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Bega Valley Shire Coastal Processes and Hazards Definition Study

Volume 1: Final Report

Bega Valley Shire Council

Bega Valley Shire Coastal Processes and Hazards Definition Study – Volume 1: Final Report

Prepared for:	Bega Valley Shire Council
Prepared by:	BMT WBM Pty Ltd (Member of the BMT group of companies)

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Synopsis: The Bega Valley Shire Coastal Processes and Hazards Definition Study Report provides a summary of the regional and local coastal processes affecting the Bega Shire coastline and presents the methodology and outcomes of investigations undertaken to assess coastal hazard extents (coastal erosion, recession and inundation) within the Bega Valley Shire study area. Erosion/recession hazards have been defined for three timeframes (immediate, 2050 and 2100) using a risk-based approach providing for variability and uncertainty.

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Executive Summary

The Bega Valley Shire Local Government Area (LGA) is located on the far south coast of NSW, extending from Wallaga Lake in the north to the Victorian border in the south. Its coastline comprises a wide variety of sandy beaches between rocky headlands, nearshore reefs and estuaries. A significant proportion of the Shire's coastline is located within National Parks. Development is focussed around the major urban settlements of Bermagui, Tathra, Tura Beach, Merimbula, Pambula Beach and Eden.

This Bega Valley Shire Coastal Processes and Hazards Definition Study report provides a regional assessment of the coastal hazards impacting on the Bega Valley Shire coastline. It outlines the key coastal processes and interactions operating on the coastline and presents the projected extent of the coastal hazards arising from these processes.

Coastal Processes

Coastal processes (natural and human influenced) are the principle source of hazard in the coastal zone, and such hazards can generate significant risks to our use and development of coastal land and assets. The geologic framework of the coastline, waves and water levels interact to shape the morphology of beaches over various timescales, from days to many years. Coastal processes and their interactions that are outlined in this study include:

- **Regional Context** of geomorphology and coastline processes affecting the Bega Valley Shire shoreline, which includes the regional geology and the long term evolution and regional spatial behaviour of the coastal system within which the beaches are located;
- **Waves and Storms**, and variability in the wave climate from large scale climatological patterns such as El Nino- La Nina over seasonal, inter-annual and decadal time scales;
- **Elevated Water Levels**, which includes tides, storm surge, wave set up and wave run-up;
- **Longshore and Cross-Shore Sediment Transport** driven by waves, wind and currents;
- **Coastal Entrance Dynamics** and fluctuations of the adjacent shorelines; and
- **Projected Sea Level Rise and Climate Change Impacts** and their interaction and impacts upon all of the coastal processes described above.

The geological context and the wave and water level regime affecting the Bega Valley Shire coastal system are described in Chapter 2. The regional wave climate is a dominant component of coastal processes. The deep water wave climate of the NSW south coast comprises a highly variable wind wave climate superimposed on a persistent long period, low to moderate energy swell predominantly from the southeast to south-southeast directions. Two dominant types of storm wave generation, east coast lows and mid-latitude cyclones, determine the prevailing extreme wave climate. Design storm tide (tide plus surge) water levels applicable in the region are given in Table 2-6.

Annual and medium term variability in the wave climate is observed in the regional wave climate. Research has found a reasonable correlation between the Australian east coast wave climate and the El Nino Southern Oscillation (ENSO). Generally, there is an increase in the occurrence of tropical cyclones and east coast low cyclones, with a shift to a more easterly mean wave direction during the La Nina phase, while the

El Nino phase is associated with more southerly waves. Substantial natural variability in the wave climate is observed to occur over longer periods (years and decades). Variability in wave height and direction that persists for years to decades may result in alternate cycles of erosion and accretion and potential rotation of the shoreline due to variability in the alongshore sediment movement and the direction of intense storm waves. The data suggests an extended La Nina dominated phase prior to 1977 followed by predominantly El Nino phase through to about 2009.

Previous research has related the clockwise rotation that many of the embayed beaches along the southern and central NSW coastline have experienced to this shift from a prolonged La Nina dominated phase to a prolonged El Nino dominated phase.

Sand is transported along the Bega Valley beaches by the combined action of waves, currents and wind, with wave being the dominate factor at most locations.

During storms, increased wave heights and elevated water levels cause sand to be eroded from the upper beach/dune system (often termed 'storm bite') and transported in an offshore direction, typically forming one or more shore-parallel sand bars in the nearshore zone. During calmer weather, sand slowly moves onshore from the nearshore bars to the beach forming a wave-built berm and, subsequently, a wind-formed incipient foredune.

Typically, the cross-shore exchange of sand from the upper beach/dune area to the nearshore profile does not represent a net loss or gain of sand from the overall active beach system. While it may take several years, the sand eroded in the short-term during severe storms is returned to the beach and dune by the persistent action of swell waves and wind such that there is overall balance.

In addition, the longshore transport into and out of most beach compartments is controlled by the substantial cliffs and headlands, which allow no or very little sediment transport around the headland protrusions under present conditions.

Coastal Hazards

Coastal hazards arise where coastal processes interact with our use and development of coastal land and assets, or where human development has impeded natural coastal processes. The major coastal hazards of note defined in this report include:

- **Beach erosion**, relating to periods of intense storminess over seasons to years, and associated dune slope instability;
- Shoreline variability related to **short to medium term variations in wave climate**;
- **Long term recession**, relating to any prevailing trends of ongoing sediment deficits and potential sea level rise in the future;
- **Coastal inundation** associated with during high tides combined with storms, wave run-up and sea level rise that may overtop coastal barriers and inundate low lying land adjacent to the lower estuaries or coastal lagoons;
- **Coastal Entrance Instability** and effects on immediately adjacent shorelines; and
- **Sand drift.**

The definition of coastal hazards inherently involves uncertainty relating not only to coastal processes, but also to the uncertainties involved with climate change. There are uncertainties surrounding climate change projections, the timeframes over which this change may occur, as well as how climate change may affect the environment. Irrespective of climate change, coastal hazards have always presented a challenge to planners and managers. There is generally limited data on coastal processes (e.g. historical shoreline change, wave climate, water levels, etc.) and there are many different ways to assess the extent of hazards.

Recognising the, this study has adopted an approach whereby the coastal hazard extent is determined for three likelihood descriptors, ('Almost certain', 'Unlikely' and 'Rare'), as detailed in Section 3.1. Ascribing likelihood scales to the hazard estimates provides transparency regarding the uncertainties, limitations and assumptions used to assess hazards.

Assessment of Coastal Erosion Hazards

The beaches along the study region experience considerable short term (days; weeks; months; years) fluctuation and short to medium term (years) variability due to changes in the prevailing wave and water level conditions, including storm events and shifts in the predominant wave direction. Additionally, there may be a general regional trend of long term shoreline recession. The conceptual pattern of shoreline variability and progressive long term change is illustrated in Figure 3-2.

The 'immediate' erosion hazard extent represents the zone that could be affected by erosion in the immediate near future (e.g. over the next few years), while the 2050 and 2100 extents incorporate a landward shift in the immediate hazard line in response to shoreline recession provisions.

The erosion hazard extent is thus assessed by taking account of the combined factors of:

- Storm bite extent;
- Natural short to medium term variability of the shoreline; and
- Projection to the future, with hazard definition at years 2050 and 2100, of:
    - Any presently prevailing long term of shoreline recession; and
    - Shoreline recession caused by the effects of projected future climate change induced sea level rise.

Identification of prevailing long term trends may be difficult where variability is significant, if not dominant. For example, the shorelines immediately north of controlling headlands appear to show erosion-accretion variations in direct response to wave climate variability and associated gradients in the alongshore sand transport. The north-south aligned shorelines along the more exposed parts of the coast do not show such variability as they do not experience strong alongshore transport gradients with changing wave conditions.

The erosion hazards are thus determined and presented in terms of:

The immediate erosion hazard which includes provision for the storm bite demand volumes and provision for the effects of wave climate variability over the next few years, determined on the basis of analysis of available photogrammetry data.

The future erosion hazards for which the immediate erosion hazard extent is projected to 2050 and 2100 respectively by incorporating the effects of any underlying recession trends and sea level rise, with provision for uncertainties about those processes leading to hazard extent ranges from 'Almost certain' through 'Unlikely' to 'Rare' (See Section 3.3.8 for further details).

Storm Bite and Beach Rotation

Analysis of the photogrammetric data indicates a maximum historical storm bite demand in the range 200-250 m^3/m of beach sediment above AHD for the fully exposed ocean beaches and approximately 120-150 m^3/m for more protected embayments. In addition the photogrammetric analysis has identified that all embayments with photogrammetric coverage, with the exception of Aslings Beach, have seen a significant clockwise rotation in the regional shoreline alignment since the late 1970s (Refer to Table 3-5).

Prevailing Shoreline Recession Trends

The photogrammetric data is inconclusive with respect to identification of a clear regional long term trend of shoreline change. While the data for Tathra Beach and Merimbula/Pambula Beach suggests that those beaches may be subject to some ongoing erosion, the data of the other beaches do not show such a trend. For the present assessment, the underlying regional long term recession rates have been based on the assessed volumetric recession rate at Tathra Beach and Merimbula/Pambula Beach which indicate a nominal 'best estimate' shoreline recession rate of 0.1m/yr.

Shoreline Recession due to Sea Level Rise

It is generally accepted that with rising sea level there is an upward and landward translation of the beach profile. Figure 3-17 shows how shoreline recession is related to sea level rise in this equilibrium profile concept. This concept forms the basis of the "Bruun Rule" (Bruun 1962), which in conjunction with EVOMOD shoreline evolution modelling has formed the basis for establishing shoreline recession provisions for the 2050 and 2100 erosion hazard extents.

Another less-frequently examined influence of sea level rise on beach sediment budget is due to the infilling of coastal entrances. As sea levels rise, estuaries and lagoons will attempt to maintain a characteristic entrance geometry by raising their bed elevation in tandem, and hence potentially act as a major sink of sand, which is often derived from the adjacent beach systems. The potential effects of entrance infilling on future shoreline recession along the coastline have also been assessed through EVOMOD shoreline modelling. The modelling has identified that some parts of the Bega Valley coastline could experience significant shoreline recession due to the response of coastal entrances to rising sea levels, particularly Pambula/Merimbula Beach and Tathra Beach.

Mapping of the erosion hazard extents at the immediate, 2050 and 2100 planning horizons are presented in Annex A to C of the Figure Compendium.

Assessment of Coastal Inundation Hazards

Coastal inundation is the flooding of coastal lands by ocean waters. The main impact of the coastal inundation hazard relates to the temporary submergence of low-lying areas near and behind coastal barriers, coastal entrances and broader estuarine foreshores by elevated ocean water levels.

Coastal Inundation along Ocean Beaches and Cliffs

Assessment of the dunes height along the Bega Valley Shire beaches has identified that direct oceanic inundation of hind dune areas as a result of elevated water levels is unlikely. However, where the crest height of a cliff, shoreline structure or dune is less than the wave run-up level, waves will overtop the shoreline and may cause inundation of the land behind. Consequently, this may present a hazard if the rate of overtopping can cause a significant impact to people or assets behind it.

The susceptibility of the Bega Valley Shire coastline to hazards associated with wave overtopping have been assessed by calculating design wave run-up levels relative to existing sea level using the findings of Nielsen and Hanslow (1991) for run-up at natural beaches and the Eurotop (2007) method for headlands and coastal structures. Mapping of the susceptibility of the study area to wave overtopping hazard is provided in Annex G of the Figure Compendium.

Coastal Inundation in Lower Estuaries

During storm tide events, elevated ocean levels will propagate into lower estuary areas, with potential inundation of the adjacent land. Components of elevated ocean levels that may affect estuaries in this way may include:

- The storm tide (tide plus surge); and
- Wave set-up.

While it is generally recognised that wave set-up does not significantly propagate through fully trained entrances with deep water channels, there is uncertainty about the degree of wave set-up that penetrates untrained entrances with shallow bars, especially where wave breaking extends across the estuary mouth. It is understood that any such set-up would be less than that on the adjacent beaches, however the extent to which it needs to be provided for is not able to be defined reliably.

For the purpose of assessing the coastal inundation hazard within the untrained lower estuary areas of Bega Valley Shire, a limited wave set-up component of the total wave setup, calculated for natural beaches using Hanslow and Nielsen (1993), has been adopted, as discussed in Section 3.4.4.

A series of maps, depicting the modelled extent of the corresponding coastal inundation at the major estuaries and lagoons within the study area for the immediate, 2050 and 2100 planning timeframes are provided in Annex D to F of the Figure Compendium.

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1 Introduction

1.1 Background

The Bega Valley Shire Local Government Area (LGA) is located on the far south coast of NSW. Its coastline extends from Wallaga Lake in the north to the Victorian border in the south and comprises sandy beaches between rocky headlands, nearshore reefs and estuaries. A significant proportion of the Shire's coastline is located within National Parks. Development is focussed around the major urban settlements of Bermagui, Tathra, Tura Beach, Merimbula, Pambula Beach and Eden.

Coastal processes have in the past impacted built and natural assets along the coast and reduced the recreational amenity of the beaches. Like many other parts of the NSW coast, the Bega Valley Shire's coastline experienced significant erosion during the 1970's, impacting various coastal assets, including roads, surf clubs, caravan parks, private property and foreshore recreational areas.

Bega Valley Shire Council (Council) has recognised the importance of the coastal zone to the natural, cultural and socio-economic welfare of its community and has embarked on a process of developing a Coastal Zone Management Plan (CZMP) for the Shire. The Bega Valley Shire Coastal Processes and Hazards Definition Study is a key preceding step in the development of the CZMP.

This report documents the outcomes of the Bega Valley Shire Coastal Processes and Hazards Definition Study. It describes the coastal processes and interactions operating on the coastline of the Bega Valley Shire LGA (the Bega Valley coastline) and the extent of the coastal hazards arising from these processes (focussing on the major towns within the Shire). The report is prepared in accordance with the Guidelines for Preparing Coastal Zone Management Plans (OEH, 2013).

The Bega Valley Shire Coastal Processes and Hazards Definition Study is set out as follows:

Section 2 provides a summary of the geologic framework as well as the key coastal processes operating in the study area;

Section 3 details the methodology used to assess each coastal hazard and the approach to defining and mapping associated hazard probabilities (the likelihood of a hazard extent) at the immediate, 2050 and 2100 planning timeframes; and

Section 4 discusses the outcomes of the coastal hazard assessment for each beach compartment.

A **Figure Compendium** provides a suite of hazard maps for the combined beach erosion and shoreline recession hazards and coastal inundation hazards along the coastline at the immediate, 2050 and 2100 planning periods.

1.2 Study Area

The study area for this Coastal Processes and Hazards Definition Study includes the following key locations:

- Bermagui Coast, including the ocean beaches around Wallaga Lake and Bermagui River;
- Cuttagee / Murrah, including Baragoot Beach and Cuttagee Beach;
- Tathra, including the ocean beaches around the Bega River estuary;
- Merimbula Coast, including Merimbula/Pambula Beach and Tura Beach;
- Twofold Bay, including the ocean beaches around Lake Curalo, Nullica River, Towamba River and Fisheries Creek; and
- Wonboyn, including Disaster Bay Beach and Wonboyn Lake.

Photographs of key locations are included in Appendix C.

The width of the study area includes marine areas extending from offshore to the land and includes beaches, dunes, headlands and coastal entrances, extending inland as far as applicable to determining coastal processes and hazards extents.

The full extent of the study area is shown in Figure 1-1 to Figure 1-6.

1.3 The Coastal Zone Management Process in NSW

Coastal management in New South Wales is directed by the NSW *Coastal Protection Act 1979* (including 2002, 2010 and 2012 amendments), with further guidance from *NSW Coastal Policy* (1997), *State Environment Planning Policy No. 71 – Coastal Protection*, and the *Environmental Planning and Assessment Act 1979* (including 2010 amendments). Other guidance for land use planning in the coastal zone is given by the *NSW Coastal Planning Guideline: Adapting to Sea Level Rise* (DP, 2010) and the *Coastal Design Guidelines for NSW* (2003).

Requirements for the preparation of coastal zone management plans are outlined within the *Guidelines for Preparing Coastal Zone Management Plans* (OEH, 2013) (CZMP Guidelines), which replace the former Coastline Management Manual (NSW Government, 1990).

Compared to former Coastline Management Manual, a key change in the CZMP Guidelines (and supported by other NSW guideline documents) is the direction to adopt a risk-based approach to coastal management. A risk-based approach incorporates the uncertainty in hazards definition and provides for prioritisation of management resources towards the greatest risks in the coastal zone.

The typical process followed in preparing Coastal Zone Management Plans is given below. This study forms Step 2 of the process, being the preparation of a Coastal Processes and Hazards Definition Study for the Bega Valley Shire LGA. It should be noted that not all steps are a requirements and some steps can be combined. Also the Minister for Environment has recently announced that certification of CZMPs in accordance with the Coastal Protection Act 1979 will be reactivated.

(1) Establish a Coastal Management Committee;

(2) **Conduct a Coastal Processes and Hazards Definition Study to specifically identify and quantify hazards affecting the coastal area**;

(3) Prepare a Coastal Zone Management Study to consider all feasible management options whilst also assessing the social, economic, aesthetic, recreational and ecological issues associated with land use of the area;

(4) Prepare a Coastal Zone Management Plan consisting of the best combination of options for reducing the risks from coastal hazards, including the preparation of a strategy to implement the Plan and review the Plan through public exhibition and consultation;

(5) Council to adopt the Plan (noting that approval of CZMPs by the Minister for the Environment is required in accordance with Part 4A of the *Coastal Protection Act 1979*);

(6) Implement the approved Coastal Zone Management Plan; and

(7) Review the Coastal Zone Management Plan on a regular basis (5-10 years), to enable continued update and review of coastal risks and management measures (e.g. such as incorporating the latest sea level rise projections).

1.4 Study Objectives

The key objective of this study is to provide definition of likely hazards and associated impacts relating to coastal processes, which shall inform the preparation of a Coastal Zone Management Plan for the Bega Valley coastline. The Coastal Zone Management Plan shall provide appropriate guidance on managing existing and future risks from coastal hazards. Therefore, this Coastal Processes and Hazards Definition Study provides the technical information on hazard likelihood from which management actions can be formed, within a risk-based approach.

Specific objectives of the Bega Valley Shire Coastal Processes and Hazards Definition Study include:

- **To describe the coastal processes and interactions acting along Bega Valley's coastline**, which shall include description and mapping of beaches, dunes and headlands, the geology and geomorphology of the coastline, including the location of coastal protection and other man-made structures, and interactions between coastal entrances and open beaches; and
- **Identify, assess and map the potential extent of coastal hazards for the current year, 2050 and 2100 timeframes**, focusing on the coastal zones within the Bermagui, Cuttagee / Murrah, Tathra, Merimbula, Eden and Wonboyn study areas.

1.5 Historical Data and Reports

As part of this study, a review of relevant background information on coastal behaviour was undertaken, particularly with respect to previous assessments of coastal hazards at the beaches within the study area.

Information that was sourced and analysed for the purposes of this study includes:

- Previous technical reports and papers (as listed below and referenced throughout the report);
- Photogrammetry data, provided by the Office of Environment and Heritage (OEH) and generally covering the period between 1944 and 2011 for the following shoreline sections: Aslings Beach,

Horseshoe Bay, Cuttagee Beach, Moorhead Beach, Pambula/Merimbula Beach and Tathra Beach;

- Hydrographic surveys conducted by former Department of Infrastructure, Planning and Natural Resources, Crown Lands Division and former Department of Public Works, covering areas of Merimbula Bay, Twofold Bay, Tathra and the Bermagui River entrance area;
- Historical photographs;
- Wave time series data obtained from the Eden, Batemans Bay and Sydney Waverider buoys (provided by MHL);
- Water level time series obtained for the Bermagui and Eden water level stations (provided by MHL);
- Aerial Laser Survey topography data (provided by Council);
- Geology and resource mapping included in the NSW Comprehensive Coastal Assessment Toolkit (Troesdon et al., 2004); and
- Physical characterisation data contained within the databases of the National Land and Water Resources Audit (2001) and the Australian Estuarine Database (1998), as published on Ozcoasts.

Site inspections and discussions with various stakeholders familiar with the behaviour of the beaches were also conducted for this study.

1.5.1 Previous Reports

Coastal processes and coastal hazards have previously been investigated for some beaches in the study area. Previous reports include:

- Horseshoe Beach Coastline Hazard Advice (Department of Land and Water Conservation, 2000)

  This report describes an assessment of the coastline hazards at Horseshoe Bay Beach, Bermagui for a number of planning periods to inform a proposed development of a clubhouse at the time.

- Pambula Beach 50-year Coastal Hazard Line (Patterson Britton, 2002)

  This report describes an assessment, undertaken by the Patterson Britton & Partners, to determine the landward extent of the 50-year coastline hazard line along the southern 1150m of Pambula/Merimbula Beach. The report was largely used to guide redevelopment of the Pambula Surf Life Savings Club.

- Tathra Erosion Study (PWD, 1980)

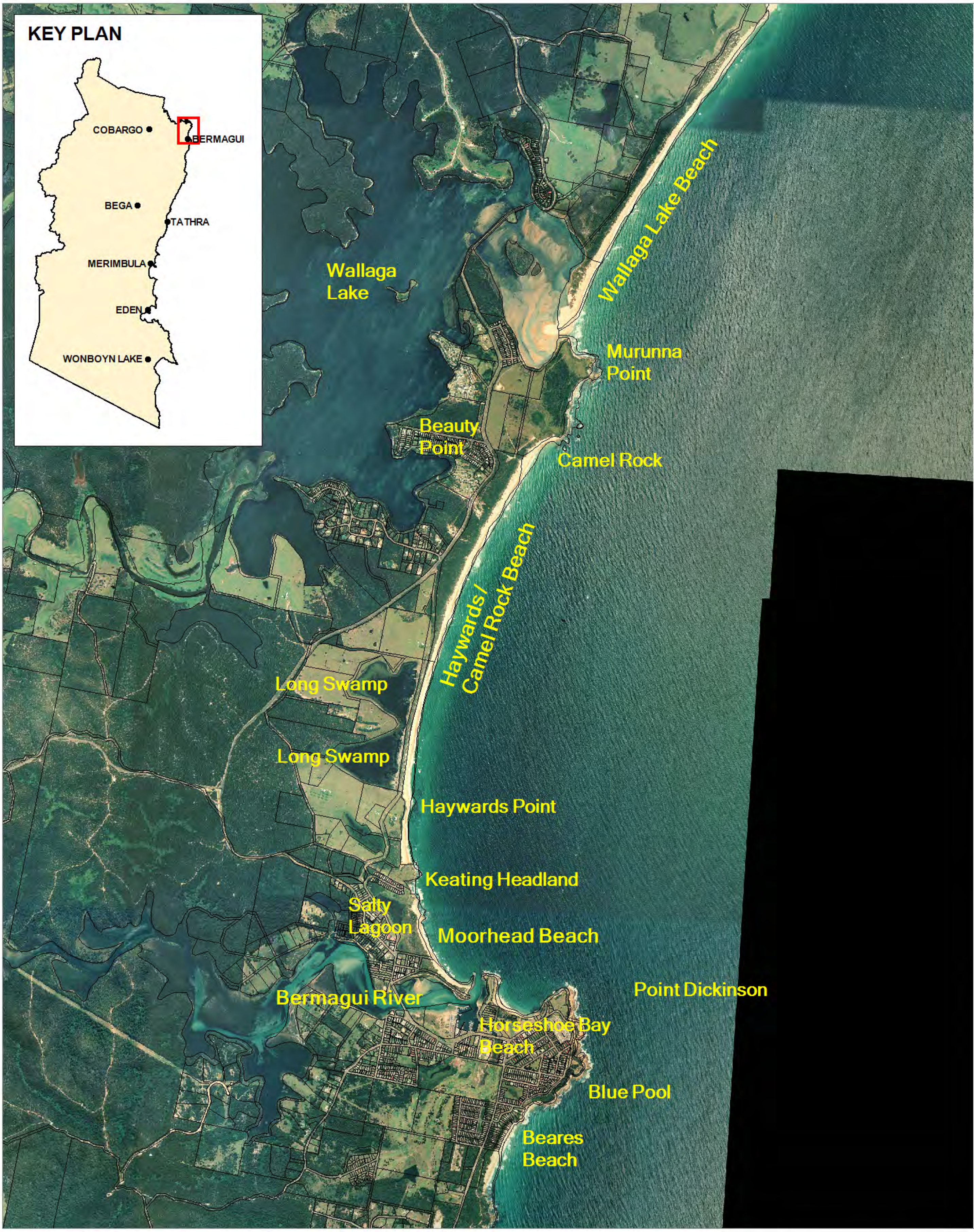
  This report summarises a comprehensive study undertaken by the NSW Department of Public Works and Department of Mineral Resources and Development to assess the coastal processes in the Tathra region. It describes sedimentological investigations, including inner and outer nearshore sediment characterisations, a detailed morphological examination, including bathymetrical survey, and an analysis of the sediment budget.

- Tathra Beach Coastal Hazard Study (Webb, McKeown and Associates, 2001)

  This report by Webb, McKeown and Associates describes an assessment of the coastline hazards at Tathra Beach for a number of planning periods.

- Seismic results from the inner continental shelf of the Twofold Bay/Disaster Bay region (Hudson and Ferland, 1987)

  The report describes the results and interpretation of seismic surveys and surface sediment analyses that were conducted over a 50km section of the inner continental shelf in the vicinity of Merimbula Bay, Twofold Bay and Disaster Bay.



Title:
Bermagui Coast

Figure: 1-1

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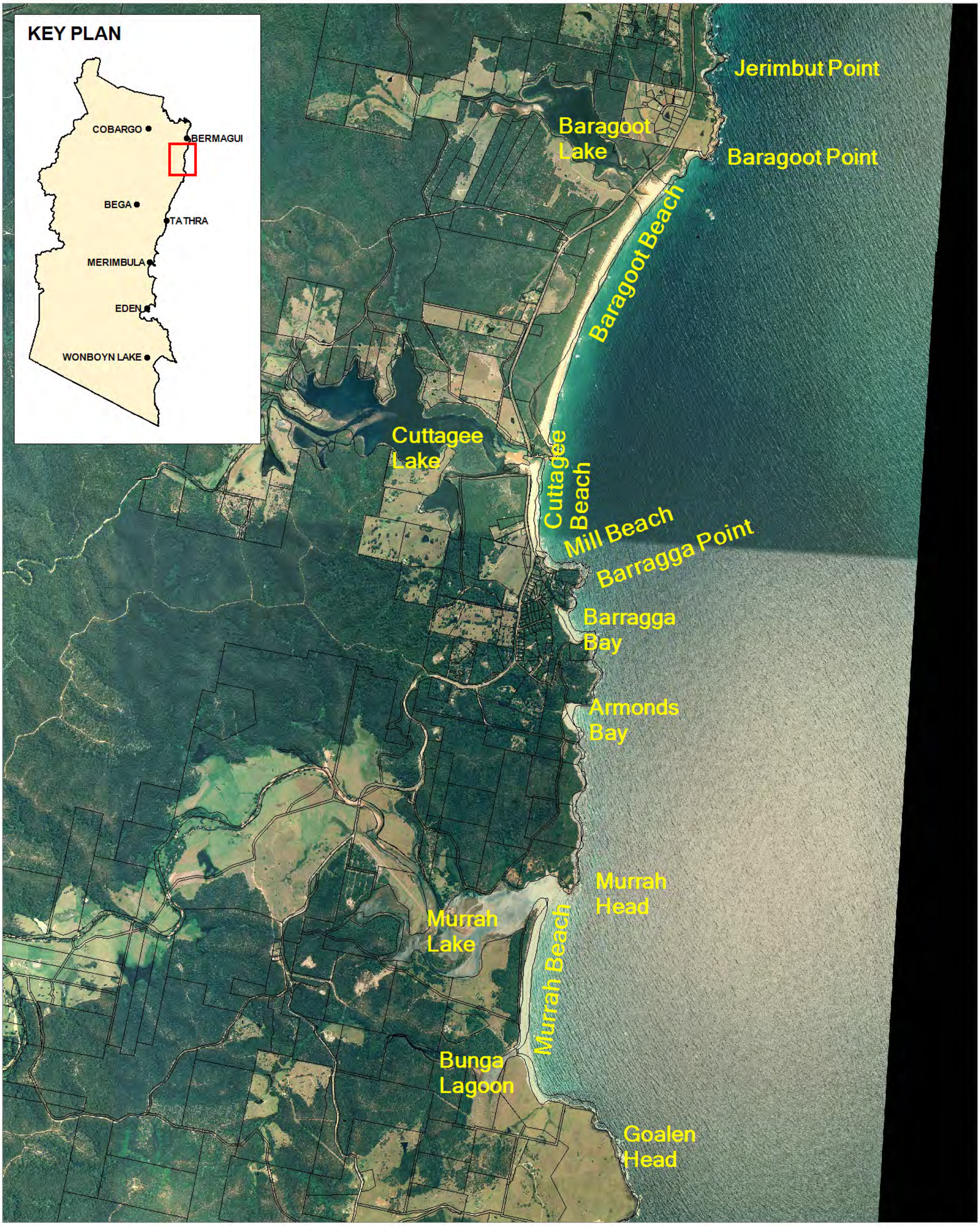

Title:
Cuttagee / Murrah Coast

Figure: **1-2**

Rev: **A**

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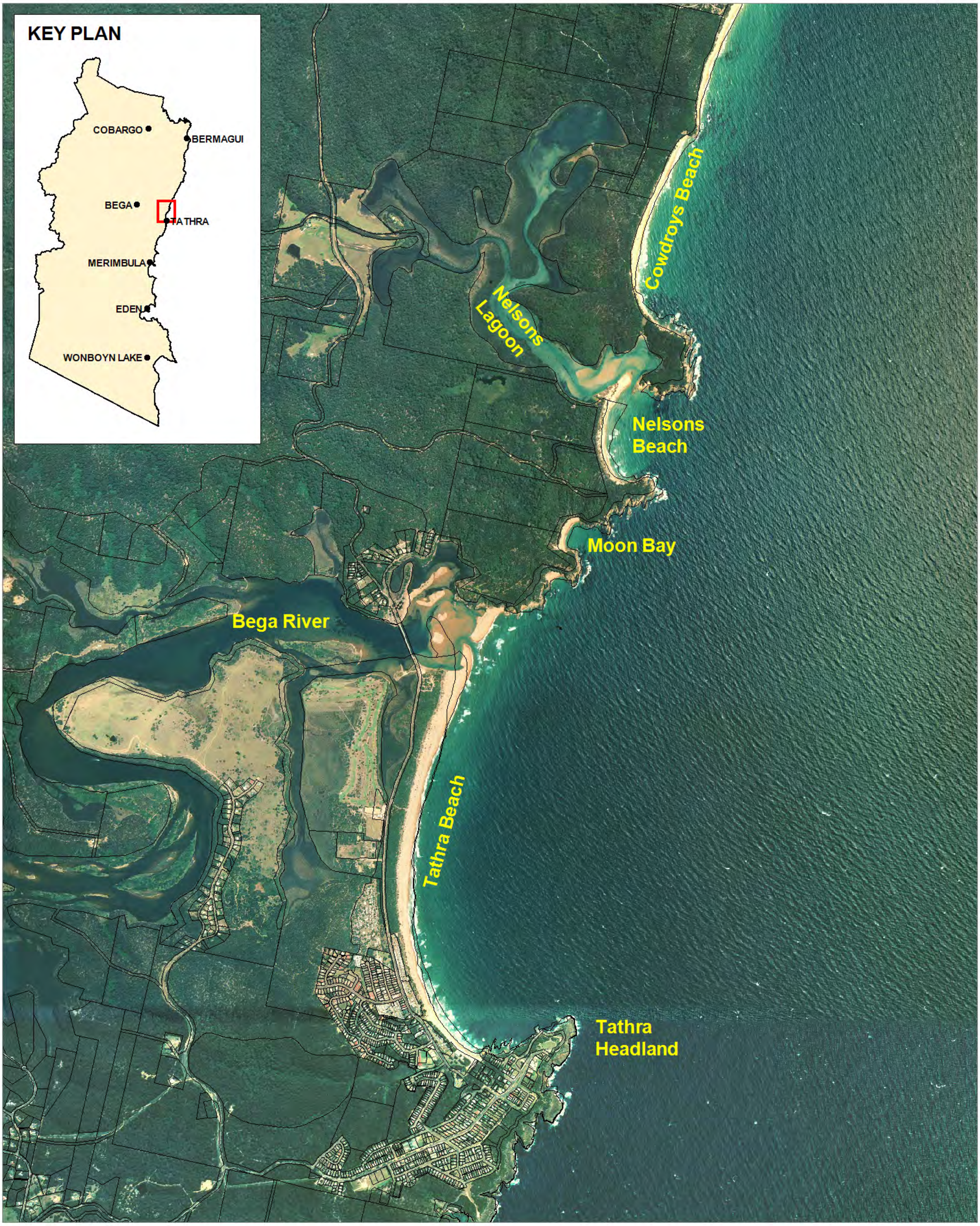

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Tathra

Figure: **1-3**

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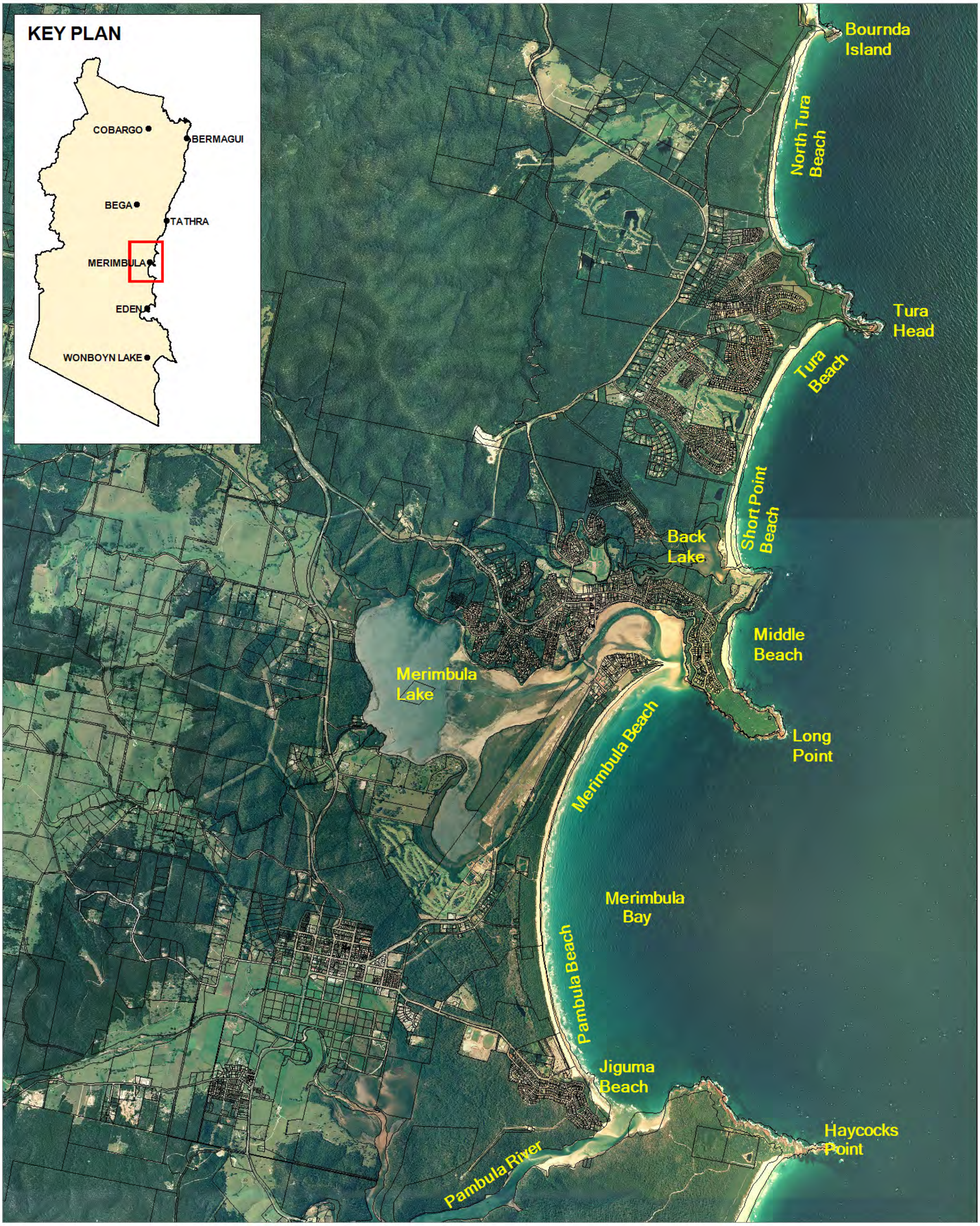

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Merimbula Coast

Figure: **1-4**

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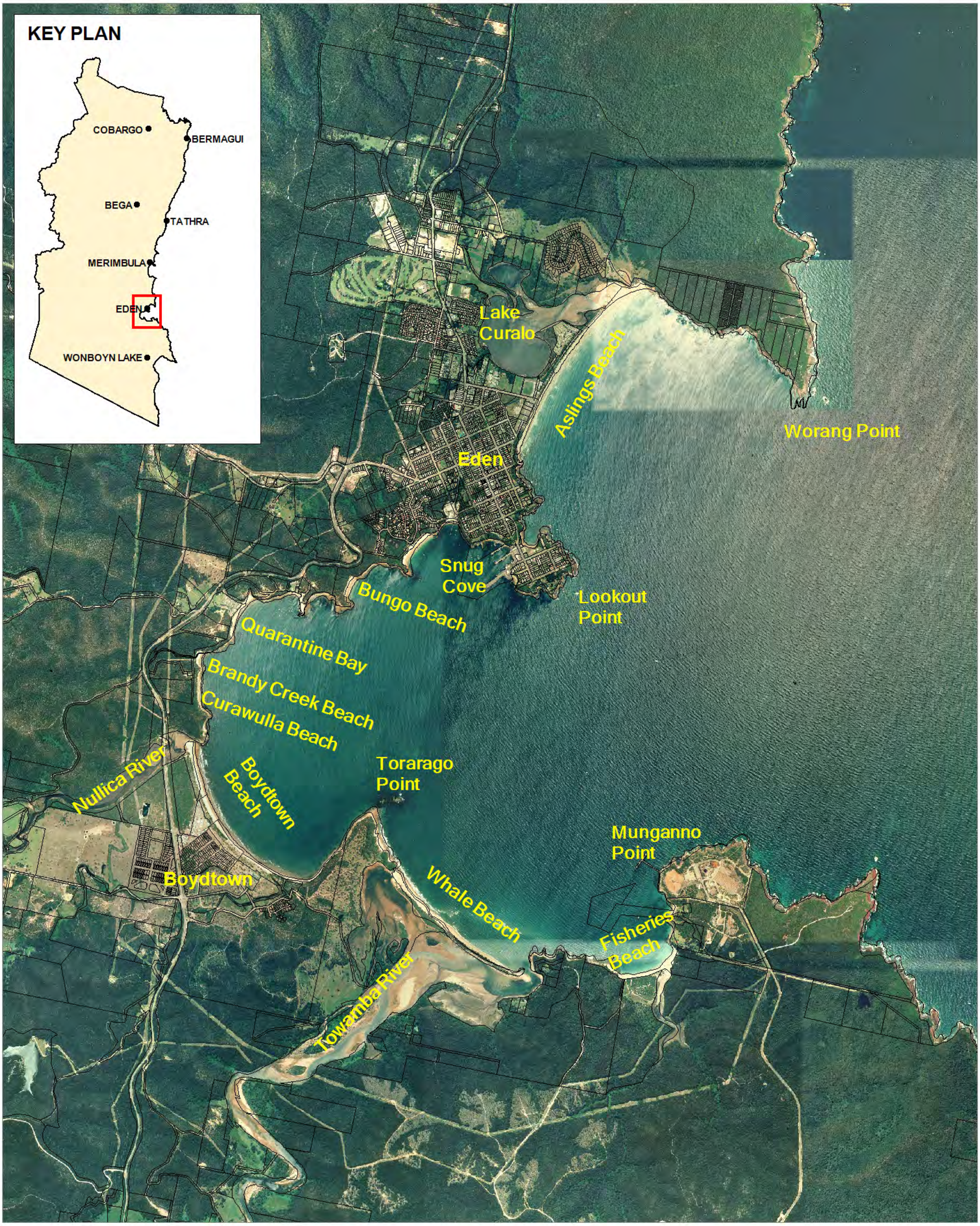

Title:
Twofold Bay

Figure: **1-5**

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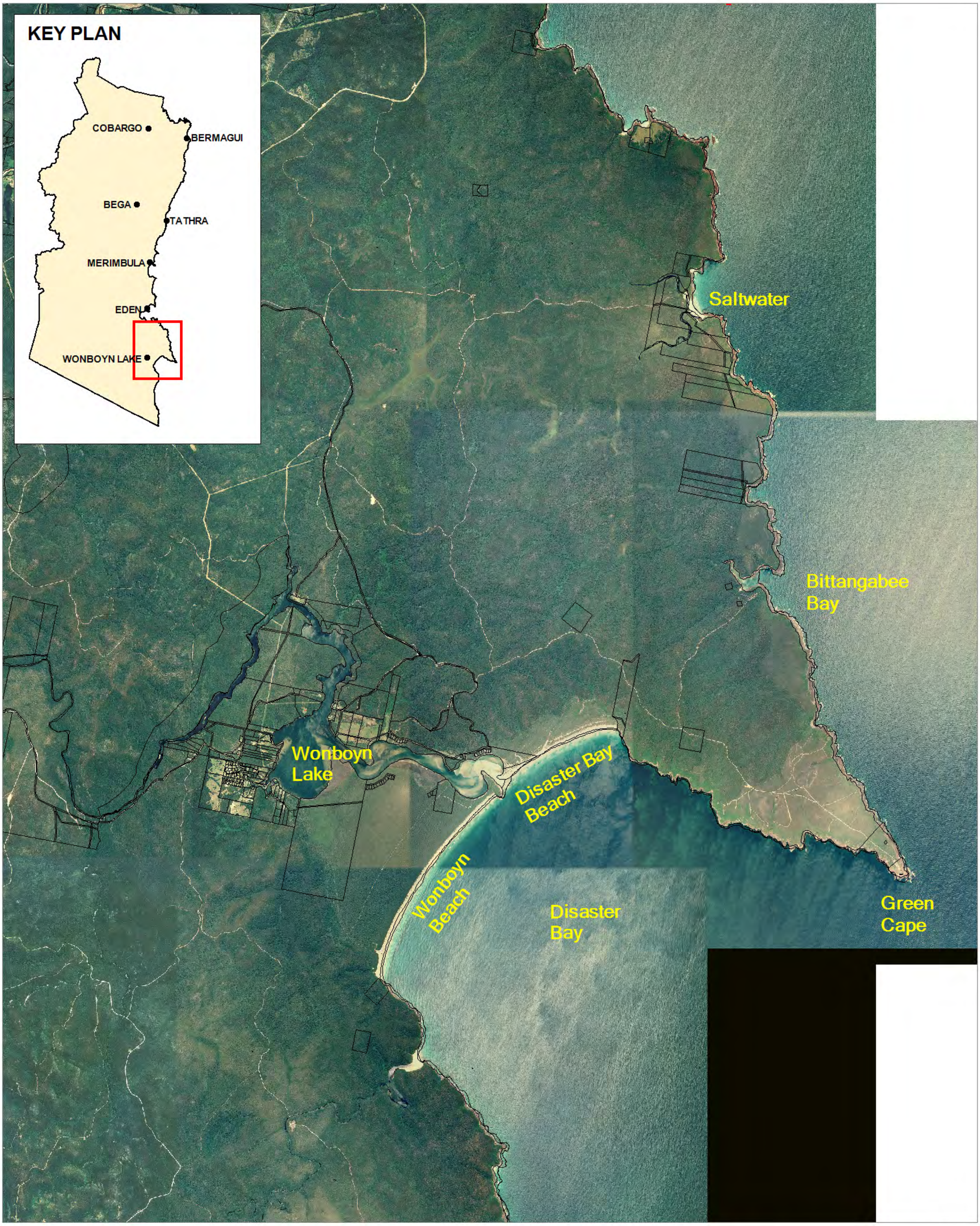

Title:
Wonboyn

Figure: **1-6**

Rev: **A**

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2 Summary of Coastal Processes

2.1 Introduction

Coastal processes (both natural and human influenced) are the principal source of risk in the coastal zone, as such processes can interact with, and detrimentally affect, coastal land, assets and values. Coastal processes essentially involve the movement of water (i.e. currents) and sediment (mostly sand) within and around the coastal zone. Sediment dynamics includes sand transport (1) within the mostly dry sandy beaches, (2) in the intertidal swash zone, and (3) in the deeper nearshore waters, and can be both alongshore transport (parallel to the shoreline) and cross-shore transport (perpendicular to the shoreline).

Coastal processes are influenced by:

- **Regional Context** of geomorphology and coastline processes affecting the Bega Valley Shire shoreline, which includes the regional geology and the long term evolution and regional spatial behaviour of the coastal system within which the beaches are located;
- **Waves and Storms**, and variability in the wave climate from large scale climatological patterns such as El Nino- La Nina over seasonal, inter-annual and decadal time scales;
- **Elevated Water Levels**, which includes tides, storm surge, wave set up and wave run-up;
- **Longshore and Cross-Shore Sediment Transport** driven by waves and currents;
- **Coastal Entrance Dynamics** and fluctuations of the adjacent shorelines; and
- **Projected Sea Level Rise and Climate Change Impacts** and their interaction and impacts upon all of the coastal processes described above.

Coastal hazards arise where coastal processes interact with our use and development of coastal land and assets, or where human development has impeded natural coastal processes. The major coastal hazards of note defined in this report include:

- **Beach erosion**, relating to periods of intense storminess over seasons to years, and associated dune slope instability;
- Shoreline variability related to **short to medium term variations in wave climate**, including beach rotation;
- **Long term recession**, relating to any prevailing trends of ongoing sediment deficits and potential sea level rise in the future;
- **Coastal inundation** associated with during high tides combined with storms, wave run-up and sea level rise that may overtop coastal barriers and inundate low lying land adjacent to the lower estuaries or coastal lagoons;
- **Coastal Entrance Instability** and effects on immediately adjacent shorelines; and
- **Sand drift**.

This chapter provides a description of the geologic framework and coastal processes that have interacted to shape the morphology of the Bega Valley regional coastline. All of the coastal processes are related to or interact with each other to some degree and such interactions are described as required.

2.2 Regional Geology and Geomorphology

The beach systems of the study region are the product of its geological history and the persistent influence of the prevailing waves, currents and winds on the unconsolidated sediments of the continental shelf and coastal zone over millennia during the late Quaternary period (last 400,000 years). The beaches and associated dunes, tidal inlets and nearshore active seabed areas have evolved over long timeframes, linked to:

- Changes in relative level between land and sea through cycles of climate change, associated with glacial and inter-glacial periods;
- Wind-generated waves and currents that transport unconsolidated sediments within coastal systems;
- Sources, supply and movement of sediments that form the beaches; and
- Progressive evolutionary changes of the shorelines, dune barriers and active seabed areas.

The sandy coastal barriers as seen today result from the morphological evolution of the continental shelf and coastline predominantly during the late Quaternary period covering two epochs, most notably:

- The late Pleistocene covering the last 120,000 years including the last major ice age (20,000 – 30,000 years Before Present [BP]); and
- The Holocene covering the past 10,000 years of the most recent warmer post-glacial period.

While there are various interpretations of sea level changes over that time, Figure 2-1 illustrates the general pattern of cyclic variation associated with the glacial and inter-glacial periods over the past 350,000 years (Chappell 1983; Roy 2001).

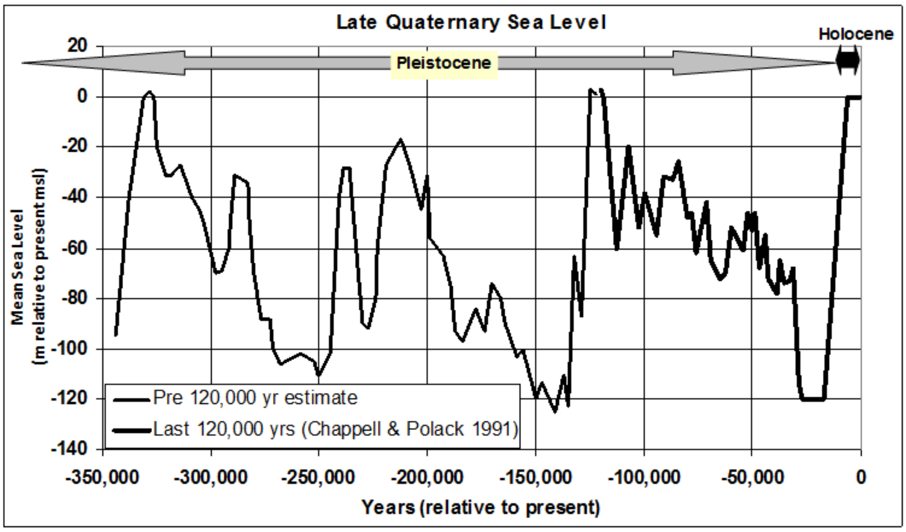


Figure 2-1 Late Quaternary Sea Level History

BMT WBM

Over the Pleistocene-Holocene geological timeframe of the past 120,000 years, the sea level fell by about 120 metres, associated with the last glacial period, and subsequently rose to its present level (Lambeck & Chappell 2001). The falling stage to about 20-30,000 years BP was gradual but not at a constant rate, with significant fluctuations superimposed on the downward trend. The post-glacial rising stage after 18,000 BP was relatively rapid (average about 10 mm/yr), reaching about 1-2m above present mean sea level at 6,000 to 7,000 years BP and subsequently falling to and remaining relatively stable at the present level since about 3-5,000 years BP (Chappell & Polach 1991; Sloss *et al* 2007). The more recent trend of sea level rise has been well documented, as illustrated in Figure 2-2 (Church and White 2006). There is clear evidence of contemporary climate change with global warming, most probably exacerbated by anthropogenic emissions of greenhouse gases, particularly carbon dioxide (IPCC, 2007b). Additionally, there is evidence of minor cyclic oscillations in the Pacific Ocean sea level, referred to as the so-called Inter-decadal Pacific Oscillation (IPO) (Goodwin 2005).

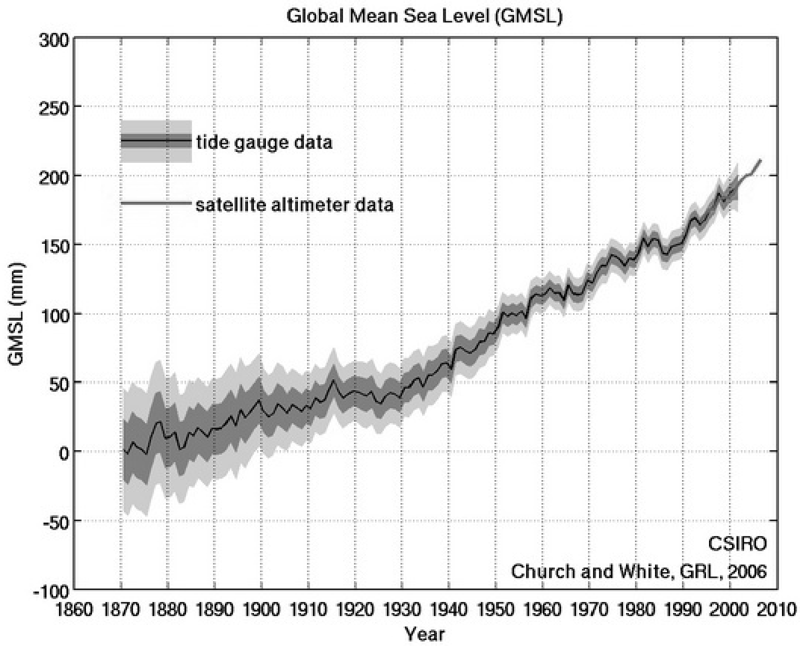


Figure 2-2 Global Sea Level since 1870 (from Church & White, 2006)

While past sea level changes have shaped the current coastal barriers and beach systems as we see them today, the present and projected future sea level rise will have further impacts on the coastline that need to be understood and taken into account in the management of coastal resources and developments.

2.2.1 The Continental Shelf

The continental shelf of NSW and adjacent Tasman Sea formed due to continental rifting and sea floor spreading that occurred between 80 and 60 million years ago (ma). Compared with other coastlines around the world, the south-east Australian continental shelf is very narrow, and this accounts for the high energy wave regime observed (Roy, 2001).

The continental shelf of NSW varies in width from around 20 km offshore of headlands to around 50 km offshore of embayments. The shelf is widest offshore between Sydney and Sugarloaf Point, Newcastle (up to 53 km), and Moreton to Fraser Island (75 km wide off Noosa). Typically, the shelf is steeper and narrower along southern NSW, becoming shallower and wider northwards from Sugarloaf Point. In general, the shelf is relatively steep in the inner shelf (< 60 m water depth), more gently sloping in the mid shelf (60-120 m water depth) and nearly flat on the outer shelf (>120 m water depth) out to the shelf break (Keene et al., 2008). The shelf break is marked by a well-defined change in slope (from an average of ~ 0.5°on the shelf to +5-10° on the slope zone), and occurs in around 140-150 m water depth south of ~ 33°S and 70 to 130 m north of this.

Coastal barriers along the present coastline increase in size towards the northern end of NSW and southern Queensland, due to the northward directed wave-driven sediment transport. Headlands and other topographic bedrock features that interrupt the transport of sand alongshore are fewer in northern NSW. As such, coastal embayments tend to be wider and more complex in the north NSW region (Roy, 2001).

In southern NSW (south of ~ 33°S), including along the Bega shoreline, the continental shelf is steeper and narrower, and topographic controls (headlands, reefs etc) are more prevalent, reducing the potential for longshore sediment transport past those features. In general this means there is less sediment in coastal barriers of the south coast, compared with those along the northern NSW coast.

Over the Quaternary (last 2 million years), there has been a long term transfer of available sediments from south to north along the NSW coast (particularly during periods of lower sea levels), leaving the southern NSW coast as a rocky, embayed coastline with limited sediment availability and beaches and coastal compartments that are mostly closed in terms of longshore sediment bypassing (Roy, 2001).

Based upon a review of the bathymetric data collated for the Bega region, the continental shelf break is located in around 120 to 140 m water depth. The width of the shelf varies across the region, from around 15 km wide off Bermagui (Beares Beach), to 33-35 km wide off the coast of Merimbula and Eden.

2.2.2 Sources of Beach Sand

Nearshore and inner shelf sediment in the Bega Valley region, extending to water depths up to 60 m, comprise predominantly fine to medium grained quartz sand. Sedimentological investigations available for the region, including Roy (2001), Hudson and Ferland (1987), PWD (1980) and Coastal & Marine Geosciences (1999), suggest that the sand that forms the beaches and dune systems within the Bega Valley region is essentially all mature marine sand derived from the continental shelf, rather than contemporaneously derived fluvial sand, with the exception of the beaches of Tathra Bay and parts of Twofold Bay.

Tathra Bay

The Bega River contributes locally to sediment supply into the Tathra region (PWD, 1980 and Coastal & Marine Geosciences, 1999) and, consequently, the beaches of Tathra Bay comprise a mixture of marine and fluvial sands.

At Tathra Beach, infrequent flood events likely deliver a mix of fluvial sands from upstream and marine sand from the entrance bar into the immediate nearshore zone, which is then reworked onshore during calm periods by waves. Following erosion events, sand on Tathra Beach tends to be coarser and appear more fluvial in origin, as the finer grained marine sands have been transported offshore into sand bars. During calm periods, finer grained sands are reworked onshore to the beach. Likewise, sand is generally much finer at the southern end of Tathra Beach, where it is more protected from the predominant swell and is further away from the Bega River sand source.

The fluvial influence diminishes to the north and south of Tathra Bay, with the beach sediments of Nelson Bay containing a minor portion of fluvial sand, and those of Cowdroys Beach being almost entirely of marine origin. The sediments on Tathra Beach comprise approximately equal amounts of fluvial and marine derived sands, except near the river mouth where fluvial sand is dominant.

Twofold Bay

Beach sediments within Twofold Bay contain fluvial inputs (mud, sands, with variable lithics) sourced from the Towamba and Nullica Rivers. The sediments vary from other beaches in the Bega region, due to their fluvial content. The sediment types also vary between the beaches of Twofold Bay with fine to medium, well sorted quartzose sands in the Aslings Beach compartment and moderately sorted, muddy fine sands south of Lookout Point (Hudson and Ferland 1987). These distinct differences reflect the different sources of sediment and suggest that there is little if any sediment interaction between Aslings Beach and the remainder of Twofold Bay.

2.2.3 Onshore Sand Supply

Conceptual models have been presented (Roy and Thom 1981; Cowell *et al* 2000; Roy 2001) for the shoreward migration of sand during and subsequent to the sea level rise and cross-shelf transgression (Figure 2-3) and equivalent behaviour for falling sea level (regression) (Figure 2-4). Both transgressive and regressive reworking led to net shoreward movement of the sand.

According to Roy (2001), as sea level rose quickly from around 120 m below present 20,000 years BP to about present sea level by 6,500 years BP, barriers moved landwards into available embayments by a process of retreat, or recession. Once sea level stabilised, depending upon the sediment availability in the nearshore zone and nearshore slope, a variety of coastal features were formed, such as the beaches and estuaries that we see today.

Initially, once sea level stabilised, the rate of onshore sediment supply to the coast was large, and shorelines prograded (or grew) seaward quickly as sediment was delivered onshore from the nearshore zone. The rate of onshore sediment supply then reduced to rates in the order of 1 to 4 m^3/year per linear metre of shoreline around 2,000 years BP (Roy, 2001). It has been suggested (Roy *et al* 1997; Cowell *et al* 2000; Roy 2001; Goodwin *et al* 2005) that there remains a small but relatively significant shoreward supply of up to about 4m^3/m/year, at least in some parts of the study area.

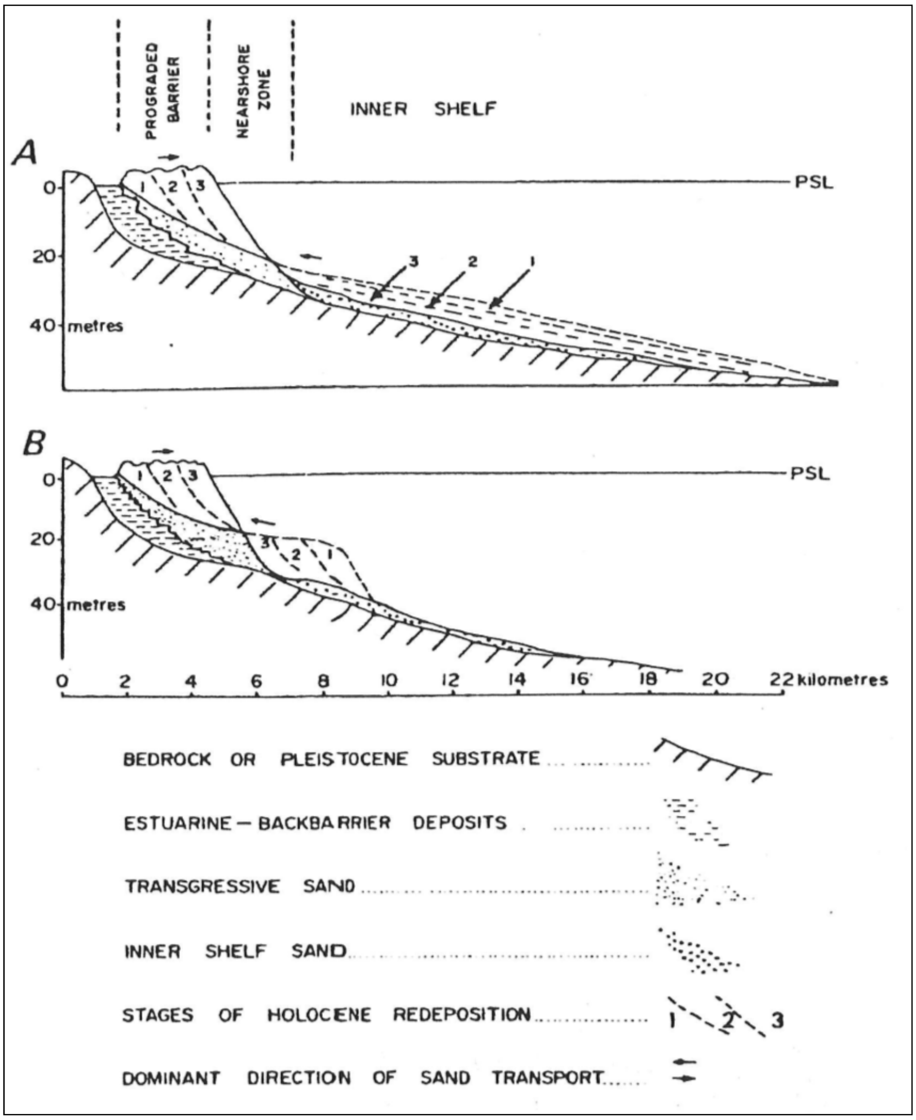


Figure 2-3 Conceptual dune barrier formation following sea level high-stand (Roy & Thom 1981)

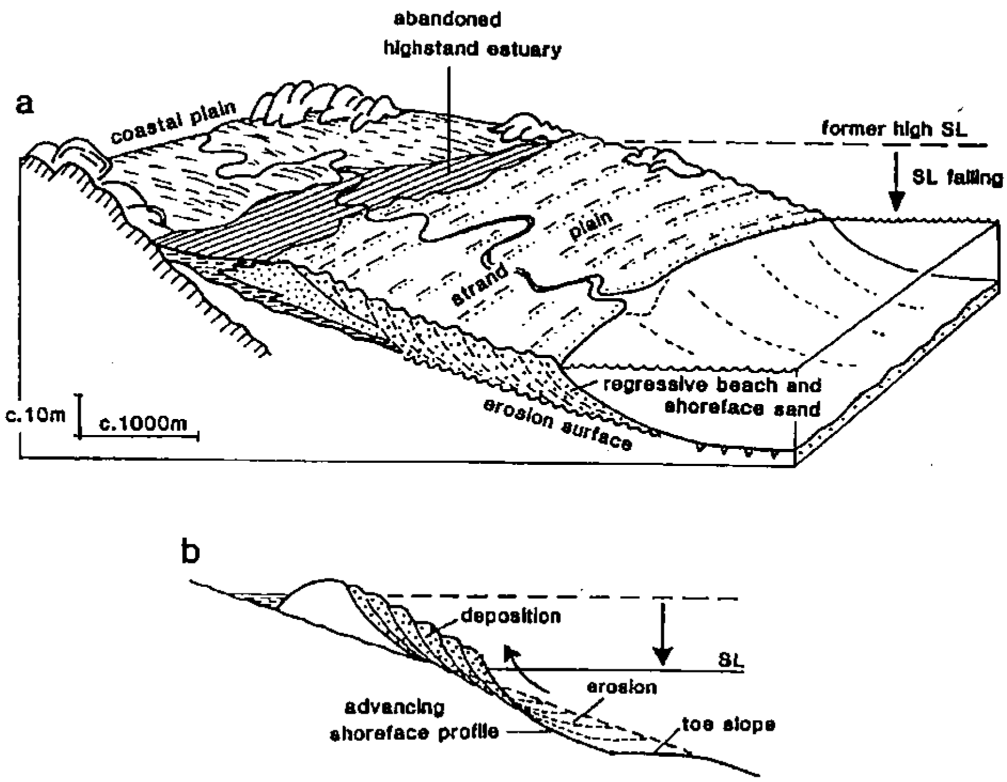


Figure 2-4 Falling sea level – regressive barrier formation (Roy 2001)

2.3 Regional Wave Climate

The deep water wave climate of the NSW south coast comprises a highly variable wind wave climate superimposed on a persistent long period, low to moderate energy swell predominantly from the southeast to south-southeast directions. Typically, the swell may range up to 3-4m significant wave height with wave periods in the range 8 to 14 seconds. Prevailing wind waves are incident from a wide range of directions, but predominantly the east to southeast sectors, consistent with the wind climate for the region, and range from small short period local ‘sea’ conditions to large storm waves in excess of 7-8m significant wave height.

2.3.1 Wave and Storm Generation Sources

The wave climate of the south east Australian coastline has some seasonality due to the seasonal dominance of the major wave generation sources. While there is some seasonality to the timing of the wave generation sources, storm(s) of sufficient magnitude to cause erosion may occur at any time during the year.

The dominant wave generation sources include (Short and Trenaman, 1992; Short, 2007, see Figure 2-5):

- Tropical cyclones (November to May), tracking towards the Tasman Sea (usually well offshore of the coast), which may generate north easterly waves, and can reform as ex-tropical cyclones;

- East coast cyclones (typically May, June and July), said to generate the strongest winds, heaviest rainfall and largest waves experienced on the NSW Coast. These small intense storms may form anywhere along the coast, generating south easterly to easterly waves;
- Mid-latitude cyclones (occur throughout the year particularly March to September) form in the Southern Ocean and Tasman Sea and generate the predominant south easterly swell experienced along the coast. Mid-latitude cyclones form closer to the southern Australian continent in winter than summer, thus typically forming higher waves in winter;
- The subtropical anticyclone produces fine, warm weather on the NSW coast, and particularly during summer, may generate weak north east to easterly swells; and
- Onshore sea breezes forming in summer on hot days (as the land heats faster than the ocean, causing hot air to rise over the land and cooler air from the ocean to move in to replace it), which when persistent over days may generate weak north east to east wind waves.

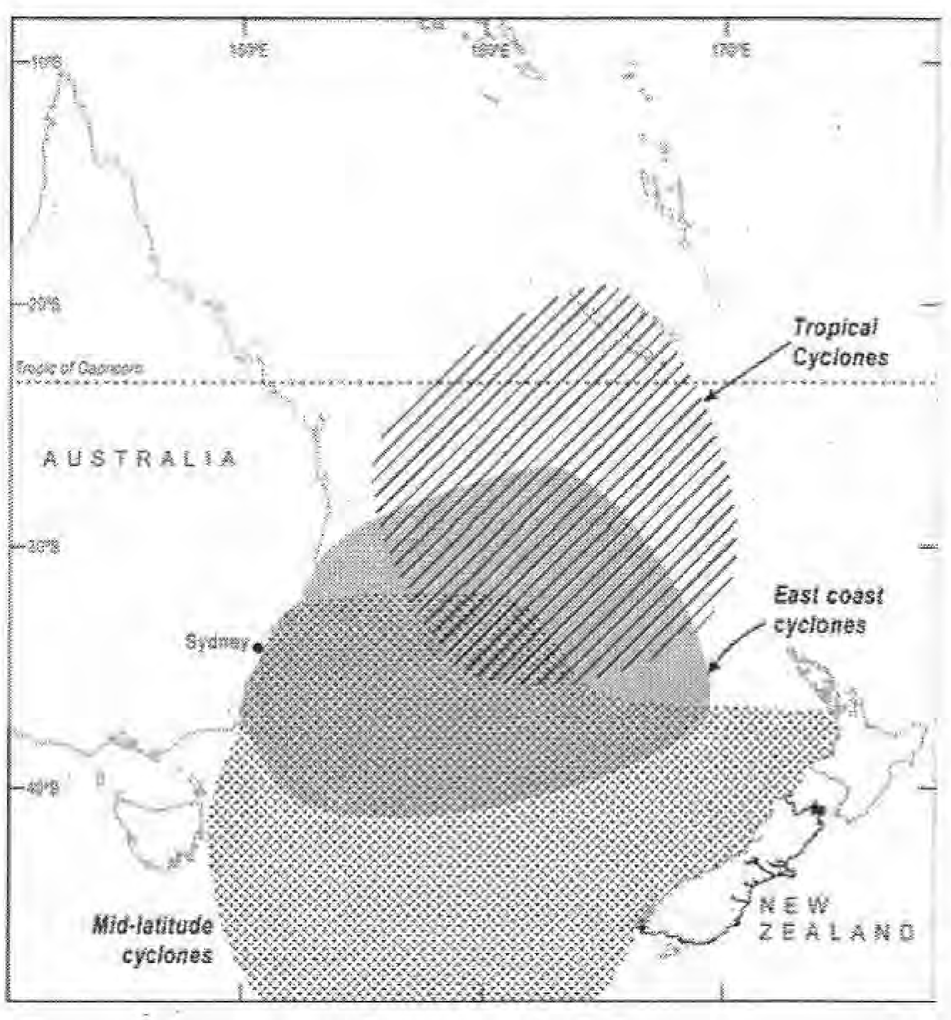


Figure 2-5 Wave generation sources on the South East Australian Coast (Short 2007)

2.3.2 Storm History

A range of sources documenting storms prior to the commencement of offshore wave measurement (Callaghan and Helman 2008, Lennon 1980, Lawson and Treloar, 1985) were reviewed to compile a storm history relevant to the south coast for this study.

This revealed that periods of intense storm activity on the south coast occurred between approximately:

- 1864 to 1870;
- 1881 to 1883;
- 1923 to 1929;
- 1934; and
- 1969 to 1978.

It is interesting to note that the storm periods tend to last for up to a decade, and these periods of storm intensity tend to recur every 20 to 40 years or so. This is consistent with the cycles of variability observed in Australia's climate generally, such as relating to thePacific Decadal Oscillation (PDO) and the El Nino Southern Oscillation (ENSO) and other climatic cycles, as discussed in Section 2.3.6.

Without precise wave data measurement, it is not possible to accurately compare the storms, or include these storms in average recurrence interval or other statistical calculations. While it is not possible to gauge the relative intensity of the storms, the number of storms during and between years demonstrates the variability in the wave climate. That is, there are periods of more frequent and intense storms, and periods of relative calm.

The period of storms during the 1970s was observed to greatly affect the Bega Valley Shire, such as:

- Storms during the 4 – 7th February 1971 generated the largest floods on the Bega River observed for more than 50 years;
- Storms in June 1974, which are well documented as the most damaging in living memory for many parts of the NSW coast, appear to have affected the Bega Valley coast;
- A series of severe storms in June 1978, which particularly affected the Tathra region;
- 22 – 23 June 1975, with reports in the local paper (the Magnet & the Voice) documenting substantial damage from this event, of a greater magnitude than 1974 at some locations; and
- Storms in 1972 were also reported locally to be damaging to the Bega Valley coast.

While a number of storm events with offshore wave heights in excess of 6 m have occurred in recent years, the impact of these storms in terms of damage appears to have been comparatively moderate. This is likely due to the fact that high waves during these events did not coincide with extreme water levels and the relatively accreted state of most beaches in recent years.

2.3.3 Measured Wave Data

Measured wave data from Waverider buoys at Eden, Batemans Bay and Sydney (refer Figure 2-7) were provided by the Department of Public Works Manly Hydraulics Laboratory (MHL), with data collection funded by OEH. The Waverider buoys are moored in water depths between 70 and 90m, at around 10 km offshore.

The Eden Waverider buoy has been measuring significant wave height (H_s), maximum wave height (H_{max}) and peak wave period (T_p) since February 1978 (and hourly output since March 1985). The Eden site was upgraded to also record wave directions in December, 2011.

The Sydney Waverider buoy has recorded wave direction data since March 1992. Although the buoy was installed in 1976, the data from 1992 only has been reviewed, which now provides 20+ year of records that include wave direction. The Batemans Bay Waverider buoy has measured H_s, H_{max} and T_p since May 1986, and mean wave direction since February 2001.

The Sydney and Batemans Bay Waverider data was primarily utilised to extend and fill gaps in the Eden wave data records and to generate a long term directional wave data time series, representative for the Bega Valley region, as there is only 1.5 years of directional data available from Eden.

Basic wave parameter statistics derived from the hourly wave dataset (based on wave recording during the period between March 2001 and March 2013) are presented in terms of significant wave height and mean wave direction in Table 2-1 and for significant wave height and spectral peak period in Table 2-2.

Table 2-1 illustrates the predominance of the southeast and south-south-east wave direction sectors, showing that there is a relatively large proportion (approx. 50%) from these directions. Modal significant wave heights are between 1 and 2 m with spectral peak periods predominantly in the range of 6 to 14 seconds.

The tables show further that significant wave heights in excess of 8m have been observed during the measurement period (2001 to 2013). The highest recorded (hourly) significant wave height was recorded on 8 March 2012 and was 8.06m. In that event, the recorded significant wave height of 5.0m was exceeded for 20 hours, 6.0m for 7 hours and 7.0m for 2 hours (See also Figure 2-6).

Table 2-1 Offshore Wave Height and Direction Occurrence Frequency – Bega Valley Region (%)

	Wave Direction Sector																
Hs (m)	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW	TOTAL
< 1	0.01%	0.03%	0.28%	0.68%	1.05%	1.55%	2.75%	2.74%	0.51%	0.13%	0.02%	0.00%	0.01%	0.04%	0.03%	0.01%	9.83%
1 TO 2	0.01%	0.10%	1.74%	6.55%	8.28%	8.33%	13.80%	19.14%	6.82%	0.94%	0.01%					0.00%	65.71%
2 TO 3	0.00%	0.02%	0.56%	2.30%	2.56%	2.11%	2.94%	6.18%	2.76%	0.32%	0.00%					0.00%	19.75%
3 TO 4			0.06%	0.29%	0.39%	0.31%	0.52%	1.30%	0.60%	0.10%							3.57%
4 TO 5			0.01%	0.02%	0.06%	0.08%	0.13%	0.33%	0.19%	0.03%							0.85%
5 TO 6					0.02%	0.03%	0.04%	0.08%	0.05%	0.01%							0.24%
6 TO 7						0.01%	0.01%	0.02%	0.01%								0.04%
7 TO 8							0.01%	0.00%	0.00%								0.01%
> 8								0.00%									0.00%
TOTAL	0.02%	0.14%	2.66%	9.84%	12.36%	12.42%	20.20%	29.78%	10.93%	1.52%	0.04%	0.00%	0.01%	0.04%	0.03%	0.02%	100.00%

Table 2-2 Offshore Wave Height and Peak Period Occurrence Frequency – Bega Valley Region (%)

	Tp (s)									
Hs (m)	2 TO 4	4 TO 6	6 TO 8	8 TO 10	10 TO 12	12 TO 14	14 TO 16	16 TO 18	> 18	TOTAL
< 1	0.07%	0.70%	1.93%	2.84%	2.39%	1.70%	0.15%	0.03%	0.01%	9.83%
1 TO 2	0.12%	5.97%	14.24%	21.21%	14.43%	8.60%	1.02%	0.13%	0.00%	65.71%
2 TO 3		0.38%	3.32%	6.45%	5.85%	3.31%	0.38%	0.05%	0.00%	19.75%
3 TO 4			0.12%	0.93%	1.52%	0.83%	0.14%	0.02%	0.00%	3.57%
4 TO 5				0.10%	0.42%	0.28%	0.04%	0.02%		0.85%
5 TO 6				0.00%	0.12%	0.11%	0.00%	0.00%		0.24%
6 TO 7					0.02%	0.03%	0.00%			0.04%
7 TO 8						0.01%				0.01%
> 8						0.00%				0.00%
	0.19%	7.05%	19.60%	31.55%	24.75%	14.86%	1.73%	0.25%	0.02%	100.00%

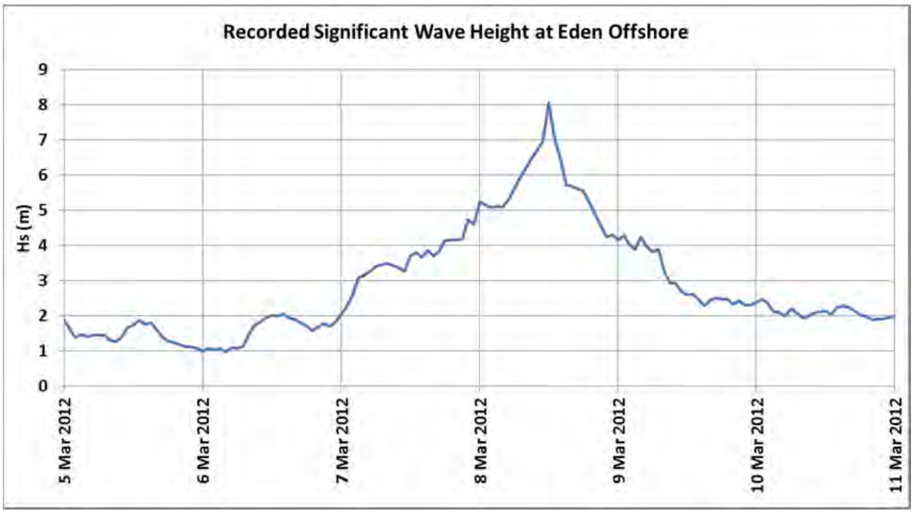


Figure 2-6 Significant Wave Height during the March 2012 event

2.3.4 Offshore Extreme Waves

The Bega Valley coast is subject to periodic large coastal storm events. These storm events arise from a range of synoptic weather systems. Shand *et al*. (2011) have previously analysed the extreme wave climate along the NSW coast, based on historical measurement data at nine offshore wave buoys (refer to Figure 2-7).

Table 2-3 presents the one-hour exceedance extreme significant wave height estimates provided in Shand *et al*. (2011). The table suggests that the central coast is exposed to the largest extreme wave heights along the SE Australian coast. In addition, it suggests that the extreme wave heights estimates for Eden are notably higher than those for Batemans Bay.

Shand *et al*. (2011) also examined the effect of storm direction on the extreme wave height for those wave buoys that record wave directions. The directional extreme values for the 10 year ARI storm event are summarised in Table 2-4. The table shows that for Sydney and Batemans Bay, extreme waves are predicted to be largest from the south-east to southern sectors (135 to 180 degrees north). In addition, it shows that all directional wave buoys predict significantly lower wave height estimates for the wave direction north of east (i.e. 0 to 90 degrees North).

The non-directional wave height estimates for Eden were determined from 31 years of data, and correlate well with the highest recorded significant wave height (H_s) of 8.06m, recorded on 8 March 2012. As such, these extreme wave height estimates have been adopted in this assessment. Directional extreme wave height estimates were derived by scaling the non-directional estimates for Eden according to the directional extreme value estimates for the Batemans Bay buoy.

Wave data from the offshore wave buoy at Eden was analysed to examine the peak wave period during significant storms. Figure 2-8 presents a scatter diagram of recorded peak wave period and significant wave height during storms with a peak significant wave height in excess of 5m. Figure 2-8 shows that most storm waves along the Bega Valley coast have a peak wave period between 10 and 14 seconds.

Figure 2-7 Locations of Offshore Wave Recorders along SE Australian Coast relative to the Bega Valley Shire

Table 2-3 One Hour Exceedance H_s along SE Australian Coast (Shand *et al*., 2011)

	Significant Wave Height (m), including ±90% Confidence Limits			
Location	**1 yr ARI**	**10 yrARI**	**50 yr ARI**	**100 yr ARI**
Brisbane	5.1(±0.2)	6.6(±0.3)	7.6(±0.4)	8.0(±0.4)
Byron Bay	5.2(±0.2)	6.4(±0.2)	7.2(±0.3)	7.6(±0.3)
Coffs Harbour	5.2(±0.2)	6.7(±0.3)	7.7(±0.4)	8.1(±0.4)
Crowdy Head	5.4(±0.2)	7.0(±0.4)	8.0(±0.5)	8.5(±0.5)
Sydney	5.9(±0.2)	7.5(±0.4)	8.6(±0.5)	9.0(±0.5)
Botany Bay	5.7(±0.2)	7.4(±0.3)	8.6(±0.4)	9.1(±0.4)
Port Kembla	5.4(±0.2)	7.1(±0.3)	8.3(±0.4)	8.8(±0.5)
Batemans Bay	4.9(±0.2)	6.3(±0.4)	7.3(±0.5)	7.7(±0.5)
Eden	5.4(±0.2)	7.0(±0.3)	8.1(±0.4)	8.5(±0.5)

Table 2-4 Directional Variation in 10 year ARI One Hour Exceedance H_s (Source: Shand *et al*., 2011)

	Hs (m), including ±90% Confidence Limits			
Location	**Omni-Directional**	**0 to 90 degrees**	**90 to 135 degrees**	**135 to 225 degrees**
Brisbane	6.6(±0.3)	4.6(±1.2)	6.6(±0.6)	5.7(±0.4)
Byron Bay	6.4(±0.2)	4.3(±2.1)	6.4(±1.6)	6.1(±0.4)
Sydney	7.5(±0.4)	4.5(±0.7)	6.2(±0.7)	7.5(±0.5)
Batemans Bay	6.3(±0.4)	4.5(±1.4)	5.6(±1.2)	6.1(±0.7)

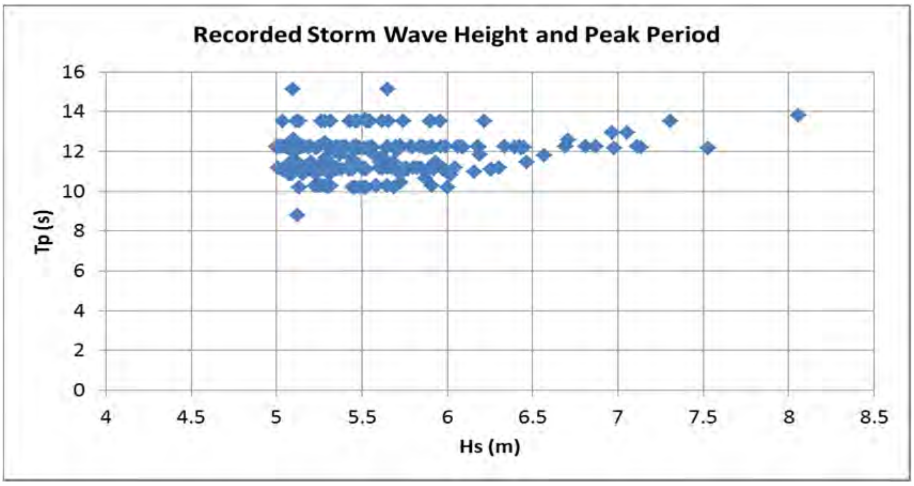


Figure 2-8 Recorded Storm Wave Heights and Peak Wave Period at Eden Waverider Buoy

2.3.5 Nearshore Waves

Waves arriving in the nearshore zone have been transformed from offshore through refraction and bed friction attenuation. To simulate ambient and extreme wave conditions at all nearshore areas along the study region, wave modelling was carried out using the wave modelling package SWAN.

SWAN is a third generation spectral wave model that estimates wave parameters in coastal regions from given wind, wave and current conditions and is developed by Delft University of Technology (Delft 2010). SWAN models are capable of simulating the following physical phenomena of interest to this study:

- Wave shoaling and refraction, due to depth, bottom friction and bathymetric features;
- Wave frequency shifting due to non-stationary depth;
- Nonlinear wave-to-wave interactions (quadruplets and triads); and
- White capping and depth-induced breaking.

Bathymetric data for the study area, derived from a collation of available Australian Hydrographic Charts and various hydrographic survey datasets, were combined to produce a series of digital elevation models (DEMs) with a grid cell size of up to 5m in the nearshore areas of interest. A range of SWAN model grids were created from the DEMs to provide a regional model of 500m spacing, a continental shelf model of 250m, and several nested grids of finer (50m) resolution at the nearshore areas.

Typical nearshore transformation coefficients and wave refraction patterns along the study region are shown in Figure 2-9. These show:

- Maximum wave height coefficients for deep water wave directions in the range 50-120 degrees, the more north-easterly being for north-facing beaches (e.g. Horseshoe Bay) and the southern ends of strongly embayed beaches (Pambula Beach, Twofold Bay and Moorhead) while the east to east-southeast directions relate to the more exposed north-south aligned open coastline beaches;
- Decreasing wave height coefficients for more southerly waves, particularly at those beaches in more sheltered areas immediately north of prominent headlands; and
- Smaller wave height coefficients for embayed beaches, compared to the exposed open coastline beaches.

These effects are illustrated also in Figure 2-10, which shows relatively direct propagation of most waves at the exposed north-south aligned ocean beaches and zones of substantial wave height reduction within the embayments, particularly along the sheltered beach areas north of headlands for the southeast to southerly sector waves.

The varying nature of wave propagation to the shoreline leads to quite different patterns of wave exposure and associated longshore sand transport regimes along the study region coastline. No particular wave condition results in uniform alongshore transport. The net transport rates at each location along the coast depend on the prevailing range of propagated nearshore waves that is unique to each location and will vary in response to variations in the incident deep water wave conditions.

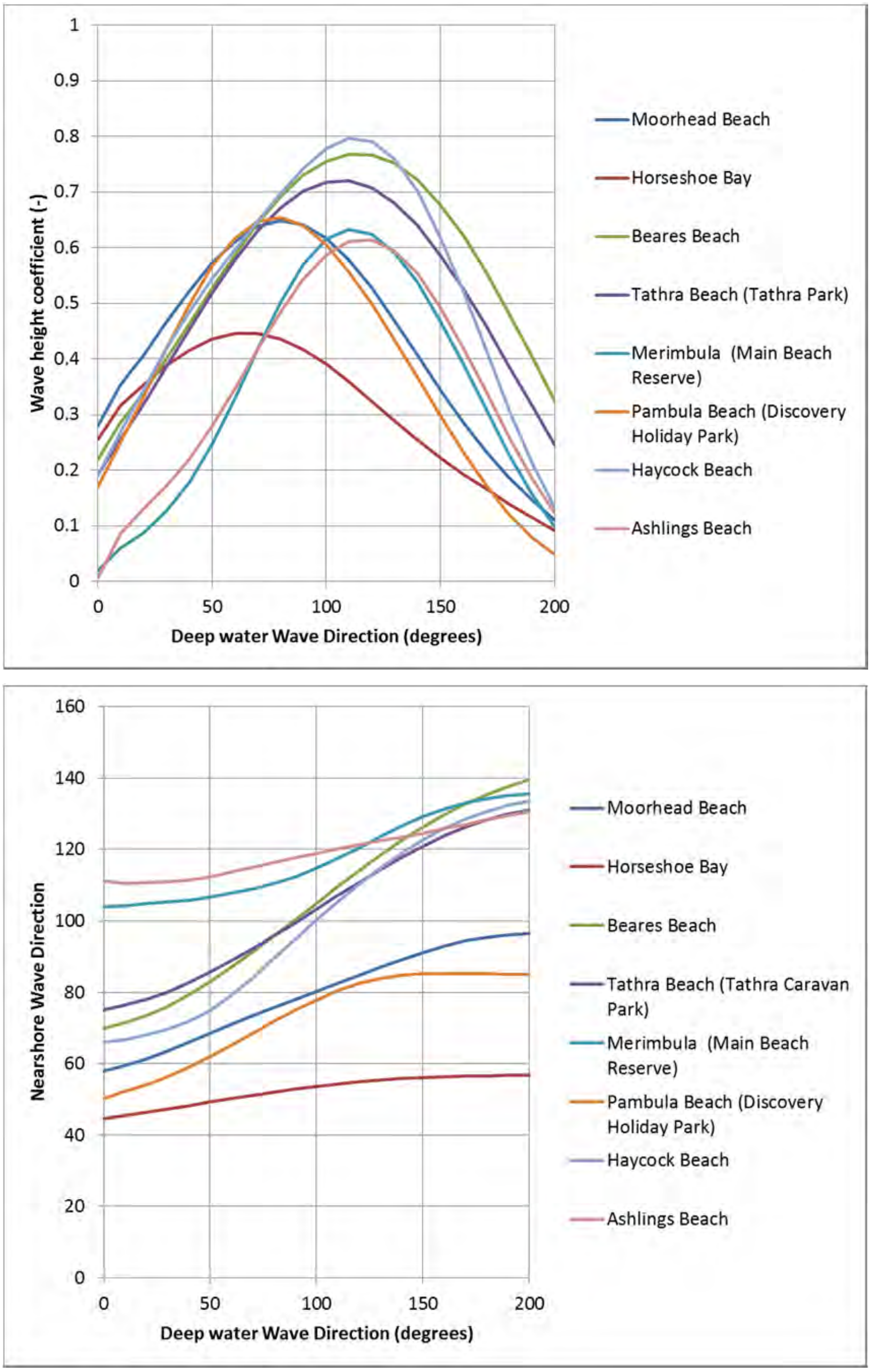


Figure 2-9 Typical Nearshore Wave Height Coefficients (top) and Directions (bottom) – $H_{s,0}$=2.0m & $T_{p,0}$=10s

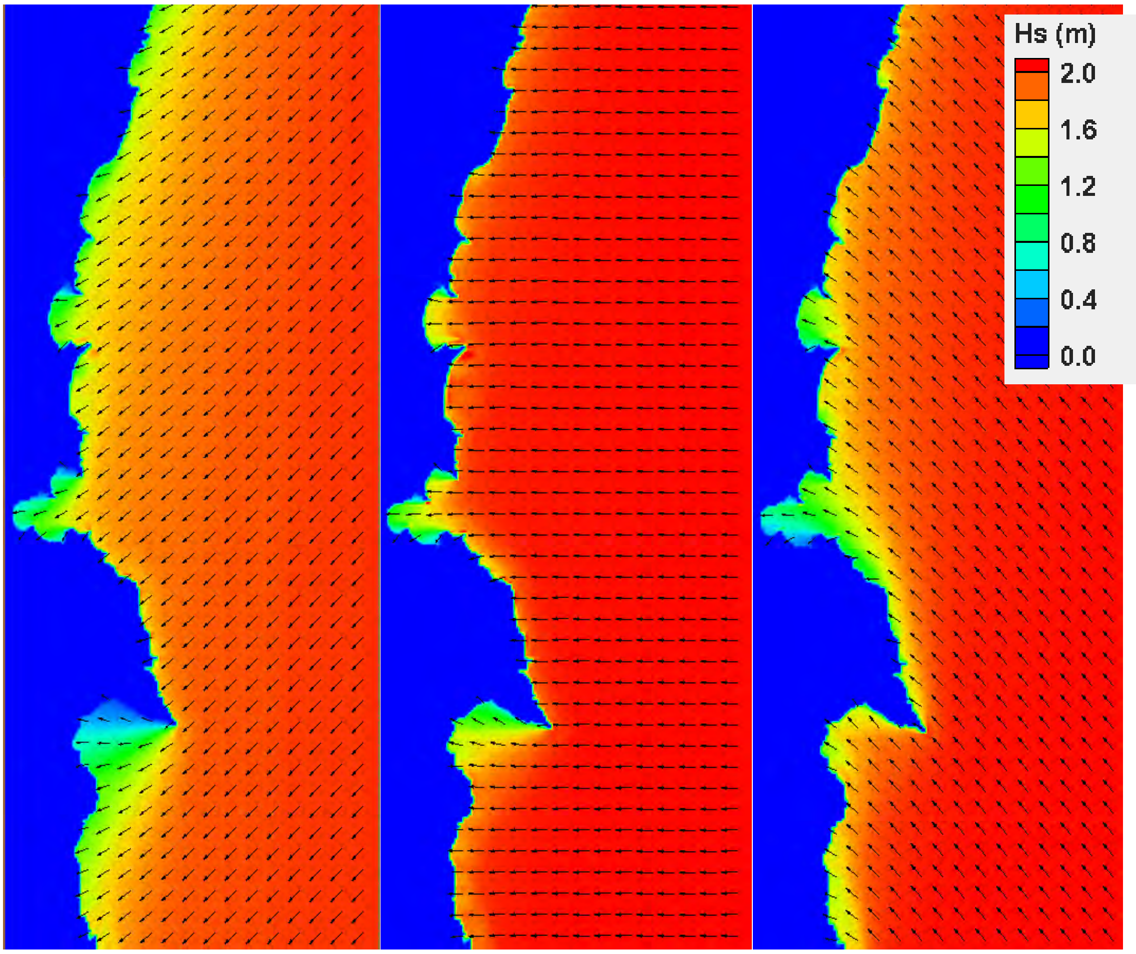


Figure 2-10 Typical Wave Refraction Patterns along Study Region

2.3.6 Wave Climate Variability

Variability in the wave climate between years is observed in the NSW wave climate. There may be subtle shifts in the wave climate (wave height, wave direction) between years and even decades that relates to the intensity and frequency of storms (affecting wave height) and storm generation sources (affecting wave direction). Such shifts in wave climate may manifest on the shoreline as a period of erosion or accretion, and variation in the direction and rate of longshore sediment transport, both within an embayment (manifesting as rotation) and between embayments.

Reasonable correlation has been found between the south east Australian wave climate and the El Nino Southern Oscillation (ENSO). Generally, there is an increase in the occurrence of tropical cyclones and east coast low cyclones during the La Nina phase (Goodwin 2005; Phinn and Hastings, 1992; Hemer *et al.,* 2008, CSIRO, 2007). Relating to these wave generation sources, the La Nina phase has been associated with more northerly (easterly) wave directions (Short, *et al.,* 2000; Goodwin 2005; Ranasinghe *et al.,* 2004). Mean wave power has also been found to be higher during the La Nina phase, likely due to the greater frequency / intensity of tropical and east coast low cyclones, which occur in addition to the predominant mid-latitude cyclones (e.g. refer Phinn and Hastings, 1992; Ranasinghe *et al*., 2004; You and Lord, 2008). During the El Nino phase there are generally fewer tropical and east coast cyclones and mid-latitude cyclones remain dominant, resulting in a more southerly mean wave direction (Ranasinghe *et al.*, 2004; Goodwin, 2005).

Climate variability at decadal time scales (10-30 years) is also an intrinsic characteristic of the Australian regional climate (Power *et al.*, 1999). A notable component of the climate variability on decadal scales is found to be related to the Inter-decadal Pacific Oscillation (IPO) (Power *et al*., 1999; Salinger *et al.*, 2001; Folland *et al.*, 2002). The sea surface temperature anomaly associated with the negative (or cool) phase of the IPO produces an increased frequency of east coast low pressure systems, higher rainfall and associated flood activity (Rakich *et al*., 2008; Verdon *et al*., 2004). Verdon *et al.* (2004) demonstrated that the frequency of La Nina events is increased during the negative phase of the IPO.

Helman (2007, 2008) reported that major energy periods in the storm history of the east coast can be correlated with the negative phase of the IPO (refer to Figure 2-11). An increase in wave height and more frequent storms arriving from the east and east north east directions are expected during such periods, associated with such wave generation mechanisms.

The high storm activity during the decade of the 1970s is typically associated with the greatest beach erosion extents in the historical record on NSW beaches (Forster, *et al.*, 1975; Thom and Hall, 1991; McLean and Shen, 2006). The higher frequency of storms during this period suggests that the recovery of the beach between storms (or lack thereof) was significant in the resulting extent of beach erosion, in addition to the magnitude of individual storms (Short *et al*., 2000; Ranasinghe *et al*., 2004; McLean and Shen, 2006). Since the 1970s, the wave climate was relatively calmer to around 2007, during which time extensive beach recovery and accretion was observed.

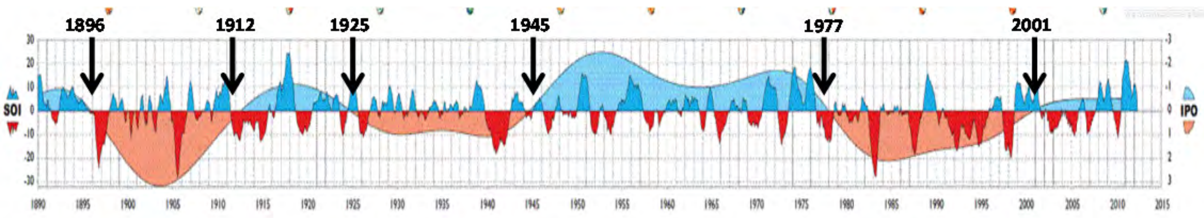


Figure 2-11 Correlated ENSO and IPO patterns since 1890
Figure from: http://www.longpaddock.qld.gov.au/products/australiasvariableclimate/index.html

While there is good correlation between ENSO and IPO and the storms that produce high waves, these climatic indicators alone are not adequate to describe or predict the extent of variability observed in the wave climate (height and direction), nor the shoreline response. The interrelationships between IPO, ENSO and other climatic drivers (e.g. Southern Annular Mode and Indian Ocean Dipole) and how they affect wave climate are not yet fully understood.

Comprehensive analysis of these interrelationships is restricted by the relatively short duration of reliably recorded directional wave data. Nevertheless, it is most probable that substantial natural variability in the wave climate occurring over the longer term (years and decades) has significant consequent effects on shoreline behaviour. More southerly waves (associated with La Nina-dominated phase of the IPO) tend to cause higher rates of northward sand transport, resulting a clockwise realignment of embayments, while more easterly waves (associated with El Nino dominated phase of the IPO) cause higher transport rates to the south, resulting in an anti-clockwise realignment.

The key message is that natural variability in the wave climate is observed to occur over longer periods (years and decades). Variability in wave height and direction that persists for years to decades will result in alternate cycles of erosion and accretion (beach oscillation) and rotation (longshore sediment movement) on the shoreline. A series of storms (and associated water levels) over months to years and even decades will have a cumulative effect upon the shoreline, which may result in greater erosion than a single severe storm alone. Periods of higher or lower storminess in the wave climate (and subsequent cycles of erosion and accretion) can be expected to continue in the future.

2.4 Water Levels

2.4.1 Tides

Tides of the NSW coastline are classified as micro-tidal and semi diurnal with significant diurnal inequality. This means that the tidal range is < 3.0 m, and there are two high tides and two low tides per day that are generally at different levels (i.e. the two high tide levels are different in any one day).

Tidal measurements are taken at Bermagui and Eden, describing the northern and southern ends of Bega's coastline, and further north at Batemans Bay. Batemans Bay is considered an open ocean site. Tidal planes and ranges determined for the sites by MHL (2012) are given in Table 2-5. The tidal range at Bermagui and Batemans Bay is similar at 1.69 m, while at Eden is reported to be 1.85 m.

While there is some variation in tidal level along the NSW coast, it is generally agreed that shore-parallel tidal currents along the coastline are negligible. Near the larger estuary entrances such as the Bega or Bermagui Rivers (when the Bega River entrance is open), significant local currents may occur in the nearshore zone, driven by the tidal volume flowing through the entrance on the falling and rising tide. At some entrances, the local currents may be strong enough to generate tide-driven sediment transport.

Table 2-5 Tidal Planes and Ranges for Bega Valley region (from MHL, 2012)

Site	HHWSS (m AHD)	MHWS (m AHD)	MHW (m AHD)	MSL (m AHD)	MLW (m AHD)	MLWS (m AHD)	ISLW (m AHD)	Range (m)
Eden	0.89	0.48	0.38	-0.09	-0.56	-0.67	-0.89	1.85
Bermagui	0.87	0.53	0.43	-0.03	-0.48	-0.58	-0.82	1.69
Batemans Bay	0.90	0.58	0.47	0.00	-0.46	-0.57	-0.80	1.69

**Where: Highest High Water Solstice Spring (HHWSS); Mean High Water Spring (MHWS); Mean High Water (MHW); Mean Sea Level (MSL); Mean Low Water (MLW); Mean Low Water Spring (MLWS); and Indian Spring Low Water (ISLW).*

2.4.2 Elevated Water Levels

Elevated water levels during a storm may comprise the following elements:

- **Barometric pressure set up** of the ocean surface due to the low atmospheric pressure of the storm;
- **Wind set up** due to strong winds during the storm "piling up" water onto the coastline;
- **Astronomical tide,** particularly the HHWSS;
- **Wave set up**, which is the super elevation of the water surface due to the release of energy by breaking waves. It is directly related to wave height, so will be greater during storm conditions; and
- **Wave runup**, which is the vertical distance of the uprush of water from a breaking wave on the shore.

The components comprising the ocean elevated water level, excluding wave set up and wave run up, have been analysed by MHL (2013) for the sites of Eden and Bermagui. The 1 in 20, 1 in 50 and 1 in 100 year ARI still water levels at these sites (ie. elevated water levels excluding wave set up and run up) are given in Table 2-6. The table shows that the probabilistic still water levels for Eden are similar to those for Bermagui.

Table 2-6 Extreme Still Water Levels along Bega Shoreline (MHL, 2013)

Return Intervals	*Eden (m AHD)*	*Bermagui (m AHD)*
1:20 years	1.28	1.27
1:50 years	1.29	1.30
1:100 years	1.30	1.32

2.4.2.1 Wave Set Up

As waves approach a beach across the surfzone they cause changes in the mean water level which is associated with gradients in the radiation stress of the wave train (i.e., the pressure force in excess of hydrostatic pressure caused by the presence of waves). Once waves have broken, kinetic energy is released and the mean water level is raised, sometimes substantially above the still water level. Maximum setup occurs at the beach face. The amount of setup depends on wave height, wave steepness and beach slope.

The influence of wave set-up on elevated water levels in estuaries varies with the specifics of the entrance. There is growing evidence that propagation of wave setup through trained estuary entrances is minimal. Measurements documented by Hanslow and Nielsen (1993) from the Brunswick River entrance (NSW north coast) indicated that even when waves were breaking across the entrance, measurements of mean water surface extending up-river for some 200 to 300m showed only a very small transfer of wave setup. However, where estuary entrances are shallow, wave setup may be significant.

2.4.2.2 Wave Run-up

Wave run-up is the vertical distance on the shore that the uprush of water from a breaking wave reaches above the local mean sea level. It is the wave run-up mechanism that governs the volume of water that overtops a coastal barrier, for example, dunes, seawalls and entrance berms. Wave run-up levels are dependent upon factors including wave height, wave period, storm surge, beach slope and permeability, the roughness of the foreshore area and wave regularity. Run-up is higher on steeper slopes and impervious materials. Thus steep-sloped rock headlands generate greater run-up than gently sloped beaches.

Wave run-up is variable due to the irregular nature of waves and is commonly assumed to have a Rayleigh statistical distribution matching that of the prevailing waves.

Figure 2-12 illustrates the potential effects of wave overtopping at headland locations. It shows the former road to Tathra Wharf, which has been damaged by wave overtopping on a number of occasions in the past at elevations more than 10m above mean sea level.

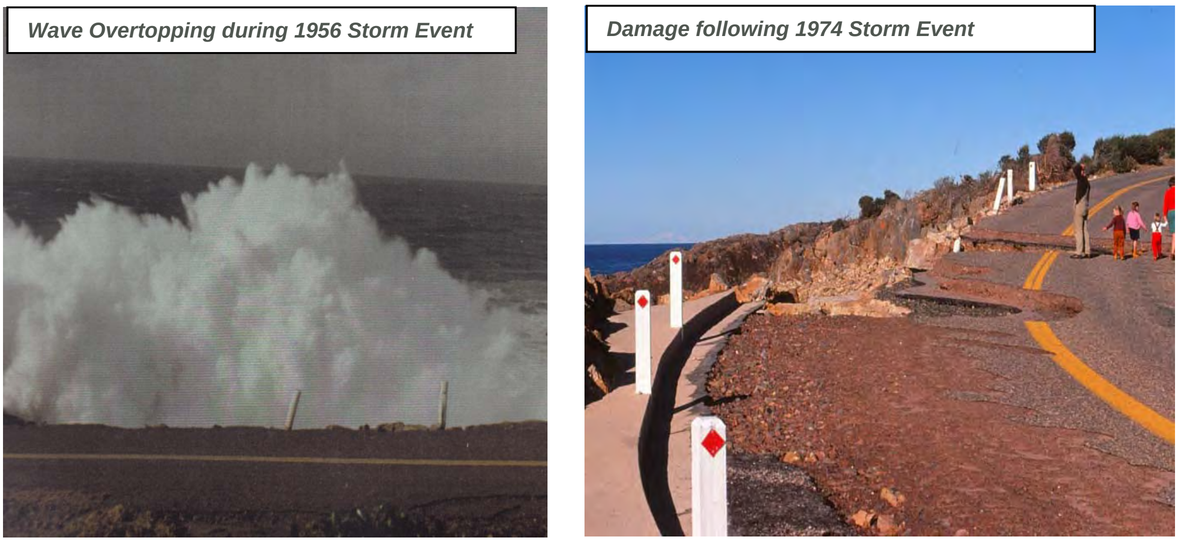


Figure 2-12 Wave Overtopping at Tathra Headland

For definition of inundation hazard, the rate and frequency of overtopping is an important consideration when determining the effectiveness of protection offered by existing dune barriers and coastal structures, particularly with future sea level rise. Analyses of wave run-up levels and the associated potential for significant wave overtopping have been undertaken for each of the locations of interest, as reported in Section 3.4.3.

2.4.3 Elevated Estuary Water Levels

Water levels within the lower estuaries of rivers and creeks may be elevated due to the backwater effects of elevated ocean levels (notably when coincident with catchment runoff). There is uncertainty about the extent to which wave setup will propagate through river and creek entrances. It is likely that, for relatively small creeks with shallow bars at their mouths, there may be a component of setup that increases the lower estuary water levels, though it will be significantly less than occurs along the adjacent beaches.

Flood levels at and immediately upstream of estuary mouths tend to be dominated by the ocean water levels before an entrance breakout. However, small creek systems respond more quickly to rainfall runoff from their catchments than larger river systems, with greater likelihood of high flood discharges coinciding with the peak storm surge, which may increase levels further upstream due to the flood flow gradient.

2.5 Wind Climate

In the coastal region, the prevailing winds are directly responsible for the general *sea* state. More importantly, winds are responsible for the transport of sand from the sub-aerial beach face into incipient dunes and foredunes, allowing for the growth of dunes and storage of sediment.

The Bureau of Meteorology records wind conditions at Merimbula Airport (refer to Figure 2-13). Based upon a review of wind rose data compiled by the BoM for 9 am and 3 pm, the following general wind climate may be assumed for the coast of Bega Valley region:

- Annually, the predominant wind direction is south-westerly, then westerly at 9 am. By 3 pm, the dominant annual wind direction is more variable, with north easterly winds clearly dominant;
- Seasonally, for the summer months at 9 am, north easterly then south westerly winds are dominant. By 3 pm in summer, north easterly winds are very dominant, with south easterly and easterly winds also occurring to a lesser degree;
- For the autumn months at 9 am, south westerly then westerly winds are very dominant, with little influence from easterly directions. By 3 pm in autumn, north easterly winds are dominant, but increasingly south westerly winds become prevalent also;
- In winter at 9 am, south westerly and westerly winds are clearly dominant, with minor influence from north westerly directions. By 3 pm in winter, both south-westerly or north-easterly directions are dominant; and
- In spring at 9 am, south westerly, easterly and north easterly directions are all dominant, with the influence of south westerlies decreasing towards summer. By 3 pm, north easterly winds are very dominant, with around 20% of winds also arriving from the south east also.

The seasonality of winds observed for the region is consistent with the temperature inversion between land and sea observed in coastal NSW generally. During spring and summer particularly, winds are generally offshore in the morning (due to the cooler land mass relative to the sea), and onshore from the east to north east direction in the afternoon, as the land mass is heated during the day and the overlying air is heated and rises causing cool air to flow in from the sea to replace it. During the cooler months, winds tend to originate from the west to south directions. Occasional afternoon sea breezes occur during cooler months, however, these are of lesser strength than those in summer months.

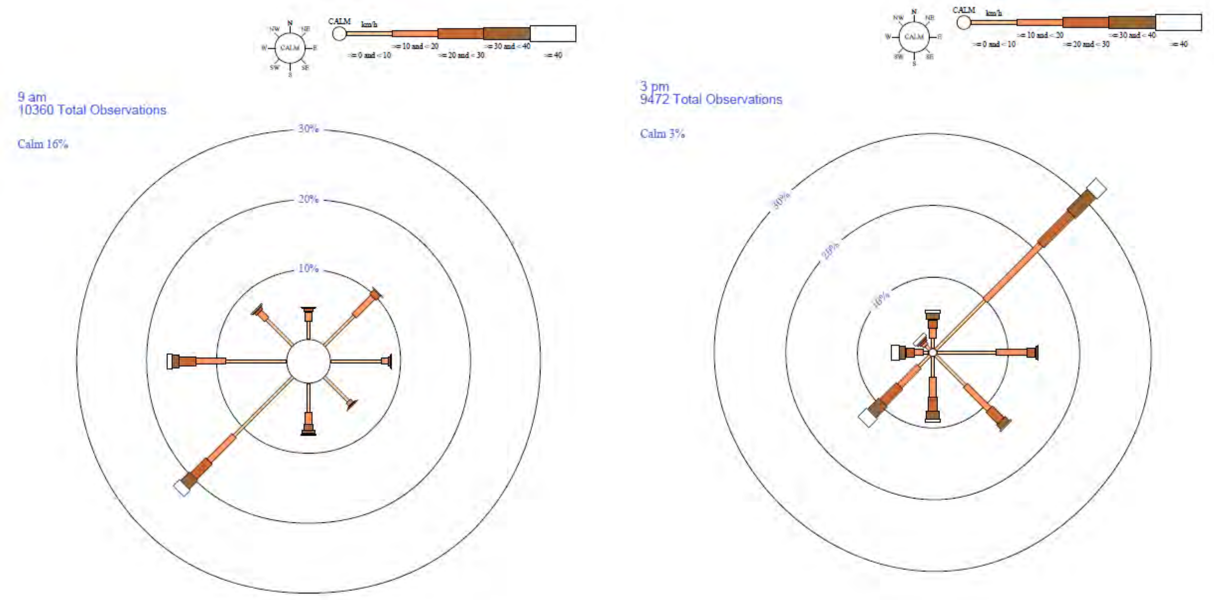


Figure 2-13 Annual Wind Statistics for Merimbula Airport at 9am (left) and 3pm (right) (Source: BoM, 2012)

2.6 Sediment Transport

Sand is transported along the Bega Valley beaches by the combined action of waves, currents and wind. Waves have three key effects on sand transport in the nearshore zone, namely:

- As wave break they generate radiation stresses, which may drive longshore currents (particularly within the wave breaker zone);
- Their orbital motion may impose shear stresses on the seabed, which may mobilise and put into suspension the seabed sediment. The asymmetry of wave orbital motion in shallower water causes a differential in the forcing on the bed sediments that is stronger towards the shoreline, resulting in an onshore mass transport of sand; and
- They cause a bottom return current in the surfzone (undertow - strongest during storms when they typically dominate over the mass transport associated with wave asymmetry) and rip currents.

Currents generated by tide, waves and wind provide the primary mechanism for the transport of the sand that has been mobilised and put into suspension by wave/current action.

Along most of the Bega shoreline, wave-driven alongshore current (generated by wave breaking at an angle to the shore) is considered to be the dominant current with respect to sediment transport. However, around the larger estuary entrances such as the Bega or Bermagui Rivers (when the Bega River entrance is open), significant local currents may occur in the entrance, which are likely to influence the overall sediment transport regime in those areas.

Wave effects on longshore transport are complex due to the variability of wave conditions, the irregular occurrence of storm events with their associated high waves and elevated water levels and the effects of protruding headlands and coastal structures. In simple terms, sand transport at a typical beach location may be regarded as involving longshore and cross-shore sand movement processes. These act concurrently and interact together.

2.6.1 Longshore Sediment Transport

Waves approaching the shoreline from an oblique angle generate a current alongshore, which transports sediment. Depending on the prevailing wave direction, the sediment transport may be directed either north or south along the coast.

Longshore sediment transport (also commonly referred to as littoral drift) occurs predominantly in the mid to outer surfzone (or inner nearshore zone), diminishing in strength with distance offshore into deeper water. Winds and tides may contribute to longshore currents (and may dominate the currents outside of the surfzone). For the same wave height, the highest transport rates occur when the incoming wave is at an angle of 45° to the shoreline. Where the angle of wave attack is close to perpendicular to the shore, there is little to no generation of longshore current.

Where there is a longshore variation in the rate of longshore sand transport, there will be a net gain or loss of sand from the beach unit. That is, where more sand is transported out of a beach area than is being brought in over an extended period of time, the beach will erode. The erosion will occur initially in the surfzone where sand transport is greatest, and manifest as beach retreat following onshore/offshore readjustment of the nearshore profile. Correspondingly, beach accretion may occur where longshore transport brings more sand than is taken away.

Along most of the NSW coastline, the net longshore sediment transport is to the north, due to the predominant south east wave climate relative to the general north to south orientation of the coastline. The net northerly transport is considered to be more pronounced in northern NSW because the beach embayments are longer and headlands are less common, allowing for higher rates of longshore transport with relatively fewer structural constraints.

Along the Bega coastline, beaches tend to be strongly controlled by bounding cliffs and headlands and many beaches are strongly embayed with no or very little sediment bypassing around the headland protrusions under present conditions. At those locations, the sediment is largely contained within the beach compartment.

2.6.1.1 Beach Rotation

Beach rotation is largely a longshore transport process and relates to the clockwise or anti-clockwise shift in beach orientation in response to shifts in wave direction and height over seasons to years and even decades (Short *et al.*, 2000; Ranasinghe *et al.* 2004). Beach rotation is essentially an increase in beach width at one end while the opposing end experiences a decrease in width.

Many of the embayed beaches along the southern and central NSW coastline have experienced a clockwise rotation since the late 1970s, which resulted in significant shoreline erosion at their southern end and accretion at the northern end. It is considered that this rotation is due to medium term variability in the wave climate, related to a shift from a prolonged La Nina dominated phase to a prolonged El Niño dominated phase (Ranasinghe *et al.* 2004).

Also the beaches in the study area have experienced beach rotation since the late 1970s, as evidenced in Figure 2-14.

Figure 2-14 shows aerial photographs of the northern end of the Cuttagee Beach/Baragoot Beach embayment at 1967 (left) and 2010 (right). The figure demonstrates the significant accretion that has been experienced at this end of the beach compartment. At the southern end of the embayment, a trend in the opposite direction can be identified, as discussed in Section 3.3.5.

The phenomenon of beach rotation forms a component of the observed extent of "erosion" on beaches, and as such is an important consideration in this coastal hazard assessment.

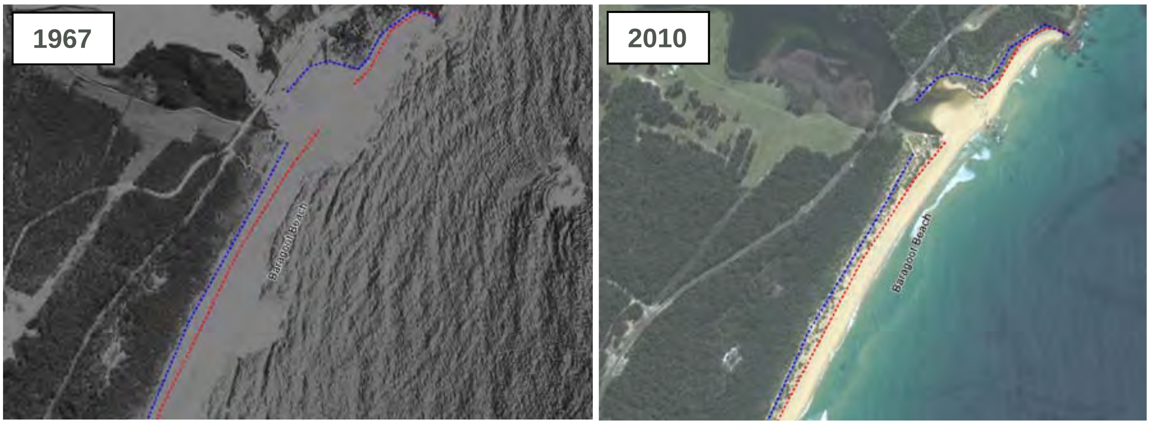


Figure 2-14 Shoreline Accretion at Northern End of Baragoot Beach

2.6.2 Cross Shore Sediment Transport

During storms, increased wave heights and elevated water levels cause sand to be eroded from the upper beach/dune system (often termed 'storm bite') and transported in an offshore direction, typically forming one or more shore-parallel sand bars in the nearshore zone. As the sand bars build up, more of the wave energy becomes dissipated within the surfzone and wave attack at the beach face reduces. The severity of wave attack at the dune is dependent on wave height and elevated water level (the combination of tide, storm surge and wave setup) and preceding beach condition (i.e. if the beach is generally in an accreted or eroded state prior to the storm). In addition, depending upon the orientation of the coastline relative to the direction of the incoming storm, the beach may either experience unimpeded wave power and severe erosion, or may be shadowed and protected from incoming wave energy (e.g. by protruding headlands or offshore reefs/islands).

During calmer weather, sand slowly moves onshore from the nearshore bars to the beach forming a wave-built berm and, subsequently, a wind-formed incipient foredune.

Typically, the cross-shore exchange of sand from the upper beach/dune area to the nearshore profile does not represent a net loss or gain of sand from the overall active beach system. While it may take several years, the sand eroded in the short-term during severe storms is returned to the beach and dune by the persistent action of swell waves and wind such that there is overall balance. In addition, for stable embayments, the longshore transport into and out of the compartment is equal over the long term, enabling an overall balance in the cycle of storm erosion and recovery.

2.6.3 Aeolian Transport

Aeolian or windborne sediment transport originates from the dry sub-aerial upper beach face and berm and unvegetated incipient dunes and foredunes, supplying sediment to landward foredunes. Aeolian transport is specific to particular sediment grain sizes, such that sediments which are too coarse (and thus heavy) are less able to be transported by the wind.

Aeolian transport is the key process for natural development of foredunes, particularly where vegetation enables the windblown sediment to be captured and stabilised. The sediment is thus stored within the beach system, rather than transported further landward where it is otherwise removed from the active beach system. At all beaches, Aeolian transport contributes positively to the growth of incipient foredunes and storage of sediment in vegetated foredunes. Where there are areas of unvegetated dunes (which may occur naturally), sediment may be lost from the immediate marine-based coastal system.

In most cases along the Bega Valley Shire coast, the incipient dunes and foredunes are sufficiently vegetated to capture windblown sediments, and thus retain the sediment within the immediate coastal system. For example at Tathra, the loss of sediment landward of the foredunes was considered to be insignificant in terms of the overall sediment budget for the beach (PWD, 1980). Where dune blowouts occur, however, there may be localised losses of sediment.

Windblown sediment transport or sand drift can present a hazard where back beach development is being inundated by dune sands. Loss or damage to vegetation on sand dunes, (e.g. the creation of informal tracks by walkers or four-wheel drive vehicles, and weeds such as Bitou Bush), may initiate dune blowouts and subsequent destabilisation of the dune system. This may have consequences for the retention of sediment within foredunes and therefore, the protection available to beaches during periods of erosion by waves and high water levels.

It should be noted that not all areas of active, unvegetated dune pose a hazard that requires stabilisation. For example, the entrance berms for coastal lakes are typically unvegetated (due to their intermittent nature). Attempts to revegetate these features can affect the location and occurrence of entrance breakouts, with flow-on effects such as erosion of areas previously unaffected by breakouts, or retention of higher water levels where the berm is higher than may otherwise have occurred naturally.

It is unknown what effect predicted changes to future wind regimes with climate change may have upon aeolian transport volumes. However, while ever dunes are vegetated, windblown sediment is more likely to be captured and retained within the beach system.

2.6.4 Sand Mining

Review of the sand mining maps produced by Troesden *et al.* (2004) does not identify any areas of beach sand mining in the Bega region.

2.7 Coastal Entrances

Untrained entrances to coastal creeks, lakes or lagoons are subject to variability in both their location along the coastline and the adjacent shoreline shape. They may migrate along the beach from time to time depending on prevailing alongshore sand transport and/or stormwater discharge behaviour. The entrances may tend to close during periods of low rainfall and re-open by natural scour in high runoff events. Lateral movements of coastal entrances may affect the adjacent beaches and coastal assets.

The main coastal entrances in the Bega Valley Shire are listed (from north to south) in Table 2-7. Wallaga Lake, Bega River, Back Lake, Merimbula Lake, Lake Curalo, Wonboyn Lake and Pambula Lake have estuary processes/management plans in place or underway, which provide a detailed assessment of the complex tidal, fluvial and coastal processes that shape these systems. For the purposes of this study, the focus of discussions given in this report is on the interaction of these systems with open coast beach systems and hazards associated with coastal inundation.

2.7.1 Coastal Entrance Sedimentation

Coastal entrances can act as both a sink and a source for marine sediment along the coastline and are part of the natural sediment transport system.

Tidal delta shoals and entrance berms of coastal lagoons and creeks are a short term sink for marine sediment. Marine sediment is carried into the entrances on the incoming tide, which is typically greater than the outgoing tide, forming a flood tidal delta and shoal. When the creeks have minimal freshwater outflow for a period of time, the combination of tides and longshore transport processes act to close the entrance.

During flood conditions, the freshwater flows from the catchment will erode the entrance shoals, depositing the marine sediments back into the surf zone. In subsequent calm conditions, the marine sediments will be both reworked back into the entrance area to once again form shoals, as well as alongshore by the longshore currents. Over the long term, these processes can largely balance each other and the sediment budget may be considered to be in equilibrium.

Sea level rise may however impact on this dynamic equilibrium as higher water levels will have the tendency to alter the hydrodynamic conditions of coastal estuaries, which in turn is likely to result in morphologic changes. Although the effects of sea level rise on coastal entrances are not fully understood, these systems are expected to adjust to sea level rise dynamically, while maintaining a characteristic entrance geometry that is unique to its environmental setting. Generally, this will lead to growth of the marine deltas, with sediment sourced from adjacent beach systems (Van Goor et al, 2001, Van Goor et al., 2003, Stive, 2004). This process can potentially cause erosion an order of magnitude or more greater than that predicted with the equilibrium profile concept by Bruun (Woodworth et al., 2004, IPCC, 2007a).

The potential impacts of the morphologic changes in the entrance on the adjacent coastline in terms of shoreline recession will be influenced by the scale of the entrance system relative to that of the adjoining beach system. Therefore, a Sedimentation Demand Parameter (SDP) was defined and calculated for each entrance system in the Shire.

The SDP was defined as the ratio between the marine delta size, based on surface sedimentology data shown on the Quaternary Geology mapping (Troesdon et al., 2004), and the length of the adjoining shoreline. A large SDP value indicates that the adjacent shoreline is relatively sensitive to coastal entrance sedimentation (i.e. it may need to erode significantly to provide sufficient sediment to the entrance system as these systems attempt to main equilibrium as sea levels rise).

Conversely, a small SDP value indicates that the adjacent shoreline is relatively insensitive to coastal entrance sedimentation.

Table 2-7 Entrance Sedimentation Sensitivity Indicators of Bega's Estuaries and Lagoons

Coastal Entrance	Area of Marine Deltas (km^2)	Sedimentation Demand Parameter (SDP) (m^2/m)
Wallaga Lake	1.2	216
Bermagui River	0.9	585
Baragoot Lake	0.08	23
Cuttagee Lake	0.4	416
Murrah Lake	0.3	141
Bunga Lagoon	0.004	2
Wapengo Lake	1.4	1,192
Middle Lagoon	0.1	36
Nelsons Lagoon	0.5	640
Bega River	1.5	454
Wallagoot Lake	1.1	259
Bondi Lake	0.004	1
Bournda Lagoon	0.085	20
Back Lake	0.089	25
Merimbula Lake	2.5	418
Pambula River	1.3	2,177
Lake Curalo	0.3	134
Nullica River	0.4	163
Towamba River	0.8	450
Wonboyn Lake	2.6	408

3 Coastal Hazards Definition Assessment Methodology

3.1 Hazard Probability Zones

The definition of coastal hazards inherently involves uncertainty relating not only to coastal processes, but also to the uncertainties involved with climate change. There are uncertainties surrounding climate change projections, the timeframes over which this change may occur, as well as how climate change may affect the environment. Irrespective of climate change, coastal hazards have always presented a challenge to planners and managers. There is generally limited data on coastal processes (e.g. historical shoreline change, wave climate, water levels, etc.) and there are many different ways to assess the extent of hazards.

A risk-based approach has been adopted for defining hazards in the study area. A risk assessment approach is a powerful methodology for dealing with uncertainty in processes and information. Rather than attempting to provide a single answer with absolute and potentially unfounded accuracy, the risk assessment approach allows consideration of a range of events, their likelihood, consequence and thus the overall level of risk.

The use of the risk assessment framework for managing coastal hazards is prescribed in the CZMP Guidelines, as well as the NSW Government's *NSW Coastal Planning Guideline: Adapting to Sea Level Rise*. The accepted process for identifying and managing risks is outlined in the Australian Standard Risk Management Principles and Guidelines (AS/NZS ISO 31000:2009).

A risk is considered to be the probability of an event occurring and the consequential impact of the event upon the asset or value. Under the Australian Standard, risks are analysed in terms of their 'likelihood' and their 'consequence'. Coastal hazards are considered to be the event that is to be analysed through risk management, therefore both 'likelihood' and 'consequence' of the hazards needs to be analysed.

The Hazards Definition phase of the NSW coastal management process is suited to defining the 'likelihood' or probability of occurrence of coastal hazards, through the analysis of coastal processes, historical beach response, and likely future response. Based upon the Australian Standard for Risk Management (AS/NZS ISO 31000:2009) and its companion document (Handbook HB 436:2004), the scale of 'likelihood' or probability of occurrence for a hazard impact is given in Table 3-1. It is important to note that this is a qualitative scale, not a quantitative mathematical probability assessment. The timeframes over which coastal hazards probability has been assessed is defined in Table 3-2, namely the immediate (2014), 2050 and 2100 planning horizons.

Ascribing likelihood to the hazard estimates provides transparency regarding the uncertainties, limitations and assumptions used to assess hazards. In addition, ascribing likelihood to coastal hazards can educate coastal planners and the wider community that hazard lines are estimates only and not precise predictions of future shoreline response.

The consequences of coastal hazards should be analysed as part of the subsequent Coastal Zone Management phase of the NSW coastal management framework (refer Section 1.3), and will relate to the type of coastal hazard impact and the assets and values of coastal land affected. For example, the consequence of 'almost certain' beach erosion at one beach may involve the loss of one or many houses, but at another beach it may be the loss of national park lands or foreshore reserves. The resulting 'risk' is different based on the value or asset exposed to the hazards (i.e. 'consequence'), not just the extent of the hazard (i.e. 'likelihood'). During the coastal management stage, consequence and likelihood are combined to give the level of risk from coastal hazards at various locations along the coastline. Management responses may then be developed and targeted towards areas at highest risk.

During this study, it has been found that the historical beach response and other data was not comprehensive or sufficiently detailed to differentiate between the five likelihood categories that are typically used in ISO 31000 risk assessments (see Table 3-1). Rationalisation of these categories has thus been required, with focus given to 'almost certain', 'unlikely' and 'rare' probabilities for the immediate, 2050 and 2100 planning horizons. It has been presumed that these categories will provide a sufficient level of detail for coastal planning purposes.

Furthermore, to aid in the understanding of the hazard estimates by the community, we have updated the likelihood descriptors for the purpose of the hazards mapping, as shown in Table 3-1, and have assumed that:

- The '**almost certain**' descriptor is readily understandable, and remains as is;
- The **'unlikely'** descriptor provides the best estimate for future hazard that should be expected to occur, albeit infrequently, for use in hazard management and planning; and
- The **'rare'** descriptor provides a worst case scenario of future hazard (similar to the "probable maximum flood" estimate provided for flood hazard mapping), which would not be expected to occur, but may occur in an extreme case.

The use of the above descriptors does not compromise Council's ability to apply a risk based approach to developing the Coastal Zone Management Plan (indeed, the equivalent likelihood descriptors remain available within this report for easy transition into a risk assessment).

It is noted that the assessment technique undertaken to provide an analysis of likelihood to the beach erosion hazard estimates is necessarily qualitative. The assessment has been fully disclosed within this document to provide a justifiable and defensible explanation for the assigning of likelihoods to the various hazard extents derived. Irrespective of this being a qualitative assessment, the benefits to the community and Council from this risk based approach (such as the provision of sensitivities around the uncertainty of hazard assessment) remain. It is further noted that there is currently no available and reliable method for assessing a quantitative hazard probability.

Our understanding of coastal processes and potential for hazards impacts has improved and will continue to improve, allowing for improvements in determination of likelihood or probabilities in the future. Council is encouraged to continue to expand their data collection in order to have ongoing datasets with which to refine the coastal risk assessment into the future. This would include for example conducting regular beach surveys, both on a periodic basis and following consequential storms. The surveys could be conducted along the existing photogrammetric cross-shore transects, and new transects at regular intervals (100m or so) that extend from the top of the dune to the water line or further where practicable. The surveys should be repeated across the same transects, and regular LiDAR surveys will add to the data collation exercise.

Table 3-1 Risk Likelihood / Probability

Likelihood	Description
Almost Certain	There is a high possibility the event will occur as there is a history of casual occurrence.
Likely	It is likely the event will occur as there is a history of infrequent occurrence.
Possible	The event has occurred at least once in the past and may occur again.
Unlikely	There is a low possibility that the event (or chain of events) will occur, however, there may be a history of infrequent or isolated occurrences at some locations.
Rare	It is highly unlikely that the event (or chain of events) will occur, except in extreme / exceptional circumstances, which have not been recorded historically.

Table 3-2 Timeframes for Coastal Planning

Timeframe	
Immediate	Present day conditions (2014)
2050	Expected conditions by circa 2050
2100	Expected conditions by circa 2100

3.2 Climate Change Projections Relevant to the Definition of Coastal Hazards

Scientific research on potential impacts of climate change indicates that the following fundamental impacts have the potential to affect the individual coastal processes that generate coastal hazards:

- Sea level rise;
- Changes to the wave climate; and
- Changes to storm surge behaviour.

A summary of the climate change parameters that have been incorporated in this coastal hazard assessment is provided below.

3.2.1 Sea Level Rise

The former NSW Government's Sea Level Rise Policy Statement (now repealed) recommended that an increase in mean sea level above 1990 levels of 0.4 m by 2050 and 0.9 m by 2100 (relative to 1990 level) be used in all coastal assessments in NSW, based upon IPCC (2007b) and CSIRO (2007) reports (see DECCW, 2009).

With the repeal of the document in 2012, the NSW Government now acknowledges that local councils "have the flexibility determine their own sea level rise projections to suit their local conditions" (NSW Environment and Heritage, 2012). The Office of Environment and Heritage

(OEH) has recommended that councils consider sea level rise projections that are ‘widely accepted by competent scientific opinion’, or indeed consider a range of probable projections (OEH, 2013).

Bega Valley Shire Council has adopted a sea level rise policy for planning purposes that is consistent with the former NSW Government’s Sea Level Rise Policy and provides for an increase in mean sea level of 0.91m by 2100 above 1990 levels (BVSC, 2013).

The global average rate of sea level rise measured over the last century was 1.7 mm/year (Church *et al.*, 2010). (CSIRO/ARECRC, 2012) indicates that the global rate of sea level rise over the last decades has been substantially larger and estimated based on analysis of tidal gauge data and satellite observations that the rate has been around 3.1 ± 0.4 mm/year since 1992. Wainwright and Lord (2014) analysed a number tidal gauges along the NSW coastline and found a similar rate of mean sea level rise at those gauges.

Assessment Report 5 (IPCC, 2013) provides the latest projections on global sea level rise from the Intergovernmental Panel on Climate Change. Figure 3-1 presents the global sea level rise projections for the four principal greenhouse gas emission scenarios, or Representative Concentration Pathways (RCPs), considered in this report.

This figure shows that sea level rise policy benchmark adopted by Bega Valley Shire Council is consistent with the projected global mean sea level rise by 2100 for RCP 8.5 (more or less the “business as usual” scenario). Accordingly, the *‘unlikely’* sea level rise is based on Council’s benchmarks.

While projections of Assessment Report 5 indicate the rate of sea level rise is likely to be higher, the recent rate of sea level rise can be used to estimate the sea level rise that can be expected by 2050 and 2100 as a minimum or ‘almost certain’ probability. The *‘almost certain’* sea level rise from present to 2050 and 2100 calculated from a rate of 3.1 mm/year is given in Table 3-3.

There is a chance that sea level rise may exceed the current IPCC projections. In this case, a higher sea level rise value should also to be investigated, albeit as a worst case or rare scenario. Evidence from the previous interglacial period (some 125,000 years ago during the Pleistocene) indicates that sea levels were some 4-6 m higher than present, and global temperatures were about 3-5 °C higher than present (Church *et al*., 2010). It is thought that the higher sea levels at that time were due to contributions from the Greenland Ice Sheet and the Antarctic Ice Sheet to a lesser degree (Church *et al*., 2010 citing Otto-Bliesner *et al*., 2006).

Over the next century, sea level rise of 0.5 m by 2050 and 1.3 m by 2100 (i.e. an approximately 50% faster rate of rise than the ‘Unlikely’ projections) are considered a reasonable worst case scenario. The higher than projected sea level rise also provides for investigation of impacts where sea level rise occurs faster than projected.

The sea level rise provisions adopted for the investigation of future coastal hazards are given in Table 3-3.

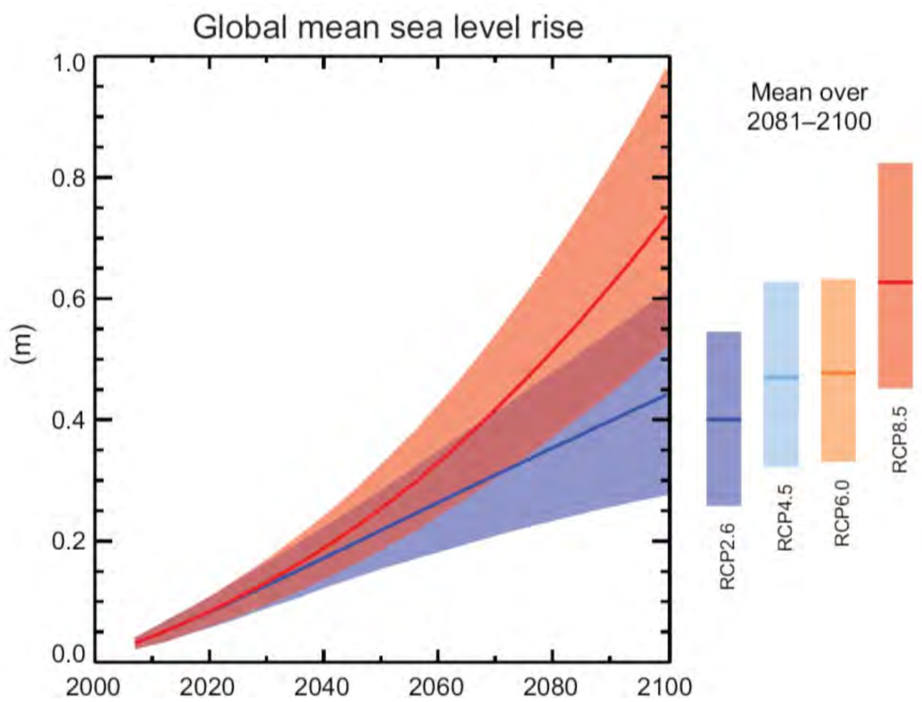


Figure 3-1 Projected Sea Level Rise to 2100, Relative to 1986-2005 Level (source: IPCC 2013)

Table 3-3 Sea Level Rise Values Applied in this Study (metres above present day levels*)

Likelihood	*2050*	*2100*
Almost Certain	0.12 m	0.28 m
Unlikely*	0.34 m	0.84 m
Rare	0.5 m	1.3 m

** Note that OEH has advised that an estimated sea level rise of 0.06m between 1990 and present should be considered in coastal assessments.*

3.2.2 Storm Surge

Storm surge comprises the barometric pressure and wind set up components that, when added to the astronomical tidal level and wave set up, comprise elevated water levels during a storm. Elevated water levels may increase the severity of coastal erosion by moving the wave impact and swash zone further up the beach face. Elevated water levels also result in inundation of low lying lands where it is connected with the ocean through a coastal entrance of a creek, lagoon or river.

For changes in storm surge due to climate change for Batemans Bay, McInnes *et al.* (2007) calculated +1% or –1% change by 2030, and either a -3% or +1% change by 2070. This has been extrapolated to about 0.005 m by 2050 and 0.01 m by 2100.

Given that the percentage changes equate to very small changes in water level and are somewhat inconclusive as to the direction of the change (increase or decrease), no provisions have been included in the coastal hazards assessment for potential future changes in storm surge.

3.2.3 Wave Climate

Theoretically, an increase in storm intensity or wave height means that beaches may experience greater erosion of sand during individual storms, while increased storm frequency means that beaches have less time to recover and accrete sand upon the upper beachface before the next storm occurs. Any increase in storm intensity or frequency due to climate change will be coupled with a rise in sea level, further intensifying potential storm erosion. Further, a sustained shift in the wave direction (even if not combined with a change in wave height) may impact upon coastlines, because it is the wave direction relative to the orientation of the shoreline that is a key determinant for longshore sediment transport rates (within or between embayments).

McInnes *et al.* (2007) investigated future wave heights (average swell and storm waves) and future wave directions due to climate change for Batemans Bay, which is considered relevant to the Bega Shire. For Batemans Bay, McInnes *et al.* (2007) calculated that storm waves may increase by 7% or 11% by 2030, and increase by 32%, or decrease by 6% by 2070. Projections for changes to swell wave height from the dominant SSE direction for Batemans Bay were either a 0% or 8% increase by 2030, then either a decrease or increase by 8% by 2070. Projected changes to swell wave direction given by McInnes *et al.* (2007) suggested a shift of up to 3.8° more easterly at Batemans Bay. Such shifts in wave direction are within the variability of the existing wave climate.

The historical shifts in wave climate that occur naturally are greater in range than the predicted shifts in the future wave climate given McInnes *et al.* (2007). Indeed, McInnes *et al.* (2007) suggest that the historical variability of wave climate over the past 60 years most likely reflects the range of possible conditions over the next century. The resolution of the climate change models (CCM2 and CCM3) used to derive the predictions for both studies is not sufficiently precise to replicate all of the climatic systems important to the NSW coast. Most notably, the models cannot fully simulate the occurrence of east coast low weather systems that are responsible for extreme waves in NSW.

Given the above limitations, changes to storm wave height or mean wave direction due to climate change were not investigated as part of the coastal hazards assessments.

3.3 Assessment of Erosion Hazard

The beaches along the study region experience considerable short term (days; weeks; months; years) fluctuation and short to medium term (years) variability due to changes in the prevailing wave and water level conditions, including storm events and shifts in the predominant wave direction. Additionally, there may be a general regional trend of long term shoreline recession.

The conceptual pattern of shoreline variability and progressive long term change is illustrated in Figure 3-2. It can be seen that a beach location may experience periods of sustained shoreline accretion despite the longer term erosion trend. Correspondingly, there may be periods of recession at greater than the longer term trend rate. The short to medium term fluctuations may thus mask the longer term trend and care must be taken in interpreting shoreline change data, particularly over limited time periods.

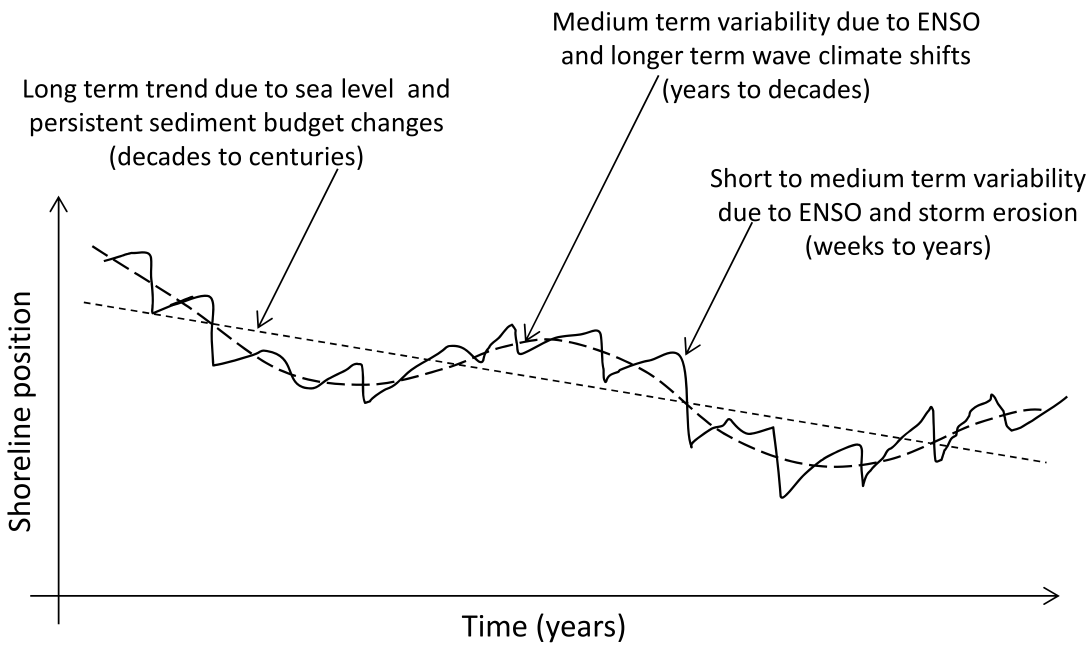


Figure 3-2 Conceptual Shoreline Variability

3.3.1 Adopted Approach

The erosion hazard extents for the immediate, 2050 and 2100 planning times are based on the contemporary behaviour and forward projections of historical shoreline behaviour derived from the available data, together with analysis using either conventional coastal engineering methods and modelling of shoreline responses to sea level rise (SLR) and other likely climate change factors.

The erosion hazard extent is thus assessed by taking account of the combined factors of:

- Storm bite extent;
- Natural short to medium term variability of the shoreline; and
- Projection to the future, with hazard definition at years 2050 and 2100,of:
  - Any presently prevailing long term of shoreline recession; and
  - Shoreline recession caused by the effects of projected future climate change induced sea level rise.

The 'immediate' erosion hazard extent represents the zone that could be affected by erosion in the immediate near future (e.g. over the next few years), while the 2050 and 2100 extents incorporate a landward shift in the immediate hazard line in response to shoreline recession provisions.

For the purposes of defining the extents of the erosion hazards within the study area, the following approach has been followed in determining the erosion hazards:

(1) Establishing the 'immediate' erosion hazard line for each likelihood descriptor that incorporates;

(a) The storm bite component to the crest of the erosion scarp calculated on the basis of removal of the design storm bite volumes from above the erosion profile across the beach/dune above AHD. The baseline shoreline from which the storm bite is measured is taken as the dune/beach position derived from a topographic LiDAR survey of 2008; and

(b) Shoreline variability related to short to medium term variations in wave climate, as derived from analysis of historical movements in the shoreline position;

(2) Projecting the 'immediate' erosion extents, which contain the provisions above by estimates of the shoreline recession to 2050 and 2100, incorporating;

(a) An provision for the underlying progressive trend of shoreline recession, based on analysis of available photogrammetric data and assessment of coastal processes; and

(b) The future recession as a result of shoreline responses to potential future sea level rise.

It should be noted that there is a zone of reduced foundation capacity that extends landward of these erosion hazard estimates, as discussed in Section 3.3.7.

3.3.2 Analysis of Photogrammetric Data

Photogrammetric data provides information on changes to beach volume and the position of dunes over time. While inaccuracies can be common in older dates of photogrammetric data, the photogrammetry was considered to be sufficiently accurate for all dates analysed in this study. Photogrammetry provides data on changes above mean sea level, therefore consideration of longer term trends is based primarily on movements of the upper beach/dune system. However, the photographs present individual 'snap-shots' that describe beach state at one particular time. Knowledge of the timing and intensity of major historical storm erosion events relative to the photogrammetry dates is taken into account in interpreting the available data.

Photogrammetric data coverage for the Bega Valley Shire includes:

- Moorhead (Bermagui coast), with reliable data at 1944, 1963, 1977, 1988, 1999, 2007, 2011;
- Horseshore Bay (Bermagui coast), with reliable data at 1944, 1963, 1977, 1988, 1996, 1999, 2011;
- Cuttagee Beach (Southern end of Baragoot /Cuttagee embayment), with reliable data at 1963, 1977, 1979, 1980, 1986, 1988, 1993, 1999, 2001, 2007, 2011;
- Tathra Beach, with reliable data at 1966, 1972, 1975, 1980, 1988, 1993, 1999, 2007, 2011;
- Pambula / Merimbula Beach, with reliable data at 1962, 1972, 1975, 1977, 1979, 1989, 1993, 2001, 2007, 2011; and
- Aslings Beach (Twofold Bay), with reliable data at 1964, 1986, 1996,1999, 2001, 2011.

The extents of each photogrammetric data set are shown in Appendix A.

The photogrammetric data has been processed to calculate beach / dune volumes for each profile cross-section, and both average and cumulative volumes along representative sections of shoreline analysed. The envelope of volumetric variability in the photogrammetric data over a period of several years or decades may provide a measure of the potential storm bite volume even where the data does not relate to any particular storm event, provided any long term trends are taken into account. This recognises both storm erosion and short term (months to years) variability due to alongshore fluctuations.

As well, the horizontal distances to several specified level contour positions have been determined to indicate beach width variability and any movements of the dune face. For this study, positions of the +1.5m, +2.5m and +4m AHD contours have been analysed, with movements in the +4m contour indicating any progressive shift over the long term in the extent of storm erosion, also an indicator of long term recession.

Review of photogrammetric processing methods by Hanslow (2007) concluded that both the horizontal movement of a selected dune contour position and the sub-aerial beach volume calculation have statistical significance to be appropriate for use in hazard assessments. Both of these methods have advantages and disadvantages. Both the sub-aerial beach volume data (cumulative block volumes, individual profile volumes) and dune contour position movements have been used to assess storm bite potentials, as well as historical long term shoreline trends.

3.3.3 Beach Erosion (Storm Bite)

The beach erosion hazard probabilities have been based upon the observed dune/beach volume losses recorded in the available photogrammetry data.

For each photogrammetric profile, the available data was processed to calculate the beach / dune volume variability between two consecutive survey dates. Photogrammetric data from profiles near and across creek mouths and drainage lines were not included in the assessment of beach erosion extents, as the volume changes in these locations are generally dominated by processes other than storm erosion (eg. flood and break out events). Furthermore, the photogrammetric data for Aslings Beach has not been included in the assessment, as the available dates for this beach were deemed to be inadequate for the purposes of the analysis.

Analysis of the photogrammetric data suggests that most beaches within the Shire have experienced their greatest beach erosion during the 1970s (See also Figure 3-8 to Figure 3-10).

Figure 3-3 to Figure 3-7 present the maximum beach/dune volume losses between two consecutive survey dates for each beach with photogrammetric coverage. These figures indicate a maximum historical storm bite demand in the range 200-250 m^3/m of beach sediment above AHD for the fully exposed ocean beaches and approximately 120-150 m^3/m for more protected embayments, with generally somewhat lower storm bite volumes at the where headlands provide significant protection against incoming storm waves. These historical storm bite volumes are consistent with typically observed maximum storm bite volumes elsewhere along the NSW coastline.

The photogrammetric analysis of Tathra Beach found somewhat higher erosion volumes at some profiles along this beach between 1972 and 1975 data (with maximum volume losses of up to approximately 280 m^3/m). However, it is considered that these observed volumetric losses were not only caused by storm erosion processes, but also influenced by beach response to the substantial scour that occurred at the Bega River entrance during the February 1971 flood event. As such, these volumes are not considered representative indicators for the storm bite capacity at that beach.

The photogrammetric data of Horseshoe Bay suggests that historical storm demand at Horseshoe Bay has been limited to less than 50m^3/m, substantially less than the storm bite volumes at the other embayed ocean beaches within the Shire or typically observed elsewhere along the NSW coastline. While the bay's northerly aspect combined with its sheltered position behind Point Dickinson produces a comparatively low wave energy environment, it is considered unlikely that the values of the photogrammetric analysis provide a reliable estimate of the storm bite capacity for this beach. Kidd (2000) suggested a design storm demand of 80 – 100 m^3/m for Horseshoe Bay, which is considered to be a more appropriate estimate of the storm bite capacity at this location.

In deriving 'Almost certain' and 'Unlikely' hazard extents, it has been assumed that the conditions that produced the most eroded profiles in the past will occur again in the future. For exposed ocean beaches, a regional beach erosion provision of 200 m^3/m was adopted as the "Almost certain" probability of occurrence of beach erosion and 250 m^3/m for the "Unlikely" probability of occurrence. Similarly, a uniform beach erosion value of 120 m^3/m and 150 m^3/m was adopted for the "Almost certain" and "Unlikely" hazards at protected embayments and less exposed beaches.

There are limitations in the extent, coverage and accuracy of available historical data that must be acknowledged. It is possible that the largest beach erosion has not been recorded by historical (photogrammetric) data. To account for this uncertainty, a "Rare" beach erosion hazard has also been derived. In lieu of supporting data that would enable a more refined approach, an additional volume provision of 20% was applied to the "Unlikely" estimates.

A summary of the beach erosion volumes adopted in the assessment of the beach erosion extents are presented in Table 3-4.

For a given beach erosion volume, the landward erosion distance depends on the height and shape of the dune affected. The foredune along many beaches of study area has a typical height of about 4-5m (AHD). Where the average dune height is about 5m, a storm bite of 250m^3/m would correspond to about 50m recession. Higher dunes will erode less distance.

Each beach location was analysed on an individual basis. The storm bite component to the crest of the erosion scarp was calculated on the basis of removal of the design storm bite volumes from above the erosion profile across the beach/dune above 0 AHD. The baseline shoreline for this was a LiDAR survey conducted in 2008. The beaches in the region exhibited a generally accreted beach and dune condition at this time with most embayed beaches showing an overall southerly orientation.

Table 3-4 Adopted Design Beach Erosion Volumes above AHD

Likelihood*	Exposed ocean beach	Protected embayments
'Almost Certain'	200 m^3/m	120 m^3/m
'Unlikely '	250 m^3/m	150 m^3/m
'Rare'	300 m^3/m	180 m^3/m

Figure 3-3 Storm Erosion Assessment – Moorhead

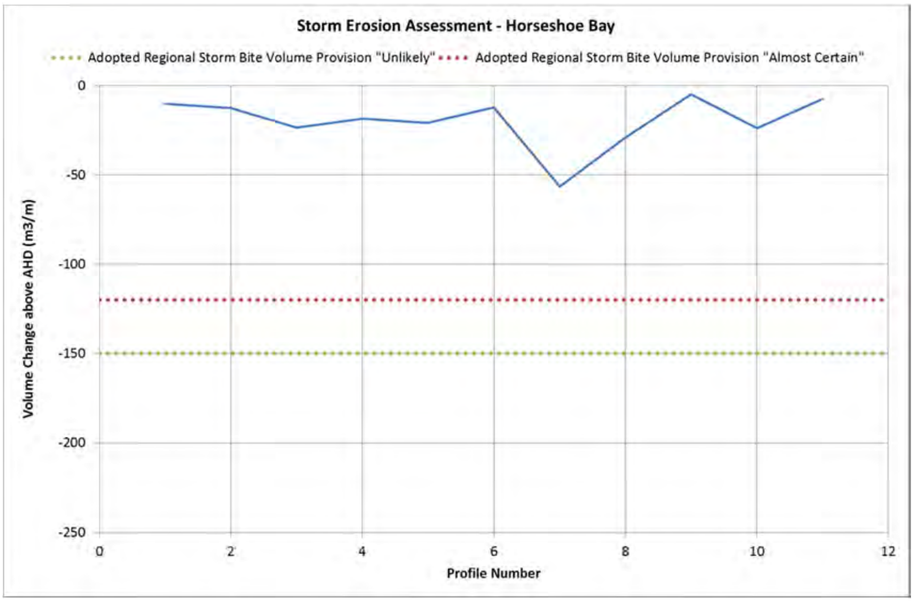


Figure 3-4 Storm Erosion Assessment – Horseshoe Bay

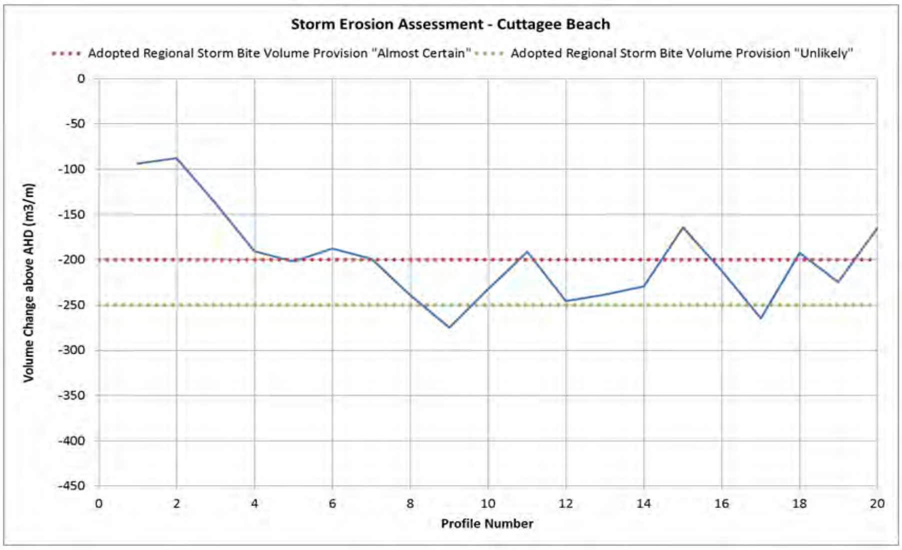


Figure 3-5 Storm Erosion Assessment– Cuttagee Beach

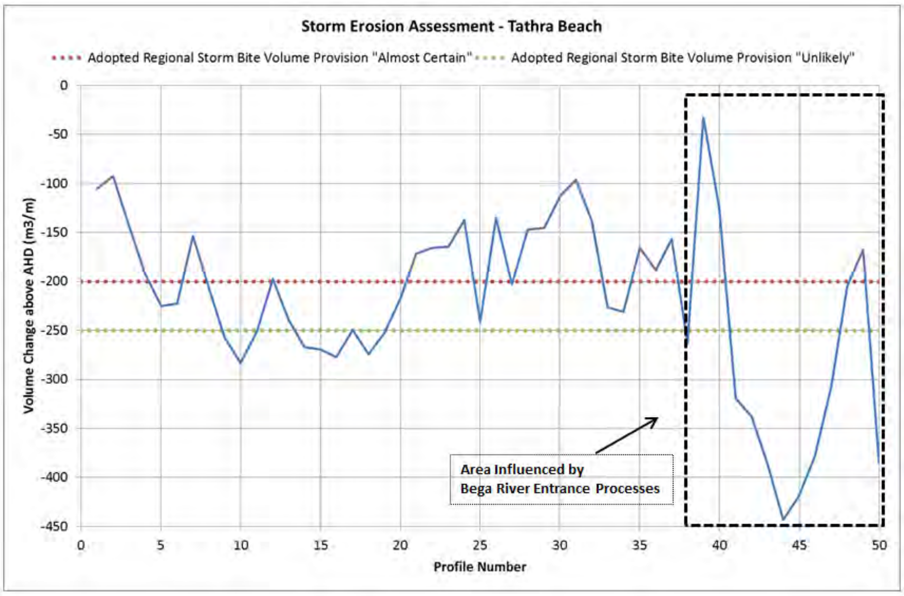


Figure 3-6 Storm Erosion Assessment – Tathra Beach

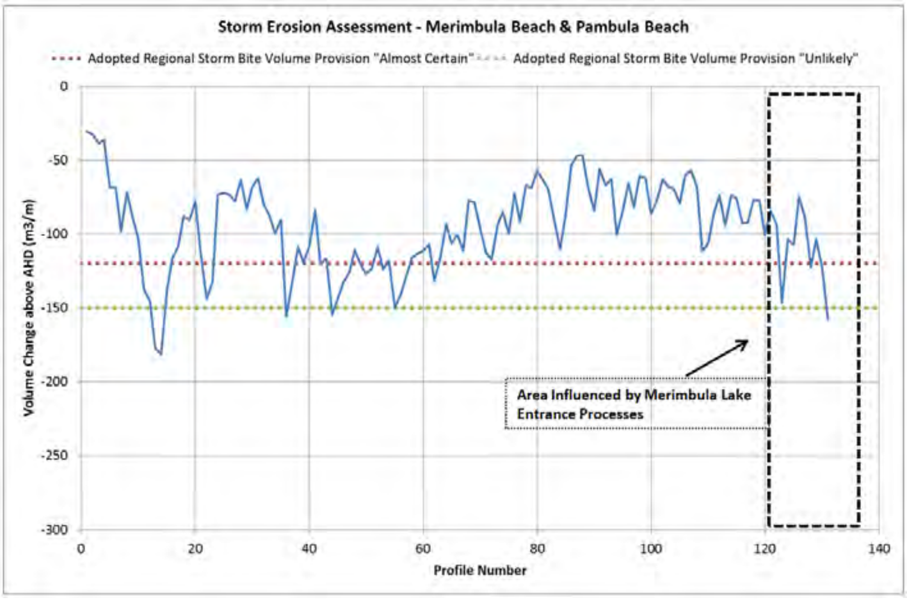


Figure 3-7 Storm Erosion Assessment – Pambula / Merimbula Beach

3.3.4 Beach Rotation

Many of the embayed beaches along the southern and central NSW coastline have experienced a clockwise rotation since the late 1970s, which resulted in significant shoreline erosion at their southern end and accretion at the northern end. It is considered that this rotation is due to medium term variability in the wave climate, related to a shift from a prolonged La Nina dominated phase to an El Niño phase (Ranasinghe *et al.* 2004).

Ranasinghe *et al.* (2004) suggested that a reversal to a La Nina dominated phase (positive SOI) would result in a similar anti-clockwise adjustment of the regional beach alignment. This would occur rapidly following the SOI shift (in order of a few months).

The beach rotation discussions have been based upon observed shoreline realignments at selected beaches in the study area. Available photogrammetric data and aerial photography was analysed to estimate the rotation that has been experienced since the shift from the La Nina dominated phase (1947 to 1977) to a phase of El Niño dominance.

The analysis of photogrammetric data involved calculation of the average movement of the +4.0m AHD contour position at each end of an embayment between the early1970s and the mid/late 2000s, relative to the overall average movement of the dune face position within the embayment (refer to top and bottom graphs in Figure 3-11 to Figure 3-16).

On this basis, the beach rotations are calculated, with results presented in Table 3-5. This table demonstrates that all embayments, with the exception of Aslings Beach, have seen a clockwise rotation since the 1970s. In addition, the table shows that the beach rotation has generally been larger (up to 0.6º) at the exposed embayments (Cuttagee Beach/Baragoot Beach and Tathra Bay) compared to the more protected beach units.

Table 3-5 Summary of Beach Rotation Analysis

Location*	*Movement at Southern end*	*Movement at Northern end*	*Beach Rotation*
Horseshoe Bay	-2m	+2m	+0.4°
Cuttagee/Baragoot Beach	-14m	+25m*	+0.6°
Merimbula Bay	-11m	+6m	*+0.2°*
Tathra Bay	-20m	+17m	+0.6°
Aslings Beach	+2m	+2m	+0.0°

* *Determined from dune vegetation lines in 1967 and 2010 aerial photography (no photogrammetric data available); Refer to Figure 2-14)*

For this study it is considered that beach rotations to date are captured within the photogrammetric analysis and as such no separate provision for future beach recession due to this phenomenon is included. However, it is recommended that beach rotations continue to be observed and analysed, particularly in relation to longer term El Niño and La Nina events, and if significant anomalies occur then a review of this policy may be warranted.

3.3.5 Shoreline Recession

Shoreline recession, or long term recession, is defined in the Coastline Management Manual (NSW Government, 1990) as the permanent landward movement of the shoreline position. Unlike beach erosion, shoreline recession results in permanent changes to the coastline.

Shoreline recession is typically related to sand sinks or longshore transport differentials. However, a landward movement of the shoreline is also predicted in response to rising sea levels, as illustrated with the Equilibrium Profile (or Bruun Rule) concept and discussed in greater detail in Section 3.3.6.1. Rates will vary along the shoreline depending on the shoreline configuration and the prevailing processes.

The shoreline recession provisions incorporated in the erosion hazard extents for the 2050 and 2100 planning times have been based on the following:

(a) A provision for the underlying progressive trend of shoreline recession, based on analysis of available photogrammetric data and assessment of coastal processes; and

(b) The future recession as a result of shoreline responses to potential future sea level rise.

3.3.5.1 Analysis of Historical Shoreline Recession

Historical shoreline recession trends may be identified most readily in the photogrammetry data in terms of either:

- Persistent progressive changes in the volume of sand contained in the beach/dune system; and/or

- Persistent and progressive changes in the position of the dune scarp.

Beaches experiencing long term recession are characterised by a persistent trend of reduction in the average sand volume and, often, a prominent back beach escarpment which moves landward over time. Net sand losses generally affect the nearshore area initially, typically due to alongshore gradients in the longshore sand transport rates. When the nearshore area has been depleted of sand progressively by longshore sand losses, the storm cut into the beach and dune will be unusually high and extend further landward than previously. In such a case, the beach will not recover to its former state.

The assessment of long term recession involved analysis of photogrammetric data to identify trends of recession or accretion along the Bega Valley's beaches and quantify rates of long term recession/accretion. Each photogrammetric data set was analysed to determine average block volumes changes at each beach. In addition, analysis of changes in cross-shore position of three adopted contour levels, namely RL+1.5m, RL+2.5m and +4.0m (AHD) was undertaken to identify movements in the beach width (approximate berm edge), foredune toe and main dune face respectively. It is expected that the lower levels of RL+1.5m, RL+2.5m will show more variability as the beach responds naturally to storm erosion and subsequent accretion. Similarly it is expected that the +4m contour position will be more indicative of longer term processes.

The analysis carefully considered the quality of the photogrammetric data (as evident in profile cross section diagrams) such as level inaccuracies in older photographs. Based upon this, data from certain older dates (typically 1944) for selected profiles or the entire embayment were excluded.

Figure 3-11 to Figure 3-16 present results of the photogrammetric analysis in terms of the averages within each block of the respective:

- Distances of the RL+1.5m, RL+2.5m and RL+4.0m contour lines from the baseline of the photogrammetry for each profile; and
- Volume changes above 0m AHD, seaward of a fixed position for each profile, chosen to represent the beach and dune while limiting error due to inaccuracies in the hind-dune area.

It should be noted that the changes in the lower levels (RL+1.5m, RL+2.5m) will be very responsive to ambient beach movements relating to storms and subsequent recovery as well as timing of the survey (e.g. immediately after a storm). The higher contour (RL+4.0m) is more indicative of longer term trends and a persistent recession of this value, as well as a persistent reduction in dune volume, will lead to the inclusion of a long term recession value in erosion calculations.

Typical profile shapes and their history during the observation period are presented in Figure 3-8 to Figure 3-10.

Figure 3-9 illustrates the general profile evolution along Pambula/Merimbula Beach during the observation period. It shows the magnitude of the dune that existed in 1962 to 1972, which was lost to erosion by 1979 (due to the severe storms in 1974, 1975 and 1978). It further shows the subsequent beach recovery, which in the southern parts had the form of berm widening to 1993 and dune growth to a level of approximately +4mAHD since then. A back beach escarpment is still evident in most beach profiles and the dune volume and extent in 2011 is somewhat less than the condition in 1962. The photogrammetric data indicates an average reduction in beach/dune volume of approximately 27m^3/m between 1962 and 2011 (Refer to Figure 3-15). This is equivalent to an average volumetric recession rate of approximately. 0.6m^3/m/yr (or an average shoreline recession rate of just over 0.1m per year).

The general profile evolution along Tathra Beach (Figure 3-10) shows a similar behaviour to that of Pambula/Merimbula Beach. However, the largest erosion losses occur earlier (generally by 1975) and are associated with the beach response to the February 1971 flood event of the Bega River. The average volumetric recession rate over the observation period is calculated to be approximately 0.5m^3/m/yr (equivalent to an average shoreline recession rate of about 0.1m per year).

Figure 3-8 presents the general profile evolution along Moorhead Beach and Horseshoe Bay during the observation period. It shows that the beach at Horseshoe Bay is generally stable, while Moorhead Beach has exhibited a trend of long term accretion in the form of significant growth of its dunes and seaward advancement of the shoreline position since 1963 (See also Figure 3-11).

The accretion is likely to be related to the construction of the Bermagui River training walls, completed in 1959. The photogrammetry data illustrates that accretion was particularly large in the first decades following the construction and has since moderated. In addition, the data shows that the largest accretion has occurred at the northern half of the beach. Interestingly, this historical pattern of shoreline change was replicated well by the shoreline evolution modelling undertaken as part of this study (refer to Section 3.3.6).

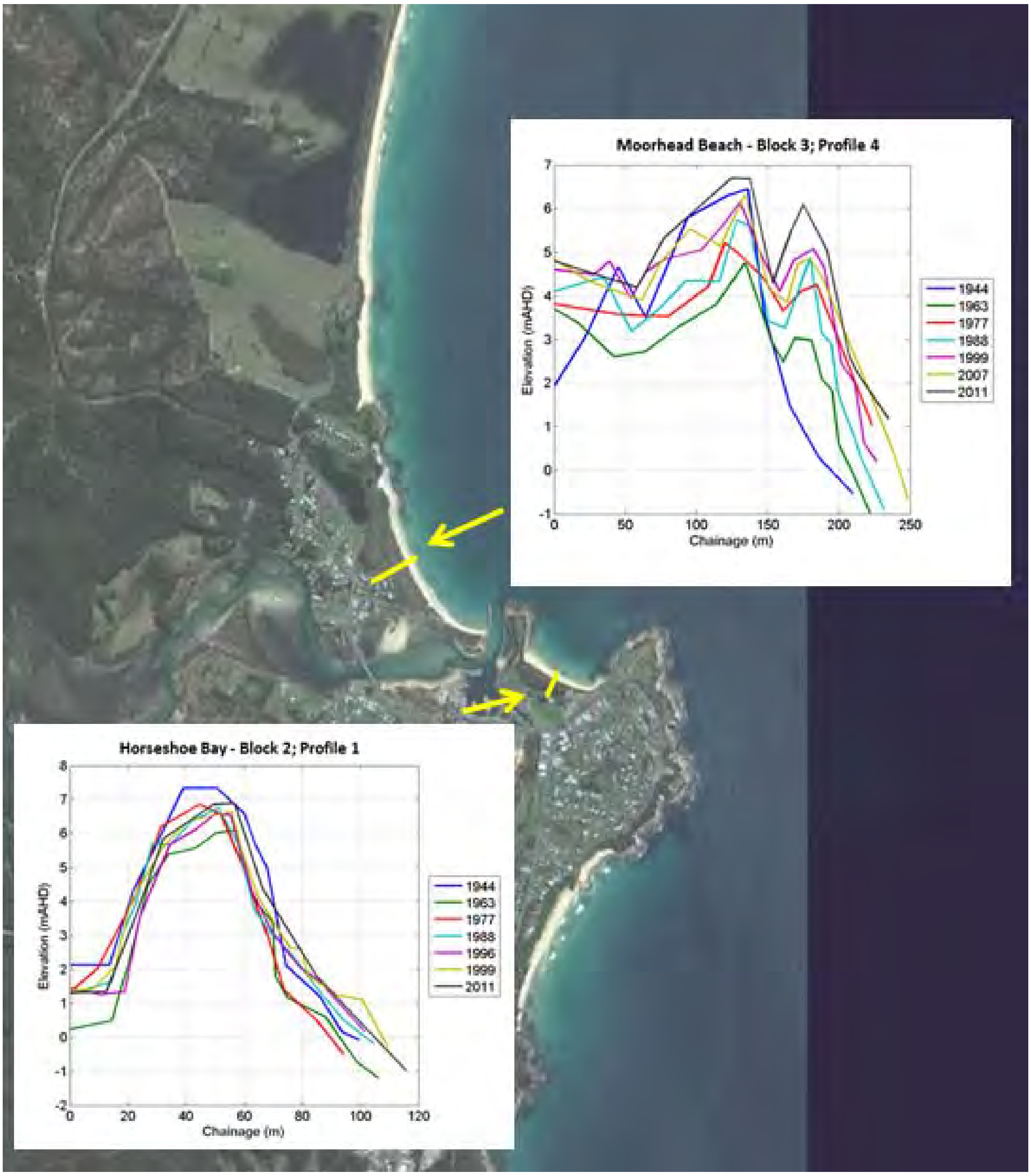


Figure 3-8 Selected Beach Profiles– Moorhead Beach / Horseshoe Bay

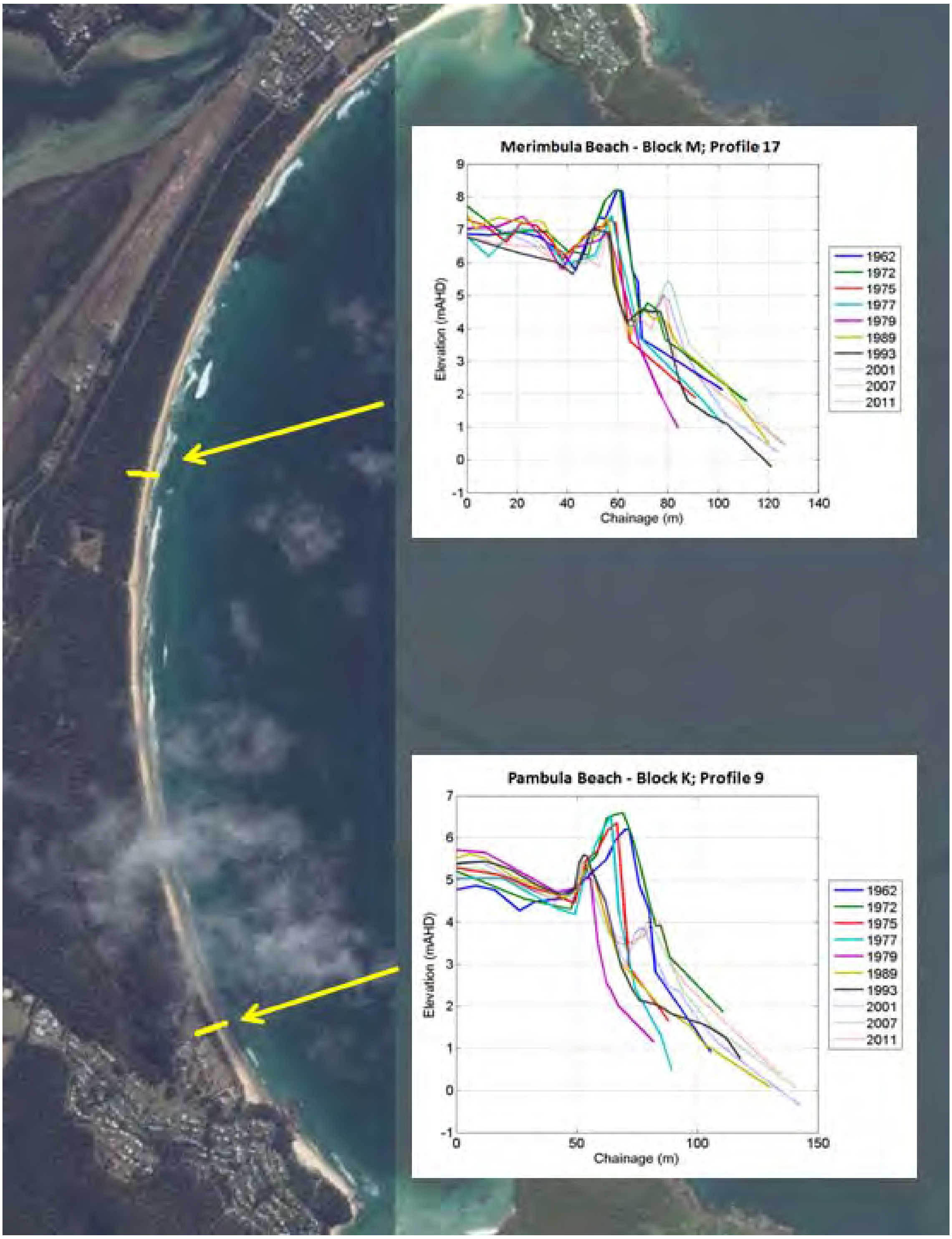


Figure 3-9 Selected Beach Profiles– Pambula/ Merimbula Beach

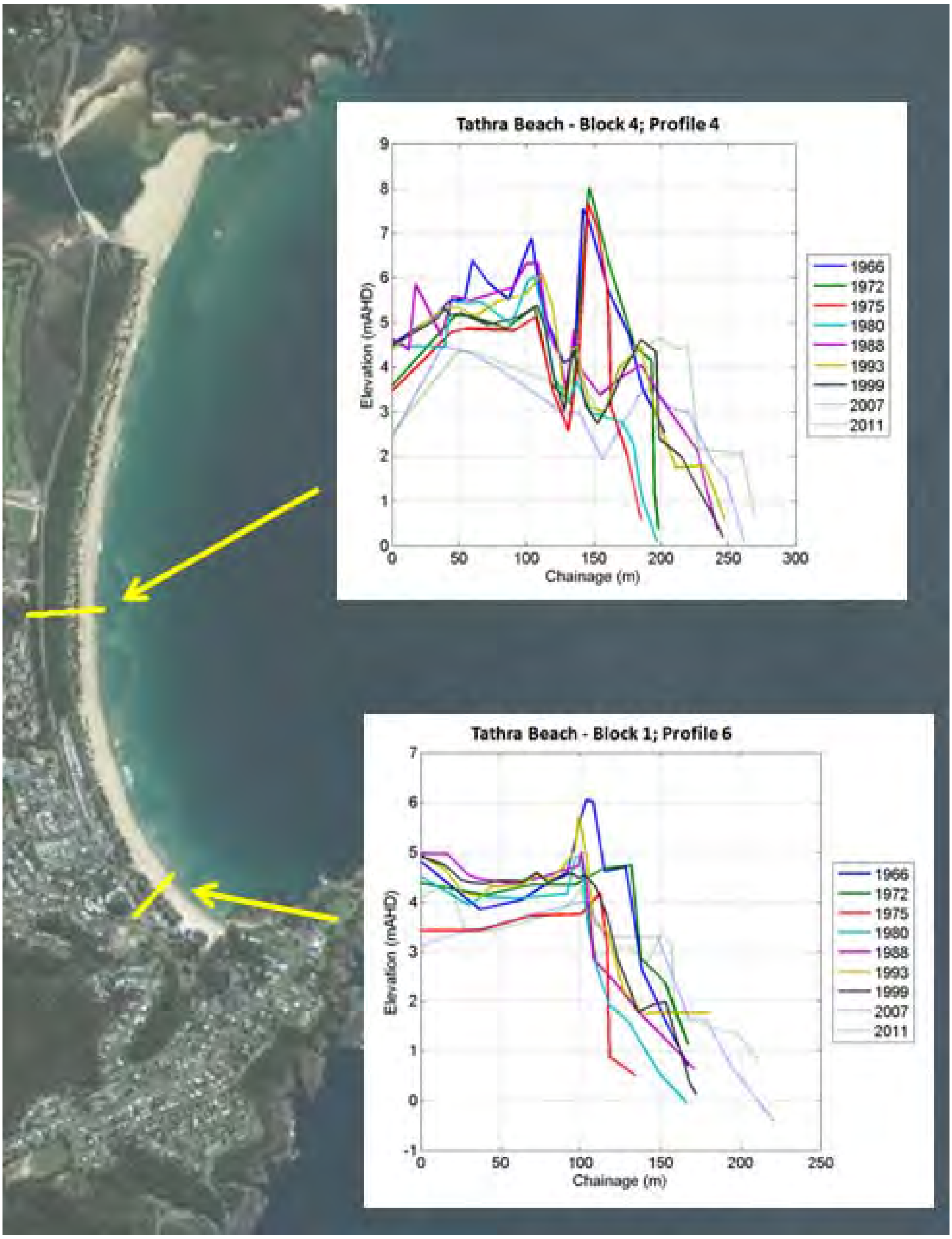


Figure 3-10 Selected Beach Profiles– Tathra Beach

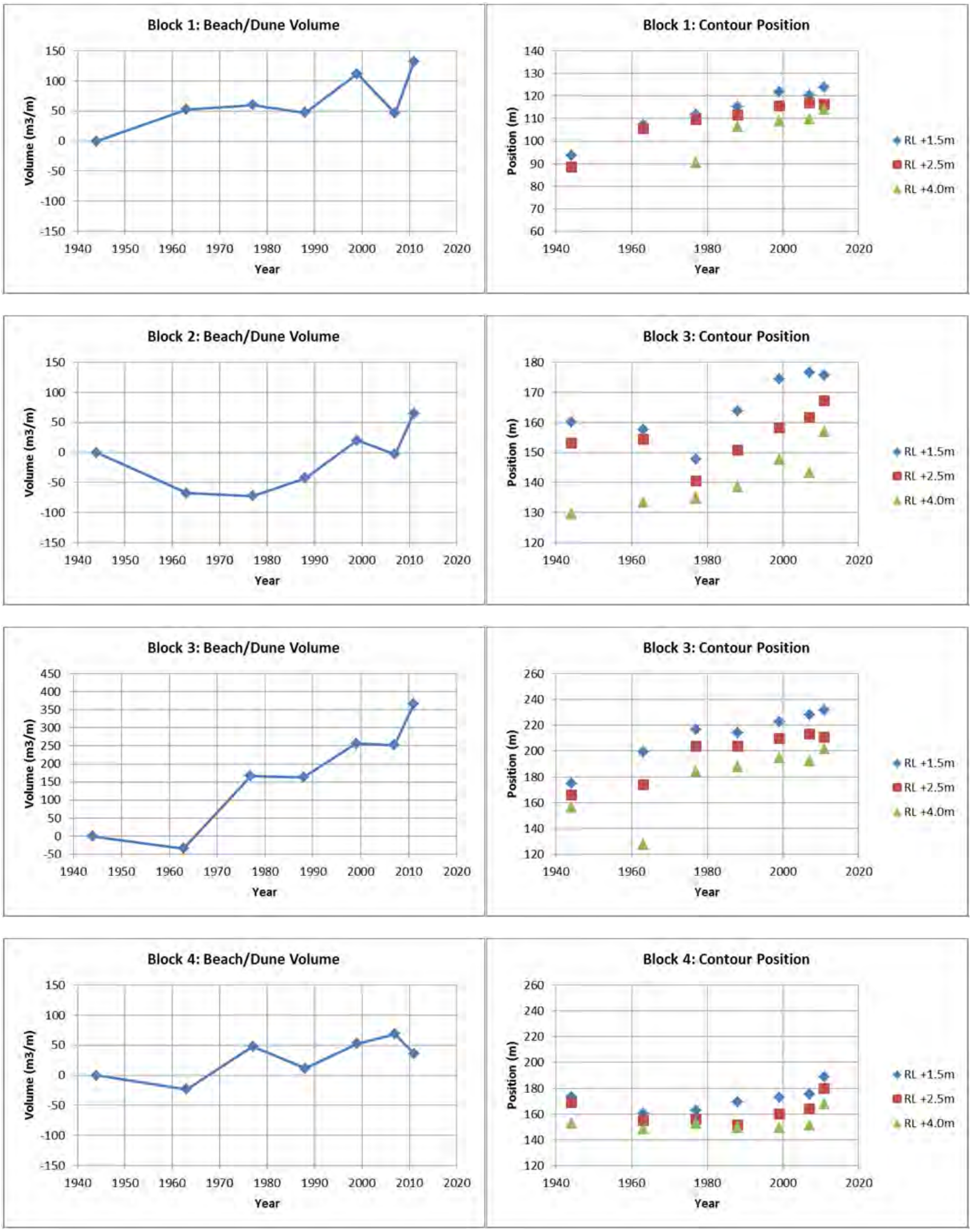


Figure 3-11 Beach/Dune Volumes and Distances: Moorhead Beach

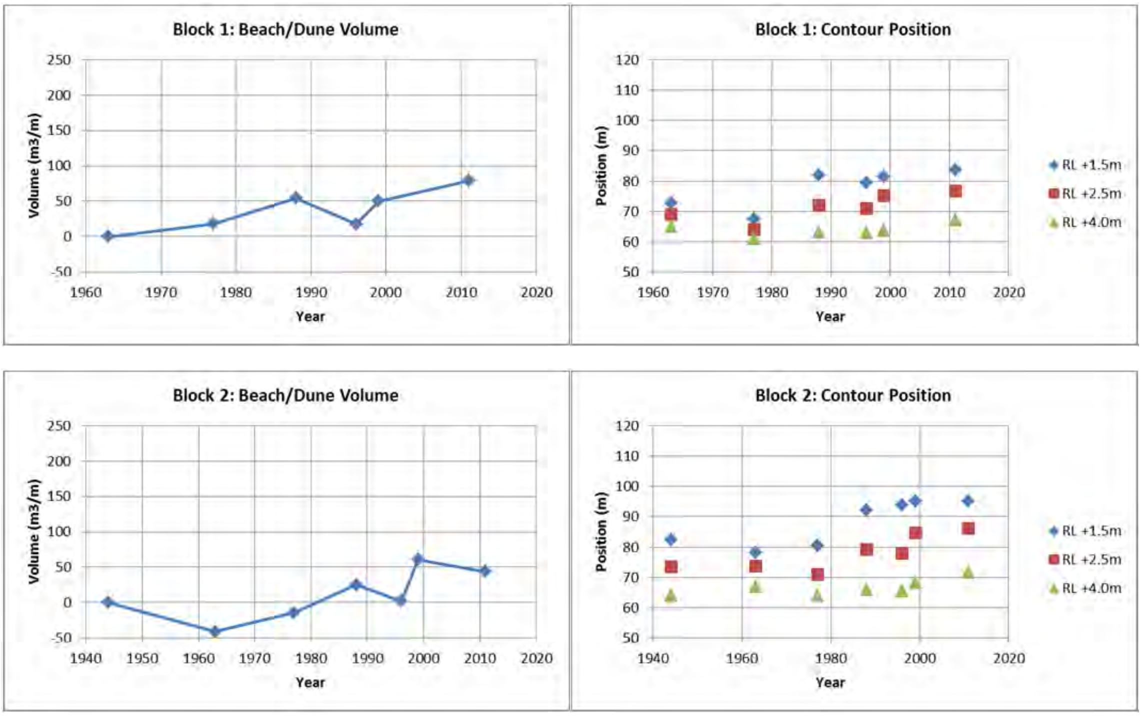
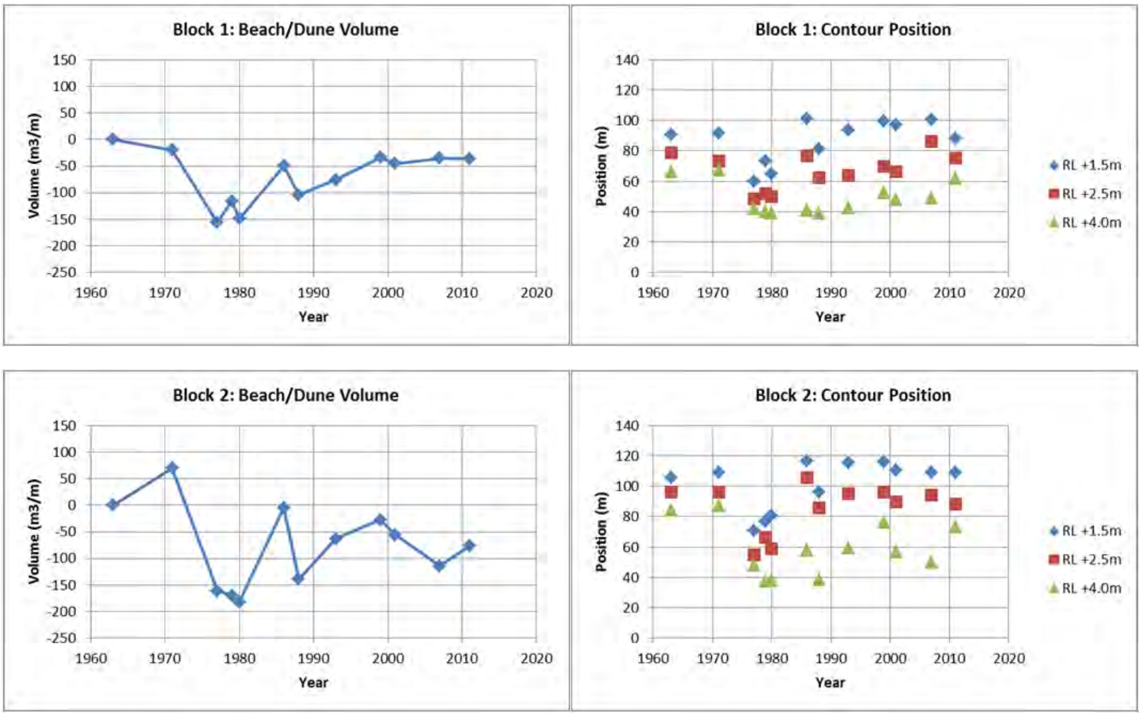


Figure 3-12 Beach/Dune Volumes and Distances: Horseshoe Bay



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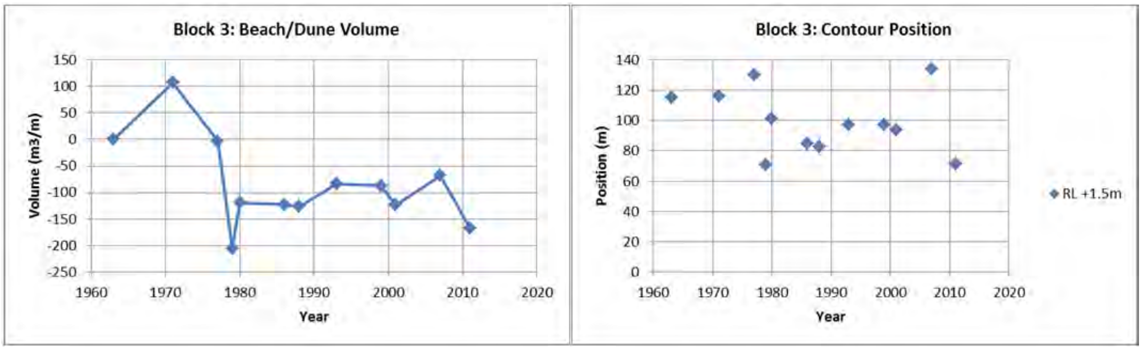

Figure 3-13 Beach/Dune Volumes and Distances: Cuttagee Beach

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Figure 3-14 Beach/Dune Volumes and Distances: Tathra Beach

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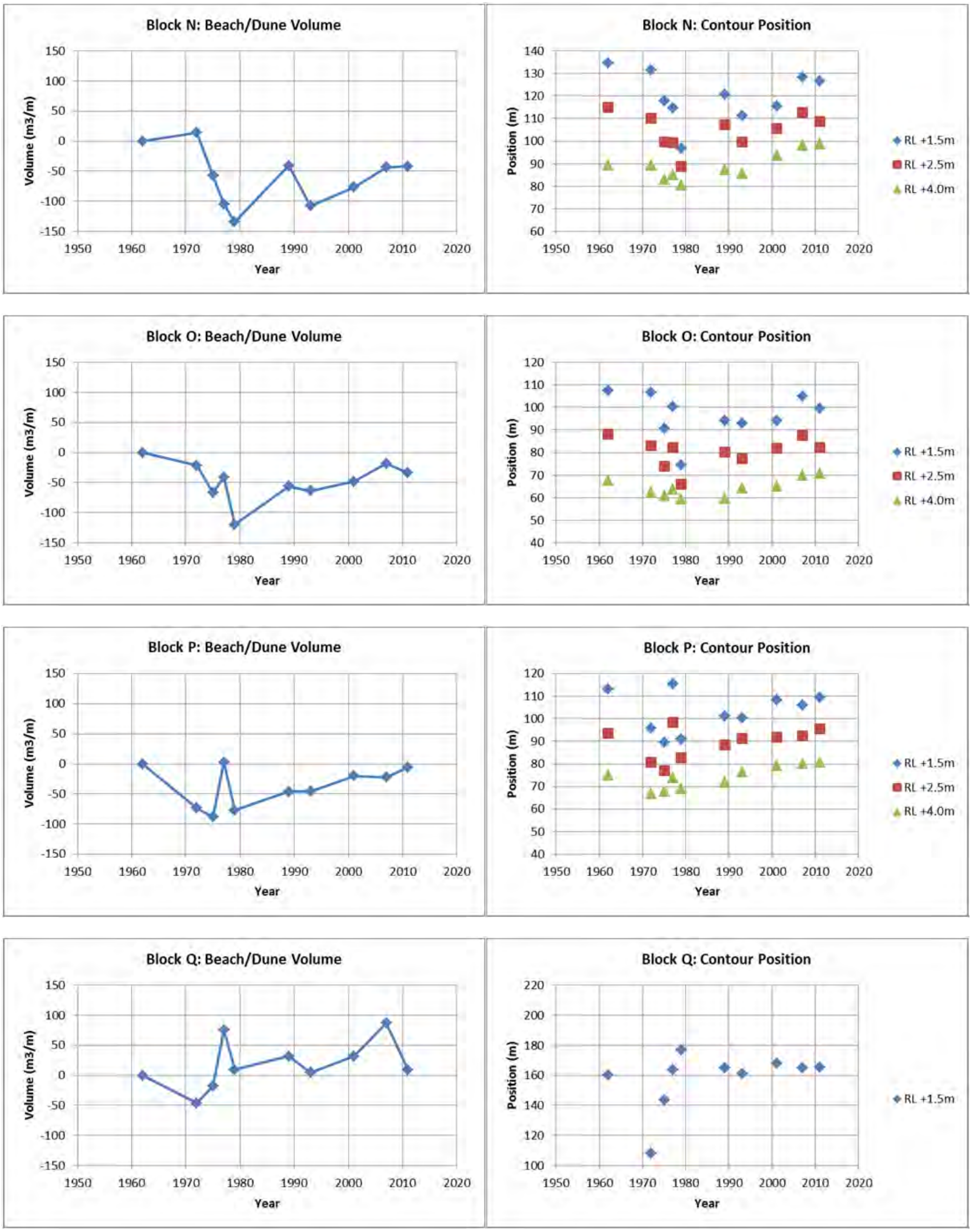
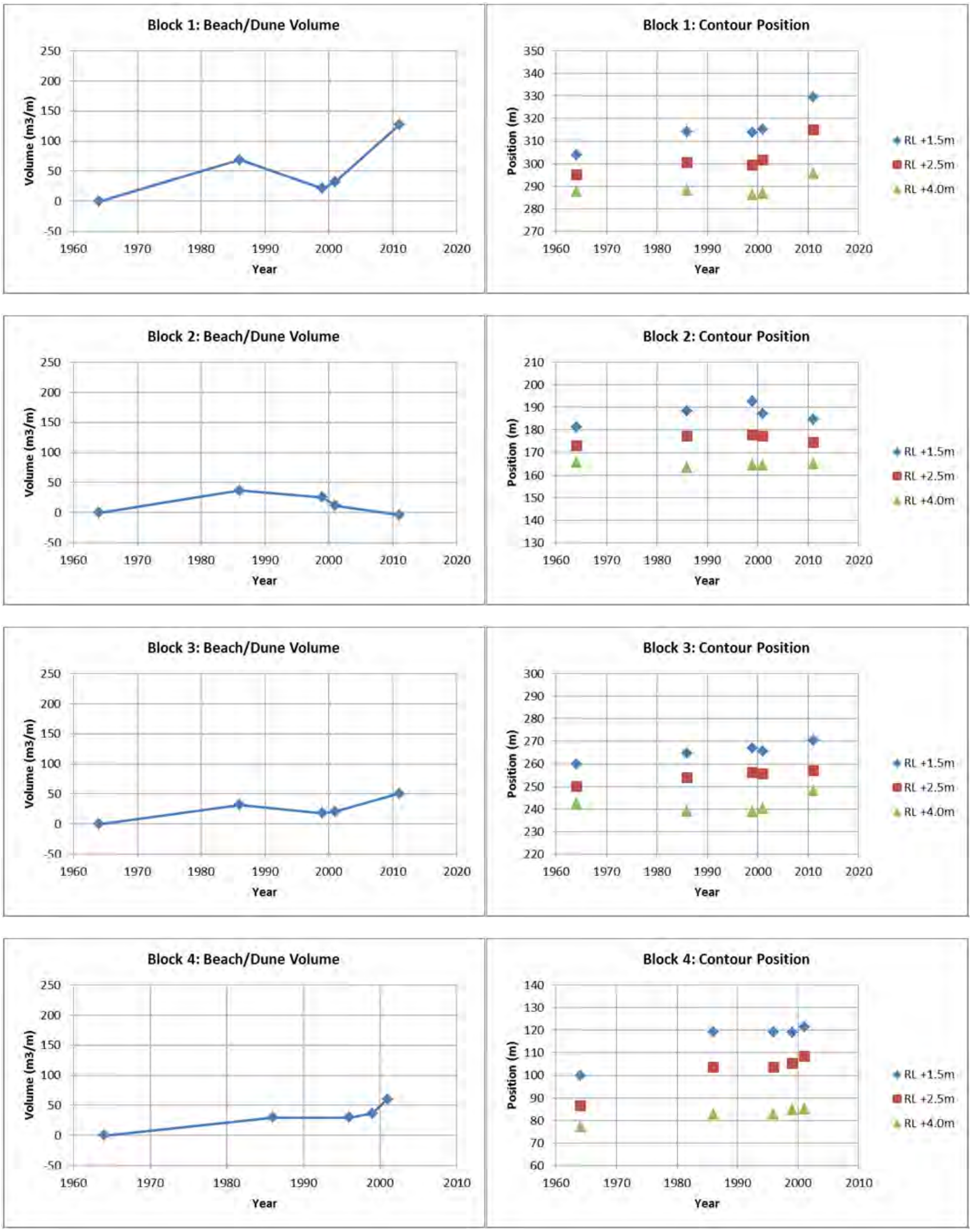


Figure 3-15 Beach/Dune Volumes and Distances: Pambula/ Merimbula Beach



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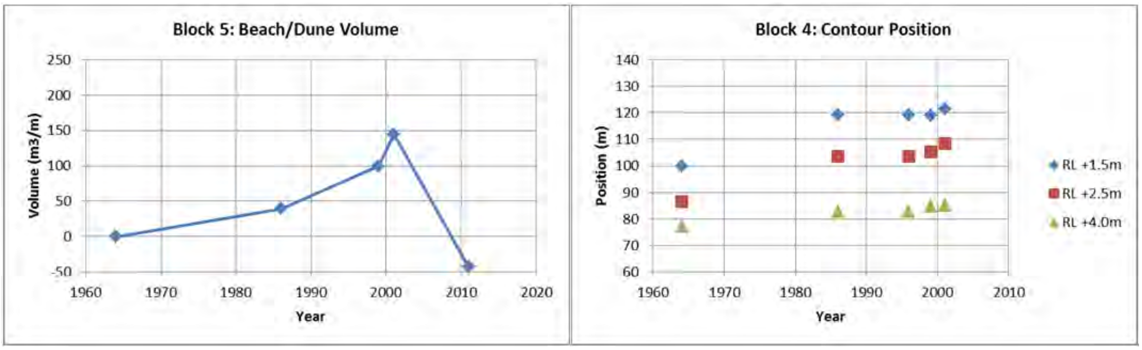


Figure 3-16 Beach/Dune Volumes and Distances: Aslings Beach

3.3.5.2 *Adopted Underlying Recession Rate*

In determining long term recession rates for future planning, consideration has been given to:

- Measured erosion rates from available photogrammetric data and other survey information;
- Available geomorphologic and geological evidence; and
- The current understanding and assessment of the prevailing coastal processes.

In addition, the findings and recommendations of the various previous reports have been reviewed and considered as appropriate.

The photogrammetric data is inconclusive with respect to identification of a clear regional long term trend of shoreline change. While the data for Tathra Beach and Merimbula/Pambula Beach suggests that those beaches may be subject to some ongoing erosion, the data of the other beaches do not show such a trend. Accordingly, it is recommended that beach monitoring be continued to form the basis of future re-assessments of the erosion hazard extents within the Shire and inform future management planning.

For the present assessment, the underlying regional long term recession rates have been based on the assessed volumetric recession rate at Tathra Beach and Merimbula/Pambula Beach which indicate a long term shoreline recession rate of about 0.1m/yr. This recession rate is reasonably consistent with the recession rate that would be expected to be occurring due to sea level rise that would have occurred over the length of the photogrammetric analysis (about 50 years). At a historical sea level rise rate of about 1.5-2.0 mm/yr, the Bruun Rule method would yield a long term recession rate of about 0.05-0.07m/yr in the absence of any sediment source or sink.

The prominent back beach escarpment that is present along those beaches provides further evidence that some beaches within the Bega Valley Shire could be subject to long term erosion.

Based on this, the recommended underlying regional long term recession rates are:

- A nominal 'best estimate' of 0.1m/yr; and
- A lower limit of zero and an upper limit of 0.2m/yr to cater for uncertainties and possible future changes.

3.3.6 Shoreline Recession due to Sea Level Rise

3.3.6.1 Equilibrium Profile (Bruun Rule) Concept

It is generally accepted that with rising sea level there is an upward and landward translation of the beach profile. This concept forms the basis of the "Bruun Rule" (Bruun 1962). Figure 3-17 shows how shoreline recession is related to sea level rise in this equilibrium profile concept.

The beaches of the study area have evolved with mean sea level relatively constant at or near the present level over about 6,000 years to a condition of cross-shore dynamic equilibrium. That is, the profile shape across the beach/dune and nearshore areas to the lower shore-face has an equilibrium form about which cross-shore storm erosion and accretion seabed changes fluctuate. In principle, that equilibrium shape tends to be maintained relative to sea level as the sea level changes if no sediment sinks and sources are introduced. This two-dimensional concept is demonstrated by the Bruun Rule (1962), in Figure 3-17.

As the sea level rises, wave, tide and wind related sand transport processes are occurring at a higher position at the beach face, with the beach and dune evolving to a more landward position to return to equilibrium with the new sea level. There is an upward and landward translation of the profile to maintain equilibrium with the prevailing conditions at the new sea level position.

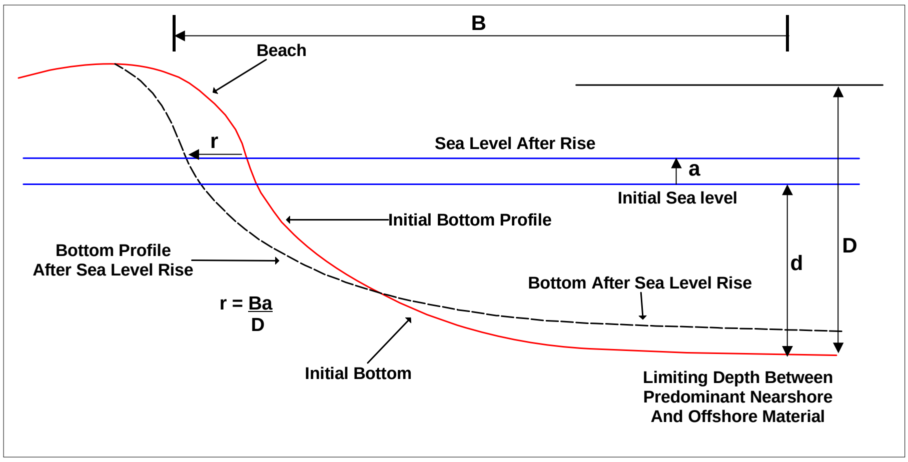


Figure 3-17 Bruun (1962) Concept of Recession due to Sea Level Rise

The 'Standard' Bruun Rule Approach

The simplified Bruun Rule as shown in Figure 3-17 for the linear recession distance *r* (in metres) is:

$$r = Ba/D$$

Where: *B* = horizontal distance offshore from the top of the dune to the depth of closure (*d*); *a* = the rise in sea level, and *D* = the vertical distance (height) from the top of the dune to the depth of closure (*d*).

Application of this 'standard' simplified Bruun Rule has been highly contested within the coastal science community (e.g. Ranasinghe *et al*., 2007), often relating to the depth of closure to which the equilibrium shape is maintained. The depth of closure is generally adopted as the depth limit at which there is little or no potential for significant cross-shore exchanges of sand, but there has been conjecture surrounding what this depth may be.

The DECCW (2010) *Coastal Risk Management Guide: Incorporating sea level rise benchmarks in coastal risk assessments* indicate the appropriate calculation of the depth of closure term required with the Bruun equation as follows: "*when using the 'Bruun Rule', use of the lower limit of profile closure (seaward limit of the Shoal Zone) as prescribed by Hallermeier (1981) is recommended in the absence of readily available information on active profile slopes at a location under consideration*".

It has also been common practice along the NSW coastline to adopt generic active profile slope factors from the closure depth to the dune crest (refer Figure 3-18) in the range of 1:50 to 1:100. However, because of the intra-regional variability in slope that exists across the offshore NSW shelf, more rigorous site-specific analysis is recommended to justify the use of a selected active profile slope.

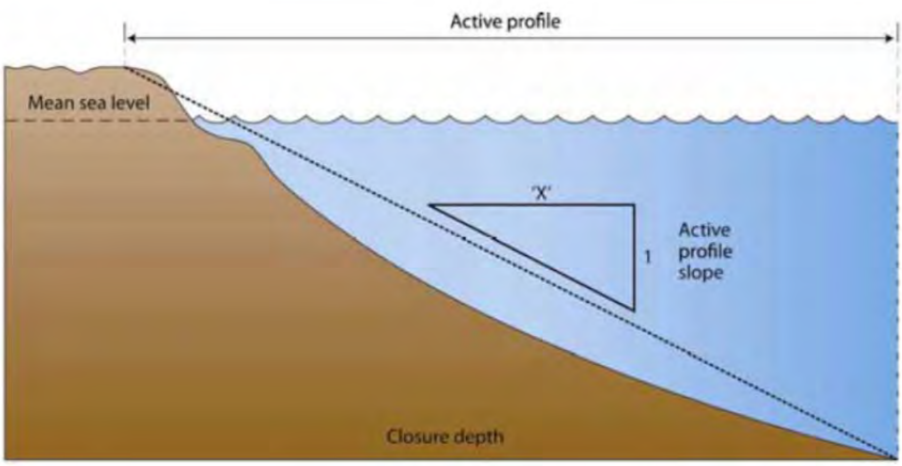


Figure 3-18 Idealised Schematic of the Active Profile Slope Applicable in the 'Bruun Rule' (from DECCW, 2010)

<u>*Depth of Closure*</u>

Hallermeier (1981) divides the nearshore zone into three zones, namely:

- The littoral zone, which "extends to the seaward limit of intense bed activity";
- The shoal zone, which "extends from the seaward edge of the littoral zone to a water depth where expected surface waves are likely to cause little sand transport" and "waves have neither strong nor negligible effects on the sand bed"; and
- The offshore zone, which is seaward of the shoal zone and water depths are relatively deep with respect to surface wave effects on the sea bed.

Hallermeier (1981) stresses that sediment motion can and does occur seaward of the shoal zone, however the seaward boundary (d_i) defined by Hallermeier (1981) aims to provide "*a physically meaningful seaward limit to the usual wave-constructed shoreface*".

Hallermeier (1981) then identifies two depths that define the landward and seaward boundaries of the shoal zone:

- Depth d_l which is the "maximum water depth for sand erosion and seaward transport by an extreme yearly wave condition"; and seaward of this,
- Depth d_i which is the "maximum water depth for sand motion by the median wave condition", corresponding to the seaward limit of the usual wave-constructed profile.

Patterson (2012; 2013) identified that the time-scale of profile response, the time required for the profile to achieve equilibrium, increases with depth and needs to be considered in determining closure depth. Nicholls *et al.* (1996, 1998) and Cowell *et al.* (2000) both refer to the closure depth in terms of the time scale considered. That is, they note that profile 'closure' occurs at greater depth as the time scale increases. Nicholls *et al.* (1998) adopt a version of the Hallermeier (1977; 1981) relationship for depth of closure of the form:

$$d_{l,t} = 2.28H_{e,t} - 68.5(H_{e,t}^{\ 2} / gT_{e,t}^{\ 2}) \qquad (1)$$

Where $d_{l,t}$ = the predicted depth of closure over *t* years, referenced to Mean Low Water; $H_{e,t}$ = non-breaking significant wave height exceeded 12 hours per *t* years; and $T_{e,t}$ = associated wave period. Thus, their depth of closure to cater for sea level rise over a planning period of 100 years will be greater than that adopted for shorter durations (e.g. the one year extreme wave originally proposed by Hallermeier).

On that basis, the depth of closure to cater for sea level rise over a planning period of 100 years will be greater than that adopted for shorter durations. Typical parameter values derived for the study region wave climate suggest a longer term (approx. 100 years) depth of closure in the range 14-15m along the exposed ocean beaches. However, this does not provide for the concept of accumulation at the lower part of the equilibrium profile translation to balance upper profile erosion, on which the Bruun Rule is based.

The Hallermeier (1981) limiting depth (d_i) of significant net cross-shore sand transport is about 32m for the exposed ocean beaches in the study area. However, use of this limiting depth (d_i) is not recommended as this corresponds to a depth of very long term profile response (centuries to millennia) and has no direct relationship to vertical profile change at the planning period of up to 100 years.

Conceptually, it is appropriate to adopt a depth in the range zone h_L to h_i, as prescribed by Hallermeier (1977; 1981). These represent the seaward limit of regular vertical profile changes and the seaward limit of significant net cross-shore sand transport, respectively. Within that range, the limitation imposed by the time-scale of profile response needs to be considered. Wright (1995) notes that there should be a thinning of the accretion in the vicinity of the closure depth and suggests an effective closure depth somewhere between h_L and h_i but does not pursue a specific choice of depth. Cowell *et al.* (2006) deal with this in a probabilistic manner in which it is accepted that the toe of the profile may experience deposition in the range of 'full accommodation' (lower profile fully filled) or 'full dilation' (zero filling at the toe) with assigned probability. As such, the range of sea level rise recession distances derived with their methodology are expected to correspond to those equivalent to the *Bruun Rule* over the range of Hallermeier closure depths from h_L to h_i.

Figure 3-19 illustrates the effective Bruun Rule slope factor that applies to typical exposed coastline parts of the Bega Valley region, being approximately 36:1 for a 5m dune height. The slope factor would be somewhat less for higher dunes, for example about 31:1 for 10m dunes and about 33:1 for 8m dunes.

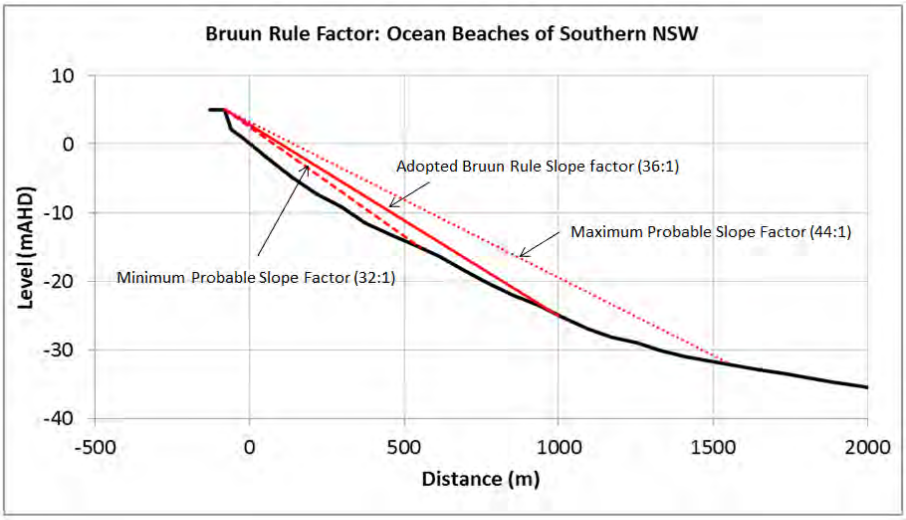


Figure 3-19 Bruun Rule Slope Factor for Southern NSW

Based on this, a Bruun Rule Slope Factor of 36:1 has been adopted in the Bruun Rule recession calculations. Thus, considering the predicted future sea level rise levels of 0.34m and 0.84m at 2050 and 2100 respectively, the Bruun Rule approach yields a shoreline recession of 12m by 2050 and 30m by 2100 for 5m dunes. While the photogrammetry shows that 5m is the typical active dune height for the beaches in the Bega region, where the recession would extend into higher hind-dune areas, those provisions need to be factored down proportionally, as outlined above.

It must be recognised that the Bruun Rule does not account for the influences of longshore sand transport processes on the profile response to sea level, nor does it account for effects of future sediment sinks and sources, such as coastal entrance sedimentation (Refer to Section 2.7).

For the assessment at each individual beach location in the study area, an allowance for coastal entrance sedimentation effects has been incorporated in the hazard extents, with guidance provided by modelling that caters for these processes.

3.3.6.2 EVOMOD Shoreline Evolution Model

BMT WBM utilises shoreline evolution modelling (EVOMOD) as a means of analysing the complex interactions of both longshore and cross shore processes that are likely to affect the shoreline in the future as the sea level rises (Patterson 2009; 2010; 2013, Huxley 2009 and BMT WBM 2012, 2013a, 2013b).. The modelling undertaken for this study using the EVOMOD system calculates shoreline movements and cross-shore profile evolution in response to both alongshore and cross shore sediment transport, driven by wave time series. It thus incorporates responses to storm erosion and subsequent recovery. The model includes the effects of coastal structures such as headlands, groynes and seawalls where they are present in the natural coastline and allows for simulation of the shoreline impacts of external sediment sources and sinks. The model is particularly effective at a regional scale as it is able to model the interactions between multiple beach units along long coastlines (i.e. headland bypassing). The modelling also will simulate the longshore responses in the absence of sea level rise or other cross-shore effects, and will also simulate the cross-shore responses in the absence of significant net longshore sand transport. As such, EVOMOD is a significant advance from the Bruun Rule (1962) for analysis of sea level rise impacts as it is able to account for the three dimensional nature of the coastline including the headland/groyne effects initiated by the shoreline retreat and the shoreline effects of sediment exchange changes with adjacent coastal lagoons and estuaries.

Sea level rise impacts on shoreline recession are inherently simulated through maintenance of the equilibrium profile condition relative to sea level as it rises. The active upper profile continues to respond to the alongshore processes and short term profile evolution relative to the changing prevailing sea level. The underlying profile slope below the transition slope (Figure 3-20) also affects how the profile progressively recedes, a flatter slope leading to greater recession, although conceptually it does not correlate with the Bruun slope factor. That slope corresponds to the lower shore-face profile shape and is a function of the geomorphological setting (e.g. ocean beach, protected embayment), wave climate and sediment characteristics.

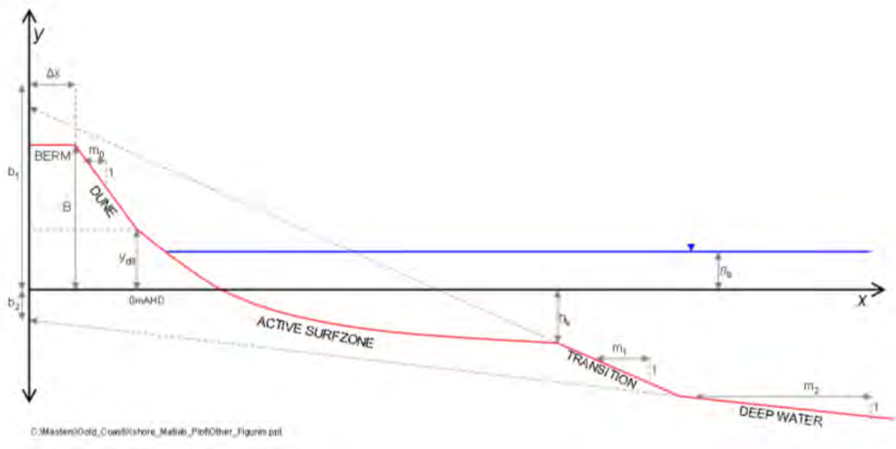


Figure 3-20 EVO-MOD Schematisation of the Beach and Nearshore Profile

Key aspects of the EVOMOD model include:

- Incorporation of the external wave model SWAN which is used to generate a set of comprehensive wave transformation tables used to define nearshore wave conditions in time series format by input of the deep water wave time series;
- Curvilinear baseline from which the shoreline definition grid points are defined such that, in combination with an external SWAN wave model, complex and highly embayed coastlines may be represented and simulated reliably;

- Incorporation of cross-shore profile evolution responses to storm erosion and recovery in combination with the effects of alongshore transport gradients on shoreline changes;
- A cross-shore profile structure in which the evolving surfzone profile is founded on an underlying profile of slope equivalent to that of the shore-face, which may be set consistent with that appropriate for Bruun Rule response to sea level change;
- Ability to include sand source/sink terms to represent onshore sand supply or loss from the active littoral system, dredging, bypassing and sediment interactions with coastal inlets; and
- Capability to respond to both sea level changes, at short time-scales (tides; storm tides over hours to days/weeks) and longer time-scales (sea level rise over decades to centuries).

3.3.6.3 Application of EVOMOD to Bega Coastline

For this assessment, EVOMOD modelling was undertaken for four specific areas within the Bega Valley Shire, namely:

- Bermagui Coast district; incorporating Beares Beach, Horseshoe Bay, Moorhead Beach, Haywards Beach and Camel Rock Beach;
- Tahtra, incorporating Tathra Beach, Moon Bay, Nelsons Bay and Cowdroys Beach;
- Merimbula Bay district, incorporating Haycock Beach, Jiguma Beach, Pambula Beach and Merimbula Beach; and
- Aslings Beach.

Model Configuration

EVOMOD uses a curvilinear grid in which each model cell is represented by a time-varying bed elevation profile. Each EVOMOD model has a typical grid resolution of 100-200m. The extent and configuration of each model is illustrated in Figure B-1 to Figure B-4 in Appendix B.

Offshore wave boundary conditions were derived from offshore wave measurements at Eden, Batemans Bay and Sydney (refer to Section 2.3.3) during the period March 2003 - March 2013. Water level boundary conditions were derived from water level measurements at Eden during the period March 2003 - March 2013. For simulations outside the period 2003-2013, the available wave and water level data has been looped to form a continuous time-series.

Model Establishment

The models have been established and validated with respect to the measured data for historical and existing shoreline conditions. A model calibration process was undertaken to ensure the existing shoreline configuration was appropriately represented by the model. Model calibration involved adjustment of the structural representation of the shoreline within the model and its wave transformation inputs as required, then remodelling of the ‘base case’ until good consistency between modelled and actual shoreline configuration was achieved. This ‘base case’ model included all key control features in the model area, including headlands, training walls, coastal inlets and bedrock horizons further landward of the shoreline where known to occur from Quaternary Geological mapping (SCCA Dataset, DPI 2005).

Model Verification

A verification process was undertaken where model results were compared with historical data to determine if model results were consistent with observed shoreline behaviour.

As part of this model validation, a hindcast of the period 1963-2013 was performed with model results compared against observed evolution of the Bermagui Coast beaches during this period.

The boundary conditions prior to 2001 used looped data from 2001-2013 (for which measured directional wave data is available). Therefore the simulation does not directly replicate the substantial storm-induced erosion during the 1970's. It is also likely that the model forcing is somewhat biased towards an El Nino dominated wave climate, due to the predominance of this ENSO pattern during the period of available wave data. Nevertheless, the significant impact of the construction of the Bermagui River training works is still well represented by the hindcast approach using available data, and actual events in the period 2001-2013 are fully represented.

The most significant impact on the Bermagui Coast during this period was the accretion at Moorhead Beach since the construction of the Bermagui River training walls in 1959, which had a stabilising effect on Moorhead Beach. The photogrammetric data indicates that this beach gained approximately 225,000m^3 in dune volume (above AHD) between 1963 and 2011.

This volume gain response can also be seen in the model predictions. Figure 3-21 compares the modelled volumes changes at Moorhead Beach with the observed changes over time, based on the photogrammetric data. In this figure, the measured photogrammetry volumes have been scaled up by a factor 2.2 to account for the full extent of beach profile change above and below AHD, as simulated in the model. Figure 3-22 presents the modelled and observed upper beach position in 2011.

The shoreline model replicates the observed shoreline changes at Moorhead Beach reasonably well, both in terms of beach volume changes and shoreline position. This provides confidence that the models are capable of simulating the major trends in shoreline behaviour.

Notwithstanding this, it must be recognised that modelling of shoreline behaviour remains an imperfect science, particularly on time scales of decades or more, and a high level of quantitative accuracy depends to a large degree on:

- Accurate representation of the area being modelled (bathymetry, seabed characteristics, computational grid resolution, etc);
- The accuracy and representativeness of the boundary conditions applied (wave conditions, winds, tides); and
- The degree of validation undertaken to ensure that all of the 'physics' of the processes important in any particular area are being properly simulated in the model.

Alternatively, shoreline modelling undertaken at a less comprehensive level can provide an invaluable 'tool' for providing both qualitative insights and quantitative information about the processes taking place. Thus, the level of modelling and analysis undertaken to date is considered sufficient for the purposes of this study in view of the facts that only limited information is available on key input parameters such as the prevailing wave climate, the location and nature of bedrock, the nature and rate of sediment supply to the shoreline and the potential responses of coastal entrances to changing sea level.

Future Recession Simulations

Following the model establishment and verification process, the models were used to simulate the shoreline behaviour from the prevailing situation in 2010 to the years 2050 and 2100 under a number of scenarios.

For each of the four models, the following simulations were conducted:

- Modelling of a 'Sea level rise' scenario, simulated for 90 years from 2010 to 2100 using the 'Unlikely Case' sea level rise projections of 0.34m by 2050 and 0.84m by 2100 (relative to 2010 levels). This scenario allows direct comparison of the model results with the Bruun Rule estimates and enables assessment of the shoreline recession due to sea level rise for the 'Unlikely' hazard descriptor.
- Modelling of a second theoretical 'Extreme Sea level rise' scenario, to investigate the impact of a 50% greater rate of sea level rise. Again, the simulation was run for 90 years from 2010 to 2100. This theoretical sea level rise case enables consideration of a faster than projected rise in sea level under a 'Rare' case scenario, explained in detail in Section 3.3.8.
- Modelling of a 'Sea level rise and coastal entrance sedimentation' scenario using the 'Unlikely Case' sea level rise projections of 0.34m by 2050 and 0.84m by 2100 (relative to 2010 levels) and allowing the marine deltas of each the adjoining estuaries and lagoons to fully adjust. That is, this scenario assumes that the coastal entrance of each estuary or lagoon will rise at an identical rate as mean sea level, and the required sediment for this rise will entirely be provided by the adjacent beach systems. This scenario enables assessment of the shoreline recession under another 'Rare' case scenario, explained in detail in Section 3.3.8.

In addition, a model scenario with no sea level rise ('Base Case') was conducted. The incremental impacts of sea level rise were assessed by running the above scenarios and comparing the modelled shoreline position at 2050 and 2100 with those of the 'Base Case' scenario. The model results for 2100 are provided in Figure 3-23 to Figure 3-26.

These indicate that a general average shoreline recession of about 25-30m at 2100 for the **'Sea level only'** scenario, reasonably consistent with the estimates using the standard Bruun Rule approach which generally would yield a recession of about 28-32m for this case. For the **'Extreme Sea level rise'** case, the model yields an average shoreline recession of about 40-45m by 2100.

The model results of the 'coastal entrance sedimentation' scenario demonstrate the potential impacts of entrance sedimentation processes as estuaries and coastal lagoons adjust to rising sea water levels. In particular, the model results of Pambula/Merimbula Beach illustrate the potential significance of this process, indicating that the shoreline recession along some parts of Merimbula Beach could be more than twice the recession predicted for the case without 'coastal entrance sedimentation' (ie. the 'Sea level rise' scenario) due to infilling of Merimbula Lake.

The realignment of Pambula/Merimbula Beach associated with the 'Sea level rise and coastal entrance sedimentation' scenario is predicted to increase linearly from approximately zero at the southern end of the beach to approximately 0.4^o at the entrance to Merimbula Lake, following a polynomial shoreline recession trend, as demonstrated in Figure 3-25. The non-uniform shoreline recession response is caused by longshore sediment transport, induced by entrance infilling. This longshore transport increases progressively towards the entrance.

At Merimbula/Pambula Beach, the non-uniformity of the shoreline response is particularly evident, because the entrance system of the adjoining estuary (Merimbula Lake) is relatively large compared to the beach system and the relatively small longshore sediment transport capacity at this beach, compared to other beaches modelled. At Tathra Beach for example, which has a similar Sedimentation Demand Parameter to Pambula/Merimbula (refer to Table 2-7), the sediment transport capacity is about three times greater, resulting in a more uniform recession estimate along this beach.

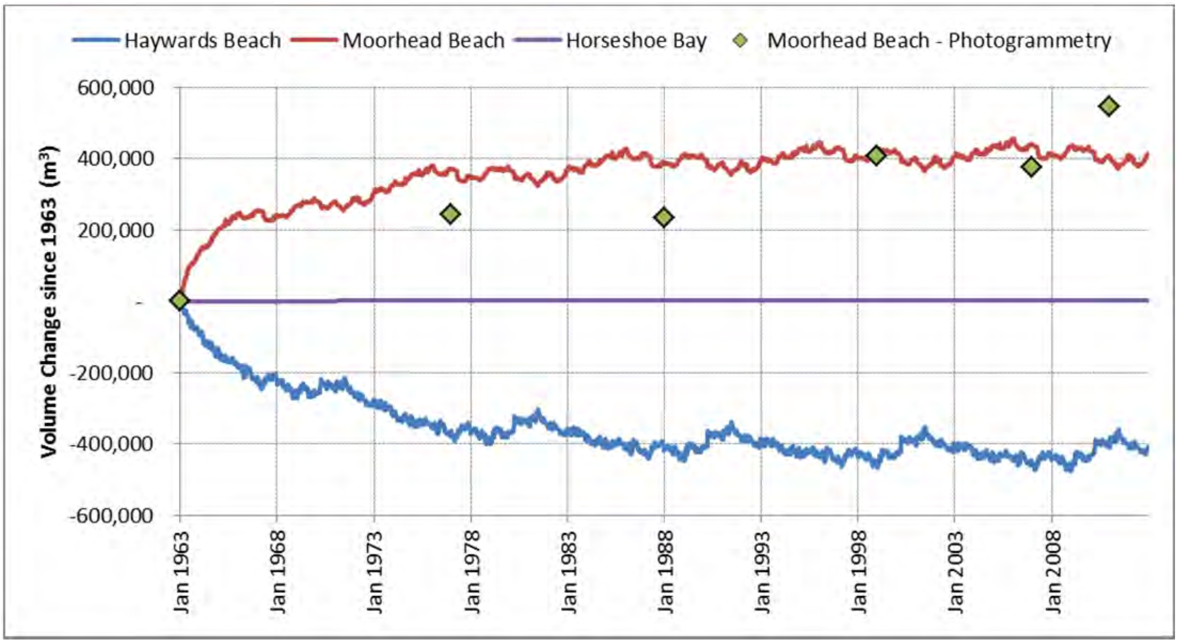
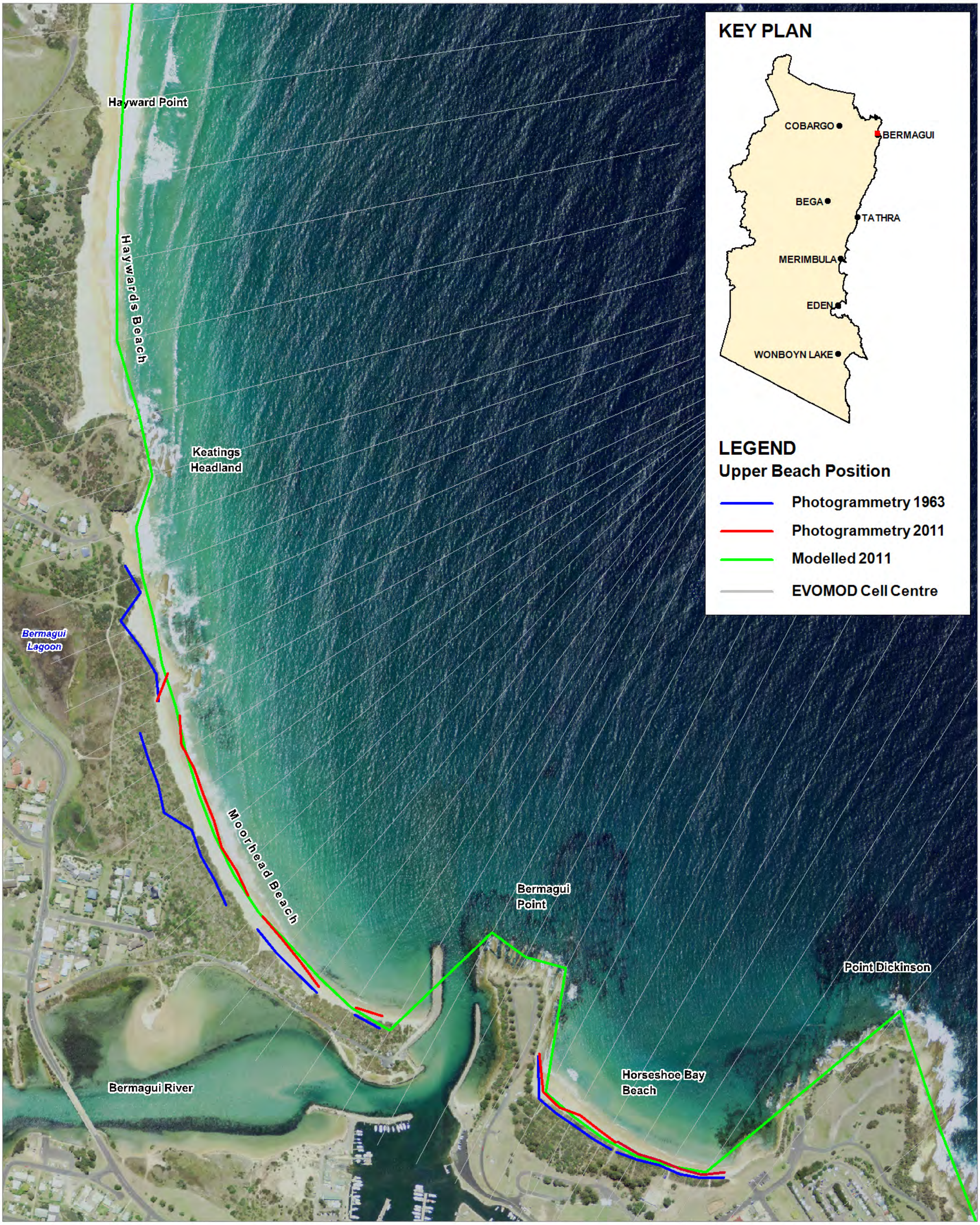


Figure 3-21 Measured and Modelled Volume Changes within Bermagui Embayment



Title:

Measured and Modelled Change in Upper Beach Position Bermagui Embayment

Figure: 3-22

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N

0m 150 300
Approx. Scale

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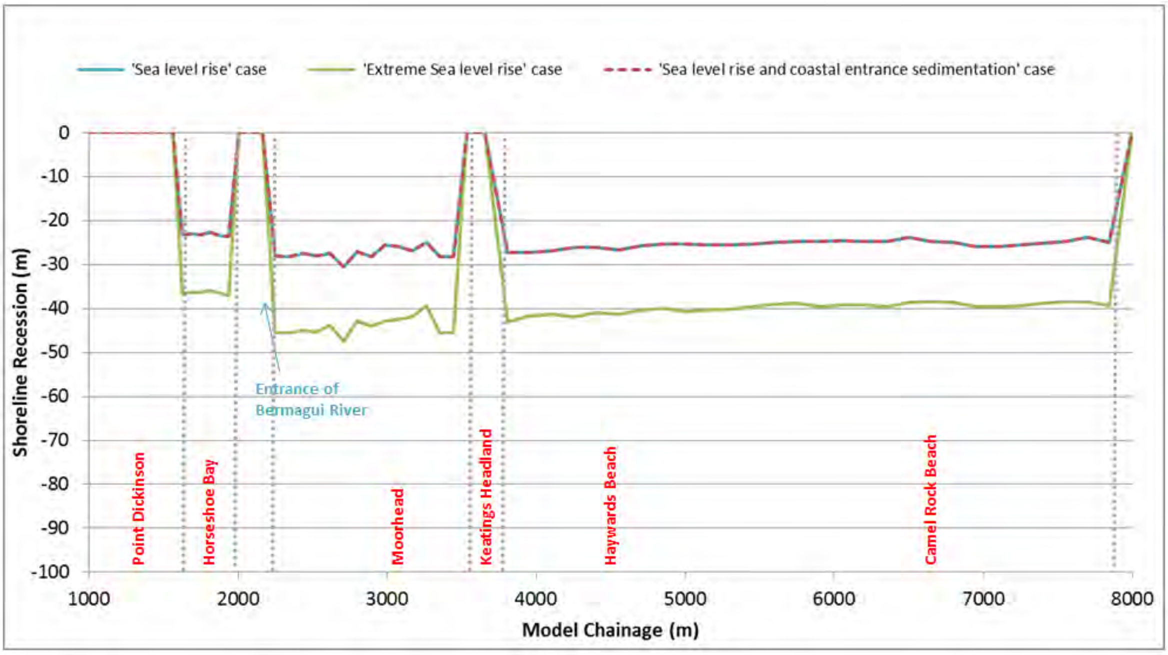

Figure 3-23 Modelled Shoreline Recession by 2100 – Bermagui Coast

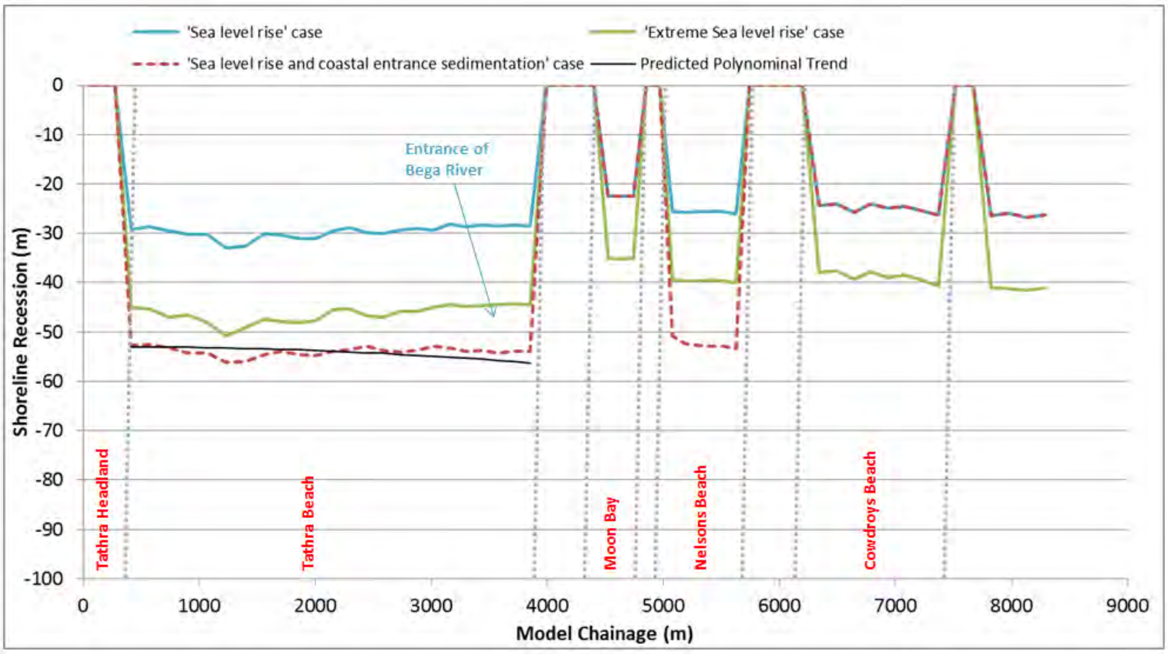

Figure 3-24 Modelled Shoreline Recession by 2100 – Tathra Bay

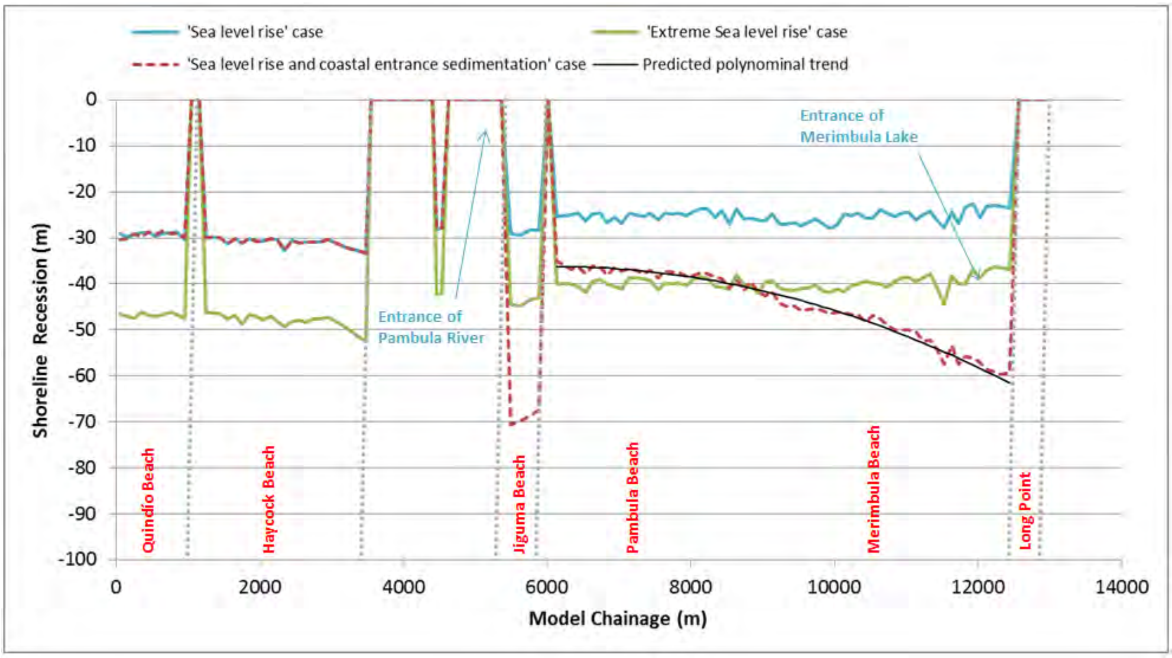

Figure 3-25 Modelled Shoreline Recession by 2100 – Merimbula Bay

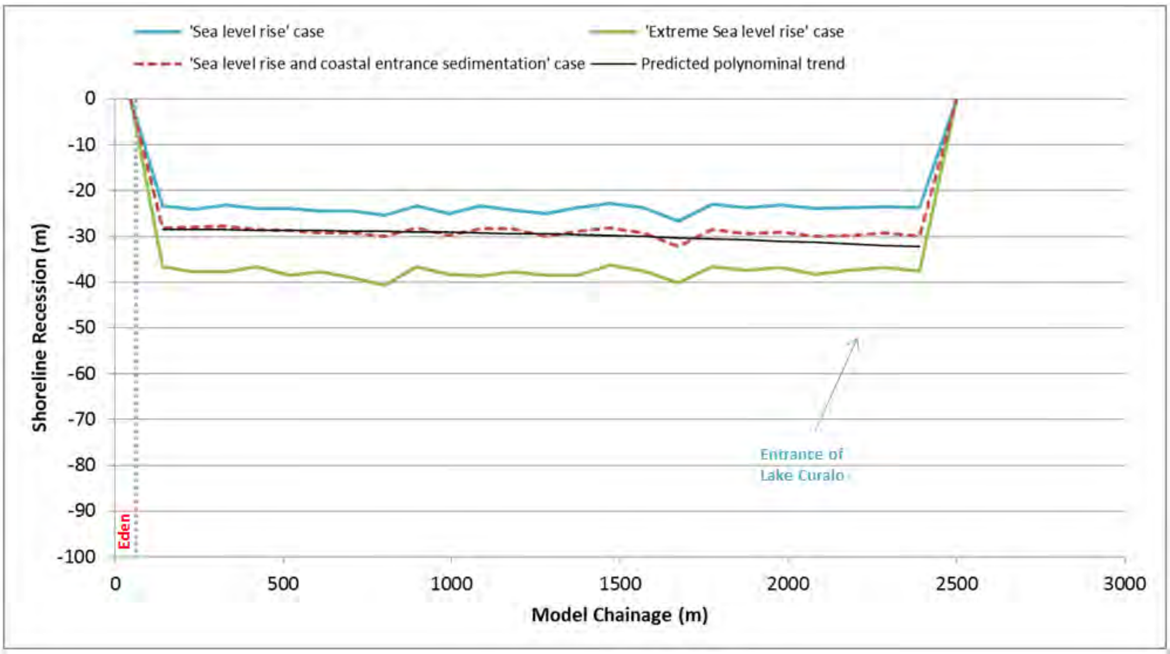

Figure 3-26 Modelled Shoreline Recession by 2100 – Aslings Beach

3.3.6.4 Analysis of Coastal Entrance Sedimentation Effects

As discussed in Section 2.7.1, sea level rise may alter the hydrodynamic regime at coastal inlets, which in turn may result in a net influx of sediment from the adjacent beach systems to the entrance. If this occurs the effect of this infilling on the adjoining beach systems could be twofold, namely:

- There may be a permanent loss of sediment from these systems; and
- There may be realignment of the regional shoreline to 'transport' the sediment influx requirement towards the coastal entrance by littoral transport processes.

Shoreline modelling was undertaken to gain a preliminary impression of the possible impacts of the entrance sedimentation phenomenon. The unknown parameter at this time is the likely response time of the entrance dynamics to seal level rise. As an indicator of a worst case scenario the entrances were assumed to respond fully to sea level rise as it occurred.

From a scientific viewpoint the shoreline modelling undertaken indicated that the shoreline recession due to the combined effect of sea level rise and coastal entrance sedimentation may be described with a polynomial trend in the form of $r = A \cdot (L - x)^2 + B$, (Where r=shoreline recession, L = length of the affected shoreline, x= distance from the coastal entrance and A and B are constants which can be derived by consideration of boundary conditions and mass conservation).

It was not possible to assess the impacts of coastal inlet sedimentation at each beach unit within the study area using EVOMOD shoreline evolution modelling directly. Instead, the above polynomial relationship has been used in combination with the CERC (1984) longshore sand transport formula to provide estimates of the shoreline recession contribution of coastal entrance sedimentation at those beaches not included in the EVOMOD models.

Of particular interest are the following indicative values of shoreline recession, adjacent to the entrances, which might be achieved if sea level rise occurs and the entrances respond fully to these changes.

- Tathra – 10m by 2050 and 25m by 2100;
- Merimbula Beach – 20m by 2050 and 35m by 2100.

3.3.7 Dune Stability and Reduced Foundation Capacity

Immediately following storm erosion events on sand beaches, a near vertical erosion scarp of substantial height can be left in the dune or beach ridge. A zone of reduced foundation capacity can exist on the landward side of sand escarpments. This can impact on structures founded on sand within this zone and the sand escarpments pose a hazard associated with sudden collapse. Following such storm events, inspection of sand scarps should be undertaken to assess the need for restricting public access and the impact on structures.

Over time the near vertical erosion scarp will generally slump through a zone of slope adjustment to the natural angle of repose of the sand (approx. 1.5 Horizontal to 1.0 Vertical). Nielsen *et al*. (1992) outlined the zones within and behind the erosion escarpment on a dune face that are expected to slump or become unstable following a storm erosion event (see Figure 3-27), namely:

- *Zone of Slope Adjustment:* the area landward of the vertical erosion escarpment crest that may be expected to collapse after the storm event; and
- *Zone of Reduced Foundation Capacity:* the area landward of the zone of slope adjustment that is unstable being in proximity to the storm erosion and dune slumping.

Amongst other factors, the width of the zone of reduced foundation capacity behind the top of an erosion escarpment is dependent upon the angle of repose of the dune sand and the height of the dune above mean sea level (refer Figure 3-27). Table 3-6 provides an indicative guide to the width of the zone of reduced foundation capacity measured landward from the top of the erosion escarpment for various dune heights.

These defined widths should be added to the immediate, 2050 and 2100 year beach erosion hazard (i.e. taken to occur in a landward direction from the edge of the beach erosion extent). Climate change is not expected to modify soil stability, and thus the hazard extents remain relevant at the 2050 and 2100 year planning period.

The allowances in Table 3-6 are provided for indicative planning purposes only and have not been included in hazard definition maps. The presence of bedrock will modify the likely foundation capacity extents. The allowances in Table 3-6 assume a dunal system made up entirely of homogeneous sands (with an assumed angle of repose of 35 degrees) and makes no allowance for the presence of more structurally competent stratums, for example indurated sands and bedrock, nor do these allowances take account of water table gradients that may be present within the dunal system. Expert geotechnical engineering assessment is recommended to establish the structural stability of foundations located (or likely to be located) within the zone of reduced foundation capacity on a case by case basis.

Following storm events where dune erosion has occurred, inspection of sand scarps in popular recreational beach areas should be undertaken to assess both the need for restricting public access and structural instability. The stability of existing and new building foundations in the vicinity of any erosion scarp will need to be assessed or designed by a qualified geotechnical engineer.

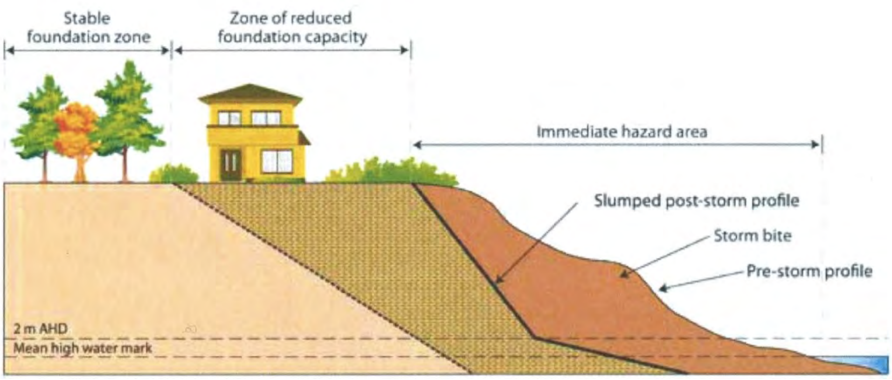

Figure 3-27 Design Profile and Zones of Instability for Storm Erosion (from DECCW 2010; after Nielsen et al 1992)

Table 3-6 Width of Zone of Reduced Foundation Capacity

RL of Dunal System (m AHD) [1]	Indicative width of Zone of Reduced Foundation Capacity (m) [2]
4	9.3
5	10.7
6	12.2
7	13.6
8	15.0
9	16.4
10	17.9

1 Assumed that surface of dunal system is approximately level (see Figure 3-27).

2 Distance measured landward from the top of the erosion escarpment following slope readjustment (see Figure 3-27).

3.3.8 Delineation of Erosion and Recession Hazard Zones

This section describes how the results of the various analyses discussed above have been combined to derive the immediate, 2050 and 2100 hazard probability zones, as shown in the figures in the accompanying Figure Compendium.

The derivation of the immediate beach erosion hazard accounts for the existing and future wave climate variability, for example an enhanced period of storminess such as observed during the 1970s or wave climate changes related to shifts in the Inter-decadal Pacific Oscillation (IPO). The 'immediate' beach erosion distance is carried forward to 2050 and 2100 as there is currently no reliable or reasonable data that would justify assuming a different extent of storm erosion and short to medium term shoreline variability in the future.

Combining the long term recession provisions for 2050 and 2100 with the immediate beach erosion hazards ensures that both wave climate variability and long term permanent change are captured within the hazard mapping.

The derivation of the 'Almost certain' hazard likelihood zones for all planning periods is summarised in Table 3-7.

The 'Unlikely' hazard likelihood zones for 2050 and 2100 were derived by combining the 'best estimate' underlying shoreline recession and modelled future long term recession due to predicted sea level rise of 0.34m by 2050 and 0.84m by 2100 (compared to 2010 levels) with the immediate 'Unlikely' erosion hazard extent. Incorporating the shoreline response to projected sea level rise into the 'Unlikely' hazard zone is not intended to imply that sea level rise itself is 'unlikely'. In fact, the recession estimates are not given a likelihood, but are adopted directly into this hazard zone. The 'unlikely' likelihood of this hazard zone relates mostly to the beach erosion component. That is, while sea level rise and the resulting shoreline recession is considered possible, the subsequent occurrence of beach erosion to a maximum extent is unlikely. The 'Unlikely' zones at all planning periods are summarised in Table 3-7.

The 'Rare' hazard likelihood zones for 2050 and 2100 were derived by combining the 'best estimate' underlying shoreline recession and modelled future long term recession due to predicted sea level rise of 0.34m by 2050 and 0.84m by 2100 (compared to 2010 levels) with the immediate

'Rare' erosion hazard extent. Incorporating the shoreline response to projected sea level rise into the 'Rare' hazard zone is not intended to imply that sea level rise itself is 'rare'. In fact, the recession estimates are not given a likelihood, but are adopted directly into this hazard zone. The 'rare' likelihood of this hazard zone relates mostly to the beach erosion component. That is, while sea level rise and the resulting shoreline recession is considered possible, the subsequent occurrence of beach erosion to a maximum extent is unlikely. The 'Rare' zones at all planning periods are summarised in Table 3-7.

Areas of known bedrock identified by the Quaternary Geology mapping (Troesdon et al., 2004) and verified by aerial photography and field observations (e.g. headlands, rock outcrops) have been incorporated when mapping the beach erosion and recession hazards. Where the hazard lines intersect with the assumed bedrock zones, the hazard lines have been clipped to the boundary of the bedrock, as beach erosion or shoreline recession processes will not notably recede bedrock within the 100 year planning timeframe.

Seawalls that are assumed to have been appropriately engineered for the coastal environment have also been included in the mapping, and assumed to constrain erosion and recession.

All regions of assumed bedrock and assumed sediment should be confirmed through a detailed geotechnical investigation, especially in areas where hazard lines coincide with development.

Beach erosion and shoreline recession hazard maps for all sections of the Bega Valley coastline for the immediate, 2050 and 2100 planning timeframes are given in the Figure Compendium. It is noted that when viewing the mapped hazard lines, the lines do not represent the actual position of the shoreline at a particular timeframe. Instead, the lines represent the potential for any point along the beach to reach such a landward extent (i.e., 'almost certain', 'unlikely' or 'rare' likelihoods) at that timeframe.

It should also be noted that there is a zone of reduced foundation capacity that extends landward of these erosion hazard lines, as discussed in Section 3.3.7.

Table 3-7 Beach Erosion and Shoreline Recession Hazard Probability Zones

Probability	Immediate	2050	2100
Almost Certain	Immediate 'typical' beach erosion[1]	Immediate 'typical' beach erosion[1] + 0.12 m SLR	Immediate 'typical' beach erosion[1] + 0.28 m SLR
Likely	NM[2]	NM[2]	NM[2]
Possible	NM[2]	NM[2]	NM[2]
Unlikely	Immediate 'maximum' beach erosion[1]	Immediate 'maximum' beach erosion[1] + 0.1m/yr long term erosion[3] + 0.34 m SLR	Immediate 'extreme' beach erosion[1] + 0.1m/yr long term erosion[3] + 0.84 m SLR
Rare	Immediate 'extreme' beach erosion'	Immediate 'extreme' beach erosion + 0.2m/yr long term erosion[3] + 0.34 m SLR	Immediate 'extreme' beach erosion + 0.2m/yr long term erosion[3] + 0.84 m SLR

[1] as measured over the past 4 decades.
[2] NM = Not Mapped due to inadequate data to differentiate likelihoods between 'almost certain' and 'unlikely'.
[3] long term erosion is only applied to those beaches which show this trend (refer Section 3.3.5.2)

3.3.9 Considerations and Uncertainties

The definition of coastal hazards inherently involves uncertainty relating to not only how prevailing oceanic conditions will manifest in the future and how reliably their effects on the shoreline can be determined, but also the considerable unknown factors involved with climate change. There are uncertainties surrounding climate change projections, the timeframes over which this change may occur and how climate change may affect the environment. while uncertainty, variability and technological limitations of the study are acknowledged, such uncertainties are not a reason to avoid quantification of the hazards. This is consistent with the *NSW Coastal Policy 1997* that states that "… lack of full scientific certainty should not be used as a reason for postponing measures to prevent environmental degradation" and "The precautionary principle is particularly relevant to the issue of climate change and sea level rise in coastal areas".

The approach adopted has been to provide a band of feasible erosion extents, in order to illustrate the variable probability associated with erosion reaching certain limits within each planning period. The upper (landward) limits of the band, the 'Rare' case represents an erosion extent that has a low likelihood of being reached. Conversely the seaward boundary of the 'Almost certain' case represents the erosion extent that has a high likelihood of being reached within the specific planning period.

Beaches can be subject to longer term trends of erosion or accretion associated with the gradual net removal or addition of sand to the active nearshore profile. Such long term trends may be extrapolated to the future in determining the erosion hazard extent. Long term recession is frequently associated with an alongshore sediment transport gradient, where the average net supply of sediment into a beach compartment is less than that transported out, or infilling of estuaries where sediment of the beach system is transported into the estuary.

Shorelines experiencing progressive long term recession must be considered in the context that the contemporary behaviour is the product of past evolutionary processes, including responses to prevailing wave climate conditions over about 6,000 years of roughly constant ocean levels. There may be short to medium term shoreline variability superimposed on a longer term trend, associated with storm erosion (days) and/or wave climate variability (months to decades). It may be difficult to identify and separate those processes. It is important that interpreted variability and persistent trends are consistent with the longer geological evolution context in order to have confidence in projections of future behaviour. In most cases, it would be unusual for a shoreline to experience a strong natural trend of recession or accretion unless there are circumstances of sand loss or supply that can be identified readily.

Extrapolation into the long term of trends that are part of cyclical variability will lead to inappropriate erosion hazard extents. Nevertheless, the variability needs to be taken into account in addition to the underlying progressive trend in defining the erosion hazard extent.

Beaches experiencing progressive long term recession due to net sand loss are often characterised by a prominent back beach dune escarpment, which moves landward over time during subsequent storm events, without recovering fully to the pre-storm condition before the next major erosion occurs. While the active beach system extends from the dune seaward to water depths of at least 12-20 metres, the zone down to about 8 m is the most active and responsive while evolution of the deeper parts occurs over progressively longer time scales. Thus, shoreline changes associated with alongshore transport gradients are concentrated initially in the upper 'littoral' zone subsequently become redistributed across the lower shore-face region over time.

Sea level rise will cause recession of the shoreline by inundation of the foreshore together with some beach, dune and nearshore profile modification. In this case, it is recognised that most beaches develop a predominant long term average shape in response to varying wave conditions and balance between offshore sand transport during storm events and subsequent beach recovery with shoreward sand movement. This is commonly referred to as the 'equilibrium' profile, recognising that it is a condition that is rarely, if ever, achieved and most probably does not relate to any particular wave condition. Nevertheless, the 'equilibrium' shape to the profile is generally maintained relative to sea level, subject to the increasing response time scale with water depth. The so-called 'Bruun Rule' is based on that concept, as discussed in Section 3.3.6. As well, modelling of sea level rise impacts also depend on adoption of an equilibrium profile shape. Uncertainties and limitations of both the Bruun Rule and the modelling relate to how the equilibrium profile is represented.

Similar to expected beach profile adjustments in response to sea level rise, coastal entrances will also be subject to change due to rising sea levels. Based on the current scientific understanding, it is not possible to accurately predict the exact scale of these morphological changes. The preliminary investigations undertaken as part of this study have identified that some parts of the Bega Valley coastline could experience shoreline recession due to the response of coastal entrances to rising sea levels, particularly Pambula/Merimbula Beach and Tathra Beach. Due to the associated risks, it is recommended that future resources be directed towards better understanding the potential effects of coastal entrance sedimentation in those areas.

3.4 Assessment of Coastal Inundation

Coastal inundation is the flooding of coastal lands by ocean waters. The main impact of the coastal inundation hazard relates to the temporary submergence of low-lying areas near and behind coastal barriers, coastal entrances and broader estuarine foreshores by elevated ocean water levels. Inundation around estuaries would include overtopping of lake and lagoon foreshores (closed or open) and low lying back beach areas hydraulically connected to the ocean (NSW Government, 1990). The elevated ocean levels may cause inundation by either ocean waters propagating into the estuaries, or by imposing a high tailwater level that precludes floodwater discharges from the waterway (thus causing localised backwater flooding).

Coastal inundation is characterised by two processes:

- A “quasi-static” component, which includes the effects of elevated ocean water levels due to astronomical tide, inverted barometric setup and wind setup (storm surge) and wave setup; and
- A “dynamic” component, which includes the effects of wave run-up and wave overtopping caused by the direct impact of waves on coastal dunes and structures.

The “dynamic” component of coastal inundation results from the combination of waves at the shoreline on top of any “quasi static” elevated ocean water level. This is generally referred to as wave run-up.

Wave overtopping at an extreme level is likely to occur for a limited time (order of 1 to 2 hours) around the high tide. Typically once a dune or barrier has been overtopped, the waves spread out in a zone behind the barrier and dissipate rapidly.

3.4.1 Elevated Ocean Levels

The design ocean water levels listed in Table 2-6 are adopted for the assessment of potential inundation. They include the “quasi-static” components of astronomical tide plus storm surge, including barometric pressure set up and wind set up.

Generally, wave set up at the inner edge of the surfzone may be estimated at approximately 15% of the nearshore breaking significant wave height (H_{sb}). Hanslow and Nielsen (1993) define the setup in terms of the intersection of the hydrostatic still water level with the beach face in the swash zone, where the setup as thus defined may reach about 38% of the root mean square wave height (H_{rms}) (about 27% H_{sb}).

3.4.2 Design Wave Conditions

The nearshore wave conditions vary with location along the coastline due to the differences in propagation from deep water. Detailed SWAN wave modelling has been used to determine the nearshore design wave heights in about 10 m water depth for each location, taking into account refraction, shoaling and bed friction attenuation.

The design wave heights for each location are described in Chapter 4. These are based on an adopted 1 in 100 year ARI storm event deep water significant wave heights with likely mean duration of 1 hour, consistent with the statistical data described in Section 2.3.4.

3.4.3 Wave Run-up and Overtopping

Where the crest height of a cliff, shoreline structure or dune is less than the wave run-up level, waves will overtop the shoreline and may cause inundation of the land behind. The wave run-up water level may not present a hazard unless the run-up is overtopping the crest at a rate or volume that would cause a significant impact to people or land behind it. For this reason, wave overtopping capacity should be considered in addition to the wave run up levels.

Because of the variability of wave heights, the assessment of inundation due to run-up processes has been based on the 2% run-up levels ($R_{u2\%}$). The 2% wave run-up level represents the run-up level that is exceeded by 2% of the incoming waves during the peak of the design storm tide event and is the most common wave run-up level used in engineering assessments (CIRIA, 2007) and.

Elevated ocean levels associated with storm surges may be of many hours duration while the peak astronomical tide level occurs over about an hour. Thus, elevated storm tide levels may exist at or near their peak levels for a maximum duration of about 2 hours around the high tide. As such, for typical wave periods of 12 seconds during severe storms, up to about 600 waves will occur, of which the 2% exceedance involves only about 12 or 14 individual waves. The severity of the inundation will depend on the extent to which the run-up level exceeds the crest level of the dune or coastal barrier.

Wave run-up levels and subsequent overtopping depends, amongst other things, on:

- Hydraulic parameters such as: ocean water level, wave height, wave period, wave direction, water depth; and
- Foreshore factors such as roughness and porosity, slope and dune/barrier crest levels.

The procedure for calculation of potential run-up levels differs somewhat for natural beaches/dunes, and cliffs and coastal structures such as seawalls. Both require determination of the local design wave parameters through propagation of the offshore design wave to nearshore, accounting for refraction and shoaling as appropriate. For dune run-up, the break point conditions are used in conjunction with the average surfzone slope. For seawalls, the water depth and wave condition (typically depth limited) near the toe of the structure are used.

A number of relationships for run-up and overtopping have been applied, depending on the nature of the coastline at each location. For a sandy beach with natural dune, the 2% run-up height ($R_{2\%}$) may be derived based on the findings of Nielsen and Hanslow (1991), who indicate:

$$R_{2\%} = 0.58 \tan\beta \sqrt{H_o{}'_{rms} L_o} \sqrt{\ln(50)}$$

Where:

$\tan_\beta$ =	Average slope across the surfzone, commonly taken as the slope of the beach face, with minimum value 0.1;
$H_{o'rms}$ =	Equivalent deep water RMS wave height
L_0 =	$\dfrac{gT^2}{2\pi}$
T =	Wave period

It is noted that the run-up is directly proportional to wave period and thus sensitive to the value used. While Nielsen and Hanslow suggest the average wave period (generally T_z) be used, it is understood (Nielsen pers. comm.) that a substantial part of their data was based on counting waves propagating through the surfzone. This is known to miss the smaller waves and provide a period estimate closer to the significant period (T_s) or spectral peak period (T_p) (Patterson 1985). For the assessments in this study, the Tp values are used to ensure conservative results.

For seawalls, the EurOtop Wave Overtopping of Sea Defences and Related Structures: Assessment Manual (Pullen et al. 2007) ('the so-called "Overtopping Manual') provides standard engineering practices for calculating exposure to wave overtopping. For the 2% wave runup height, the manual provides the following deterministic design formula:

$$R_{u2\%} = 1.75 \cdot \gamma_f \cdot \gamma_\beta \cdot \xi_{m-1,0} \cdot H_{m0} \text{ with a maximum of } R_{u2\%} = 1.00 \cdot \gamma_f \cdot \gamma_\beta \cdot \left(4.3 - \frac{1.6}{\sqrt{\xi_{m-1,0}}}\right) \cdot H_{m0}$$

Where:

γ_f = influence factor for roughness of elements on the slope

γ_β = influence factor for oblique wave attack

$\xi_{m-1,0}$ = breaker parameter

The above deterministic design formula for seawalls was also used to provide indicative estimates of extreme wave runup levels at cliffs and headlands.

Where no reliable data of the bathymetry around the base on cliffs and headlands was available, in these wave run-up calculations, it is assumed that water depths in front of cliffs are such that no wave dissipation or breaking occurs prior to impacting on the shoreline. It is noted that this assumption may results is conservative estimates of the wave run-up levels at those locations.

The wave runup heights derived from the above equations generally range from 3-4m on sandy beaches and can reach over 20m at cliff faces (Point Dickinson). The runup heights and elevations are given in Table 4-1 and are added to the design still water level. The results of the runup calculations are discussed in Section 4.

3.4.3.1 Definition of Coastal Inundation Hazards along Ocean Beaches and Cliffs

The height of the dunes and cliffs is such that direct oceanic inundation of the area behind is unlikely during the planning period and, as such, coastal inundation hazards primarily relate to hazards due to wave overtopping.

While still ocean water levels during a storm are relatively straightforward in terms of a defined hazard area, the highly complex phenomenon of wave setup and overtopping is less clear. Indicative mapping, presenting areas susceptible to wave overtopping under present-day design storm condition, has been completed only, and should be used with caution.

These areas susceptible to wave overtopping have been identified by calculating the absolute wave runup level that would be exceeded by 2% of the incoming waves during a 1 in 100 year design storm event and comparing this level with crest elevation of the front dunes and cliffs. It is possible that wave overtopping in those areas identified as being susceptible would not cause damage or lead to considerable volumes of water overtopping an area.

Furthermore, it should be recognised that wave run-up levels at cliffs may be affected by wave breaking processes that have not been accounted for in these preliminary calculations prior to impacting on the shoreline.

For future planning periods (2050, 2100), mapping of wave run up and overtopping hazards is problematic. This is because it is unknown where the shoreline position will be and at what height dunes will be behind the shoreline by 2050 and 2100. The erosion and recession extents at 2050 and 2100 provide the best indication of potential coastal processes at those future time periods including run up.

3.4.4 Coastal Inundation in Lower Estuaries

During storm tide events, elevated ocean levels will propagate into lower estuary areas, with potential inundation of the adjacent land. Components of elevated ocean levels that may affect estuaries in this way may include:

- The storm tide (tide plus surge); and
- Wave set-up.

While it is generally recognised that wave set-up does not significantly propagate through fully trained entrances with deep water channels, there is uncertainty about the degree of wave set-up that penetrates untrained entrances with shallow bars, especially where wave breaking extends across the estuary mouth. It is understood that any such set-up would be less than that on the adjacent beaches, however the extent to which it needs to be provided for is not able to be defined reliably.

For the purpose of assessing the coastal inundation hazard within the untrained lower estuary areas of Bega Valley Shire, a limited wave set-up component of the wave setup, calculated for natural beaches using Hanslow and Nielsen (1993), has been adopted.

It should also be noted that coastal inundation levels within lower estuaries may be influenced by catchment runoff discharges during oceanic flood events. Catchment runoff will result in a flow gradient through the entrance, which may be substantial at entrances with shallow bars and constricted flow channels. This has not been included in inundation levels in this report.

3.4.4.1 Definition of Estuary Inundation Hazards

For the purpose of defining the likelihood of coastal inundation within the immediate timeframe, it was considered that the ‘almost certain’ scenario would be equivalent to a 1 in 20 year ARI storm event with a wave setup provision of 50% of the predicted wave setup for natural beaches using Hanslow and Nielsen (1993). The ‘Unlikely’ scenario would be equivalent to a 1 in 100 year ARI event and a setup provision of 80% of the predicted wave setup for natural beaches using Hanslow and Nielsen (1993), while the ‘Rare’ scenario would be equivalent to a greater than 1 in 100 year ARI event resulting from an extreme climatic condition, and assuming a wave set-up component of 80% of that at natural beaches. An extreme climatic condition in this context represents the occurrence of an event of sufficient rarity, for example an extremely severe east coast low storm event, resulting in a coastal inundation level of 0.2m above the 1 in 100 year ARI event for the immediate case, 0.35m above the 1 in 100 year ARI event for the 2050 case and 0.65m above the 1 in 100 year ARI event for the 2100 case.

For the 2050 planning period extreme water levels will additionally include sea level rise. The coastal inundation levels are thus increased by 0.12m for the '*A*lmost certain', 0.34m for the '*U*nlikely' and 0.84m for the '*R*are' cases.

For the 2100 planning period extreme water levels will additionally include sea level rise. The coastal inundation levels are thus increased above the immediate case by 0.28m for the '*Almost certain*', 0.84m for the '*U*nlikely' and 0.34m for the '*R*are' case.

Table 3-8 Coastal Inundation Likelihood Summary

Probability	Immediate	2050	2100
Almost Certain	1 in 20 yr ARI storm surge + 50% of 1 in 20 yr ARI wave setup	As per immediate + 0.12 m SLR	As per immediate + 0.28 m SLR
Likely	NM[1]	NM[1]	NM[1]
Possible	NM[1]	NM[1]	NM[1]
Unlikely	1 in 100 yr ARI storm surge + 80% of 1 in 100 yr ARI wave setup	As per immediate + 0.34 m SLR	As per immediate + 0.84 m SLR
Rare	1 in 100 yr ARI storm surge + 80% of 1 in 100 yr ARI wave setup +0.2m for extreme climatic conditions	As per immediate + 0.34 m SLR + 0.35m for extreme climatic conditions	As per immediate + 0.84 m SLR + 0.65m for extreme climatic conditions

[1] *NM = Not Mapped*

3.4.4.2 Ocean Boundary Conditions for Flood Studies

In addition to coastal inundation events, flood levels in lower estuaries and lagoons may also be influenced by catchment dominated flood events or water levels during periods of entrance closure. Flood planning levels would therefore need to account for these mechanisms in addition to elevated ocean levels.

The influence of catchment flooding on the overall flood risk varies considerably with location, distance from the ocean and entrance and catchment conditions and would need to be determined explicitly for each estuary through separate flood studies.

In these flood studies, it is recommended that the envelope of effect approach described in *"Development of Practical Guidance for Coincidence of Catchment and Oceanic Inundation"* (Toniato et al., 2014) be adopted to assess the overall flood risk in the catchment. That is, design flood conditions should be determined by consideration of the coastal inundation hazards determined in this study and simulation using an appropriate hydraulic model of the following scenarios:

- 5% AEP catchment runoff event with 1% AEP ocean level;

- 1% AEP catchment runoff event with 5% AEP ocean level; and
- 1% AEP catchment runoff event during a neap tide cycle.

In the first two scenarios, the peak of the catchment runoff discharge should coincident with the peak ocean level. In the third scenario, the peak of the catchment runoff discharge should coincident with low tide during a neap tide cycle to provide an estimate of the maximum flow conditions near the entrance.

For the purpose of defining downstream boundary conditions for future flood studies, the 20 and 100 year ARI design ocean water levels at a number of entrances have been determined as part of this assessment. The recommended design water levels for present-day climate conditions are provided in Table 3-9. Note that these levels are strongly influenced by wave setup at the entrances and hence the entrances of Bermagui River and Lake Curalo have relatively low levels as their configuration is not conducive to high wave setup. The sea level rise benchmarks would be added directly to these levels to obtain ocean boundary conditions under projected sea level rise conditions.

Table 3-9 Design Oceanic Water Levels (incl. wave setup) at Selected Estuaries

Estuary Name	5% AEP	1% AEP
Wallaga Lake	2.43mAHD	2.53mAHD
Bermagui River	1.28mAHD	1.32mAHD
Bega River	2.24mAHD	2.30mAHD
Back Lake	2.46mAHD	2.57mAHD
Merimbula Lake	2.01mAHD	2.14mAHD
Lake Curalo	1.79mAHD	1.90mAHD

3.4.5 Limitations in Coastal Inundation Hazard Mapping

The analysis and mapping of coastal inundation of back beach areas, particularly lakes, lagoons and estuaries connected with the ocean, assumes that all components of the elevated water level (storm surge, sea level rise, tide, wave set up) are included when determining inundation extents using a ‘bath-tub’ approach. It is recognised that elevated ocean levels will not always penetrate into estuaries and lakes to the same peak water level, given attenuation through entrances and along channels.

Furthermore, flood levels in lower estuaries and lagoons may also be influenced by catchment dominated flood events or water levels during periods of entrance closure, which would need to be determined explicitly for each estuary through separate flood studies.

Prior to such assessments, it is reasonable to assume that flood levels in lower estuary areas of creeks and lagoons in the study area would reach a comparable level to the coastal inundation levels provided in this report. As such, Council and others may use the coastal inundation extents provided as an interim guide to assess the flood risk at those low lying areas. The coastal inundation extents should however be considered in light of existing flood risk mapping. That is, flood planning levels should be based on the higher of the coastal inundation levels or results from specific flood studies.

3.5 Coastal Entrance Instability

Untrained entrances to coastal creeks and lagoons are subject to variability in both their location along the coastline and the adjacent shoreline shape. They may migrate along the beach from time to time depending on prevailing alongshore sand transport and/or catchment runoff behaviour. The entrances may tend to close during extended periods of low rainfall and re-open by natural scour in high runoff events. These movements may affect the adjacent beaches and assets.

Assessment of the behaviour of the coastal entrances in the study region is based on review of aerial photography and historical knowledge. Each entrance has its own characteristics and is assessed independently.

3.6 Sand Drift

Sand drift occurs when sand is transported from the beach by wind action. As the surface sand in the upper beach areas dry it can be moved by persistent day-to-day winds. All sandy beaches experience sand drift to a certain extent and, during periods of strong winds, substantial volumes of sand can be moved. On natural beaches, sand drift by onshore winds is the primary mechanism for rebuilding the dune system following storm erosion. This occurs where the dune vegetation is able to trap the sand.

Sand blown inland can cause a range of hazards including:

- A permanent loss to the beach system; and
- A nuisance for coastal developments.

If sand is blown inland out of the zone of active beach fluctuations it becomes a permanent loss to the beach system. Dune systems act as reservoirs and supply sand to the nearshore areas during periods of erosion. If sand is lost inland from this system, the volume of sand available to supply the erosion demand is less and therefore the shoreline recession is greater. A long term loss as a result of sand drift therefore affects the overall sediment budget and can contribute to shoreline recession.

Dune vegetation plays an important role in minimising sand drift by acting to trap any wind-blown sand. This trapping action helps to build up the dune and keep the sand within the active beach system. Sand drift is usually initiated by the degeneration or destruction of dune vegetation. Once initiated, it can often lead to the irreversible generation of blow outs which concentrate the wind velocities and cause more sand to drift. A common cause of dune vegetation destruction is uncontrolled pedestrian access and/or vehicular traffic and vandalism.

Areas of Bega Valley Shire affected by uncontrolled access have been stabilised with targeted dune management measures. There are currently no areas that experience significant sand drift problems not controlled by these dune management practices.

4 Bega Valley Shire Hazard Assessment

4.1 Introduction

The chapter provides an outline of coastal hazards at each of the beach units within the study area. This has involved consideration of all of the available data and information relevant to each beach, particularly previous study findings and photogrammetric analyses, and assessment of future sea level rise impacts, following the methodology outlined in Chapter 3.

Broadly, the key erosion components relate to the immediate storm bite and the progressive longer term shoreline retreat associated with sea level rise. In conjunction with the actual erosion, consideration needs to be given to a zone of reduced bearing capacity which exists landward of the resultant erosion scarp. Hazards relating to local influences associated with the effects of beach rotation and the potential for oceanic inundation and entrance instability have also been considered where applicable.

The various hazard components are discussed below for each district within the study area.

4.2 Bermagui Coast

The Bermagui Coast extends from Wallaga Lake in the north to Jerimbut Point in the south (refer to Figure 1-1). The main beaches of the district include Camel Rock Beach, Haywards Beach, Moorhead Beach, Horseshoe Bay Beach and Beares Beach.

Camel Rock Beach, Haywards Beach and Moorhead Beach form a slightly embayed unit extending from Murunna Point in the north to the Bermagui River training walls in the south. The unit has a length of approximately 5.4km and comprises a series of sandy beaches divided by minor rocky outcrops, including Haywards Point and Keating Headland.

Haywards Beach and Camel Rock Beach face east-southeast and receive the full extent of the prevailing wave climate. Moorhead Beach is somewhat less exposed to wave events from the south and southeast due to the sheltering effect of Point Dickinson. The Bermagui River, with its trained entrance, is located at the southern end of Moorhead Beach. At most locations, the beach and main active dune system is backed by a bluff with a typical crest level several metres above the dune crest (see Figure 4-1). These bluffs consist of rock formations belonging to the Ben Boyd formation.

At a number of locations, creek and lagoon systems are located immediately behind the active dune system. This includes Long Swamp behind the southern end of Haywards Beach and the Bermagui River estuary and Salty Lagoon behind Moorhead Beach.

Horseshoe Bay is Bermagui's main recreational beach. It is a pocket beach of approximately 500 m long, bounded by Bermagui Point and Point Dickinson. Horseshoe Bay's northerly aspect in combined with its sheltered position behind Point Dickinson produces a low wave energy environment with significant protection against most common storm waves from the south to south east.

Beares Beach, to the south of Point Dickinson, is a nearly straight east-southeast facing beach, bounded by Blue Pool and Breakaway Point. The beach is approximately 900 m long, which in the north is interrupted by rocks and reefs. It is backed by a 20-30 m high densely vegetated bluff. In the north, the bluff is covered by residential development.

The shoreline modelling undertaken indicates that at present no bypassing occurs around the Bermagui River training walls, Bermagui Point and Point Dickinson under the influence of littoral transport processes. Despite this lack of bypassing capacity around the training walls, sand does enter the river mouth under prevailing tidal processes and become deposited in the flood tide delta. Episodic maintenance dredging of the river entrance area is being undertaken by Crown Lands (NSW Trade and Investment) in response to this sedimentation. The sand removed is typically placed at the western side of the river entrance.

Figure 4-1 Haywards Beach backed by a Bluff

Figure 4-2 Moorhead Beach from Bermagui River training walls

4.2.1 Coastal Erosion Hazard Assessment

The principal mechanisms for coastal erosion along the beaches within this district are:

- Short term storm bite erosion; and
- Shoreline recession due to underlying erosion trends and sea level rise.

4.2.1.1 Storm Bite Provision

The photogrammetric data indicates that Moorhead Beach exhibits a storm bite capacity of about 120-150 m^3/m and accordingly, a design storm bite volume of 120 m^3/m has been adopted for the 'Almost Certain' case and 150 m^3/m for the ''Unlikely'' case at this beach.

Consistent with previously determined information (Kidd, 2000), this hazard assessment has adopted a design storm bite volume of 80 m^3/m for the 'Almost certain' case and 100m^3/m for the 'Unlikely' case at Main Beach (Horseshoe Bay).

In absence of any site specific data, the storm bite component for the other beaches in the district have been based on the regional storm bite capacity for exposed ocean beaches, as outlined in Table 3-4. That is, the storm erosion extents for the 'Almost certain' case have been based on a storm bite provision of 200 m^3/m and 250 m^3/m for the 'Unlikely' case.

Along the exposed ocean beaches (Camel Rock Beach, Haywards Beach, Beares Beach), the position of the eroded scarp crest for the 'Unlikely' case typically lies 50 to 60 m landward of the 2008 frontal dune edge, with greater distances corresponding to areas where dunes are lower and/or narrower. Along Horseshoe Bay, this scarp position typically lies about 20 m landward of the 2008 frontal dune edge for the 'Unlikely' case. Some typical examples of the storm bite assessment are shown in Figure 4-3.

Where the dune system is backed by low-lying areas, there is a risk of erosion and wave overtopping over-wash. In some cases, for example at the southern end of Moorhead Beach where the Bermagui River runs immediately behind the active dune system (Figure A-6 in Figure Compendium), the immediate erosion hazard could involve breakthrough.

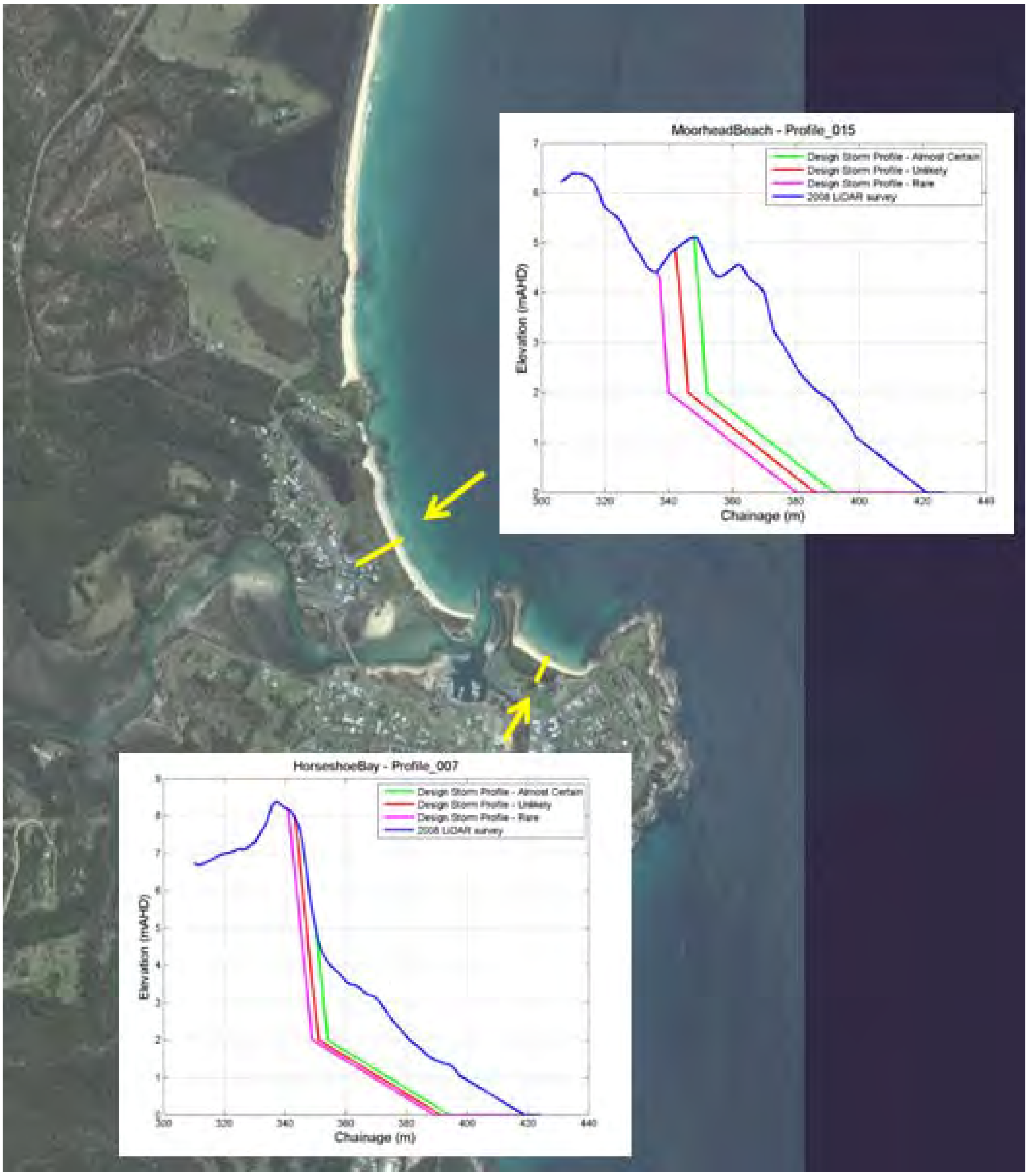

Figure 4-3 Typical Storm Bite Profiles along Moorhead Beach and Horseshoe Bay

4.2.1.2 Long Term Recession

The photogrammetric data for Moorhead Beach and Horseshoe Beach does not indicate that these beaches are experiencing a clear trend of shoreline recession and therefore no shoreline additional setback for long term recession has been included in the 'Almost certain' and 'Unlikely' hazard extents at 2050 and 2100. Providing for uncertainties in the estimates and possible future changes, a long term recession rate of 0.1 m/yr has been included in the 'Rare' case hazard extents.

In lieu of site specific data, the long term recession rates at the other beaches in the district have been based on the recommended regional underlying recession rates (Refer to Section 3.3.5).

Recession due to Sea Level Rise

Provisions for sea level rise related recession have been analysed and quantified on the basis of EVOMOD shoreline modelling in conjunction with the Bruun Rule method.

As discussed in Section 3.3.6, the shoreline modelling has demonstrated that currently no bypassing occurs around the Bermagui River training walls under the influence of littoral transport processes. The modelling has also demonstrated that sea level rise will not result in a significant influx of sediment from the adjacent beaches to the Bermagui River entrance. Accordingly, the coastal entrance sedimentation provisions incorporated in the erosion hazard extent of Moorhead Beach and Horseshoe Bay are zero.

For the ‘Unlikely’ case (with predicted sea level rise of 0.84 m), the EVOMOD model yields a shoreline recession by 2100 of approximately 28 m at Moorhead and approximately 23 m at Horseshoe Bay. The Bruun Rule yields a recession of approximately 28-32m, reasonably consistent with the modelled recession at Moorhead, but somewhat larger than the model results for Horseshoe Bay.

In recognition of the uncertainties involved in both assessment methods (the EVOMOD modelling and the Bruun Rule) and the objective of precautionary conservatism, the larger of the recession distances determined by the two methods has been adopted.

4.2.1.3 Mapping of Erosion and Recession Hazards

The erosion hazard extents have been derived on the basis of the methodology outlined in Section 3.3.9.

The immediate erosion hazard extents incorporate the design beach erosion provisions and sensitivity provisions for the identified variability in how the beach system behaves. The 2050 and 2100 erosion hazard extents incorporate the immediate hazard extents and represent its projected extent following shoreline recession over those respective timeframes.

In the mapping, consideration is given to the limit of bedrock where it is known to occur. It should be noted that there is a zone of reduced foundation capacity that extends landward of these erosion hazard lines, as discussed in Section 3.3.7.

Erosion hazard maps for the Bermagui Coast at the immediate, 2050 and 2100 planning horizons are presented in the Figure Compendium.

4.2.2 Coastal Inundation Hazard

4.2.2.1 Wave Run-up and Overtopping

Wave runup levels along the Bermagui beaches and headlands were estimated using storm tide and offshore wave statistics presented in Chapter 2. Wave propagation modelling, providing for refraction and attenuation due to bed friction across the continental shelf, was undertaken to provide an estimate of the design wave conditions at each beach.

Using the method of Nielsen and Hanslow (1991) for run-up at natural beaches and the Eurotop (2007) method for headlands, design wave run-up levels ($R_{u2\%}$) relative to existing sea level were calculated for the different parts of the Bermagui Coast, as listed in Table 4-3.

Mapping of the susceptibility of the Bermagui Coast to wave overtopping is provided in the Figure Compendium.

With the exception of areas at and adjacent to the Bermagui River and at the swamp areas near Keating Headland, the dune system is generally sufficiently high to accommodate wave run-up without direct inundation of developed areas from the sea.

Table 4-1 Design Wave Run-up Levels for Bermagui Coast

Location	*Shoreline Type*	*Elevated Ocean Level (excl. wave setup)*	*2% Runup Height (m)*	*Design Wave Runup Level (mAHD)*
Camel Rock Beach	Sandy beach	1.32mAHD	4.12m	5.4mAHD
Haywards Beach	Sandy beach	1.32mAHD	4.13m	5.5mAHD
Moorhead	Sandy beach	1.32mAHD	3.70m	5.0mAHD
Horseshoe Bay (western end)	Sandy beach	1.32mAHD	3.18m	4.5mAHD
Horseshoe Bay (eastern end)	Sandy beach	1.32mAHD	2.78m	4.1mAHD
Point Dickinson (north facing shoreline)	Cliff	1.32mAHD	13.4m	14.7mAHD
Point Dickinson (east facing shoreline)	Cliff	1.32mAHD	21.7m	23.1mAHD
Beares Beach	Sandy beach	1.32mAHD	4.50m	5.8mAHD

4.2.2.2 Estuary Storm Tide Inundation

Design inundation levels within the lower estuaries of the Bermagui Coast district are determined on the basis of the factors outlined in Section 3.4.4.

Table 4-2 provides a summary of the adopted design coastal inundation levels for Wallage Lake. The design levels for Bermagui River are presented in Table 4-3. The extents of the inundation hazard for each planning timeframe are illustrated in the Figure Compendium.

Table 4-2 Adopted coastal inundation levels (mAHD) within Wallaga Lake estuary

Planning Horizon	*'Almost Certain'*	*'Unlikely'*	*'Rare"*
Immediate	2.00	2.53	2.73
2050	2.12	2.87	3.23
2100	2.28	3.37	4.03

Table 4-3 Adopted coastal inundation levels (mAHD) within Bermagui River estuary

Planning Horizon	*'Almost Certain'*	*'Unlikely'*	*'Rare"*
Immediate	1.28	1.32	1.52
2050	1.40	1.66	2.02
2100	1.56	2.16	2.82

4.2.3 Coastal Entrance Instability

Wallaga Lake

The Wallaga Lake entrance is untrained and exhibits the typical characteristics of an ICOLL (Intermittently Closed and Open Lakes or Lagoons) in that:

- Under normal day-to-day conditions, the entrance is open and allows tidal flow to penetrate into the lake although significantly constricted under the influence of longshore sand transport; and
- During periods of low catchment runoff and accreting beach conditions, the entrances can become closed.

Wallaga Lake is predominantly open, as the catchment inputs are generally large enough to keep the entrance open most of the time. However, when the entrance closes, water tends to build up behind the entrance berm and has the potential to inundate low lying area around the lake. When deemed necessary, the entrance is artificially opened to mitigate this impact. Consequently, the lake is open to the ocean more frequently than under natural conditions.

Interpretation of available historical aerial photography has indicated that the mouth may experience substantial changes over time, however entrance breakouts and spit erosion generally occur over a relatively short distance. Based on this, it is not expected that significant migration beyond the northern end of the current sand spit will occur during the future planning period.

Bermagui River

The entrance of the Bermagui River has been trained to provide safe navigational access to the harbour. These training walls have been subject to storm wave attack, which could lead to periodic damage necessitating repairs. However, the entrance itself has been quite stable.

The key hazard around the Bermagui River entrance relates to the potential impacts of storms at the southern end of Moorhead Beach. The dune system along this section of the coast is such that a breakthrough could occur during severe storm erosion events.

4.3 Cuttagee / Murrah Coast

The Cuttagee / Murrah Coast extends from Baragoot Point in the north to Goalen Head in the south (Refer to Figure 1-2). It includes Baragoot Beach, Cuttagee Beach, Mill Beach, Barragga Bay, Almonds Bay and Murrah Beach.

Although the Cuttagee / Murrah district is largely undeveloped, residential development does occur at Baragoot Point, Mill Beach and Barragga Bay, as well as on the shores of Baragoot Lake and Cuttagee Lake. At Cuttagee Beach, a major road (Tathra-Bermagui Road) runs in close proximity to the beach.

Baragoot Beach, Cuttagee Beach and Mill Beach form a gently curved embayment of approximately 5 km long, between Baragoot Point in the north and the Barragga Point in the south. The embayment includes a series of long sandy beaches interrupted by outcropping rock and the entrances of Baragoot Lake (usually closed), Cuttagee Lake (usually open) and two minor deflected creeks, associated with swamps behind the beach. Baragoot Beach is generally exposed to the full extent of the prevailing wave climate. Cuttagee Beach and particularly Mill Beach, on the other hand, receive some protection from Barragga Point from the dominant southeasterly swell. Most of the beaches along the embayment usually maintain a single bar, cut regularly by rips every 200-300 m (Short, 2007). At Mill Beach, several rocky outcrops occur within the nearshore area and on the beach.

Barragga Bay and Armonds Bay are small pocket beaches bounded by substantial rocky headlands. Both beaches are backed by a minor lagoon system with a small creek which drains out in the northern part of the beach.

Murrah Beach is an open 2km wide embayment between Murrah Head in the north and the base of the 2km long Goalen Head in the south. This beach is interrupted by two entrances, namely Murrah Lake (usually open) and Bunga Lagoon (mostly closed). Murrah Beach usually maintains a single bar, cut regularly by rips every 200-300 m.

Figure 4-4 Cuttagee Beach, Looking North

Figure 4-5 Mill Beach and Barragga Point

Figure 4-6 Barragga Bay with Creek draining out onto Beach

4.3.1 Coastal Erosion Hazard Assessment

The principal mechanisms for coastal erosion along the beaches within this district are:

- Short term storm bite erosion; and
- Shoreline recession due to underlying erosion trends and sea level rise.

4.3.1.1 Storm Bite Provision

There is currently no photogrammetric data available for the Cuttagee / Murrah Coast beaches from which site-specific design storm bite provisions can be derived, with the exception of Cuttagee Beach.

The photogrammetric data for Cuttagee Beach indicates that this beach exhibits a storm bite capacity up to about 200-250 m^3/m, and accordingly, a storm bite volume of 200 m^3/m has been adopted for the 'Almost certain' case and 250 m^3/m for the 'Unlikely' case along this beach.

For the other beaches in the district, the beach erosion provisions have been based on the regional storm bite provisions outlined in Table 3-4. That is, the storm erosion extents for the 'Unlikely' case have been based on a storm bite provision of 250 m^3/m along the exposed ocean beaches and 150 m^3/m along protected embayments.

Along most exposed ocean beaches (i.e. Baragoot Beach, Cuttagee Beach, Murrah Beach) , the position of the eroded scarp crest for the 'Unlikely' case is typically 50 to 60 m landward of the 2008 frontal dune edge, with greater distances corresponding to areas where dunes are lower and/or narrower. For the more protected beaches (Mill Beach, Baragga Bay, Armond Bay), a typical erosion distance of 30-35 m was found for the 'Unlikely' case, increasing to 35-40 m for the 'Rare' case.

4.3.1.2 Long Term Recession

The photogrammetric data for Cuttagee Beach does not indicate that this beach is experiencing a clear trend of shoreline recession and therefore no shoreline additional setback for long term recession has been included in the 'Almost certain' and 'Unlikely' hazard extents at 2050 and 2100. Providing for uncertainties in the estimates and possible future changes, a long term recession rate of 0.1 m/yr has been included in the 'Rare' probability hazard extents.

In lieu of site specific data, the long term recession rates at the other beaches in the district have been based on the recommended regional underlying recession rates (refer to Section 3.3.5).

Recession due to Sea Level Rise

Provisions for sea level rise related recession for this district have been estimated on the basis of the Bruun Rule method in conjunction with the 'polynomial trend' method (described in Section 3.3.6.4) to account for potential coastal entrance sedimentation impacts as appropriate.

For the 'Unlikely' case (with predicted sea level rise of 0.84 m), the Bruun Rule yields a shoreline recession of approximately 27-30 m by 2100, depending on dune heights behind the shoreline.

The 'polynomial trend' method yields an additional (more or less uniform) shoreline recession of approximately 6 m by 2100 along Cuttagee Beach and Baragoot Beach due to combined effect of future entrance sedimentation at Baragoot Lake and at Cuttagee Lake. Along Murrah Beach, the method yields a similar recession of approximately 7 m due to future entrance sedimentation at Murrah Lake.

4.3.1.3 Mapping of Erosion and Recession Hazards

The erosion hazard extents have been derived on the basis of the methodology outlined in Section 3.3.9.

The immediate erosion hazard extents incorporate the design beach erosion provisions and sensitivity provisions for the identified variability in how the beach system behaves.

The 2050 and 2100 erosion hazard extents incorporate the immediate erosion hazard and represent its projected extent following shoreline recession over those respective time-frames. Each of the beach erosion probabilities ('Almost certain', 'Unlikely' and 'Rare') have been adopted across the length of the beach embayment and /or to the limit of bedrock where it is known to occur. It should be noted that there is a zone of reduced foundation capacity that extends landward of these erosion hazard lines, as discussed in Section 3.3.7.

Erosion hazard maps for the Cuttagee / Murrah Coast at the immediate, 2050 and 2100 planning horizons are presented in the Figure Compendium.

4.3.2 Coastal Inundation Hazard

4.3.2.1 Wave Run-up and Overtopping

Wave runup levels along the Cuttagee / Murrah beaches and headlands were estimated using storm tide and offshore wave statistics presented in Chapter 2. Wave propagation modelling, providing for refraction and attenuation due to bed friction across the continental shelf, was undertaken to provide an estimate of the 1 in 100 year ARI design storm conditions at each beach.

For the sandy beach areas in the district, the adopted wave run-up level ($R_{u2\%}$) is 5.5mAHD. Mapping of the potential overtopping hazard, based on this level, is presented in the Figure Compendium.

With the exception of areas at and adjacent to the creek and lagoon entrances, the dune systems along Baragoot Beach / Cuttagee Beach and Murrah Beach are generally sufficiently high to accommodate wave run-up without direct inundation from the sea.

Waves may overtop the dunes of Barragga Bay and Armonds Bay, which could result in flooding of the lagoon systems behind the beach. It is however unlikely that wave overtopping will impact on development behind Barragga Bay and Armonds Bay.

4.3.2.2 Estuary Storm Tide Inundation

Design inundation levels within the main lower estuaries in the Cuttagee / Murrah district have been determined on the basis of the factors outlined in Section 3.4.4. The adopted design coastal inundation levels for each hazard probability descriptor and planning timeframe are summarised in Table 4-2.

The extents of the inundation hazard for each planning timeframe are illustrated in the Figure Compendium.

Table 4-4 Adopted coastal inundation levels (mAHD) - Lower estuaries of Cuttagee / Murrah Coast

Planning Horizon	*'Almost Certain'*	*'Unlikely'*	*'Rare"*
Immediate	2.02	2.59	2.79
2050	2.14	2.93	3.29
2100	2.30	3.43	4.09

4.3.3 Coastal Entrance Instability

The four main entrances within this district (Baragoot Lake, Cuttagee Lake, Murrah Lake and Bunga Lagoon) are all untrained and exhibit the typical characteristics of an Intermittently Closed and Open Lakes or Lagoons.

The entrances of Baragoot Lake, Cuttagee Lake and Bunga Lagoon are predominantly closed, as the influences of oceanic processes (primarily waves) are dominant compared with catchment inputs. The catchments of these systems are relatively small and therefore catchment flows are insufficient to keep the entrances permanently open.

Murrah Lake is backed by the Murrah River, which has a substantial catchment. As a result, Murrah Lake is predominantly open.

All four entrances exhibit substantial scour during periods of heavy rainfall to allow the discharge of stormwater. Interpretation of available historical aerial photography has indicated that entrance breakout and spit erosion generally occur over a relatively short distance around the current location of each entrance. Furthermore, the undeveloped status of the areas around the entrances is such that entrance processes do not present significant hazards.

4.4 Tathra

This district extends from Wajurda Point in the north to Tathra Headland in the south. It includes Tathra Beach and Moon Bay (Refer to Figure 1-3).

Tathra Beach is a 3.3km long uninterrupted sandy beach bounded by the mouth of the Bega River in the north and the base of the 700 m long Tathra Head in the south. The beach is backed by multiple barriers. The current barrier has been developed during the Holocene. Behind this, there is evidence of a more ancient barrier, which would have been established during previous interglacial periods during the Pleistocene. The Tathra Golf Course is located on the relict barrier.

The beach sediments vary somewhat along the embayment, with generally much finer sand at the southern end and coarser sediment (and more fluvial in origin) at the northern end. An offshore bar occurs along most of Tathra Beach and merges with the entrance lobe of the Bega River at the northern end.

Moon Bay is a small (300 m long) indented embayment that faces in a general south eastern direction. It is bounded by outcropping headlands at each end.

4.4.1 Conceptual Coastal Processes

The coastal system of Tathra Beach has a history of erosion, in particular during the 1970s when the erosion escarpment receded past the surf club and threatened several developments.

The Tathra Bay beach system is morphologically dynamic and the position of the shoreline is the result of the constant interaction of wind, waves, tides, floods and sediments. The behaviour of the Bega River has a major influence on the shoreline behaviour.

The tidal delta of the Bega River extends onto the adjacent beach and any change in the entrance will necessarily impact on the incident waves, sediment transport and shoreline position and alignment. The delta and entrance are shaped by a number of processes interacting together, including (i) ocean waves transporting marine sand onshore, (ii) longshore sand transport along Tathra Beach, (iii) tidal movement of sand in the lower reaches of the river, and (iv) Aeolian sand transport from the beach berm at Tathra.

During significant flood events a mix of fluvial sands from upstream and marine sand is eroded from the entrance spit and bar and delivered to the coastal zone where it is initially deposited in an offshore lobe that extends more than 1 km offshore and is subsequently reworked onshore by waves during calm periods. Due to the water depths at the lobe, the rate of this onshore supply is comparatively small.

Scouring of the entrance during major flood events may erode millions of cubic metres of sediment offshore (PWD, 1980; CMG 2000) and may result in a dramatic change of the entrance, as evidenced by substantial damage to the Hancock Bridge during the February 1971 flood event (refer to Figure 4-7).

PWD (1980) estimated that during the February 1971 flood event (the largest flood on record), a volume of approximately 1.5 million m^3 was removed from the entrance bar and an additional 0.5 million m^3 from the entrance spit.

The strong longshore transport capacity along Tathra Beach provides a source of marine sand to be reworked back into the estuary entrance by wave action. Re-establishment of the entrance sand spit typically occurs over a period of months following a major scour event (CMG 2000). Rebuilding of the entrance bar occurs over longer timeframes (a few years). Hence, for up to a few years following a major flood event, the beach may experience a significant reduction in beach volumes, with erosion that tends to disperse along the entire embayment as a result.

The shoreline alignment is also influenced by variability in the prevailing wave conditions. Embayments such as Tathra Bay tend to align themselves perpendicular to the predominant wave direction and any change in this direction would result in a regional realignment of the shoreline. On a macro scale the changes may appear minor, but locally significant shoreline movements may be experienced, particularly at the extremities of embayments.

Superimposed on this, there will be variability in the shoreline position due to beach response to storm events and subsequent recovery.

Figure 4-7 Hancock Bridge after February 1971 flood event (Image: O. Hinde)

Figure 4-8 Tathra Beach in 1970s

Figure 4-9 Tathra Beach (August 2013)

4.4.2 Coastal Erosion Hazard Assessment

The principal mechanisms for coastal erosion within the Tathra embayment are:

- Short term storm bite erosion;
- Short to medium term fluctuations due to entrance dynamics following flood events; and
- Shoreline recession due to underlying erosion trends and sea level rise.

4.4.2.1 Storm Bite Provision

The photogrammetric data for Tathra Beach indicates that this beach exhibits a storm bite capacity consistent with the regional storm bite capacity of exposed ocean beaches, with the exception of the southern most 500m of the beach. Accordingly, a storm bite volume of 200 m^3/m has been adopted for the 'Almost certain' case and 250 m^3/m for the 'Unlikely' case along Tathra Beach, with the exception of the southern end of the beach.

Along this southern most 500m of the beach, the adopted storm bite provision for the 'Almost certain' case increases (linearly) from 100 m^3/m at the southern end to 200 m^3/m at a location just south of the Tathra Beach Family Park site. Similarly, the adopted storm bite volume for the 'Unlikely' case increases from 125 m^3/m at the southern end to 250 m^3/m just south of the Tathra Beach Family Park site.

For Moon Bay and Nelsons Beach, there is no photogrammetric data. Therefore, in lieu of site specific estimates, the adopted beach erosion provisions for these beaches have been based on the regional storm bite capacities for protected embayments, as outlined in Table 3-4. That is, the storm erosion extents for the 'Almost certain' case have been based on a storm bite provision of 120 m^3/m and 150 m^3/m for the 'Unlikely' case.

Along most of Tathra Beach, the 'Unlikely' position of the eroded scarp crest is located 55m landward of the 2008 frontal dune edge, with the smaller distances along the most southern 500m of the beach. For Moon Bay and Nelsons Beach, a typical erosion distance of 30 to 40m was found for the 'Unlikely' case, increasing to 35-45 m for the 'Rare' case.

Some typical examples of storm bite assessment for Tathra Beach are shown in Figure 4-10.

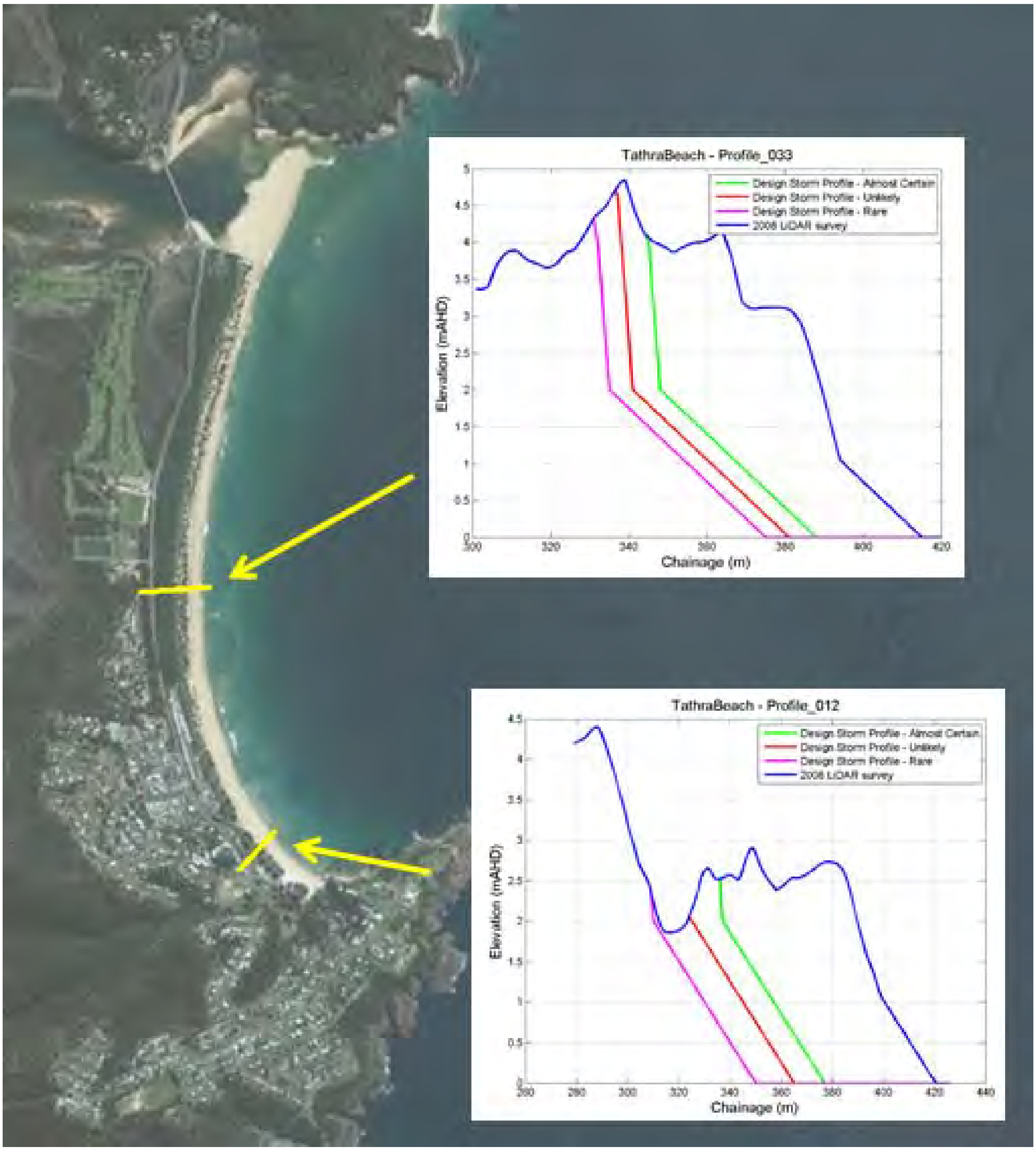

Figure 4-10 Typical Storm Bite Profiles along Tathra Beach

4.4.2.2 Shoreline Erosion due to Entrance Scouring

As mentioned above, during major flood events substantial amounts of sediment can be removed from the entrance spit and bar of the Bega River, which initiates a beach response throughout the embayment whereby sand is transported towards the entrance to help reform the spit and entrance bar. This migration of sand leads to a temporary loss of beach sand from the beach, which may cause significant erosion along the embayment.

To account for potential future shoreline erosion due to entrance infilling following flood events of the Bega River, an erosion provision equivalent to a temporary removal of 1 million m^3 of sand has been incorporated in the hazard extents for the 'Unlikely' and the 'Rare' cases.

4.4.2.3 Long Term Recession

The photogrammetric data indicates that Tathra Beach is exhibiting a moderate ongoing loss of beach sand and therefore a future long term retreat of this section of coast is likely.

The 'best estimate'' long term recession rate for Tathra Beach is 0.1 m/yr, with upper and lower limits of zero and 0.2 m/yr.

Sea Level Rise Recession

Provisions for sea level rise related recession have been analysed and quantified on the basis of EVOMOD shoreline modelling in conjunction with the Bruun Rule method.

For the 'Unlikely' case (with predicted sea level rise of 0.84 m), the EVOMOD model yields a shoreline recession by 2100 of approximately 30 m along Tathra Beach, consistent with the shoreline recession estimates obtained using the Bruun Rule.

It should be noted that the shoreline modelling of the 'Sea level rise and coastal entrance sedimentation' case yielded a shoreline recession along Tathra Beach in the range of 20-25 m by 2050 and 50-55 m by 2100, somewhat larger than the 15-20 m by 2050 and 45-50 m by 2100 yielded for the **'**Extreme Sea level rise' scenario. This value is not included in hazard mapping.

4.4.2.4 Mapping of Erosion and Recession Hazards

The erosion hazard extents have been derived on the basis of the methodology outlined in Section 3.3.9.

The immediate erosion hazard extents incorporate the design beach erosion provisions and sensitivity provisions for the identified variability in how the beach system behaves.

The 2050 and 2100 erosion hazard extents incorporate the immediate erosion hazard and represent its projected extent following shoreline recession over those respective time-frames. Each of the beach erosion probabilities ('Almost certain', 'Unlikely' and 'Rare') have been adopted across the length of the beach embayment and /or to the limit of bedrock where it is known to occur. It should be noted that there is a zone of reduced foundation capacity that extends landward of these erosion hazard lines, as discussed in Section 3.3.7.

Erosion hazard maps for Tathra at the immediate, 2050 and 2100 planning horizons are presented in the Figure Compendium.

4.4.3 Coastal Inundation Hazard

4.4.3.1 Wave Run-up and Overtopping

For Tathra Beach, design run-up levels ($R_{u2\%}$) were calculated to be approximately 5.1mAHD at the southern part increasing to approximately 5.4mAHD at the northern end. Dune elevations along the southern part of the bay including along Tathra township, are typically at 4.5 – 4.8mAHD, indicating that those areas may experience overtopping during severe storm events at present. It is likely that this area will experience enhanced wave run-up and overtopping in the future as sea level rises. Also, the dunes behind Moon Bay and Nelsons Beach may experience overtopping during infrequent storm events at present.

At Tathra Headland, the Tathra Wharf and the lower parts of Wharf road may become subject to wave overtopping during severe storm events.

4.4.3.2 Estuary Storm Tide Inundation

Design coastal inundation levels within the lower parts of the Bega River have been determined on the basis of the factors outlined in Section 3.4.4. The adopted design coastal inundation levels for each hazard probability descriptor and planning timeframe are summarised in Table 4-5.

The extents of the inundation hazard for each planning timeframe are illustrated in the Figure Compendium.

Table 4-5 Lower estuary coastal inundation levels (mAHD) – Bega River

Planning Horizon	*'Almost Certain'*	*'Unlikely'*	*'Rare"*
Immediate	1.88	2.30	2.50
2050	2.00	2.64	3.00
2100	2.16	3.14	3.80

4.4.4 Coastal Entrance Instability

The Bega River is untrained and its entrance dynamics have a significant effect on Tathra Beach, as there are substantial exchanges of beach sand with deposits in the lower estuary.

During periods of low catchment runoff and accreting beach conditions, the entrance has a tendency to close. This behaviour results from the relatively small tidal compartment of the river, which is insufficient to keep the entrance permanently open. It has a significant effect on the flooding potential of the low lying areas of the catchment. When deemed necessary, the entrance is artificially opened to mitigate this impact.

During periods of heavy rainfall, the entrance tends to scour naturally to allow discharge of stormwater. During such periods, millions of cubic metres of sand may erode from the spit and entrance bar of the Bega River and be transported offshore. Flood scour at the Bega River entrance has caused substantial damage to land and development adjacent to the river mouth in the past.

Available historical aerial photography indicates that entrance breakouts and spit erosion in recent decades have generally occurred at the northern end of Tathra Beach. However, CMG (2000) suggests that the entrance has previously been located at least 1.5km south in a topographic low point (termed 'the old spit"). CMG (2000) also suggests that without artificial opening flood waters have the potential to breakout again at this low point in the future.

Figure 4-11 Bega River entrance (Image: OEH)

4.5 Merimbula Coast

The Merimbula Coast extends from Bournda Island in the north to Haycock Point in the south (refer to Figure 1-4). It includes North Tura Beach, Tura Beach, Short Point Beach, Middle Beach, Merimbula Beach, Pambula Beach and Jiguma Beach.

Merimbula Bay is an approximately 5 km wide, strongly curved embayment between Long Point and Haycock Point. It encompasses Merimbula Beach, Pambula Beach, Jiguma Beach and two additional smaller beaches. Merimbula Beach begins at the entrance of Merimbula Lake in the north then sweeps in a broad east-facing arc for approximately 6 km to the shaly rocks at Pambula. Further to the south is Jiguma Beach, an approximately 360 m long beach that faces northeast and has headlands at each end. The mouth of the Pambula River is located to the south of Jiguma Beach.

Tura-Short Point Beach curves to the southwest, then south for 3.5 km between Tura Head and Short Point. It is backed by a broad valley in the north and Back Lake lagoon in the south. The beach faces east and is exposed to the full extent of the prevailing wave climate.

North Tura Beach runs in a broad 3 km long east-facing arc from Bournda Island in the north, to Tura Head in the south. Much of the beach is backed by substantial bluffs with heights of up to 60m.

Figure 4-12 Merimbula Beach

Figure 4-13 North Tura Beach

4.5.1 Coastal Erosion Hazard Assessment

The principal mechanisms for coastal erosion within the Merimbula Coast district are:

- Short term storm bite erosion;
- Short to medium term fluctuations due to entrance dynamics following flood events; and
- Shoreline recession due to underlying erosion trends and sea level rise

4.5.1.1 Storm Bite Provision

The photogrammetric data indicates that Pambula Beach exhibits a storm bite capacity of about 120-150 m^3/m, while the data for Jiguma Beach and Merimbula Beach suggest a somewhat smaller capacity, about 80-100 m^3/m. Accordingly, a storm bite volume of 120 m^3/m has been adopted for the 'Almost certain' case and 150 m^3/m for the 'Unlikely' case for Pambula Beach, and 80 and 100 m^3/m for the 'Almost certain' and 'Unlikely' cases respectively along Jiguma and Merimbula Beach.

There is no photogrammetric data for the other beaches in this district. Therefore, in lieu of site specific estimates, beach erosion provisions for these beaches has been based on the regional storm bite capacities, outlined in Table 3-4. That is, for the exposed beaches in the district (North Tura Beach, Tura Beach, Short Point Beach, Middle Beach) the storm erosion extents for the 'Almost certain' case have been based on a storm bite provision of 200 m^3/m and 250 m^3/m for the 'Unlikely' case.

Within Merimbula Bay, the 'Unlikely' position of the eroded scarp crest is typically 30 to 40 m landward of the 2008 frontal dune edge, with greater distances corresponding to areas where dunes are lower and/or narrower. For the exposed ocean beaches (North Tura Beach, Tura Beach, Short Point Beach, Middle Beach), this distance was typically 50 to 60 m.

Some typical examples of storm bite assessment for Pambula / Merimbula Beach are shown in Figure 4-14.

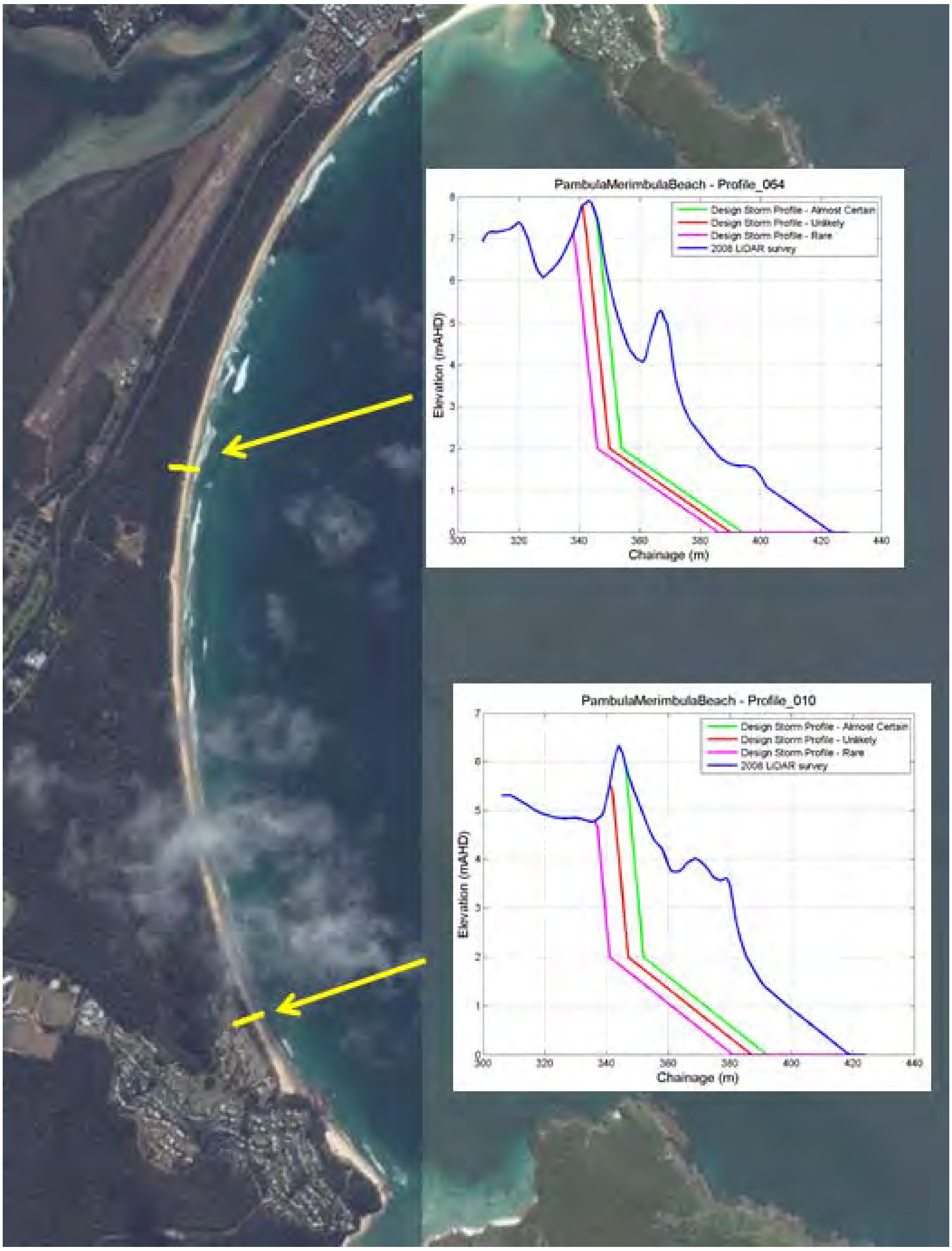

Figure 4-14 Typical Storm Bite Profiles along Pambula / Merimbula Beach

4.5.1.2 Long Term Recession

The photogrammetric data indicates that the beaches of Merimbula Bay are exhibiting a moderate ongoing loss of beach sand and therefore a future long term retreat of this section of coast is likely.

The 'best estimate' long term recession rate for Merimbula Beach, Pambula Beach and Jiguma Beach is 0.1m/yr, with upper and lower limits of zero and 0.2m/yr, respectively.

In lieu of site specific data, the long term recession rates of North Tura Beach, Tura Beach, Short Point Beach and Middle Beach have been based on the estimates for Merimbula Bay.

Recession due to Sea Level Rise

Future recession due to sea level rise for the beaches within Merimbula Bay has been assessed using the EVOMOD shoreline model and as discussed in detail in Section 3.3.6. Recession provisions for the other beaches in the district have been estimated on the basis of the Bruun Rule method.

Based upon the modelling output, the extent of future long term recession due to sea level rise for the 'Unlikely' case (with predicted sea level rise of 0.84 m by 2100) is estimated to be in the range of 9-13 m by 2050 and 28-33 m by 2100 along Merimbula/Pambula Beach, reasonably consistent with the shoreline recession estimates obtained using the Bruun Rule.

It should be noted that shoreline modelling of the "sea level rise and coastal entrance sedimentation**'** case yielded a shoreline recession along Pambula/Merimbula Beach larger than the recession predicted for the 'Extreme Sea level rise' case (Refer to Figure 3-25). The model results reveal that if infilling of the Merimbula Lake entrance responds fully to rising sea levels then this will potentially have an impact on the future shoreline position along Merimbula Beach and Pambula Beach. These values were not included in hazard mapping.

The shoreline modelling also demonstrates that the recessionary response of Jiguma Beach to sea level rise will be influenced by the structural features along this section of the coastline. Consequently, the maximum shoreline recession that can be experienced at Jiguma Beach will be controlled by the bedrock features that are present at this beach.

4.5.1.3 Mapping of Erosion and Recession Hazards

The erosion hazard extents have been derived on the basis of the methodology outlined in Section 3.3.9.

The immediate erosion hazard extents incorporate the design beach erosion provisions and sensitivity provisions for the identified variability in how the beach system behaves.

The 2050 and 2100 erosion hazard extents incorporate the immediate erosion hazard and represent its projected extent following shoreline recession over those respective time-frames. Each of the beach erosion hazards ('Almost certain', 'Unlikely' and 'Rare') have been adopted across the length of the beach embayment and /or to the limit of bedrock where it is known to occur. It should be noted that there is a zone of reduced foundation capacity that extends landward of these erosion hazard lines, as discussed in Section 3.3.7.

Erosion hazard maps for the Merimbula Coast at the immediate, 2050 and 2100 planning horizons are presented in the Figure Compendium.

It is noted that the erosion hazard mapping does not take into account the potential influence on future recession of the rock protection that is known to exist along the foredune that is fronting the Pambula Caravan Park and Surf Club. This does not presume that they would be removed but rather is intended to provide Council with advice on where the erosion could extend should it be removed, depending on consideration in subsequent management planning, or fail during the planning period.

4.5.2 Coastal Inundation Hazard

4.5.2.1 Wave Run-up and Overtopping

Along Pambula Beach and Merimbula Beach, design run-up levels ($R_{u2\%}$) were calculated to be approximately 5.3mAHD with somewhat lower levels at the northern end of Merimbula Beach, in the lee of Long Point. Dune elevations along the southern part of Pambula Beach (along the Caravan Park and Surf Club) are typically at or below 5.5mAHD, indicating that those areas may experience overtopping during infrequent storm events at present. It is likely that those areas will experience enhanced wave run-up and overtopping in the future as sea level rises.

Along the other parts of Merimbula Coast beaches, the dune system is generally sufficiently high to accommodate wave run-up without direct inundation from the sea, with the exception of areas at and adjacent to the entrance of Back Lake.

Mapping of the susceptibility to wave overtopping is provided in the Figure Compendium.

4.5.2.2 Estuary Storm Tide Inundation

Design inundation levels within the lower estuaries have been determined on the basis of the factors outlined in Section 3.4.4. The adopted design coastal inundation levels for each hazard probability descriptor and planning timeframe are summarised in Table 4-6 to Table 4-8.

The extents of the inundation hazard for each planning timeframe are illustrated in the Figure Compendium.

Table 4-6 Adopted coastal inundation levels (mAHD) within Pambula River estuary

Planning Horizon	*'Almost Certain'*	*'Unlikely'*	*'Rare"*
Immediate	1.78	2.22	2.42
2050	1.90	2.56	2.92
2100	2.06	3.06	3.72

Table 4-7 Adopted coastal inundation levels (mAHD) within Merimbula Lake estuary

Planning Horizon	*'Almost Certain'*	*'Unlikely'*	*'Rare"*
Immediate	1.73	2.14	2.34
2050	1.85	2.48	2.84
2100	2.01	2.98	3.64

Table 4-8 Adopted coastal inundation levels (mAHD) within Back Lake estuary

Planning Horizon	*'Almost Certain'*	*'Unlikely'*	*'Rare"*
Immediate	2.02	2.57	2.77

Planning Horizon	*'Almost Certain'*	*'Unlikely'*	*'Rare"*
2050	2.14	2.91	3.27
2100	2.30	3.41	4.07

4.5.3 Entrance Instability

Pambula River

The mouth of the Pambula River is located at the southern part of Merimbula Bay behind Haycock Point, a substantial headland that provides a lower wave energy climate compared to the other locations along the embayment. The entrance is permanently open. Between Pambula Lake and the mouth, the river channel is confined by bedrock on each side and also the mouth lies between outcropping rock. Due to the bedrock confinement, it is not expected that any significant migration will occur during the future planning period.

Merimbula Lake

The entrance of Merimbula Lake is located at the northern end of Merimbula Beach behind a substantial headland which provides a lower wave energy climate compared to the other locations along the embayment. It is permanently open even though it has little a relatively small catchment compared to lake size.

The entrance behaviour of Merimbula Lake is governed by geomorphic controls at the entrance (Haines, 2006). The entrance channel is naturally trained by bedrock associated with the headland, resulting in tidal flow velocities through the entrance that are large enough to prevent closure. With higher mean sea level, the relative influence of these geomorphic controls may reduce (i.e. the bedrock base in the entrance would be deeper, and thus ebb tide flows that maintain an open entrance may not be as concentrated), which may increase the susceptibility to closure of the entrance.

Interpretation of available historical aerial photography has indicated that entrance breakout and spit erosion generally occur over a relatively short distance around the current location of the entrance.

Back Lake

Back Lake is a comparatively small estuary and its ocean entrance is predominantly closed. The tidal flows are insufficient to keep the entrance permanently open.

When closed, catchment runoff tends to gradually fill the lake and has the potential to inundate low lying areas around the lake. When deemed necessary, the entrance is artificially opened to mitigate this impact. Bake Lake is one of the most regularly opened lakes on the NSW South Coast (Haines, 2006).

During periods of heavy rainfall, the entrance tends to scour naturally to allow discharge of stormwater. Webb, McKeown and Associates (1997) indicate that the entrance opens about twice per year for around a week each time.

Interpretation of aerial photography and geological surveys has indicated that entrance breakouts and spit erosion generally occur over a relatively short distance.

Figure 4-15 Pambula River entrance (Image: OEH)

Figure 4-16 Merimbula Lake entrance (Image: OEH)

Figure 4-17 Back Lake entrance (Image: OEH)

4.6 Twofold Bay

Twofold Bay is an open oceanic embayment between Wurang Point in the north and Munganno Point in the south. The bay consists of two bights, divided by Lookout Point. The primary beach of the northern bight is Aslings Beach. The southern bight includes Whale Beach, Boydtown Beach and a large number of smaller beaches, separated by outcropping bedrock, as shown in Figure 1-5.

Most of beaches in the southern bight have comparatively low dunes and are backed by small lagoons that drain into the bay via minor creeks that run over the beaches. Two major towns are located on Twofold Bay, namely Eden and Boydtown.

Aslings Beach is the main recreational and surf beach for Eden. It is 2.3 km long, slightly curved and faces in a general southeastern direction. The beach is sheltered from large north and northeasterly waves by Worang Point, which extends some 2 km to the southeast from its base at Aslings Beach. The entrance of Lake Curalo is located on the northern end of Aslings Beach.

Boydtown Beach lies in the southern bight, approximately 7 km south of Eden. It is a curved beach of approximately 2 km long between Northcote Point and Torarago Point and faces in in a general north eastern direction. The beach is backed by a 2 km wide, low Holocene barrier. At the northern end of the beach, the Nullica River drains into the bay. The beach is further interrupted by Boydtown Creek in the southern part.

Whale Beach lies on the other side of Torarago Point. This 2km long, north east facing beach consist of a very narrow barrier that lies across the mouth of the Towamba River. Under normal day-to-day conditions, the river drains into the bay at the southern end of the beach, against Brierly Point.

The sediment types vary between the beaches of Twofold Bay with fine to medium, well sorted quartzose sands in the northern bight (Aslings Beach) and moderately sorted, muddy fine sands with fluvial input south of Lookout Point (Hudson and Ferland 1987). These distinct differences reflect the different sources and suggest that there is little if any sediment interaction between Aslings Beach and the remainder of Twofold Bay.

Figure 4-18 Aslings Beach

Figure 4-19 Quarantine Beach

Figure 4-20 Boydtown Beach

4.6.1 Coastal Erosion Hazard Assessment

The principal mechanisms for coastal erosion along the beaches within this district are:

- Short Term storm bite erosion; and
- Shoreline recession due to underlying erosion trends and sea level rise.

4.6.1.1 Storm Bite Provision

There is currently no photogrammetric data available for the beaches within Twofold Bay from which site-specific design storm bite provisions can be derived, with the exception of Aslings Beach.

The photogrammetric data for Aslings Beach indicates that this beach exhibits a storm bite capacity of about 120-150 m^3/m. Accordingly, a storm bite volume of 120 m^3/m has been adopted for the ‘Almost certain’ case and 150 m^3/m for the ‘Unlikely’ case for this beach.

For the other beaches in Twofold Bay, in lieu of site specific estimates, beach erosion provisions for these beaches has been based on regional storm bite capacities, outlined in Table 3-4. That is, the storm erosion extents for the ‘Almost certain’ case have been based on a storm bite provision of 120 m^3/m and 150 m^3/m for the ‘Unlikely’ case. These values are considered conservative at the beaches within the southern bight, given the more protected setting of those beaches with photogrammetric data.

Along most beaches within the bay, the position of the eroded scarp crest for the ‘Unlikely’ case is located approximately 30 to 40 m landward of the 2008 frontal dune edge, with greater distances corresponding to areas where dunes are lower and/or narrower. Some typical examples of the storm bite assessment are shown in Figure 4-21.

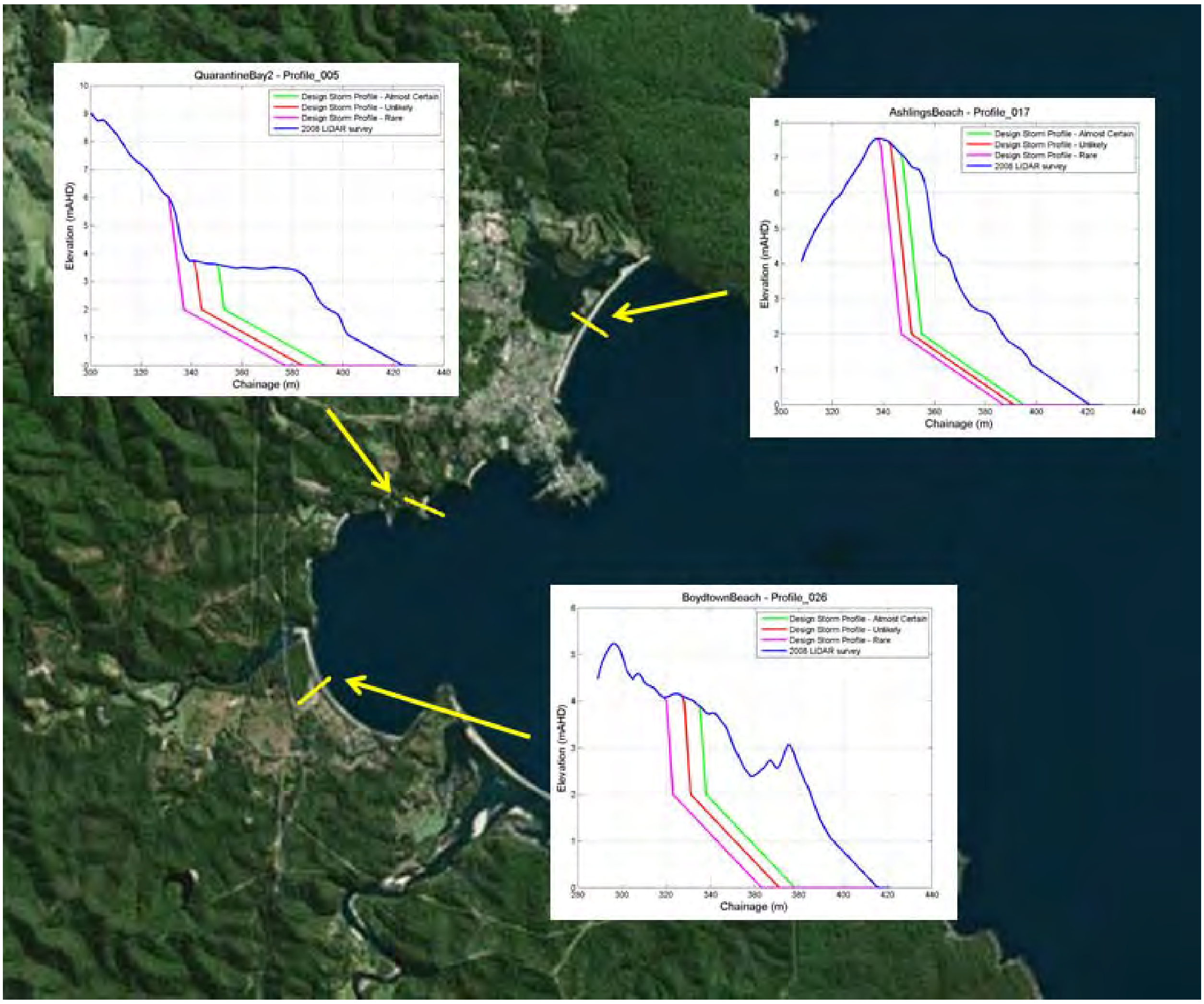

Figure 4-21 Typical Storm Bite Profiles at Selected Beaches in Twofold Bay

4.6.1.2 Long Term Recession

The photogrammetric data for Aslings Beach does not indicate that this beach is experiencing a clear trend of shoreline recession and therefore no shoreline additional setback for long term recession has been included in the 'Almost certain' and 'Unlikely' hazard extents at 2050 and 2100. Providing for uncertainties in the estimates and possible future changes, a long term recession rate of 0.1 m/yr has been included in the 'Rare' hazard extents.

In lieu of site specific data, the long term recession rates at the other beaches in the district have been based on the recommended regional underlying recession rates (Refer to Section 3.3.5).

4.6.1.2.1 Recession due to Sea Level Rise

Future recession due to sea level rise at Aslings Beach has been assessed using the EVOMOD shoreline model and as discussed in detail in Section 3.3.6. Based upon the modelling output, the extent of future long term recession due to sea level rise for the 'Unlikely' case (with predicted sea level rise of 0.84m by 2100) is estimated to be in the range of 10-15 m by 2050 and 25-30m by 2100 along Aslings Beach.

Recession provisions for future long term recession due to sea level rise at the other beaches within Twofold Bay have been estimated on the basis of the Bruun Rule method in conjunction with the 'polynomial trend' method (described in Section 3.3.6.4) to account for the coastal entrance sedimentation impacts as appropriate. This resulted in a setback provision for the 'Unlikely' case of 12m for the 2050 planning horizon and 30m for the 2050 planning horizon.

4.6.1.3 Mapping of Erosion and Recession Hazards

The erosion hazard extents have been derived on the basis of the methodology outlined in Section 3.3.9.

The immediate erosion hazard extents incorporate the design beach erosion provisions and sensitivity provisions for the identified variability in how the beach system behaves.

The 2050 and 2100 erosion hazard extents incorporate the immediate erosion hazard and represent its projected extent following shoreline recession over those respective time-frames. Each of the beach erosion probabilities ('Almost certain', 'Unlikely' and 'Rare') have been adopted across the length of the beach embayment and/or to the limit of bedrock where it is known to occur. It should be noted that there is a zone of reduced foundation capacity that extends landward of these erosion hazard lines, as discussed in Section 3.3.7.

Erosion hazard maps for Twofold Bay at the immediate, 2050 and 2100 planning horizons are presented in the Figure Compendium.

It is noted that the erosion hazards along Cattle Bay are based on assumption that seawalls along this embayment are of a sufficient standard to limit shoreline erosion along this section of the shoreline.

4.6.2 Coastal Inundation Hazard

4.6.2.1 Wave Run-up and Overtopping

Wave run-up levels along the beaches and headlands of Twofold Bay were estimated using storm tide and offshore wave statistics presented in Chapter 2. Wave propagation modelling, providing for refraction and attenuation due to bed friction across the continental shelf, was undertaken to provide an estimate of the 1% AEP design storm conditions at each beach.

Using the method of Nielsen and Hanslow (1991) for run-up at natural beaches and the Eurotop (2007) method for headlands, design run-up levels ($R_{u2\%}$) relative to existing sea level were calculated for the different parts of Twofold Bay. Due to the varying degree of wave exposure, wave run-up levels vary considerably throughout the bay. The adopted design run-up levels for each beach are summarised in Table 4-9.

Mapping of the susceptibility of Twofold Bay to wave overtopping is provided in the Figure Compendium.

The wave overtopping assessment indicates that several areas within the bay may experience overtopping during severe storm events at present, including the areas behind Cattle Bay, Cocora Beach, Bungo Beach, Quarantine Bay, Brandy Creek Beach, the southern parts of Boydtown

Beach and Fisheries Beach. It is likely that these areas will experience enhanced wave run-up and overtopping in the future as sea level rises.

Table 4-9 Adopted Design Wave Run-up Levels for Twofold Bay Beaches

Location	*Elevated Ocean Level (excl. wave setup)*	*2% Runup Height (m)*	*Design Wave Runup Level (mAHD)*
Aslings Beach (northern end)	1.32mAHD	2.86m	4.2mAHD
Aslings Beach (southern end)	1.32mAHD	3.80m	5.1mAHD
Yamungo Bay	1.32mAHD	1.46m	2.8mAHD
Snug Cove	1.32mAHD	1.24m	2.6mAHD
Cattle Bay	1.32mAHD	1.24m	2.6mAHD
Cocora Beach	1.32mAHD	2.22m	3.5mAHD
Bungo Beach	1.32mAHD	2.77m	4.1mAHD
Rixons Beach	1.32mAHD	2.85m	4.2mAHD
Quarantine Bay	1.32mAHD	2.77m	4.1mAHD
Brandy Creek Beach	1.32mAHD	3.22m	4.5mAHD
Curawullla Beach	1.32mAHD	3.22m	4.5mAHD
Boydtown Beach (Northern end)	1.32mAHD	3.22m	4.5mAHD
Boydtown Beach (Southern end)	1.32mAHD	2.64m	4.0mAHD
Whale Beach (Northern end)	1.32mAHD	3.59m	4.9mAHD
Whale Beach (Southern end)	1.32mAHD	3.00m	4.3mAHD
Fisheries Beach	1.32mAHD	1.81m	3.1mAHD

4.6.2.2 Estuary Storm Tide Inundation

Design inundation levels within the lower estuaries have been determined on the basis of the factors outlined in Section 3.4.4. The adopted design coastal inundation levels for each hazard probability descriptor and planning timeframe are summarised in Table 4-10 to Table 4-12.

The extents of the inundation hazard for each planning timeframe are illustrated in the Figure Compendium.

Table 4-10 Adopted coastal inundation levels (mAHD) within Lake Curalo estuary

Planning Horizon	*'Almost Certain'*	*'Unlikely'*	*'Rare"*
Immediate	1.60	1.90	2.10
2050	1.72	2.24	2.60

Planning Horizon	*'Almost Certain'*	*'Unlikely'*	*'Rare"*
2100	1.88	2.74	3.40

Table 4-11 Adopted coastal inundation levels (mAHD) within Nullica River estuary

Planning Horizon	*'Almost Certain'*	*'Unlikely'*	*'Rare"*
Immediate	1.71	2.05	2.25
2050	1.83	2.39	2.75
2100	1.99	2.89	3.55

Table 4-12 Adopted coastal inundation levels (mAHD) within Towamba River estuary

Planning Horizon	*'Almost Certain'*	*'Unlikely'*	*'Rare"*
Immediate	1.63	1.95	2.15
2050	1.75	2.29	2.65
2100	1.91	2.79	3.45

4.6.3 Entrance Instability

Lake Curalo

The entrance of Lake Curalo is located at the northern end of Aslings Beach behind a substantial headland which provides a lower wave energy climate compared to the other locations along the embayment. The lake has an untrained entrance that is predominantly closed.

During periods of low catchment runoff and accreting beach conditions, the entrance has a tendency to close. This behaviour results from the relatively small tidal compartment of the river, which is insufficient to keep the entrance permanently open.

When the entrance closes, water tends to build up behind the entrance berm and has the potential to inundate low lying area around the lake. When deemed necessary, the entrance is artificially opened to mitigate this impact. Consequently, the lake is open to the ocean more frequently than under natural conditions.

Interpretation of available historical aerial photography has indicated that entrance breakouts and spit erosion generally occur over a relatively short distance at the northern end of Aslings Beach. Furthermore, the dune elevations along Aslings Beach are such that entrance breakouts are not expected to occur along Aslings Beach Road during the future planning period

Towamba River

The narrow barrier that forms Whale Beach lies across the mouth of the Towamba River. The entire barrier is at risk of beach erosion during oceanic storm events. During major flood events, the barrier is often breached at various locations and occasionally the beach is washed away completed (Short, 2007).

Figure 4-22 Lake Curalo entrance (Image OEH)

Figure 4-23 Whale Beach and Towamba River entrance (Image: OEH)

4.7 Wonboyn

The Wonboyn district encompasses Disaster Bay Beach and the Wonboyn Lake entrance (refer to Figure 1-6). Disaster Bay Beach is a 2.4km long, slightly curved beach between the base of the Green Cape headland and the entrance of the Wonboyn Lake. The beach is backed by a 500 m wide Holocene sand barrier, without any development. Two small creeks, which are usually dry, run through the barrier and drain into the ocean via the beach. The beach along the embayment usually maintains a single bar, cut regularly by rips every 200-300m (Short, 2007).

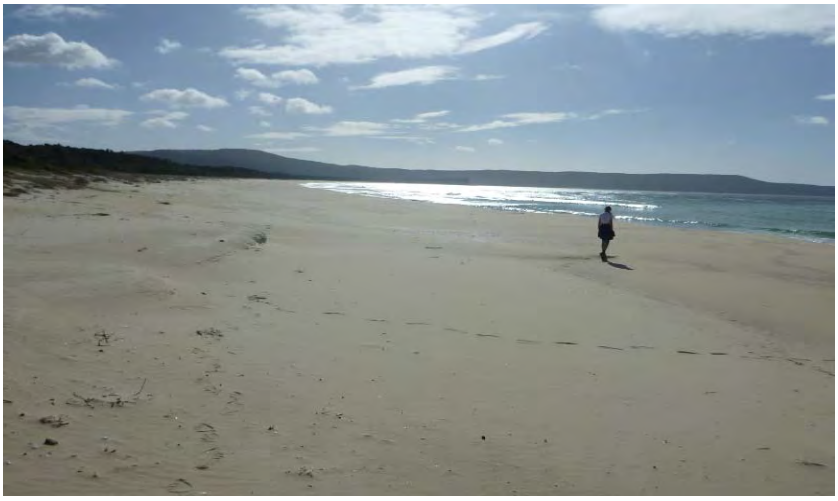

Figure 4-24 Disaster Bay Beach

4.7.1 Coastal Erosion Hazard Assessment

The principal mechanisms for coastal erosion along the beaches within this district are:

- Short term storm bite erosion; and
- Shoreline recession due to underlying erosion trends and sea level rise.

4.7.1.1 Storm Bite Provision

There is currently no photogrammetric data available for Disaster Bay Beaches from which site-specific design storm bite provisions can be derived. Therefore, the beach erosion provisions have been based on the regional storm bite provisions outlined in Table 3-4. That is, the storm erosion extents for the 'Almost certain' case have been based on a storm bite provision of 200 m^3/m and 250 m^3/m for the 'Unlikely' case.

A typical erosion distance of 40-50 m was found for the 'Almost certain' case, increasing to 50-60 m for the 'Unlikely' case.

4.7.1.2 Long Term Recession

In lieu of site specific data, the long term recession rates for this section of the coast have been based on the recommended regional underlying recession rates (refer to Section 3.3.5.2).

Accordingly the adopted long term recession rates at the Wonboyn beaches are:

- A nominal 'best estimate' of 0 m/yr; and
- A 'worst case' estimate of 0.1 m/yr to cater for uncertainties and possible future changes.

Recession due to Sea Level Rise

Provisions for sea level rise related recession for this district have been estimated on the basis of the Bruun Rule method in conjunction with the 'polynomial trend' method (described in Section 3.3.6.4) to account for the coastal entrance sedimentation impacts as appropriate.

For the 'Unlikely' case (with predicted sea level rise of 0.84 m), the Bruun Rule yields a shoreline recession of approximately 30 m by 2100 for Disaster Bay Beach.

The 'polynomial trend' method yields an additional (more or less uniform) shoreline recession of approximately 15m by 2100 due to potential future entrance sedimentation at Wonboyn Lake.

4.7.1.3 Mapping of Erosion and Recession Hazards

The erosion hazard extents have been derived on the basis of the methodology outlined in Section 3.3.9.

The immediate erosion hazard extents incorporate the design beach erosion provisions and sensitivity provisions for the identified variability in how the beach system behaves.

The 2050 and 2100 erosion hazard extents incorporate the immediate erosion hazard and represent its projected extent following shoreline recession over those respective time-frames. Each of the beach erosion hazards ('Almost certain', 'Unlikely' and 'Rare') have been adopted across the length of the beach embayment and/or to the limit of bedrock where it is known to occur. It should be noted that there is a zone of reduced foundation capacity that extends landward of these erosion hazard lines, as discussed in Section 3.3.7.

Erosion hazard maps for Disaster Bay Beach at the immediate, 2050 and 2100 planning horizons are presented in the Figure Compendium.

The undeveloped status of the beach is such that erosion and recession processes do not present significant hazards.

4.7.2 Coastal Inundation Hazard

4.7.2.1 Wave Run-up and Overtopping

Design run-up levels ($R_{u2\%}$) along Disaster Bay Beach were calculated to be approximately 4.6mAHD. Dune elevations along the beach vary generally between 4 and 5 mAHD, indicating that some sections of the beach may experience overtopping during infrequent storm events at present. It is likely that those areas will experience enhanced wave run-up and overtopping in the future as sea level rises.

Mapping of the susceptibility of the district to wave overtopping is provided in the Figure Compendium.

4.7.2.2 Estuary Storm Tide Inundation

Design inundation levels within the lower estuaries have been determined on the basis of the factors outlined in Section 3.4.4. The adopted design coastal inundation levels for each hazard probability descriptor and planning timeframe are summarised in Table 4-5.

The extents of the inundation hazard for each planning timeframe are illustrated in the Figure Compendium.

Table 4-13 Adopted coastal inundation levels (mAHD) within Wonboyn Lake estuary

Planning Horizon	*'Almost Certain'*	*'Unlikely'*	*'Rare"*
Immediate	1.72	2.13	2.33
2050	1.84	2.47	2.83
2100	2.00	2.97	3.63

4.7.3 Entrance Instability

The entrance of Wonboyn Lake is located at the southern end of Disaster Bay Beach. It is untrained and exhibits the typical characteristics of an ICOLL (Intermittently Closed and Open Lakes or Lagoons) in that:

- Under normal day-to-day conditions, the entrance is open and allows tidal flow to penetrate into the lake although significantly constricted under the influence of longshore sand transport; and
- During periods of low catchment runoff and accreting beach conditions, the entrance can become closed.

Wonboyn Lake is predominantly open, as the catchment inputs are generally large enough to keep the entrance open most of the time, and the entrance is partially protected from the dominant southerly wave climate.

Interpretation of available historical aerial photography has indicated that entrance breakouts and spit erosion generally occur over a relatively short distance to the immediately north of the rocky outcrop that separates Disaster Bay Beach from Wonboyn Beach. Furthermore, the undeveloped status of the areas around the entrances is such that entrance processes do not present significant hazards.

Figure 4-25 Wonboyn Lake entrance (Image: OEH)

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Appendix A Extents of Photogrammetric Survey Data

NOTES:

1. Orthophoto image was prepared by DECCW from vertical aerial photography flown on 27th of March 2007.
2. Unauthorised reproduction and/or the use of the maps for any other purpose is expressly forbidden.
3. Co-ordinate system is Integrared Survey Grid (ISG) and co-ordinates are in metres.

100 0 100

Scale in metres

NSW GOVERNMENT Environment, Climate Change & Water

BERMAGUI BEACH 27/03/2007

Photogrammetrist: R.Clout & C.Gray

Project Supervisor: Bruce Coates

Date : MAY 2011

NOTES:

1. Orthophoto image was prepared by DECC from vertical aerial photography flown on 27th of March 2007.
2. Unauthorised reproduction and/or the use of the maps for any other purpose is expressly forbidden.
3. Co-ordinate system is Australian Map Grid (AMG) and co-ordinates are in metres.

Co-ordinate system is Map Grid of Australia

150 0 150
Scale in metres

CUTTAGEE BEACH 27/03/2007

Photogrammetrist: R.Clout & C.Gray

Project Supervisor: Bruce Coates

Date : APRIL 2011

NOTES:

1. Orthophoto image was prepared by DECC from vertical aerial photography flown on 10th of May 2011.
2. Unauthorised reproduction and/or the use of the maps for any other purpose is expressly forbidden.
3. Co-ordinate system is Australian Map Grid (AMG) and co-ordinates are in metres.

NSW Office of Environment & Heritage

TATHRA BEACH
10/05/2011

Photogrammetrist: R.Clout & C.Gray

Project Supervisor: Bruce Coates

Date : JUNE 2012

300 0 300
Scale in metres

NOTES:

1. Orthophoto image was prepared by DECC from vertical aerial photography flown on 27th of MARCH 2007.
2. Unauthorised reproduction and/or the use of the maps for any other purpose is expressly forbidden.
3. Co-ordinate system is Integrared Survey Grid (ISG) and co-ordinates are in metres.

500 0 500
Scale in metres

NSW Environment, Climate Change & Water

PAMBULA/MERIMBULA
27/03/2007

Photogrammetrist: R.Clout & C.Gray

Project Supervisor: Bruce Coates

Date : FEBRUARY 2011

NOTES:

1. Orthophoto image was prepared by OEH from vertical aerial photography flown on 27th of June2011.
2. Unauthorised reproduction and/or the use of the maps for any other purpose is expressly forbidden.
3. Co-ordinate system is Intergrated Survey Grid (ISG) and co-ordinates are in metres.

Office of Environment & Heritage

AYSLINGS BEACH 27/06/2011

Photogrammetrist: R.Clout & C.Gray

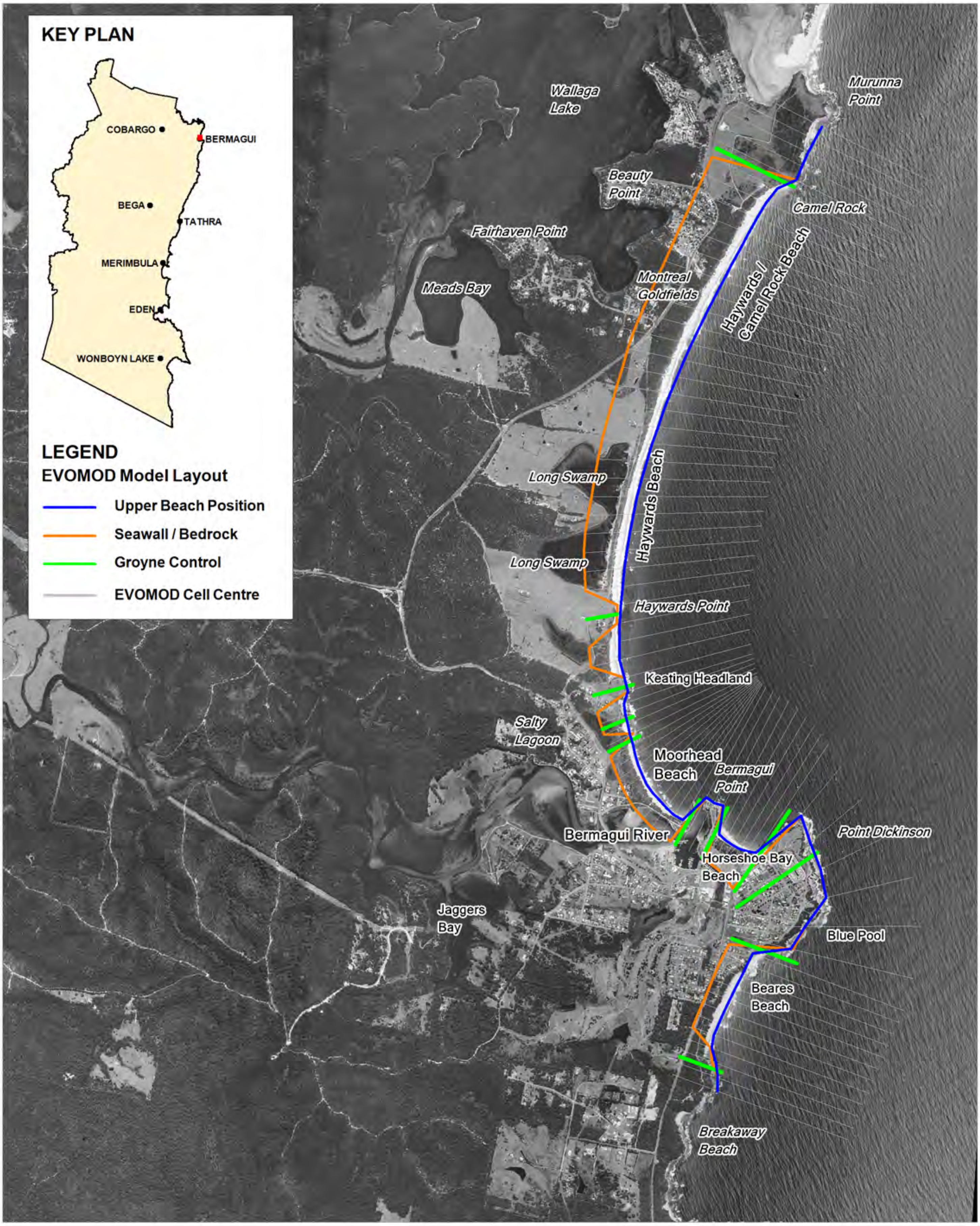
Project Supervisor: Bruce Coates

Date : MARCH 2012

150 0 150

Scale in metres

Appendix B EVOMOD Model Layouts



Title:

Model Layout of Bermagui Coast EVOMOD Model

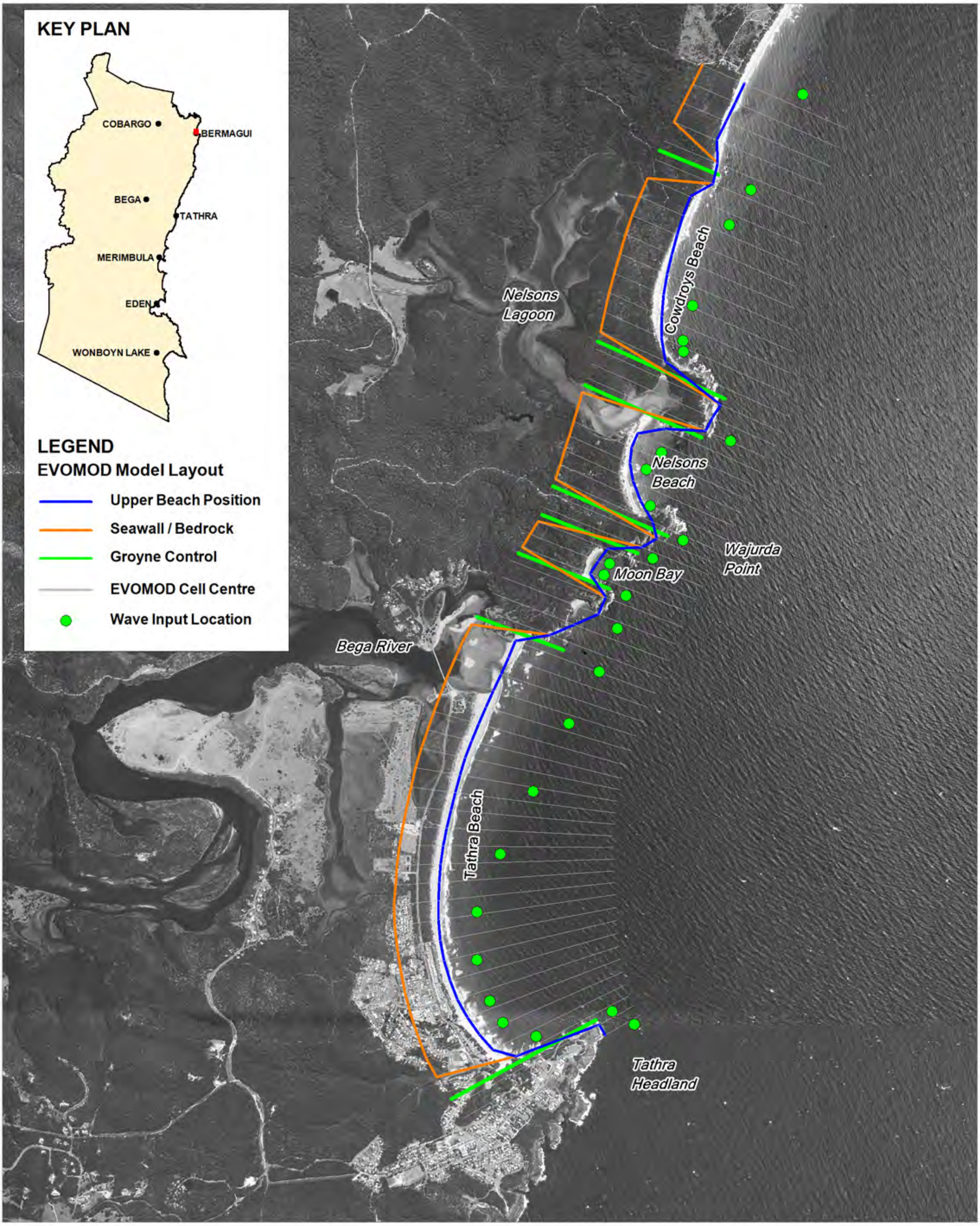
Figure: **B-1**

Rev: **A**

BMT WBM

www.bmtwbm.com.au

Filepath : I:\B20741.i.JJ_BegaValley_CHDS\DRG\COA_200_140809_EVOmod_Calibration_Moorhead.WOR



Title:
Model Layout of Tathra EVOMOD Model

Figure: **B-2**

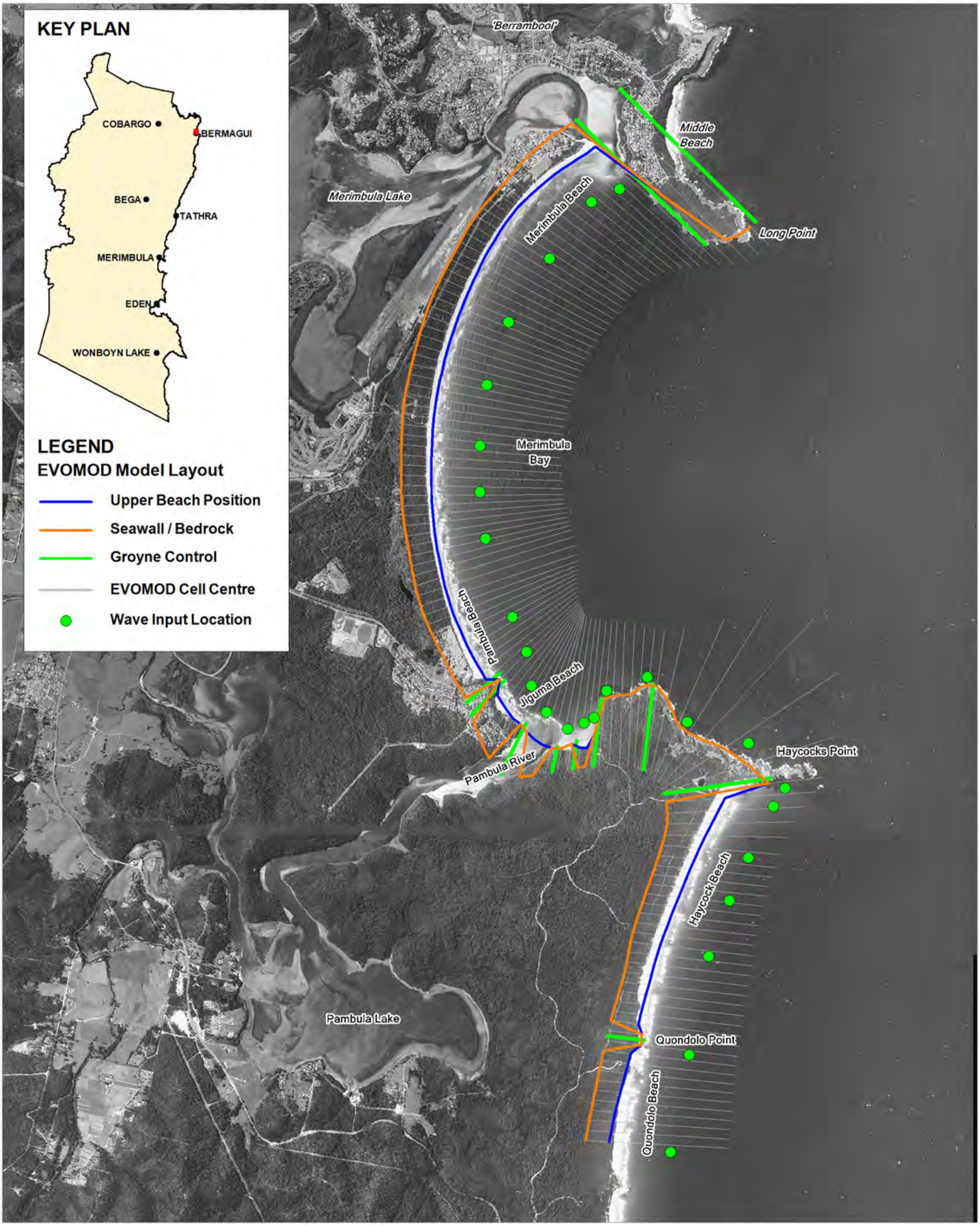
Rev: **A**

N

0 0.75 1.5km
Approx. Scale

BMT WBM
www.bmtwbm.com.au

Filepath : I:\B20741.i.JJ_BegaValley_CHDS\DRG\COA_B-02_140809_EVOMOD_Layout_Tathra.WOR



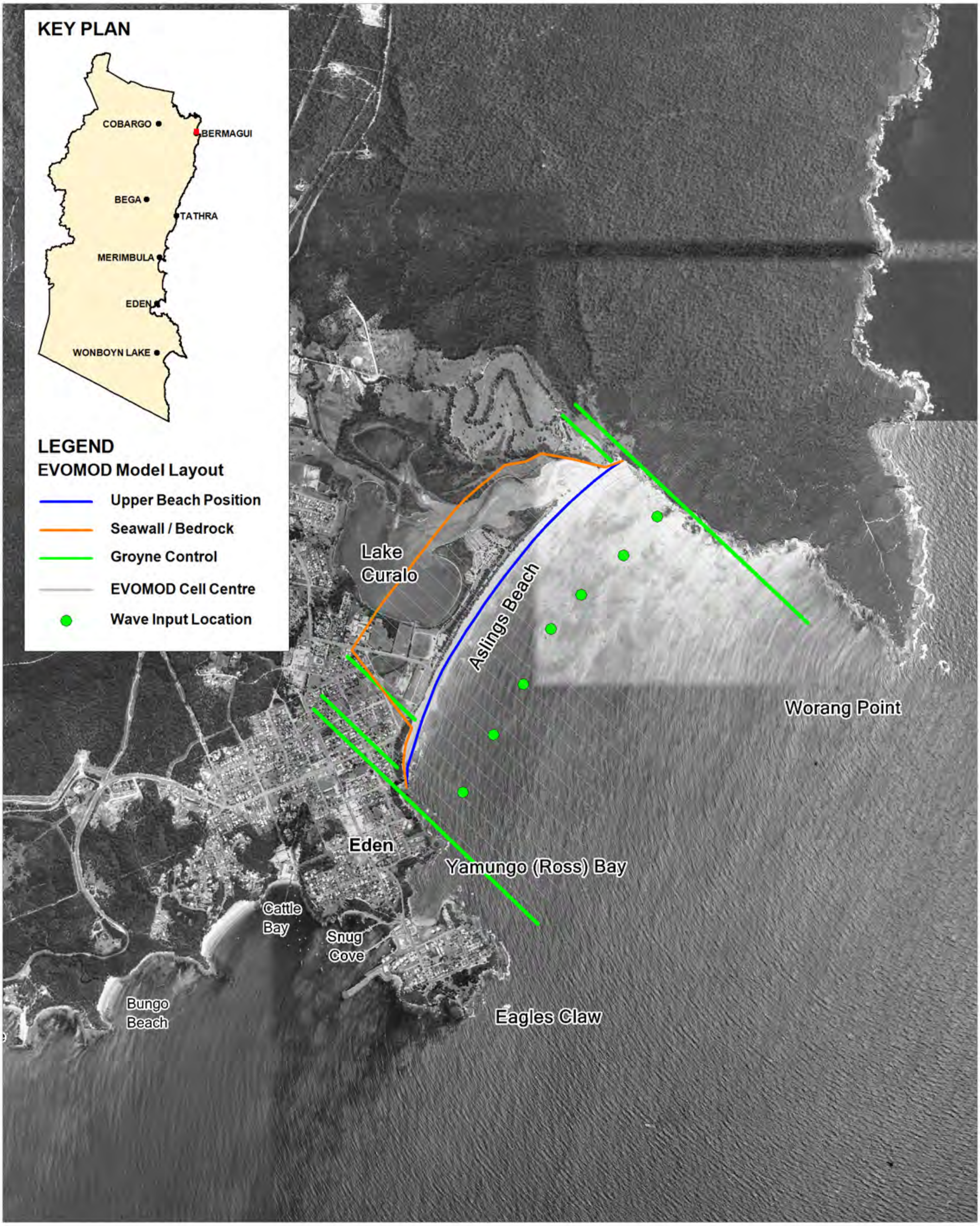
Title:
Model Layout of Merimbula Bay EVOMOD Model

Figure: **B-3**

Rev: **A**

BMT WBM
www.bmtwbm.com.au

Filepath : I:\B20741.i.JJ_BegaValley_CHDS\DRG\COA_B-02_140809_EVOMOD_Layout_Tathra.WOR



Title:
Model Layout of Ashlings Beach EVOMOD Model

Figure: B-4

Rev: A

N

0 0.5 1km
Approx. Scale

BMT WBM
www.bmtwbm.com.au

Filepath : I:\B20741.i.JJ_BegaValley_CHDS\DRG\COA_B-04_140809_EVOMOD_Layout_Aslings.WOR

Appendix C Photographs of Selected Beaches (Aug 2013)

Camel Rock Beach

Bermagui River Training Walls

Swamps behind Haywards Beach

Horseshoe Bay

Moorhead Beach

Beares Beach

Barragoot Lake

Murrah Beach

Cuttagee Lake Entrance

Bunga Lagoon Entrance

Barraga Beach

Northern end of Tathra Beach

Photographs of Selected Beaches (Aug 2013)

Tathra Beach at Tathra SLSC

Short Point Beach

North Tura Beach

Merimbula Beach

Tura Beach from Tura Headland

Pambula Beach

Photographs of Selected Beaches (Aug 2013)

Aslings Beach

Cattle Bay

Yamungo Cove

Quarantine Bay

Snug Cove

Boydtown Beach

Photographs of Selected Beaches (Aug 2013)

Whale Beach

Disaster Bay Beach

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