbel and Weibull procedures described in the section above. The results are presented in Table 4.

Table 4 Extreme offshore waves at Portland

ARI (years)	Hs (m), offshore Portland	
	Gumbel	Weibull
100	11.00	11.07
50	10.41	10.44
10	8.91	8.99

The above analysis is based on yearly maxima.

A representative inshore wave climate is required to assess the coastal processes in the study area. The wave climate has been developed using SWAN, utilising hindcast offshore wave data and transforming the offshore waves to inshore locations using wave transformation modelling.

The modelled wave parameters were extracted at ten locations along the Portland coast in depths of 5, 10 and 15 m. Figure 3 shows the location of the cross-sections where data were extracted. The 15 m depth contour is located approximately at the seaward end of the cross-sections.



Figure 3 Study area showing locations where model results have been extracted.

A summary of model results is presented in Table 5. The model results show that wave heights are smaller at the western end of the study area and increase toward the east. The waves from the south reach the coast almost unimpeded. These would refract and shoal as they approach the Minerva reef which is located at approximately 400-600 m offshore of the Portland coast. The average wave directional flux varies from approximately 140 deg (south-east) at the western locations and turning southerly at the eastern locations.

Table 5 Summary of wave transformation modelling results

Location	Median Hs (m)	Hs exceeded 12 hr/yr (m)	Average Direction (deg N)	100 yr ARI Hs (m)
1	0.48	2.0	142.6	4.4
2	0.43	2.0	152.5	4.6
3	0.56	2.3	159.7	5.2
4	0.55	2.5	165.3	5.9
5	0.56	2.3	168.6	6.0
6	0.46	2.6	170.8	6.4
7	0.78	2.8	172.6	6.4
8	0.63	2.7	180.1	6.3
9	0.76	3.0	176.6	6.9
10	0.90	3.5	181.3	7.7

2.2 Recession due to cross-shore transport

Morphological response of the shoreline due to storm wave conditions occurs over relatively short periods (hours to days). This response primarily involves the erosion of the subaerial beach face through offshore transport and deposition near the storm wave break point to form an offshore bar. It is referred to as the cross-shore or onshore-offshore transport.

The storm waves combined with the storm surge are largely responsible for the short-term erosion of the beach face. While the headlands of Cape Nelson and Point Danger provide a shelter to the study area from the severe south-west waves from the Southern Ocean, it is fully exposed to the south-east waves.

SBEACH was employed to predict the beach response and erosion as a result of extreme storm events. SBEACH, an acronym for Storm induced Beach Change was developed at the US Army Engineer Waterways Experiment Station, Coastal and Hydraulics Laboratory to calculate beach and dune erosion under storm water levels and wave action. SBEACH is an empirical based program that calculates the net cross-shore sand transport rate in four zones from the dune or beach face, through the surf zone and into the offshore past the deepest break-point bar produced by short period incident waves. The wave model is relatively sophisticated and computes shoaling, refraction, breaking, breaking wave re-formation, wave and wind induced set-up and set-down and run-up.

The predicted shoreline recession and the resulting maximum surface elevation plus wave set-up caused by the 100 year ARI storm at different locations are summarized in Table 6 .

Table 6 Shoreline recession due 100 year ARI storm

Location	Storm recession (m) at 2m AHD	Maximum water elevation + setup (m)
1	22	2.54
2	15	2.46
3	7	2.35
4	10	2.81
5	13	2.43
6	7	2.38
7	22	2.82
8	13	2.54
9	4	2.43
10	3	2.45

2.3 Recession due to longshore transport

The long-term recession at the Portland foreshore has been evaluated by assessing longshore transport rates along the coast in conjunction with the recession rates estimated by historical aerial photographs.

Longshore transport (LST) or littoral drift is the movement of sand approximately parallel to the shore. It occurs when the waves arrive at an oblique angle to shore-normal. The variations in the magnitude and direction of longshore transport leads to areas of erosion and accretion as well as changes in beach alignment. Where the LST rate decreases in the direction of longshore transport, accretion will occur. Littoral drift may be a result of natural causes (headlands, sediment influx from rivers, wave, current and wind patterns) or because of man-made structures (breakwaters, jetties, groynes, marinas). On the open beaches of the study area, the LST is predominantly driven by swell.

Longshore computations are usually applied to beach systems assuming that infinite amounts of sand are available for sediment transport. However, real beaches will often not have infinite sources. This is especially valid for the study area where it is believed that erosion has been caused by the lack of sand to maintain the beaches. Most of the sections of the beach along the Portland foreshore have sand available only near low tide. At high tide, the waves run up to the cliff. At some sections, the beach is completely starved of sand and the waves and the water level run up the edge of the cliffs.

In these circumstances computation methods usually calculate the potential to move sand on the basis that sand is there to be moved.

The two methods used to compute LST produce very similar results as shown in Table 7. Both indicate that the sediment transport at Portland is from the west to the east and that the LST potential increases gradually from the west to the east. Larger rates of LST occur due to the refraction of approaching waves which arrive at the eastern locations at an angle less oblique to the offshore contours than at the western locations. Larger angles of wave breaking at the offshore contours will produce large rates of LST than the smaller angles.

Table 7 LST potential rates along the Portland coast

Location	LITDRIFT m ³ /year	Kamphius m ³ /year
1	42,000	44,000
2	27,000	22,000
3	97,000	74,000
4	61,000	46,000
5	122,000	143,000
6	136,000	112,000
7	159,000	277,000
8	352,000	321,000
9	208,000	303,000
10	372,000	363,000
Average	156,200	172,000

These potential longshore transport rates were translated into recession rates utilizing the methodology described in Appendix B.

Recession rates estimated from aerial photography are presented in Table 8.

Table 8 Long-term shoreline recession (m per year)

Location	Recession from aerial photos (m)
1	1.0
2	1.2
3	2.3
4	4.2
5	1.6
6	1.3
7	1.9
8	1.1
Average	1.82

2.4 Recession due to sea-level rise

Any sea-level rise has the potential to cause recession of unconsolidated shorelines if the beach profile is in equilibrium with the prevailing wave climate. Bruun (1962, 1983) investigated the long term erosion along Florida's beaches, which was assumed to be caused by a long term sea-level rise. Bruun hypothesised that the beach assumed a profile that was in equilibrium with the incoming wave energy.

The Bruun Rule is simplistic in that it predicts that the recession (R) is equal to the sea-level rise divided by the slope of the active nearshore bed profile. Due to its simplicity and lack of easy-to-use alternatives, coastal scientists and engineers have been using Bruun Rule for almost five decades. The effective application of Bruun Rule is possible if the assumptions underlying the Bruun Rule are managed and justified. The assumptions of Bruun are:

- The beach profile is in an equilibrium state
- All sand transport occurs perpendicular to the coastline (cross-shore transport)
- Uniform slope and sediment size along the profile
- Only unconsolidated material is present

The results of the application of Bruun Rule for the next 20, 60, and 90 years are presented in Table 9.

Table 9 Predicted shoreline recession in 2100, 2070 and 2030

Location	Recession (m) Bruun's Rule		
	2030 (m)	2070 (m)	2100 (m)
1	5	16	27
2	3	11	19
3	4	12	20
4	2	7	12
5	4	12	20
6	4	12	22
7	4	13	23
8	4	13	23
9	6	18	31
10	4	14	24

2.5 Coastal Hazard Lines

The coastal hazard lines or zones define the area enclosed by the zone that is subject to coastal erosion and recession. Any land, infrastructure or assets situated within the coastal hazard zone are under threat of damage and/or complete loss.

The coastal hazard lines have been calculated for the purpose of planning purposes only. These should be considered as allowances for setbacks for erosion and recession and comprise of the following components:

- Recession due to cross-shore transport (SBEACH)
- Recession due to longshore transport (LITDRIFT)
- Recession due to sea-level rise (Bruun Rule)

The coastal hazard lines are thus computed as: A+B+C and are presented in Table 10 and Map M1.

Table 10 Coastal Hazard Lines (m from existing coast line)

Location	Coastal recession predicted by 2030 (m)	Coastal recession predicted by 2070 (m)	Coastal recession predicted by 2100 (m)
1	63	146	211
2	54	134	196
3	47	127	189
4	48	124	183
5	53	133	195
6	47	127	191
7	62	143	207
8	53	134	197
9	46	130	197
10	43	125	189

3.0 Hydrologic and Hydraulic Modelling

Hydrologic and hydraulic modelling has been undertaken using an existing MIKEFLOOD model, sourced from Water Technology Ltd Pty. A detailed description of this model and the associated results can be found in the Glenelg Hopkins CMA Surry River Estuary Flood Study, Study Report found in Appendix C.

Flood modelling, comprising of a hydrological model and a hydraulic model, was undertaken to predict flood extents for the 24 hour duration, 100 year ARI flood event (identified as being the critical event by WaterTechnology, 2008), as a result of projected sea-level rise and increase in extreme rainfall intensity for the year 2100.

3.1 Hydrologic Modelling

Climate change is likely to result in drier conditions for most regions. However, extreme rainfall events are likely to increase in frequency and intensity. As the study area consists of backshore lagoons and is bounded by the Surry River, the increase of rainfall intensity is expected to have an effect on flood extents within the catchment.

Using the approach recommended by CSIRO (refer to Appendix A), a 15.8% increase in 24 hour accumulation rainfall return levels is projected by 2055, with a 43.2% increase by 2090.

The relationship between peak flow and rainfall intensity (the 'Rational Method') was used to estimate the change in peak flow for a given change in rainfall intensity:

$$Q = CIA$$

That is, the estimated peak flow for the existing 100 year ARI rainfall event was multiplied by the estimated increase in rainfall intensity for the 100 year ARI event for the 2100 scenario to obtain an estimated hydrograph for the 100 year ARI flow in 2100.

The peak flow in the Surry River at Heathmere for the 100 year ARI flood event (2010 conditions) is 83 m³/s.

The hydrographs utilised in the WaterTechnology 2008 investigation were increased by 43.2% to represent the predicted inflows for the 2100 scenario. The peak flow in the Surry River upstream of the study area for the 100 year ARI flood event (2100 conditions) has been computed as 119 m³/s.

3.2 Hydraulic Modelling

The MIKEFLOOD model calculates flood levels and flow patterns and also models the complex effects of backwater, overtopping of embankments, waterway confluences, bridge constrictions and other hydraulic structure behaviour.

The model was run for the 2010 scenario (existing conditions scenario from WaterTechnology), utilising the inputs as provided by the Glenelg Hopkins Catchment Management Authority (GHCMA). This included hydrographs representing the inflows and a constant downstream water-level of 1.1m AHD.

The model was then run for the 2100 scenario. Each of the inflow hydrographs were increased by 43.2% and the downstream water-level was increased by 0.8m to 1.9m AHD. As a sensitivity test, the downstream water-level was also increased by 1.2m to 2.3m AHD.

Figure 4 shows the results of the flood modelling for the 2010 and 2100 scenarios. This shows that there is negligible impact on predict flood levels for the Surry River (this was also the case for the model run with the 1.2m sea-level rise). This is consistent with the findings of WaterTechnology (2009) and is reported to be due to the steep water surface gradient at the mouth of the Surry River.

Please note that any land which is not flood prone, but is surrounded by flood or coastal hazard has been labelled at risk, due to the loss of access.



Figure 4 Comparison of 2010 and 2010 flood model extents

3.3 Closing of the River Mouth

The Surry River mouth is regularly blocked by sand, due to the high rate of longshore transport and low river flows during certain times of the year. Figure 5 shows the time series of recorded water-levels provided by the GHCMA for a location just upstream of the Princes Highway bridge (SURRY_RV.csv provided on 21/04/2010).

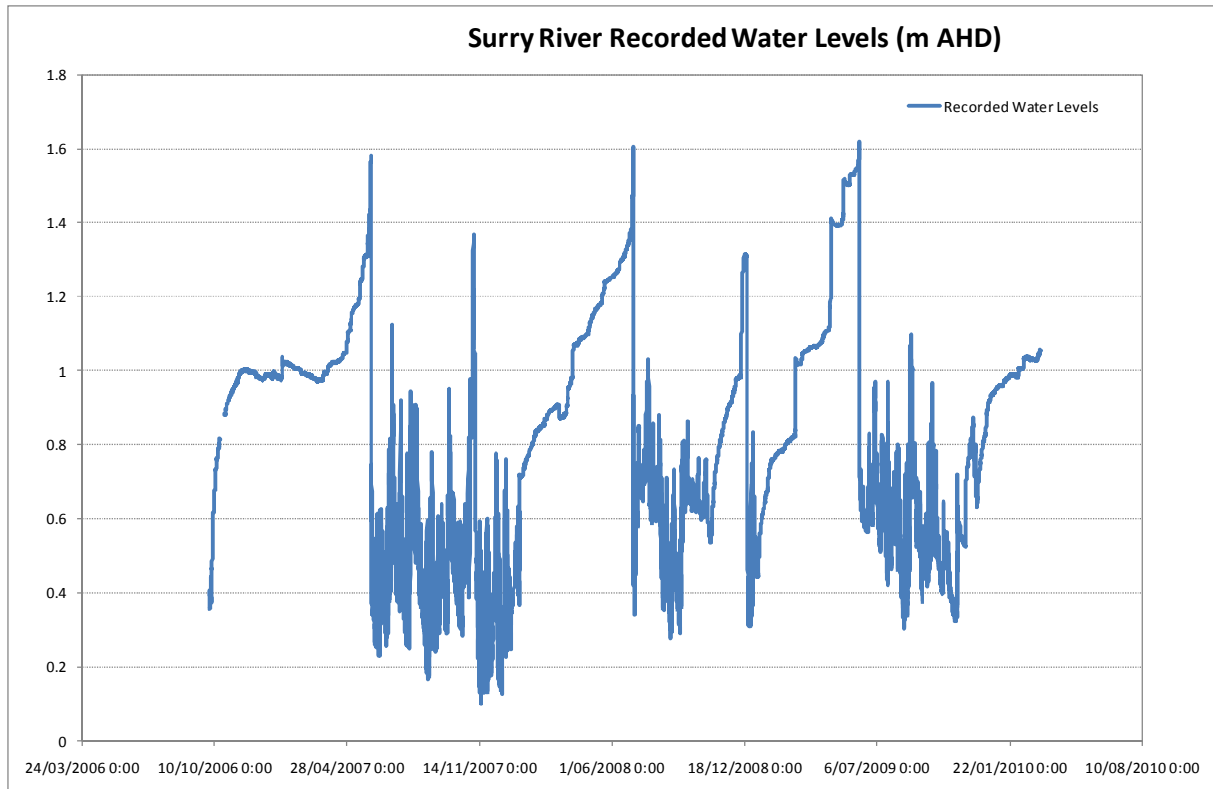


Figure 5 Surry River recorded water-levels

This plot shows that the river mouth has been blocked a number of times during the period of record. These times are identifiable as times when there is no tidal influence on the water levels. The three highest recorded water-levels are:

- 09/06/2009 – 1.62m AHD
- 02/07/2008 – 1.61m AHD
- 02/06/2007 – 1.57m AHD

As these levels are below the water-level estimated for the downstream boundary of the hydraulic modelling for the 2100 conditions, the inundation area identified in these plots will cover any area at risk of inundation due to closure of the river mouth.

A further analysis of the data indicates that the river mouth has been blocked for approximately 55% of the time of this record (3/10/2006 to 9/3/2010).

With less regular rainfall and more extreme coastal conditions expected due to climate change, it is anticipated that the closure of the entrance will occur more regularly in the future. This may also prove to be a significant flooding issue in the future, if the river mouth sandbar height increases in line with sea-level rise. Dry weather flooding due to closure of the river mouth may occur more regularly, and may be to a higher water-level.

4.0 Geology

There are many natural and artificial processes affecting the geomorphology of the Glenelg Shire coastline between Dutton Way and Narrawong. Due to the exposed nature of the coastline from marine and aeolian processes, the region is subjected to many phases of erosion and deposition. Continual erosion, without protective measures, will weaken the natural cliff line, which may induce phases of landslips. The continual landslides and the removal of slump material will force the coastline to recede in an inland direction. In addition to the potential cliff recession, the sand dune morphology in the vicinity of Narrawong will continue to migrate inland. For the detailed geological, geomorphologic and geotechnical engineering evaluation refer to Appendix D.

The study area under investigation is a naturally dynamic, high energy environment. Erosional and depositional processes are ongoing but maybe affected by any climate change process.

Specific effects of climate change on the geological and geomorphological processes are difficult to predict, but existing features may be impacted. It should be noted that the following discussion is not based on any detailed site assessment, analytical models or references but on local engineering judgment. A summary of potential effects, consequences and potential mitigation techniques are highlighted below.

4.1 Sea-level Rise

- Should the sea-level rise, in combination with any changes in precipitation, temperature or wind speed, there is the potential to have a significant impact on the morphology of the coastline.
- Removal of the protective barrier to the inland sand-dunes and cliffs may increase the potential for the dunes and cliffs to be subjected to increased erosion and weathering effects and may migrate inland until equilibrium is reached between the various processes involved and the sediment supply or erosion.

4.2 Wind Speed

- Predominant geomorphological features which are estimated to be affected will be the sand dunes and ridges, present between Dutton Way and Narrawong.
- Any increase in the wind speed may lead to an increase in the rate of sediment transport and dune migration. A decrease is estimated to reduce the rate of sediment transport.
- Currently, the widest section of sand dune formation extends up to 40m inland from the coastline, in the vicinity directly to the southwest of the Surry River delta. Should wind speeds significantly change, there is potential for the dunes migration patterns to change.
- A potential method of mitigating any adverse effects of potentially changing wind speeds is to encourage the development of suitable, sustainable vegetation, as it will have the effect of anchoring and binding the sediment with the root structure, which will increase the dunes resistance to erosion and migration.

4.3 Precipitation

- The level of saturation within a cliff, bluff or sand dune can have a significant control on its stability. It is recommended to ensure all installed drainage paths and channels are in good condition and free from obstructions.
- By controlling and channeling any excess water away from the coastal morphologies, this can reduce the potential risks of slope failure, slumps and coastal recession.
- Where drainage channels cannot be installed or utilized, there is a potential risk that the excess surface run-off will flow through the coastal landscapes along a path of least resistance.
- With a potential increase in the volume of surface run-off, these natural channels may enhance physical and chemical erosional processes
- Changes in rainfall patterns, would impact vegetation, which may have the effect of anchoring the soil, limiting the possibility of erosion and removal.

4.4 Temperatures

- An increase in temperatures may exacerbate the potential for additional physical weathering processes to occur, i.e. thermal expansion of materials
- An increase in development and tourism may lead to an increased volume of people visiting the beach and surrounding area. Pedestrian movements, if uncontrolled, can have a significant effect on the dune morphology.
- There is a possibility that with increased visitor numbers, there is greater potential for dune erosion and failure, as the visitors may not remain on designated pathways.
- To potentially mitigate some of these erosional causes, should an increase in traffic be expected, sufficient vehicle and pedestrians pavements may be considered to increase the safety of both the public and environment.

5.0 Groundwater Investigation

Groundwater processes are generally slow and systems take time to adjust to changes. Based on a predicted sea-level rise of 15 cm, the maximum possible groundwater rise of 15 cm is not significant, and any consequences are likely to be localised. Even at greater predicted changes (up to 82 cm) significant consequences are possible only where groundwater is currently shallow or where other stresses are also present (such as groundwater pumping). The most likely risks are associated with higher groundwater levels and not with potential changes in groundwater quality. Therefore, whilst some of the potential consequences are quite serious (non-potable water, infrastructure damage), the likelihood of most groundwater-related consequences is considered relatively low, resulting in relatively low risk ratings. A summary of the reasons for rating of potential risks is provided below.

- 1) Assuming that groundwater bores identified in the study area are being used as a potable supply of drinking water, the risk of water quality degradation due to the inundation of more saline groundwater as a result of sea-level rise, has been assessed as 'Low' to 'High' for predicted values of sea-level rise to 2100. Available groundwater quality data suggests that groundwater in the study area currently meets standards for potability. Whilst the loss of potable water is a serious outcome, it is expected that rising sea-levels as predicted are not very likely to significantly impact groundwater supplies given the hydrogeological setting of the study area. The predicted area of surface water flooding (Figure 4) includes only a few bores located near the Surry River. The potential risks could be assessed more accurately with more information about current groundwater levels and actual use of the groundwater.
- 2) The risk that potential groundwater inundation is inferred to have on the interruption of estuarine circulation and subsequent degradation of the environment (impact to aquatic and wetland ecosystems), is considered to transition from 'Low' (existing conditions) to 'Moderate' by 2030 as a result of potential sea-level rise. Disruption of the river drainage is more likely as a direct outcome of sea-level rises (rather than groundwater), as shown by the extent of predicted flooding in this area (Figure 4).
- 3) The loss of biodiversity due to exposure and sensitivity of plant and animal species to the intrusion of more saline and/or potentially contaminated groundwater (e.g. from near-surface infrastructure such as septic systems), is considered to be at a 'Low – Moderate' risk by 2030 and through to 2100, as a result of potential sea-level rise. The predicted height of sea-level rise is not likely to lead to significant areas of groundwater salination, except where salination may be caused by flooding of potentially saline water (for example, see Map M1, predicted inundation).
- 4) It has been identified that the potential damage and corrosion of coastal assets (eg. buildings, roads and services) due to elevated groundwater levels and potential flooding, poses the most significant risk as a result of predicted sea-level rise. In the Site area, there is a relatively thin zone of unsaturated soil above the water table. A rise in the water table of nearly a metre could saturate much of the currently unsaturated zone, especially in areas of lower elevation. By 2070 and through to 2100, the risk to coastal infrastructure as a result of groundwater inundation is inferred to be 'Moderate – High'. This is a result of the relatively high monetary value of coastal assets (eg. residential property) and their inability to adapt to rising sea-levels. The lower the depth to the groundwater table and the higher the salinity of groundwater, the higher the risk for subsurface services and infrastructure to be damaged. Buoyancy and lateral pressure effects to buildings and services as a result of a rising groundwater table, potentially decrease their structural integrity. This assessment has taken into consideration that there is a need to prioritise coastal assets and maintain their integrity.
- 5) Similar to the risk posed to coastal assets, the risk that groundwater inundation due to rising sea-levels will degrade the drainage and induce water logging of soil, potentially leading to the rezoning of development areas and/or zoning restrictions, is considered to transition from 'Low' (under existing conditions) to 'Moderate' around 2070 and through to 2100. Historical groundwater levels indicate that immediately behind the primary dune area, the groundwater table may be less than 1 m for the ground surface. The risk of groundwater inundation is significantly higher when groundwater levels are within 1 m of the ground surface, due to the capillary zone of the upper soil horizon becoming saturated with water almost to the surface.

6.0 Acid Sulphate Soils

The presence of 'Potential Acid Sulphate Soil' (PASS) material along coastlines has important implications for land use and development in these areas. 'Acid Sulphate Soils' (ASS) are soils, sediments or rock that contain elevated levels of metal sulphides (principally pyrite – FeS₂) (EPA Vic, 1999). Exposure of these metal sulphides to oxygen as a result of activities such as erosion, drainage or excavation, can result in the production of sulphuric acid. The generation of acid subsequently results in acidification of soil, sediment, rock, surface water and groundwater. ASS material is generally found within 1.5 m of the soil surface (EPA Vic, 1999a). Runoff and leachate generated from ASS material can adversely impact aquatic ecosystems, agricultural practices and engineering works. Acid leachate also has the potential to mobilise metals from soil and sediment into groundwater or surface water. Waste ASS material is required to be managed in accordance with the requirements of the *Industrial Waste Management Policy (Waste Acid Sulphate Soils)* (EPA Vic, 1999a).

Based on the Department of Primary Industries (DPI) *Acid Sulphate Soil Hazard Maps* (2003), PASS material is expected to be present at the Site. This information is compiled by DPI to provide information on acid sulphate soil distribution and indicate to land managers where caution is needed or where further investigation and analysis is required before any land disturbance. It is suggested that, due to the scale of the maps, those areas adjacent to those assessed as having potential PASS material be also investigated.

Although the region between Dutton Way and Narrawong was not assessed specifically, an assessment at Yambuk, 30km east of Narrawong was undertaken.

Field peroxide tests were performed on sediments from Yambuk, with the results illustrating that there was a slight to significant effervescence to the sample when placed into a peroxide solution. This can be interpreted to denote that the samples taken in Yambuk have a low to slight possibility of having a high concentration of iron sulphides. Due to the geological and geomorphological similarities an extrapolation of results has been performed by ASRIS and it is feasible to assume, that the deposits between Dutton Way and Narrawong have similar iron sulphide content.

Coastal erosion due to predicted sea-level rise is likely to expose PASS soil at the Site, which may result in the generation of acid sulphate soils and acidic leachate. It is expected that groundwater inundation as a result of sea-level rise at the Site, will not result in exposure of PASS material at the Site, as it is more likely that soils will become flooded rather than exposed to air. However, potential remedial measures that require drainage or excavation of soil or sediment, may result in the exposure of PASS material to oxygen and subsequent generation of acid. Seawater infiltration as a result of sea-level rise, into estuarine sediments containing freshwater and organic and iron-rich sediments may result in the formation of ASS. That is, the highly oxygenated seawater could oxidize the sulphate minerals in the previously anaerobic sediments. This may occur in areas of the Site adjacent to the Surry River and it is this process that is likely to have resulted in the identification of PASS material previously mapped across the Site. The presence of carbonate bearing fossiliferous limestone at depths as shallow as 0.46 m (based on the geologic log of bore B50538) and near-surface shell bearing sand, may act to neutralise acidic discharges that may potentially occur.

A more detailed analysis of the potential for acid sulphate soil generation at the Site should be conducted prior to any works involving the drainage or excavation of soil in areas of currently mapped PASS material. Remedial measures to reduce the erosion of coastal PASS material and prevent the mixing of seawater and freshwater in organic and iron-rich estuarine sediments, may also need to be considered. It is recognised that the best technique to manage PASS soils is to avoid their disturbance. Therefore, remedial measures that involve drainage or excavation of soils should be considered less preferable to those that do not. Consideration of areas containing PASS material should also be given in the planning of development areas where subsurface construction may be considered.

Further discussion on Acid Sulphate Soils can be found in Appendix E.

7.0 Impact of Climate Change

The above investigations have resulted in both qualitative and quantitative assessments of the potential impact of climate change on study area. These impacts include inundation from sea-level rise, coastal erosion due to storm events, inundation from increased rainfall and increases in ground-water levels. Map M1 shows the predicted impact of climate change on the study area.

One way of quantifying the impact of climate change on an area is to calculate the potential “*cost of damage*”. Costs are generally classified as either tangible (can be assigned a monetary value) or intangible (those for which no market exists). Tangible costs can be further broken down into direct and indirect costs. Direct costs are easiest to classify, they are the costs that result from the physical destruction or damage to buildings, infrastructure, vehicles and crops. Indirect costs are more difficult to estimate, but are the costs incurred as consequence of the event occurring, but not due to the direct impact.

Figure 6 shows a schematic for assessing the potential “*cost of damage*” impact of climate change.

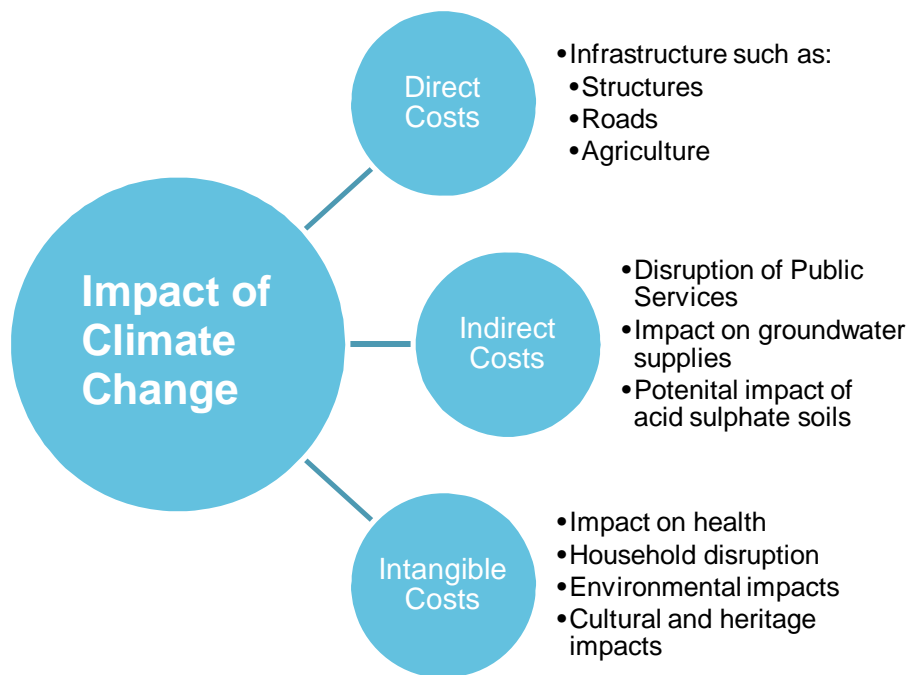


Figure 6 Impacts of Climate Change

The following sections describe the predicted costs associated with the impacts of climate change on the study area.

7.1 Direct Impacts

An assessment of the infrastructure within the identified hazard lines was undertaken using GIS. The following infrastructure was identified and costed:

- Boat ramps.
- Beach access stairs.
- Beach access ramps.
- Roads (sealed and unsealed).
- Transmission lines and poles.
- Telephone booth.
- Telstra underground cables.
- Uniting Church camp.
- Abalone Farm.
- Caravan parks (2).
- Residential land with and without structures.
- Agricultural land with and without structures.

Whilst it is difficult to place a value on some of the natural assets, the potential dollar value of the impact of climate change on the physical infrastructure within the study area has been computed in 2010 dollars. Table 11 shows the results of this analysis. Appendix F includes the detailed costing spreadsheets.

Note that the cost of the existing sea wall has been excluded from these calculations as it was difficult to define a dollar rate for this item, as the upgrade of this was also considered as an adaptation option.

Table 11 Direct costs associated with the impact of climate change on the study area

Timeframe	Direct Costs (in 2010 dollars)
2030	\$81M
2070	\$126M
2100	\$134M

7.2 Indirect Costs

Most methods available to undertake damage assessments are based on the assessment of an event such as a flood or cyclone. These events are usually unpredictable and unexpected, therefore there are significant indirect costs associated with them. Gentle et al (2001) estimates that indirect costs are usually in the range of 25 to 40 per cent of direct costs.

As the timing and impact of climate change can be determined with a little more certainty than a flood or a cyclone, it is therefore expected that the indirect costs associated with the impact of climate change will be at the lower end of this estimate. An allowance of 25% of direct costs have therefore been attributed to indirect costs. Table 12 shows the computed indirect costs (in 2010 dollars) for the various timeframes investigated.

Table 12 Indirect costs associated with the impact of climate change on the study area

Timeframe	Indirect Costs (in 2010 dollars)
2030	\$20M
2070	\$32M
2100	\$34M

7.3 Intangible Costs

Intangible costs are those for which no market exists. These are things such as,

- The impact on health
- Household disruption
- Environmental impacts
- Cultural and heritage impacts

Climate change may also have some positive benefits to the environment. For example, if the lower reaches of the Surry River become more saline, this may lead to an ecology more suited to sea birds.

Due to the difficulty in quantifying these intangible costs and attributing a dollar value to them, they have not been included in the costs computed for this investigation.

7.4 Summary of Costs

By adding the direct and indirect costs associated with the impact of climate change on the study area, we obtain the values shown in Table 13.

Table 13 Direct and indirect costs associated with the impact of climate change on the study area

Timeframe	Direct Costs (in 2010 dollars)	Indirect Costs (in 2010 dollars)	Direct + indirect Costs (in 2010 dollars)
2030	\$81M	\$20M	\$101M
2070	\$126M	\$32M	\$158M
2100	\$134M	\$34M	\$168M

As most of the identified assets within the study area are adjacent to the coastline, the most significant costs are expected to occur in the shorter term (by 2030).

8.0 Adaptation

There are numerous potential adaptation options that have been developed throughout the world to address climate change. Appendix G contains a list of potential physical adaptation options that were considered during this investigation. Many of these adaptation options were discounted as they were not considered to be appropriate for this site.

The increase in sea-level and the impact of storms on coastal erosion are considered to be the biggest impacts of climate change on the study area. Therefore, the adaptation options that are appropriate for this location either address or treat these processes.

The adaptation options that could be considered for this site come under two categories, physical solutions or planning controls. The following physical adaptation options have been considered:

- Adaptation Option A – Do Nothing
- Adaptation Option B – Rebuild Existing Sea Wall
- Adaptation Option C – Extend Sea Wall
- Adaptation Option D – Extend Sea Wall and Build New Groynes

A preliminary review has identified the following planning responses that could be considered for the study area:

- Planning Response Option A – Do Nothing
- Planning Response Option B – Prohibit Further Development
- Planning Response Option C – Provide for Limited Further Development
- Planning Response Option D – Facilitate Further Development

8.1 Physical Adaptation Options

This section describes the physical adaptation options in more detail. Please note that these options are conceptual only, and that no modelling has been undertaken on these options. It is assumed that the following measures are incorporated into all adaptation options:

- Beach renourishment (estimated cost of \$1.6M per year for 120,000 m³).
- Re-vegetation of coastal zones to stabilise the existing dune system.

8.1.1 Adaptation Option A – Do Nothing

Adaptation option A involves no physical works. Utilising planning controls and a planned retreat approach, the impacts of climate change on the study area could be minimised. Map M5A shows the potential impacts on the study area if this were implemented.

8.1.2 Adaptation Option B – Rebuild Existing Sea Wall

Adaptation option B involves rebuilding the existing sea-wall to protect the properties behind. An estimated cost of \$10,000 per linear metre has been computed to provide a rock armoured sea-wall, which will protect the properties from coastal erosion. Additional work will have to be undertaken to ensure that the impact of sea-level rise is also taken into account.

Other areas for consideration with this adaptation option include:

- Impact on groundwater levels and quality.
- Impact on acid sulphate soils.
- Impact on drainage behind the sea wall.
- Doesn't protect properties not adjacent to the sea-wall.

- Recreational values will be reduced in the area as there will not be much beach area.
- The sea-wall will require regular maintenance.

The total capital construction cost of this option is estimated to be in the order of \$67M.

8.1.3 Adaptation Option C – Extend Sea Wall

Adaptation option C involves rebuilding the existing sea-wall and extending it the entire length of the study area, to protect the properties behind. An estimated cost of \$10,000 per linear metre has been computed to provide a rock armoured sea-wall, which will protect the properties from coastal erosion. Additional work will have to be undertaken to ensure that the impact of sea-level rise is also taken into account.

Other areas for consideration with this adaptation option include:

- Impact on groundwater levels and quality.
- Impact on acid sulphate soils.
- Impact on drainage behind the sea wall.
- Recreational values will be reduced in the area as there will not be much beach area.
- The sea-wall will require regular maintenance.

The total capital construction cost of this option is estimated to be in the order of \$100M.

8.1.4 Adaptation Option D – Extend Sea Wall and Build New Groynes

Adaptation option D involves rebuilding the existing sea-wall and extending it the entire length of the study area and incorporating rock armoured groynes, to protect the properties behind. An estimated cost of \$12,500 per linear metre has been computed to provide a rock armoured sea-wall with groynes (50 m long at 150 m spacing), that will protect the properties from coastal erosion. Additional work will have to be undertaken to ensure that the impact of sea-level rise is also taken into account.

Other areas for consideration with this adaptation option include:

- Impact on groundwater levels and quality.
- Impact on acid sulphate soils.
- Impact on drainage behind the sea wall.
- Recreational values may be improved in the area as beaches will be developed between groynes.
- Maintenance of the sea-wall will be less as the rock groynes will remove some of the wave energy before it hits the wall.

The total capital construction cost of this option is estimated to be in the order of \$125M.

8.2 Planning Response Options

In addition to considering the physical adaptation response that should be taken to address the issue of coastal erosion in the study area, consideration also needs to be given to the most appropriate planning response. The selection of the physical adaptation response must occur concurrently with the selection of the planning response.

The next stage of this study will involve a detailed review of the options available to respond to these issues from a land use planning perspective and will inform Council so that it can adopt a policy position on how to respond to the issue of coastal climate change within the study area.

A preliminary review has identified the following planning responses that could be applied to respond to the findings of this report:

- Planning Response Option A – Do Nothing
- Planning Response Option B – Prohibit Further Development
- Planning Response Option C – Provide for Limited Further Development
- Planning Response Option D – Facilitate Further Development

These responses could of course be applied to different parts of the study area depending on the degree of impact from coastal erosion.

In considering which planning response is appropriate for the study area, consideration will need to be given to relevant State strategies including the Victorian Coastal Strategy (2008) which sets out State Government policy for coastal areas and provides a long term vision for the coast. The strategy identifies policies and actions to guide decision making by State and local government. The strategy identifies a hierarchy of principles that should be applied to coastal planning and management, namely:

1. *Provide for the protection of significant environmental and cultural values.*
2. *Undertake integrated planning and provide clear direction for the future.*
3. *Ensure the sustainable use of natural coastal resources.*

When the above principles have been considered and addressed:

4. *Ensure development on the coast is located within existing modified and resilient environments where the demand for development is evident and the impact can be managed.*

The strategy introduced a policy of planning for sea-level rise of not less than 0.8 metres by 2100. This policy is to be applied for planning and risk management purposes and is reflected in the Victoria Planning Provisions in Clause 15.08 of the State Planning Policy Framework. The strategy and VPPs also identify the need to allow for the combined effects of tides, storm surges, coastal processes and local conditions such as topography and geology when assessing the risks and coastal impacts associated with climate change and when considering development proposals. The strategy identifies three broad adaptation options for climate change; protect, accommodate or retreat.

The need to apply the precautionary principle to planning and management decision-making is also identified in the strategy and VPPs.

Importantly, the State Planning Policy Framework also states that planning to manage coastal hazards and the coastal impacts of climate change should:

- *Avoid development in identified coastal hazard areas susceptible to inundation (both river and coastal), erosion, landslip/landslide, acid sulfate soils, wildfire and geotechnical risk.*

The planning response option that is chosen for this study area will need to be informed by relevant State Government strategies and programs and relevant reports including:

- The Future Coasts Program
- Coastal Climate Change Advisory Committee (Issues and Options Paper Main Report – February 2010)
- Victoria Planning Provisions.

The February 2010 report of the Coastal Climate Change Advisory Committee discusses in some detail the current Victoria Planning Provisions and how they could be used or adapted to respond to the issue of coastal climate change. Various options are identified including zoning and overlay controls that could be utilised or adapted from their current form to respond specifically to issues such as coastal erosion and inundation. The second stage of this planning study will need to be informed by the recommendations of this report and resulting policy developments.

8.2.1 Planning Response Option A – Do Nothing

The Glenelg Planning Scheme currently addresses the issue of coastal erosion within the study area by prohibiting further development on land most exposed to coastal erosion through the zoning of this land as Special Use Zone 3 – Dutton Way.

An extensive area of land within the study area has been identified as being affected by coastal erosion, including the land zoned Special Use Zone 3, and has been included in a Development Plan Overlay area (Schedule 7 – Coastal Area between Portland and Narrawong).

The Development Plan Overlay provides for planning permits to be issued for specific properties (where applications are lodged prior to 31 December 2010) prior to the preparation of a development plan and requires consideration to be given to coastal processes during the preparation of the permit application for these properties. This overlay also provides for legal agreements to be entered into with landowners to acknowledge that the owner is aware of the environmental risk characteristics of the area. This legal agreement would also have the affect of informing prospective future owners of the potential impacts of sea-level rise and coastal processes on the subject land.

The Development Plan Overlay has the effect of prohibiting new dwellings from being constructed on other properties (i.e. those not listed in the overlay) by prohibiting the issue of a permit prior to the approval by Council of an approved development plan for the whole area. This places many of these landowners in an uncertain position with regards to the future options for their landholding.

Following the finalisation of this report, consideration will need to be given as to whether the current planning scheme provisions are appropriate given the findings of this study. The existing planning controls will need to be reviewed in light of the findings of this study which provides for the first time an estimate of the extent of coastal recession predicted to occur within the study area by the year 2100.

The need to remove the uncertainty that currently exists regarding the ability to develop certain landholdings within the study area is of paramount importance.

8.2.2 **Planning Response Option B – Prohibit Further Development**

Consideration will need to be given as to whether a control such as the current Special Use Zone 3 should be extended to prohibit further development across those sections of the study area where coastal erosion is predicted by this study to occur within a certain timeframe. Should such an approach be deemed appropriate, consideration may also need to be given to applying a Public Acquisition Overlay should it be determined necessary or desirable to acquire the land or a Restructure Overlay to reduce the number of lots within the study area.

8.2.3 **Planning Response Option C – Provide for Limited Further Development**

Should it be determined that further development is appropriate within all or part of the study area, consideration will need to be given as to the appropriate planning tools to provide for this. Policy guidance may be required in the Local Planning Policy Framework of the Glenelg Planning Scheme to guide decision making by Council. Consideration will need to be given as to whether a control such as the current Special Use Zone 3 should be extended across areas identified in the study as subject to coastal erosion. The application of legal agreements such as Section 173 Agreements which are registered on the Certificate of Title and inform prospective purchasers of land of environmental issues that apply to the land may also need to be considered. Should a specifically tailored zone be required to identify specific land uses that are permissible and ones that are prohibited, then the Special Use Zone may need to be applied rather than a more standard VPP type zoning where Council is unable to apply discretion as to the permissibility of uses.

8.2.4 **Planning Response Option D – Facilitate Further Development**

Should it be determined that further development will be encouraged within certain sections of the study area, consideration will need to be given as to how this development will be facilitated. Such matters as minimum lot sizes will need to be addressed should further subdivision of land be deemed appropriate. Policy guidance may also be required in the Local Planning Policy Framework to guide decision making. The current zoning of much of the study area as Rural Living Zone already provides for further development.

9.0 Conclusions and Recommendations

Table 14 shows the results of this investigation in terms of the predicted recession in coast line (from 2010). From the specialist investigations undertaken (coastal erosion, hydrologic and hydraulic modeling, geotechnical and groundwater), it was determined that coastal erosion and sea-level rise would have the biggest impact on the study area in the future.

Table 14 Summary of impact of climate change on coastal recession (m) and associated costs (2010 dollars).

Location	Coastal recession predicted by 2030 (m)	Coastal recession predicted by 2070 (m)	Coastal recession predicted by 2100 (m)
1	63	146	211
2	54	134	196
3	47	127	189
4	48	124	183
5	53	133	195
6	47	127	191
7	62	143	207
8	53	134	197
9	46	130	197
10	43	125	189
Direct + indirect costs (excluding sea-wall)	\$101M	\$158M	\$168M

The adaptation options that could be considered for this site (and their capital construction costs) include:

- Adaptation Option A – Do Nothing
- Adaptation Option B – Rebuild Existing Sea Wall (\$67M)
- Adaptation Option C – Extend Sea Wall (\$100M)
- Adaptation Option D – Extend Sea Wall and Build New Groynes (\$125M)

A preliminary review has identified the following planning responses that could be considered for the study area:

- Planning Response Option A – Do Nothing
- Planning Response Option B – Prohibit Further Development
- Planning Response Option C – Provide for Limited Further Development
- Planning Response Option D – Facilitate Further Development.

It is recommended that the results of this investigation be communicated with all stakeholders including landowners, residents and authorities, to gain their input into the preferred adaptation option. A rigorous risk assessment process could assist in identifying a preferred adaptation option.

The next phase of this investigation should include a detailed investigation into possible planning controls that could be implemented to the local planning scheme to assist Council and residents in preparing for the impacts of climate change.

10.0 Glossary

Accretion	The accumulation of (beach) sediment, deposited by natural fluid flow processes.
ACES	A computer program, developed by the US Army Corps of Engineers, that is used to determine extreme waves, wave run-up, wave transformation, littoral processes and coastal structural design.
Astronomical tide	The tidal levels and character which would result from gravitational effects, e.g. of the Earth, Sun and Moon, without any atmospheric influences.
Bar	An offshore ridge or mound of sand, gravel, or other unconsolidated material which is submerged (at least at high tide), especially at the mouth of a river or estuary, or lying parallel to, and a short distance from, the beach.
Bathymetry	The measurement of depths of water in oceans, seas and lakes; also the information derived from such measurements.
Beach profile	A cross-section taken perpendicular to a given beach contour; the profile may include the face of a dune or sea wall, extend over the backshore, across the foreshore, and seaward underwater into the nearshore zone.
Berm	A nearly horizontal plateau on the beach face or backshore.
Breaker zone	The zone within which waves approaching the coastline commence breaking, typically in water depths of around 2 m to 3 m in fair weather and around 5 m to 10 m during storms
Breaking depth	The still-water depth at the point where the wave breaks.
Coastal processes	Collective term covering the action of natural forces on the shoreline, and the nearshore seabed.
Datum	Any position or element in relation to which others are determined, as datum point, datum line, datum plane.
Deep water	In regard to waves, where depth is greater than one-half the wave length. Deep-water conditions are said to exist when the surf waves are not affected by conditions on the bottom, typically in water depths of around 60 m to 100 m.
Dunes	Accumulations of wind-blown sand on the backshore, usually in the form of small hills or ridges, stabilised by vegetation or control structures.
Dynamic equilibrium	Short term morphological changes that do not affect the morphology over a long period.
Elevation	The distance of a point above a specified surface of constant potential; the distance is measured along the direction of gravity between the point and the surface.
Erosion	On a beach, the carrying away of beach material by wave action, tidal currents or by deflation.
Geomorphology	That branch of physical geography that deals with the form of the Earth, the general configuration of its surface, the distribution of the land, water, etc.
High water (HW)	Maximum height reached by a rising tide. The height may be solely due to the periodic tidal forces or it may have superimposed upon it the effects of prevailing meteorological conditions. Nontechnically, also called the high tide.
Inshore	(1) The region where waves are transformed by interaction with the sea bed. (2) In beach terminology, the zone of variable width extending from the low water line through the breaker zone.
Littoral	(1) Of, or pertaining to, a shore, especially a seashore. (2) Living on, or occurring on, the shore.
Littoral drift	The material moved parallel to the shoreline in the nearshore zone by waves and currents.
Littoral transport	The movement of littoral drift in the littoral zone by waves and currents. Includes movement both parallel (long shore drift) and perpendicular (cross-shore transport) to the shore.
Longshore	Parallel and close to the coastline.
Longshore drift	Movement of sediments approximately parallel to the coastline.
Low water (LW)	The minimum height reached by each falling tide, also called low tide.
Mean high water (MHW)	The average elevation of all high waters recorded at a particular point or station over a considerable period of time, usually 19 years. All high water heights are included in the average where the type of tide is either semidiurnal or mixed. Only the higher high water heights are included in the average where the type of tide is diurnal.

Mean high water springs (MHWS)	The average height of the high water occurring at the time of spring tides.
Mean low water (MLW)	The average height of the low waters over a 19-year period. For shorter periods of observation, corrections are applied to eliminate known variations and reduce the result to the equivalent of a mean 19-year value.
Mean low water springs (MLWS)	The average height of the low waters occurring at the time of the spring tides.
Mean sea-level	The average height of the surface of the sea for all stages of the tide over a 19-year period, usually determined from hourly height readings.
Morphology	The form of a river/estuary/lake/seabed and its change with time.
Nearshore	In beach terminology, an indefinite zone extending seaward from the shoreline well beyond the breaker zone.
Refraction	The process by which the direction of a wave moving in shallow water at an angle to the bottom contours is changed. The part of the wave moving shoreward in shallower water travels more slowly than that portion in deeper water, causing the wave to turn or bend to become parallel to the contours.
Rip current	A strong current flowing seaward from the shore. It is the return of water piled up against the shore as a result of incoming waves. A rip current consists of three parts: the feeder current flowing parallel to the shore inside the breakers; the neck, where the feeder currents converge and flow through the breakers in a narrow band or "rip"; and the head, where the current widens and slackens outside the breaker line.
Runup	The rush of water up a structure or beach on the breaking of a wave. The amount of run-up is the vertical height above still water level that the rush of water reaches. It includes wave setup.
SBEACH	A computer program, developed by the US Army Corps of Engineers, that is used to determine, among other things, wave transformation across the surf zone, beach and dune erosion and levels of wave runup on natural beaches.
Setup	Wave setup is the elevation of the nearshore still water level resulting from breaking waves and may be perceived as the conversion of the wave's kinetic energy to potential energy.
Shoal	(1) (noun) A detached area of any material except rock or coral. The depths over it are a danger to surface navigation. (2) (verb) To become shallow gradually.
Shoreface	The narrow zone seaward from the low tide shoreline permanently covered by water, over which the beach sands and GRAVELS actively oscillate with changing wave conditions.
Shoreline	The intersection of a specified plane of water with the shore.
Significant wave height	Average height of the highest one-third of the waves for a stated interval of time.
Spring tide	A tide that occurs at or near the time of new or full moon, and which rises highest and falls lowest from the mean sea-level (MSL).
Storm surge	A rise or piling-up of water against shore, produced by strong winds blowing onshore. A storm surge is most severe when it occurs in conjunction with a high tide.
Sub-aerial beach	That part of the beach which is uncovered by water (e.g. at low tide sometimes referred to as drying beach).
Surf zone	The nearshore zone along which the waves become breakers as they approach the shore.
Swell	Waves that have traveled a long distance from their generating area and have been sorted out by travel into long waves of the same approximate period.
Tide	The periodic rising and falling of the water that results from gravitational attraction of the moon and sun acting upon the rotating earth. Although the accompanying horizontal movement of the water resulting from the same cause is also sometimes called the tide, it is preferable to designate the latter as tidal current, reserving the name tide for the vertical movement.

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