Final Report

# Nambucca Shire

# Coastal Hazard Study

December 2009 3001682.001

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## FOREWORD

Nambucca Shire Council is preparing a Coastal Zone Management Plan for the Nambucca area guided by the NSW Government Coastal Policy 1997. This report documents the Nambucca Shire Coastal Process and Hazard Definition as Stage 1 of this project.

This report has been prepared and issued by SMEC Australia to Nambucca Council (the Client). The Study has been jointly funded and administered by DECCW. Information published in this report is available for general release only by permission of SMEC Australia and the Client.

## REFERENCE

Adamantidis, C. A. and M. Glatz (2010). "Nambucca Shire Coastal Hazard Study – Final Report", Report No. 3001682-001 prepared by SMEC Australia for Nambucca Council, April 2010.

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## Glossary

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| **Accretion** | The accumulation of (beach) sediment, deposited by natural fluid flow processes. |
| **ACES** | A computer program, developed by the US Army Corps of Engineers, that is used to determine, among other things, levels of wave runup on natural beaches. |
| **Aeolian** | Adjective referring to wind-borne processes. |
| **Astronomical tide** | The tidal levels and character which would result from gravitational effects, e.g. of the Earth, Sun and Moon, without any atmospheric influences. |
| **Backshore** | (1) The upper part of the active beach above the normal reach of the tides (high water), but affected by large waves occurring during a high.<br>(2) The accretion or erosion zone, located landward of ordinary high tide, which is normally wetted only by storm tides. |
| **Bar** | An offshore ridge or mound of sand, gravel, or other unconsolidated material which is submerged (at least at high tide), especially at the mouth of a river or estuary, or lying parallel to, and a short distance from, the beach. |
| **Bathymetry** | The measurement of depths of water in oceans, seas and lakes; also the information derived from such measurements. |
| **Beach profile** | A cross-section taken perpendicular to a given beach contour; the profile may include the face of a dune or sea wall, extend over the backshore, across the foreshore, and seaward underwater into the nearshore zone. |
| **Berm** | A nearly horizontal plateau on the beach face or backshore. |
| **Breaker zone** | The zone within which waves approaching the coastline commence breaking, typically in water depths of around 2 m to 3 m in fair weather and around 5 m to 10 m during storms |
| **Breaking depth** | The still-water depth at the point where the wave breaks. |
| **Chart datum** | The plane or level to which soundings, tidal levels or water depths are referenced, usually low water datum. |
| **Coastal processes** | Collective term covering the action of natural forces on the shoreline, and the nearshore seabed. |
| **Datum** | Any position or element in relation to which others are determined, as datum point, datum line, datum plane. |
| **Deep water** | In regard to waves, where depth is greater than one-half the wave length. Deep-water conditions are said to exist when the surf waves are not affected by conditions on the bottom, typically in water depths of around 60 m to 100 m. |
| **Dunes** | Accumulations of wind-blown sand on the backshore, usually in the form of small hills or ridges, stabilised by vegetation or control structures. |
| **Dynamic equilibrium** | Short term morphological changes that do not affect the morphology over a long period. |
| **Ebb tide** | A non-technical term used for falling tide or ebb current. The portion of the tidal cycle between high water and the following low water. |
| **Elevation** | The distance of a point above a specified surface of constant potential; the distance is measured along the direction of gravity between the point and the surface. |
| **Erosion** | On a beach, the carrying away of beach material by wave action, tidal currents or by deflation. |
| **Flood tide** | A non-technical term used for rising tide or flood current. In technical language, flood refers to current. The portion of the tidal cycle between low water and the following high water. |
| **Geomorphology** | That branch of physical geography that deals with the form of the Earth, the general configuration of its surface, the distribution of the land, water, etc. |
| **High water (HW)** | Maximum height reached by a rising tide. The height may be solely due to the periodic tidal forces or it may have superimposed upon it the effects of prevailing meteorological conditions. Nontechnically, also called the high tide. |
| **ICOLL** | An acronym for Intermittently Closed or Open Lake or Lagoon |

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| **Inshore** | (1) The region where waves are transformed by interaction with the sea bed.<br>(2) In beach terminology, the zone of variable width extending from the low water line through the breaker zone. |
| **Inshore current** | Any current inside the surf zone. |
| **Inter-tidal** | The zone between the high and low water marks. |
| **Littoral** | (1) Of, or pertaining to, a shore, especially a seashore.<br>(2) Living on, or occurring on, the shore. |
| **Littoral currents** | A current running parallel to the beach, generally caused by waves striking the shore at an angle. |
| **Littoral drift** | The material moved parallel to the shoreline in the nearshore zone by waves and currents. |
| **Littoral transport** | The movement of littoral drift in the littoral zone by waves and currents. Includes movement both parallel (long shore drift) and perpendicular (cross-shore transport) to the shore. |
| **Longshore** | Parallel and close to the coastline. |
| **Longshore drift** | Movement of sediments approximately parallel to the coastline. |
| **Low water (LW)** | The minimum height reached by each falling tide. Non-technically, also called low tide. |
| **Mean high water (MHW)** | The average elevation of all high waters recorded at a particular point or station over a considerable period of time, usually 19 years. For shorter periods of observation, corrections are applied to eliminate known variations and reduce the result to the equivalent of a mean 19-year value. All high water heights are included in the average where the type of tide is either semidiurnal or mixed. Only the higher high water heights are included in the average where the type of tide is diurnal. So determined, mean high water in the latter case is the same as mean higher high water. |
| **Mean high water springs (MHWS)** | The average height of the high water occurring at the time of spring tides. |
| **Mean low water (MLW)** | The average height of the low waters over a 19-year period. For shorter periods of observation, corrections are applied to eliminate known variations and reduce the result to the equivalent of a mean 19-year value. |
| **Mean low water springs (MLWS)** | The average height of the low waters occurring at the time of the spring tides. |
| **Mean sea level** | The average height of the surface of the sea for all stages of the tide over a 19-year period, usually determined from hourly height readings. |
| **Morphology** | The form of a river/estuary/lake/seabed and its change with time. |
| **Nearshore** | In beach terminology, an indefinite zone extending seaward from the shoreline well beyond the breaker zone. |
| **Nearshore circulation** | The ocean circulation pattern composed of the nearshore currents and the coastal currents. |
| **Nearshore current** | The current system caused by wave action in and near the breaker zone, and which consists of four parts: the shoreward mass transport of water; longshore currents; rip currents; and the longshore movement of the expanding heads of rip currents. |
| **Refraction** | The process by which the direction of a wave moving in shallow water at an angle to the bottom contours is changed. The part of the wave moving shoreward in shallower water travels more slowly than that portion in deeper water, causing the wave to turn or bend to become parallel to the contours. |
| **Rip current** | A strong current flowing seaward from the shore. It is the return of water piled up against the shore as a result of incoming waves. A rip current consists of three parts: the feeder current flowing parallel to the shore inside the breakers; the neck, where the feeder currents converge and flow through the breakers in a narrow band or "rip"; and the head, where the current widens and slackens outside the breaker line. |
| **Runup** | The rush of water up a structure or beach on the breaking of a wave. The amount of run-up is the vertical height above still water level that the rush of water reaches. It includes wave setup. |

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| **SBEACH** | A computer program, developed by the US Army Corps of Engineers, that is used to determine, among other things, wave transformation across the surf zone, beach and dune erosion and levels of wave runup on natural beaches. |
| **Setup** | Wave setup is the elevation of the nearshore still water level resulting from breaking waves and may be perceived as the conversion of the wave's kinetic energy to potential energy. |
| **Shoal** | (1) (noun) A detached area of any material except rock or coral. The depths over it are a danger to surface navigation.<br>(2) (verb) To become shallow gradually. |
| **Shore** | That strip of ground bordering any body of water which is alternately exposed, or covered by tides and/or waves. A shore of unconsolidated material is usually called a beach. |
| **Shoreface** | The narrow zone seaward from the low tide shoreline permanently covered by water, over which the beach sands and GRAVELS actively oscillate with changing wave conditions. |
| **Shoreline** | The intersection of a specified plane of water with the shore. |
| ***Significant* wave** | A statistical term relating to the one-third highest waves of a given wave group and defined by the average of their heights and periods. |
| ***Significant* wave height** | Average height of the highest one-third of the waves for a stated interval of time. |
| **Spring tide** | A tide that occurs at or near the time of new or full moon, and which rises highest and falls lowest from the mean sea level (MSL). |
| **Storm surge** | A rise or piling-up of water against shore, produced by strong winds blowing onshore. A storm surge is most severe when it occurs in conjunction with a high tide. |
| **Sub-aerial beach** | That part of the beach which is uncovered by water (e.g. at low tide sometimes referred to as drying beach). |
| **Surf zone** | The nearshore zone along which the waves become breakers as they approach the shore. |
| **Swell** | Waves that have traveled a long distance from their generating area and have been sorted out by travel into long waves of the same approximate period. |
| **Tide** | The periodic rising and falling of the water that results from gravitational attraction of the moon and sun acting upon the rotating earth. Although the accompanying horizontal movement of the water resulting from the same cause is also sometimes called the tide, it is preferable to designate the latter as tidal current, reserving the name tide for the vertical movement. |

# 1 Introduction

Nambucca Shire Council is located on the NSW north coast approximately 400 km from Sydney. The area of focus is the whole coastline within Nambucca Shire from Scotts Head in the south to Valla Beach in the north.

The coastline is mainly composed of open-coast beaches and therefore, is directly exposed to the wave climate. Some erosion is visible on the foredune of Forster Beach at Scotts Head and infrastructure such as the carpark and the picnic area of South Valla Beach has already been destroyed within the last 10 years. The coastal hazard is likely to increase with time given the current scenarios for climate change and projected sea level rise.

## 1.1 Geomorphic Setting

The Tasman sea margin of southeast Australia is 1500 km long and is relatively narrow and sediment deficient by world standards (Boyd *et al.* 2004). The width of the continental shelf is particularly narrow along the section of the NSW coastline north of Smoky Cape (around 10 km wide) which includes the coastline of Nambucca Shire. The coast is also subject to strong littoral drift from south to north. It is generally well accepted for northern NSW (north of Seal Rocks) that there is a net northward littoral drift of sand with transport rates of approximately 500,000 cubic metres per year (Carley et al. 2005).

The continental shelf offshore of Nambucca can be divided into an inner zone (with bedrock outcropping close to the surface) and an outer zone representing the top of a Cenozoic sediment wedge (Boyd *et al.* 2004). Within these zones a succession of shore-normal morphological units can be found, including the shoreface, inner plain, inner and mid-slope, outer plain and continental slope.

Nambucca Shire lies close to the southern end of the subtropical zone where the East Australia Current brings warm water from offshore of tropical Queensland south along the NSW coast. This water mixes with cooler temperate waters from further south, and the boundary between these two zones is close to the Nambucca area. Figure 1.1 is a diagram showing sea surface temperatures off the NSW coast, which illustrate the influence of the East Australia Current. The East Australia current results in southward transport of fine sediment from rivers such as the Macleay at the outer zone of the continental shelf, leaving depressions in the continental shelf filled with coarse grained sand.

The present coastline was formed over the last 6500 years since the end of the last Ice Age. Sea levels rose from 120 m below present values to 1 – 2 m above present around 6500 years ago. Between 6500 and 3000 years ago, sea levels fell to around their present level and have remained stable ever since. The present-day coastal barrier built up over the last 3000 years, filling the Nambucca valley with sediment. The beaches of Nambucca Shire, including Forster and Valla Beaches, formed when sand from the continental shelf was pushed onshore during the Holocene period and settled between rocky headlands.

Nearshore marine habitat mapping using side-scan sonar of the Nambucca area has recently been conducted by the Department of Environment, Climate Change and Water (DECC&W, 2009c). This mapping has identified sediment distribution and bathymetry at a fine scale offshore of the Nambucca coastline for the purposes of mapping seabed habitats. The nearshore area consists of a series of complex reefs, interspersed by sandy or gravelly sediments. An extract from the mapping illustrating the extent of the reef is illustrated in Figure 1.2.

## 1.2 Study Area

The Nambucca Shire coastline is approximately 21 kilometres long between Scotts Head and Valla Beach. For the purposes of the coastal hazard assessment, the coastline has been divided into three areas which include:

- Scotts Head area,
- Nambucca Heads area and
- Valla Beach area.

The township of Scotts Head is partly located behind the open-coast beach of Forster Beach and partly behind the rocky headlands surrounding Little Beach. Some erosion of the dune is noticeable at the southern end of Forster Beach and some tree roots are exposed. Little Beach was severely eroded during the storm event of May 2009, with loss of mature trees along the hind-dune. Some urban development and associated infrastructure reaches the back of the dune (Figure 1.3) and its proximity to the beachfront has raised questions as to the degree of coastal hazard risk. No prior comprehensive coastal hazard assessment has been undertaken for the beachfront at Scotts Head.

Several open-coast beaches are located within the urban area of Nambucca Heads. These include Main Beach, Beilbys Beach, Shelly Beach and the northern end of Forster Beach. The Nambucca Heads coastline is approximately five kilometres long. The river entrance is directly south of Nambucca Hea ds township. Most of the urban development is located a relatively long distance from the beachfront (Figure 1.4) except for the dwellings located along Swimming Creek, the SLSC and the various beach amenities (toilet block, car park). The beachfront from Shelly Beach to Swimming Creek entrance is located adjacent to cliffs and rocky bluffs, while the rest of the coastline is mainly composed of sandy material.

The township of Valla Beach is located on the open-coast beaches of North and South Valla Beach. The Valla Beach coastline is approximately 3100 metres long. The entrance to Deep Creek is located at the northern end of South Valla Beach. Most of the beach is flanked by rocks and bluffs, except the dune separating Deep Creek from the ocean and the north end of Valla Beach coastline. Most of the urban development is located at a fair distance from the beachfront or behind rocks and hills (Figure 1.5).

## 1.3 The Coastline Management Process

The Coastline Management Process is outlined by the NSW Coastline Management Manual (1990) and consists of a three stage process, overseen by a Coastal Management Committee consisting of community, agency and local government representatives.

The three stages in the process are:

- **Stage 1** - Carry out **Coastal Process/Hazard Definition Studies** for the coastline – which involves gaining a scientific understanding of the coastal processes and hazards that affect the coastline and specifically defining what areas are at risk from coastal hazards.

- **Stage 2** - Carry out a **Coastline Management Study** which includes setting up the project framework, defining and understanding coastal zone values, defining threats to these values and identifying management options.
- **Stage 3** – Develop a **CMP**, which is a description of how the coastline will be managed. The Plan is then reviewed by the public and Government. Plans must be approved by the Minister for Environment and Climate Change and must be gazetted by Council before being implemented.

This report covers the first stage of the process, preparation of a Coastal Process and Hazard Definition Study for the Nambucca coastline.

The steps in the process are outlined in Figure 1.6.

This report documents a detailed coastal hazard assessment of the beaches at Scotts Head, Nambucca Heads, and Valla, which has been undertaken using photogrammetric data analysis and analytical assessments. It describes the coastal processes affecting the beaches and the impact of these processes on the areas of the beaches where property is at risk. The report quantifies the observed long-term beach changes, as well as estimating the beach recession that may be caused by sea-level rise as a result of climate change. The risk to property is defined in terms of the present day risk, the 2050 planning period and the 2100 planning period.

This Coastal Hazard Study has been undertaken in accordance with the following:

- NSW Sea Level Rise Policy Statement DECCW Oct 2009
- Draft Coastal Risk Management Guide DECCW Oct 2009
- Draft Coastal Planning Guideline Adapting to Sea Level Rise DOP Oct 2009

Note that a review of the geotechnical hazards within the study area has been carried out and is documented in a separate report (Nambucca Shire Council Coastal Slope Instability Study Draft June 2009). This report details the coastal hazard assessment specifically for the sandy beaches and dunes.

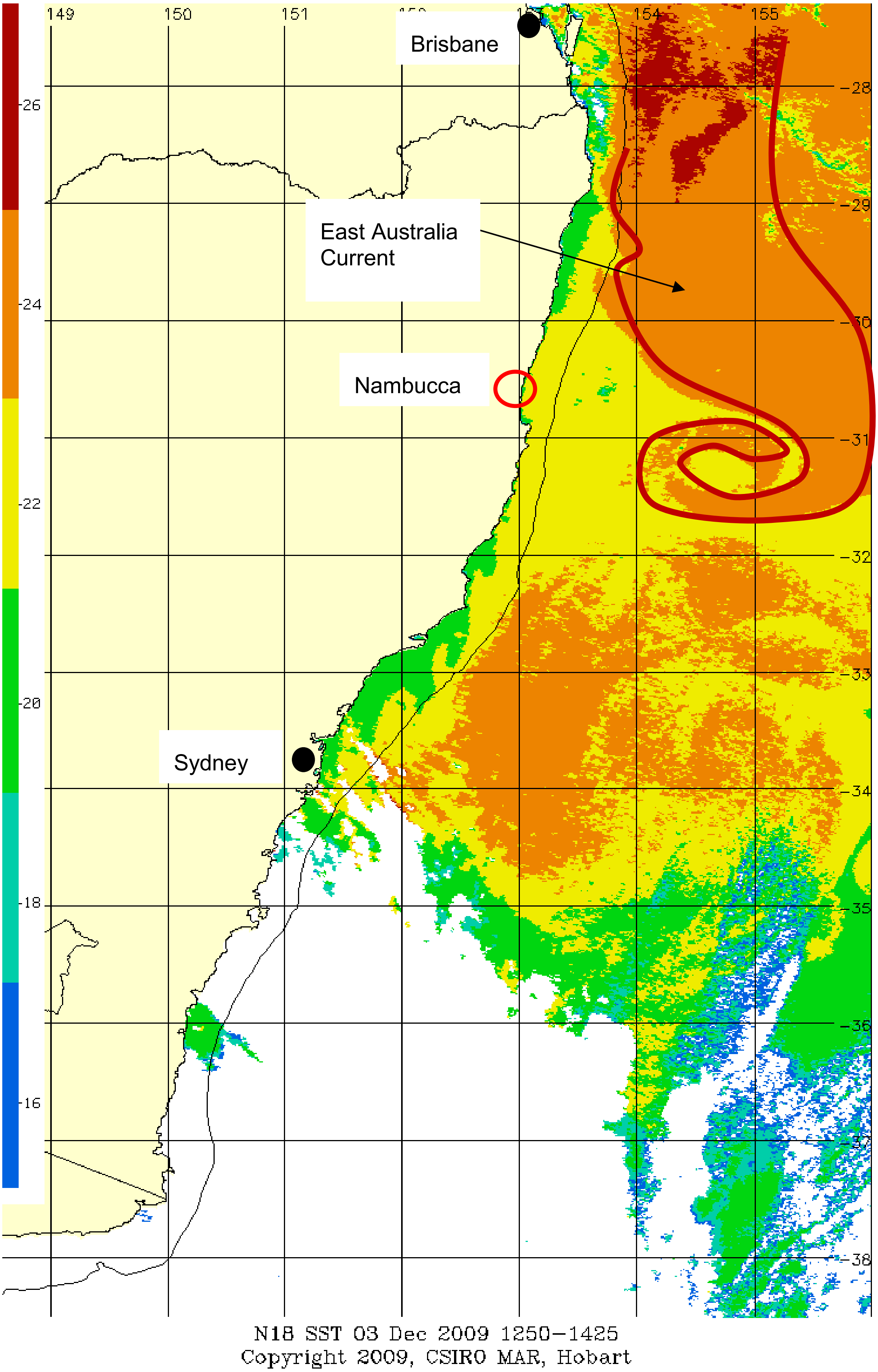



**Figure 1.1** - Map showing East Australia Current, December 2009 (from Manly Hydraulics Laboratory, 2009)

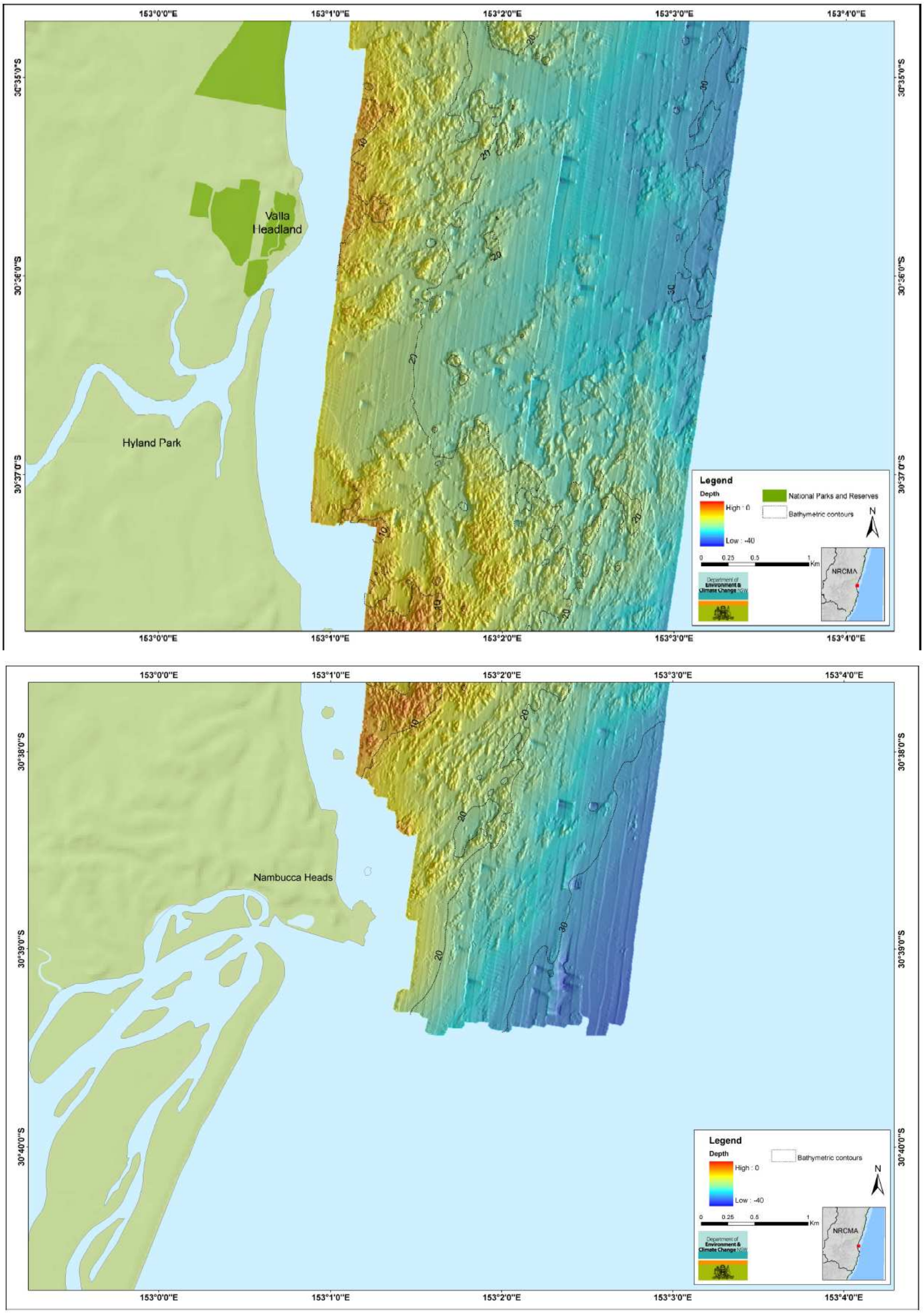



**Figure 1.2** – Nearshore Bathymetric mapping at Nambucca undertaken by DECC&W (2009c) indicating extent of nearshore rock reef.

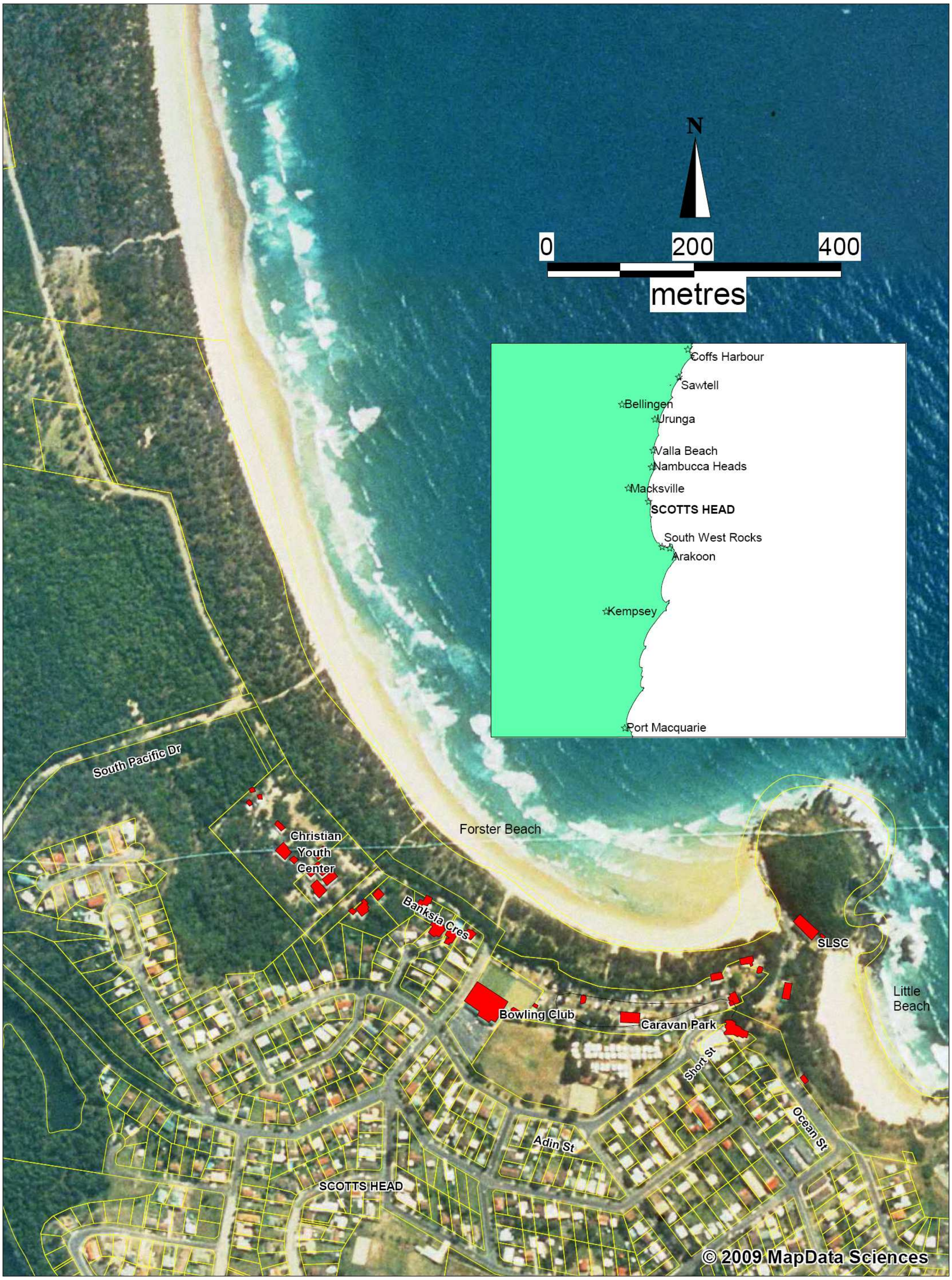



**Figure 1.3** – Scotts Head Locality Plan

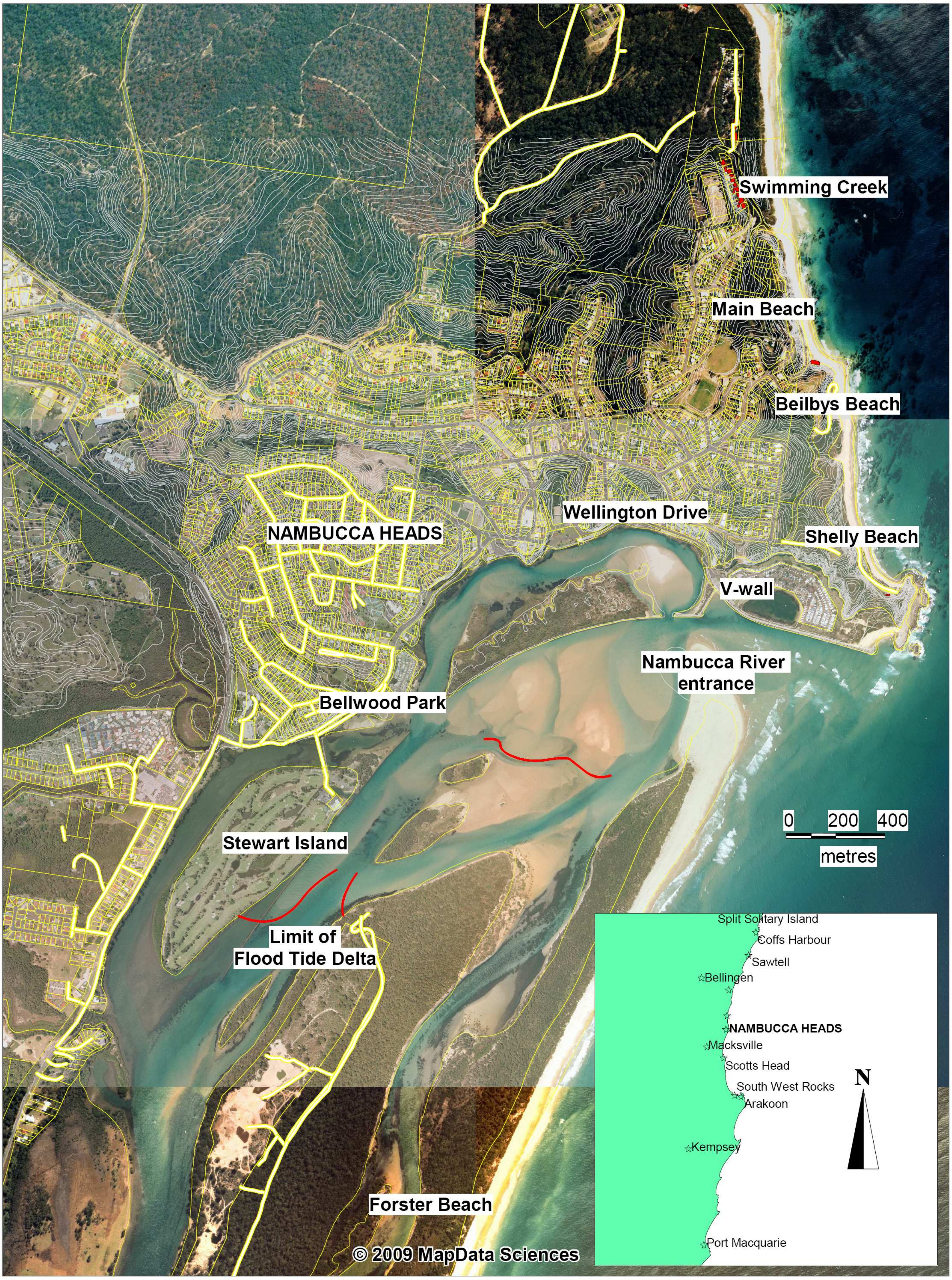



**Figure 1.4** – Nambucca Heads Locality Plan

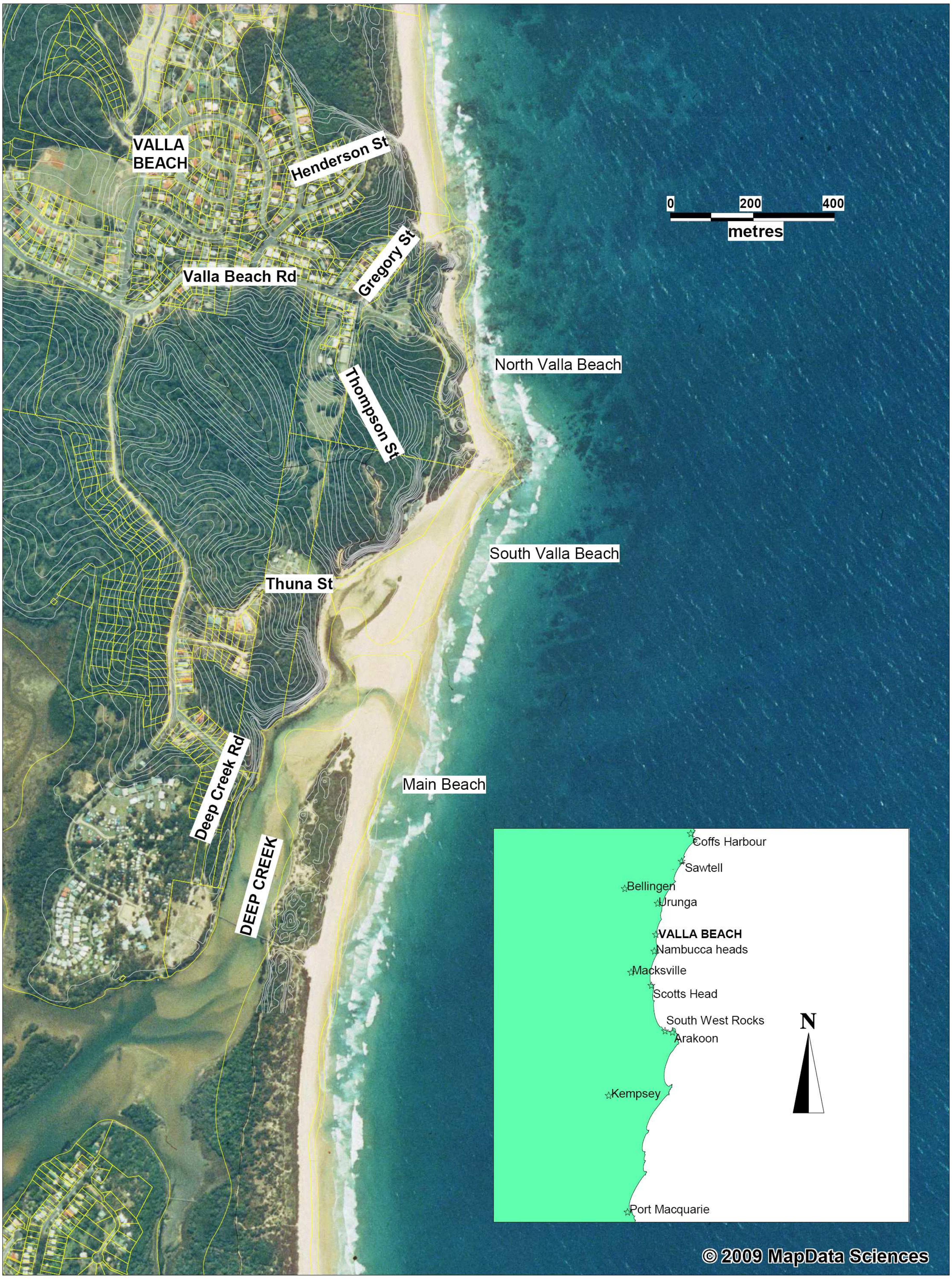



**Figure 1.5** – Valla Beach Locality Plan

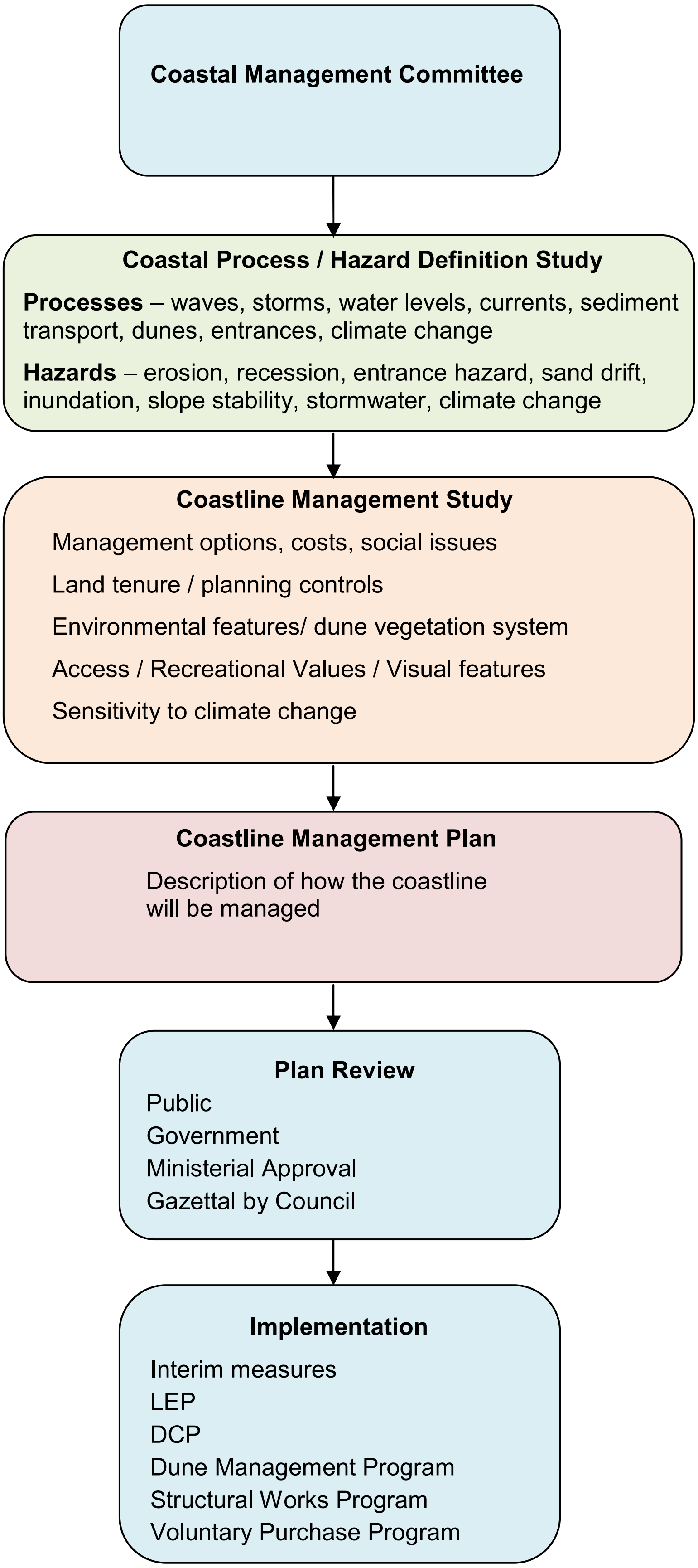



**Figure 1.6** – The NSW Coastline Management process (NSW Government, 1990)

# 2 Coastal Processes

## 2.1 Introduction

The beach is often perceived to be the sandy area between the waterline and the dunes. It includes the beach berm, where sand-binding grasses may exist, and any incipient foredune formations. Typically, however, on an open coast the overall beach system extends from some several kilometres offshore, in water depths of around twenty metres to the back beach dune or barrier region, which may extend up to several hundred metres inland (Figure 2.1). When examining the coastal processes of a beach system often it is necessary to consider this wider definition.

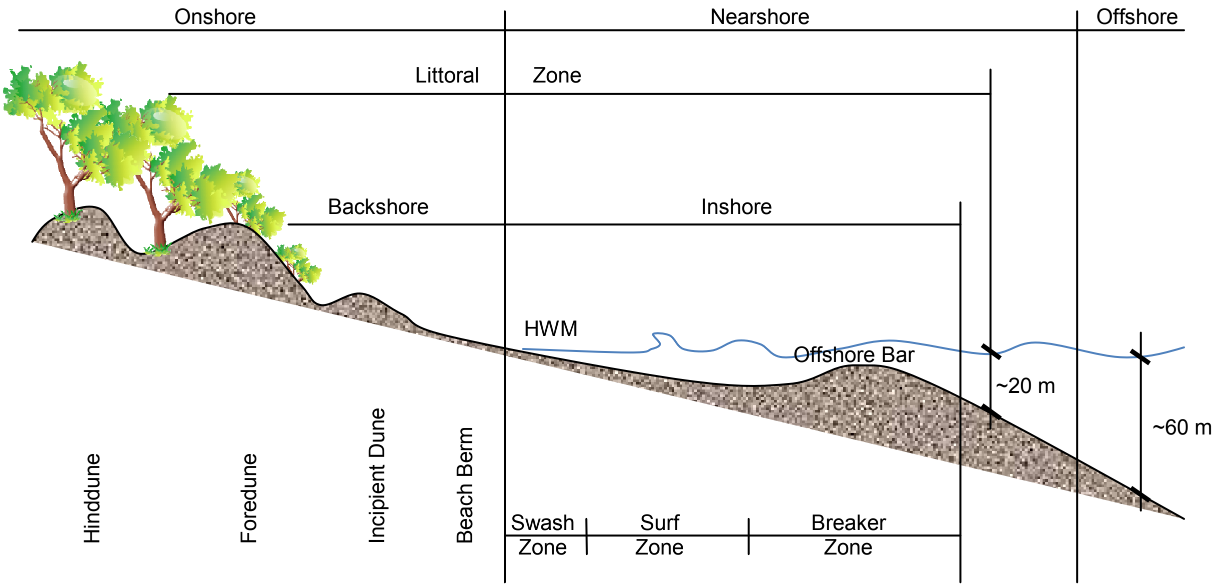



**Figure 2.1 -** Beach definition sketch (open coast beaches)

The principal hazards induced by the coastal processes that are relevant for a coastal hazard risk assessment of the beaches of Nambucca Shire include:

- short-term coastal erosion including that resulting from severe storms, the behaviour of estuary entrances and slope instability;
- long term coastline recession including that resulting from imbalances in the sediment budget, such as aeolian sand transport, climate change and beach rotation; and
- oceanic inundation of low lying areas.

The hydrodynamic forcing controlling the rate of these processes and hazards comprise the prevailing wave climate and water levels.

## 2.2 Short Term Coastal Erosion

### 2.2.1 Storm Cut

A beach typically comprises unconsolidated sands that can be mobilised under certain meteorological conditions. The dynamic nature of beaches is witnessed often during storms when waves remove the sand from the beach face and the beach berm and transport it, by a combination of longshore and rip currents, beyond the breaker zone where it is deposited in the deeper waters as sand bars (Figure 2.2). During severe storms, comprising long durations of severe wave conditions, the erosion continues into the frontal dune, which is attacked, and a steep erosion escarpment is formed. This erosion process usually takes place over several days to a few weeks. At Nambucca Heads and at Valla Beach, much of the coastline is composed of a sandy foredune fronting areas of rocky cliffs and bluffs. The erosion will therefore be limited by the presence of underlying hardpan material.

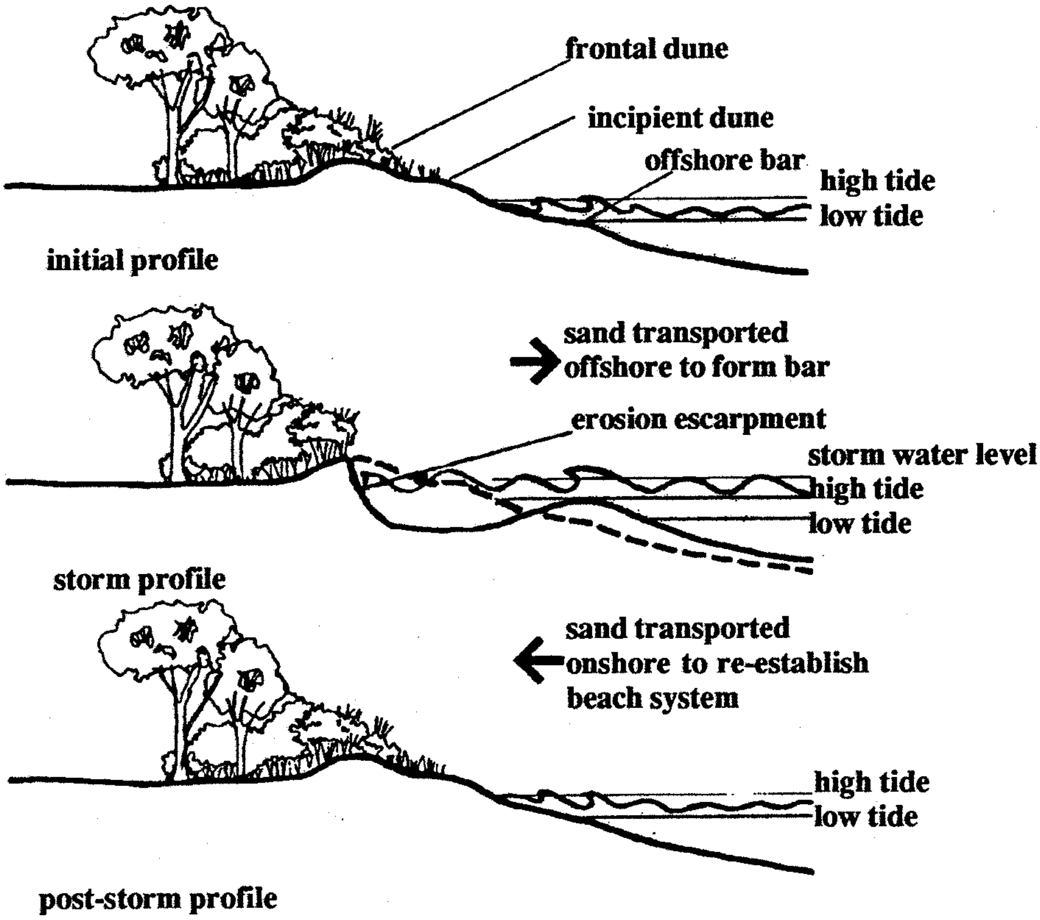



**Figure 2.2 -** Beach storm erosion/accretion cycle

The amount of sand eroded from the beach during a severe storm will depend on many factors including the state of the beach when the storm begins, the storm intensity (wave height, period and duration), direction of wave approach, the tide levels during the storm and the occurrence of rips. Storm cut is the volume of beach sand that can be eroded from the subaerial (visible) part of the beach and dunes during a *design* storm. Usually, it has been defined as the volume of eroded sand as measured above mean sea level (~ 0 m AHD datum). For a particular beach, the storm cut (or storm erosion demand) may be quantified empirically with data obtained from photogrammetric surveys, or it may be quantified analytically using a verified numerical model.

The history of severe storm erosion demand for the beaches at Scotts Head, Nambucca Heads and Valla Beach is detailed in Appendix A.

### 2.2.2 Slope Instability

Following storm cut the dune face dries out and may slump. This results from the dune sediments losing their apparent cohesive properties that come from the negative pore pressures induced by the water in the soil mass. This subsequent slumping of the dune face causes further dune recession.

Dune slumping is treated as a slope instability hazard and can be quantified with stability computations, which can serve as a guide to determining safe setback distances on frontal dunes that are prone to wave attack and slumping during storms.

### 2.2.3 Behaviour of Estuary Entrances

Various coastal hazards can be created by both trained and natural estuary entrances. Within the Nambucca Shire area, the entrance to the Nambucca River is located immediately south of the township of Nambucca Heads, and the entrance of Deep Creek is located along the beach directly south of Valla Headland. Natural entrances tend to migrate along the beach in response to freshwater flooding and coastal storm effects (NSW Government, 1990).

**Nambucca Heads**

The Nambucca river entrance has been trained for over a century, with a training wall constructed along its northern side. However, this training wall has simply duplicated the existing natural rock control that was always present at the northern side, so the entrance essentially operates as a natural river entrance. The southern side of the entrance is in a relatively natural state and had been migrating along a 500 metre wide sandy area located at the northern end of Forster Beach.

Figure 2.3 shows the varying states of the entrance to Nambucca River. In October 2006, the entrance was closed. Following a series of floods in 2008 and 2009, the entrance channel was scoured away, as shown in Figure 2.3.

At Nambucca Heads, the entrance to Nambucca River is subject to extremes of morphological dynamics due to the passage of flood events, wave action at the entrance and infilling of the entrance due to longshore drift from beaches to the south. When the entrance opening is wide, wave action can penetrate and cause erosion damage at upstream locations, such as at Bellwood Park picnic area.

Based on observations and examination of the photogrammetric data, it would appear that the river entrance dynamics may influence the dune erosion of Forster Beach, though the escarpment crests are above 9 m AHD and storm overwash of these areas is extremely unlikely. Storm overwash and coastal inundation are quantified in Appendix A. Any influences of the river entrance dynamics on storm erosion are therefore incorporated in the design storm erosion demand.

**Entrance October 2006**

**Entrance partially open July 2008**

**Entrance partially open December 2008**

**Entrance completely open July 2009**

**Figure 2.3** – Extremes of entrance behaviour, Nambucca River entrance

Breakthrough of the berm at the northern end of Forster Beach can occur on a regular basis, due to the combined effects of river floods and wave action. Such breakthroughs can cause undermining of the dune and dune vegetation at the southern end of the river entrance. However, no development is at risk as a result of these breakthroughs, and longshore drift can restore the sand spit at the southern end of the river entrance after several months. This is essentially a natural process, and the river entrance behaves like a natural, untrained river entrance at this location.

**Valla Beach**

At Valla Beach, the Deep Creek entrance migrates within a 500 metre wide area south of Valla Headland. Based on observations and examination of the photogrammetric data, it would appear that the river entrance location is fluctuating over the years and can sometimes be closed. However, the entrance to Deep Creek has tended toward being naturally open. Council records suggest that the entrance was mechanically opened for the first time in 20 years in 1991 and was opened 3 times between 1991 and January 1998. Aerial photography of the entrance which includes 11 photographs dating back to 1942 also suggest the entrance is mostly open with only one date of photography showing the entrance closed (17-6-93). The relatively high number of entrance closure events during the 1990's are likely to have been the product of lower rainfall over this period (NSW Department of Land and Water Conservation, 2000).

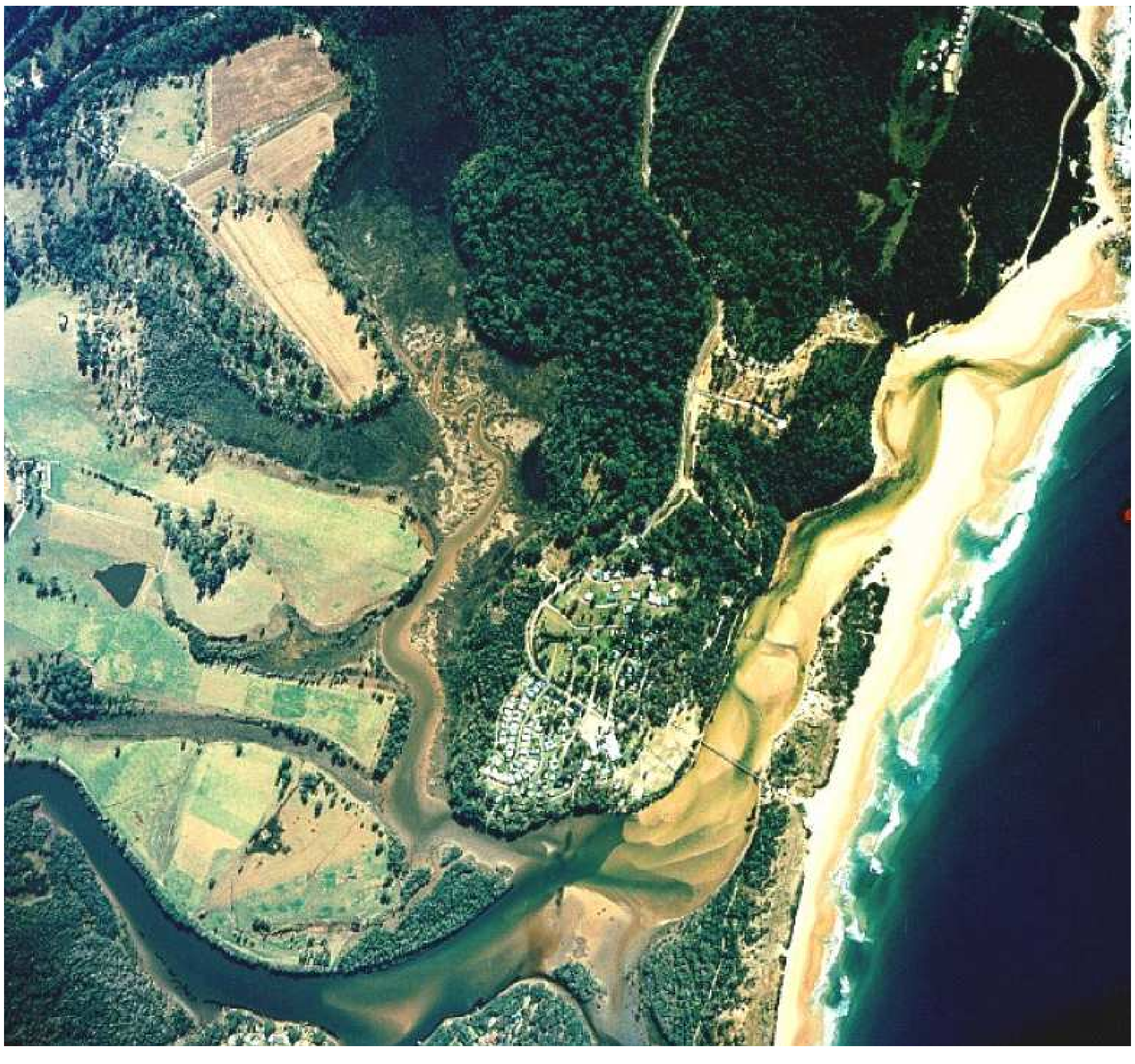
Figure 2.4 illustrates the extremes of entrance behaviour at Deep Creek.

Outside of the berm area, the river entrance dynamics may influence the dune erosion, though the escarpment crests can reach up to 11m AHD and storm overwash of these areas is extremely unlikely. Storm overwash and coastal inundation are quantified in Appendix A. Any influences of river entrance dynamics on storm erosion are therefore incorporated in the design storm erosion demand.

It is possible that future flood or storm events at Valla Beach could cause breakthrough of Deep Creek south of its current location. However, this is unlikely in the near future, given the dune height separating the river from the ocean. Such a breakthrough could threaten the existing footbridge and change the nature of the coastline, whereby the existing foreshore of Deep Creek may become a future open coastline fully exposed to ocean waves. Breakthrough of estuary entrances has been observed at other locations on the NSW coast, with an extreme case of this phenomenon observed when breakthrough and wave runup on a spit of the North Arm of the Brunswick River virtually destroyed the village of Sheltering Palms (NSW Government, 1990). By 2050, the dune width separating Deep Creek from the ocean may significantly reduce in width due to sea level rise and some breakthroughs would be expected as a result of major storms or floods.

Breakthrough of estuary entrances has been observed at other locations on the NSW coast, with an extreme case of this phenomenon observed when breakthrough and wave runup on a spit of the North Arm of the Brunswick River virtually destroyed the village of Sheltering Palms (NSW Government, 1990). The Macleay River Estuary broke through the dunes north of South West Rocks, creating a new entrance in late 1893 following a 1:100 year flood. In 1896, Public Works commenced work on the new river entrance (GECO Environmental, 2005)

Deep Creek – Entrance Closed 17/6/93



Deep Creek – Entrance Open 28/6/96

**Figure 2.4** – Extremes of entrance behaviour, Deep Creek (NSW Department of Land and Water Conservation, 2000)

## 2.3 Longer Term Beach Changes and Shoreline Recession

Following storms, ocean swell replaces the sand from the offshore bars onto the beach face where onshore winds move it back onto the frontal dune. This beach building phase, typically, may span many months to several years. Following the build-up of the beach berm and the incipient foredunes, and the re-growth of the sand trapping grasses, it can appear that the beach has fully recovered and beach erosion has been offset by beach building (Figure 2.2).

However, in some instances, not all of the sand removed from the berm and dunes is replaced during the beach building phase. Sand can be lost to sinks, resulting in longer term ongoing recession of the shoreline. Further, over decadal time scales, changes in wave climate can result in beach rotation. The signature of the medium-term oscillations in sub-aerial beach sand store caused by decadal variations in the SOI and the fluctuations resulting from minor storm events are apparent at Scotts Head, Nambucca Heads and Valla Beach, as long term beach recession has been insignificant compared to the signature of the medium term oscillations.

### 2.3.1 Sediment Budget Deficit

Once the sand has been transported offshore into the surf zone, it may be moved alongshore under the action of the waves and currents and out of the beach compartment. Some of the sand that is transported directly offshore during storms may become trapped in offshore reefs, thereby preventing its return to the beach. Other direct losses of material from the beach may include the inland transport of sand under the action of onshore winds; this mechanism being called aeolian sand transport. Over the longer term, should the amount of sand taken out of the compartment by alongshore processes exceed that moved into the compartment from adjacent beaches or other sources, then there will be a direct and permanent loss of material from the beach and a deficit in the sediment budget for the beach (Figure 2.5). This will result in an increasing potential for dune erosion during storms and long term beach recession (Figure 2.6).

Obvious processes that may lead to a deficit in the sediment budget of a beach include wind blown sand off the beach (aeolian sand transport causing transgressive dune migration), mining the beach for heavy minerals and beach sand extraction operations. Other processes, which are not so obvious because they occur underwater, include the deposition of littoral drift into estuaries and the transport of quantities of littoral drift alongshore and out of a beach compartment, which may be larger than any inputs.

The quantification of sediment budgets for coastal compartments is exceedingly difficult. The usual practice is to identify the processes and to quantify the resulting beach recession using photogrammetric techniques. Long term rates of shoreline recession have been quantified for the beaches of Nambucca Shire using photogrammetric techniques (Appendix A).

### 2.3.2 Beach Rotation

Studies of embayed beaches on the NSW coast have identified a sensitivity of shoreline alignment to wave direction (Short *et al*., 2000). This has been linked to the Southern Oscillation Index (SOI; Ranasinghe *et al*., 2004; Goodwin, 2005), which is a number calculated from the monthly or seasonal fluctuations in the air pressure difference between Tahiti and Darwin.

Sustained negative values of the SOI usually are accompanied by sustained warming of the central and eastern tropical Pacific Ocean, a decrease in the strength of the Pacific Trade Winds and a reduction in rainfall over eastern and northern Australia. This is called an *El Niño* episode. During these episodes, a more benign south-easterly wave condition is expected on the NSW coast.

Positive values of the SOI are associated with stronger Pacific trade winds and warmer sea temperatures to the north of Australia, popularly known as a *La Niña* episode. Waters in the central and eastern tropical Pacific Ocean become cooler during this time. Together, these give an increased probability that eastern and northern Australia will be wetter than normal and, during these episodes, severe storms may be expected on the Australian Eastern seaboard.

Since 1876, the maximum value of the monthly average of the SOI that has been recorded was +34.8 in August 1917. For much of that year the monthly average of the SOI was above +20 and several very severe storms were experienced along the entire NSW coast from June to November that year. From January to May, 1974, the monthly average of the SOI varied from around +20 to +10, which may have been relevant to the occurrence of the severe storms of May − June 1974.

Goodwin (2005) demonstrated that, since the 1880s, the monthly mid-shelf mean wave direction (MWD) for southeastern Australia has varied from around 125°T to 145°T with a strong annual cycle coupled to mean, spectral-peak wave period. Months and years when a more southerly MWD occurs are accompanied by an increase in the spectral-peak wave period. The most significant multi-decadal fluctuation in the time series was from 1894 to 1914, when Tasman Sea surface temperatures (SST) were 1°–1.5°C cooler, monthly and annual wave directions were up to 4°–5° more southerly and, by inference, spectral-peak wave periods were longer when compared with the series since 1915. The sustained shift in wave direction would have had a significant influence on beach and coastal compartment alignment along the NSW coast (Goodwin, 2005).

Goodwin *et al.* (2007) identifies conceptual sediment transport processes based on mean wave climate states. A more southerly wave climate consistent with an *El-Niño* event would lead to greater northerly longshore sediment transport (clockwise beach rotation) while a more easterly wave climate would lead to an anti-clockwise translation (Figure 2.7). A shift from dominant *La-Niña* to dominant *El-Niño* conditions caused by climate change would enhance northerly longshore drift and therefore increase the beach recession.

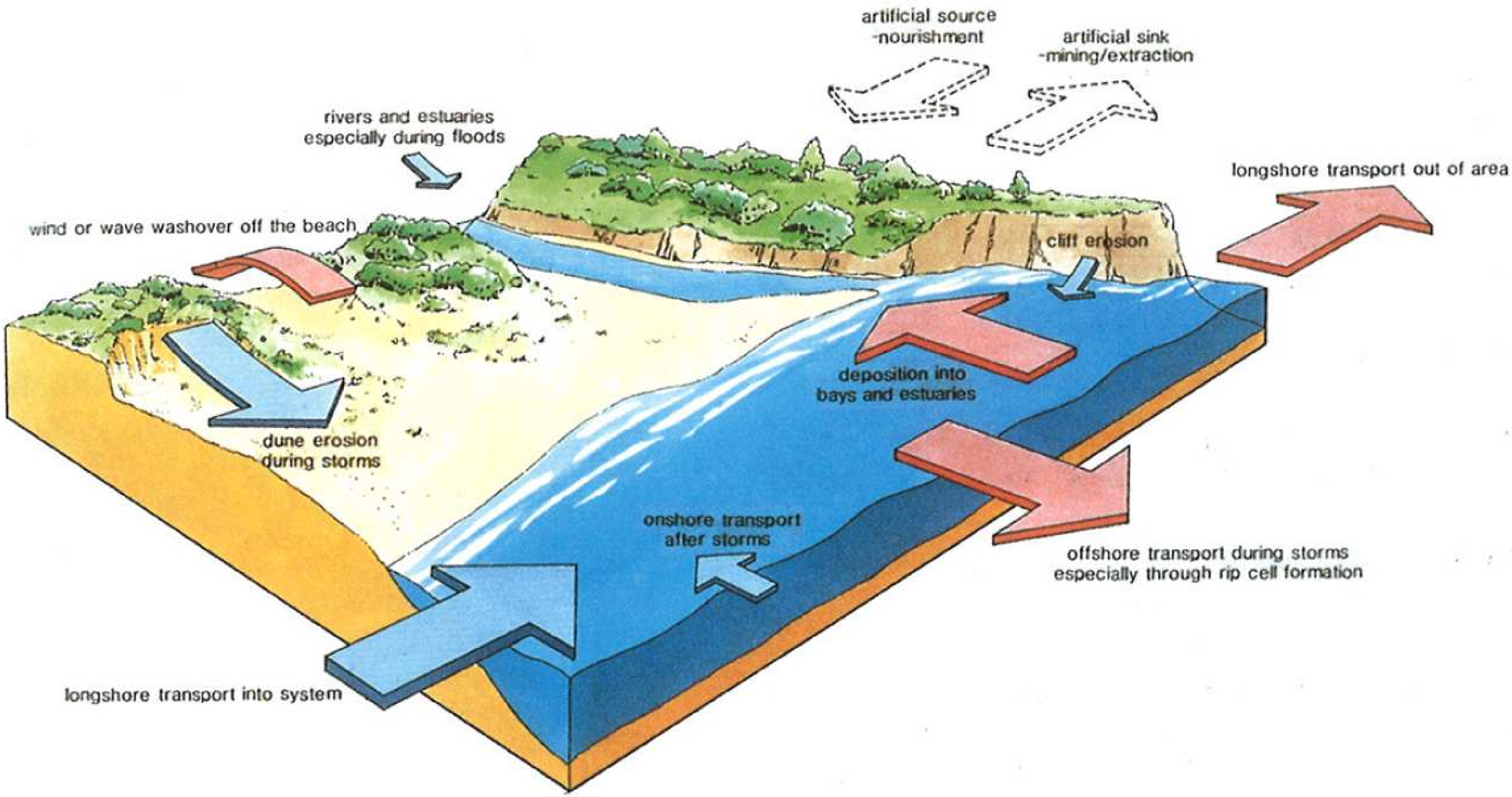



**Figure 2.5 -** Sediment budget schema (NSW Government, 1990)

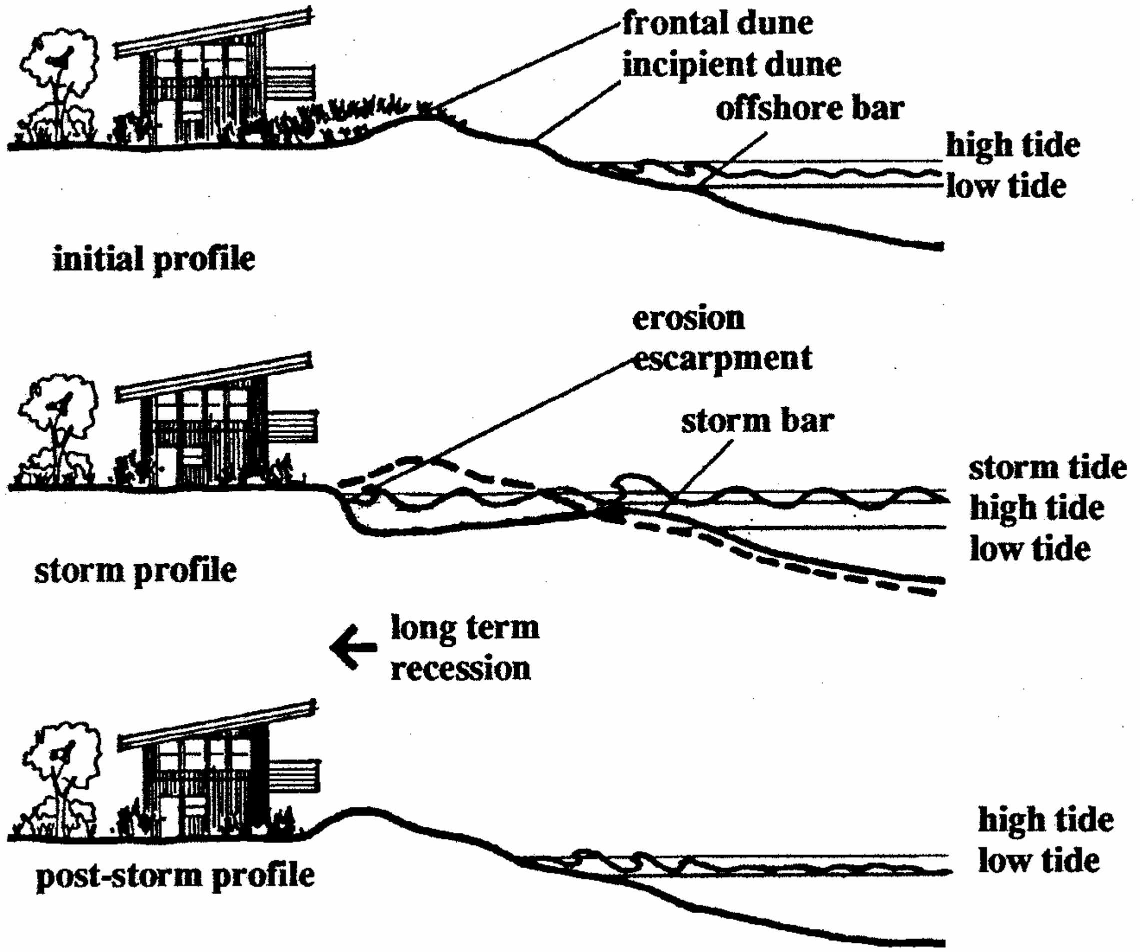



**Figure 2.6 -** Long term erosion schema

**Previous Studies of Beach Rotation**

Studies of beach rotation as a result of variations in the SOI have been undertaken at Narrabeen Beach and Palm Beach (Short *et al.*, 2000; Ranasinghe *et al.*, 2004). Data from Ranasinghe (*et al.*, 2004) indicated an anti-clockwise rotation of these beaches as a result of a positive value in the SOI and *vice versa*. A sustained SOI of +10 to +20 (a *La-Niña* episode) resulted in an anti-clockwise rotation of Narrabeen Beach by around 0.9° and a sustained SOI of around +15 to +26 resulted in a similar rotation of Palm Beach by around 0.7°. On the other hand, a sustained SOI of −10 to −16 (an *El-Niño* episode) resulted in a clockwise rotation of Narrabeen Beach by around 1.2° and a sustained SOI of −25 to −38 resulted in a clockwise rotation of Palm Beach by around 0.7°.

These rotations were reflected in the translation of the mean waterline or swash zone of the beach berm and they did not affect the dune alignment. Analysis of 23 years of monthly profiles at Narrabeen Beach showed that rotations accounted for up to 15 m and some 30 $m^3$/m (above MSL) of the shore-normal beach sand exchange (Short *et al.*, 2000). At Palm Beach, the maximum recession of the swash zone that was recorded over the 2.5 year period was around 10 m (Ranasinghe *et al.*, 2004), which represented the removal of around 20 $m^3$/m of sub-aerial beach sand store at the extreme ends of the beach. For a given degree of beach rotation, greater recession or progradation of the swash zone and, hence, greater beach sand exchange would be expected on longer beaches.

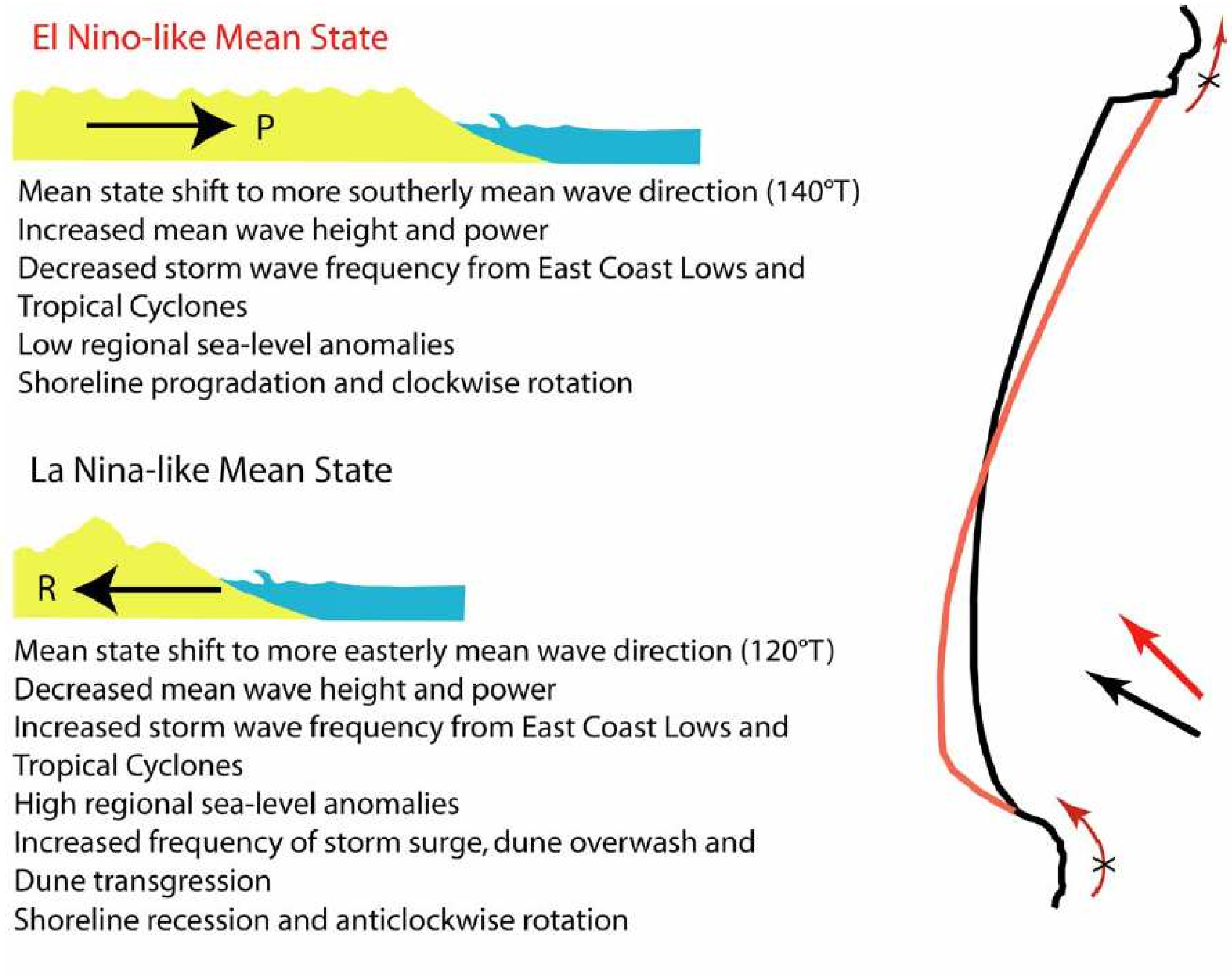



**Figure 2.7** – Wave rotation caused by *El-Niño* or *La-Niña* mean states (after Goodwin et al. 2007)

### Causes of Beach Rotation

These beach rotations were considered to be caused by changes to both the mean direction and magnitude of wave energy flux, the signature of which is reflected in the SOI. The larger magnitude of wave energy flux induced greater onshore/offshore sand transport whereas changes in direction affected also alongshore transport rates and directions.

Both Narrabeen Beach and Palm Beach are exposed open coast beaches and would experience the maximum shift in the mean direction of offshore wave energy flux. Sheltered embayments would not experience much rotation because the mean direction of wave energy flux cannot vary much. This is because the nearshore incident swell direction is controlled and limited by severe wave refraction with the beach already being aligned normal to the direction of the nearshore wave energy flux vector.

On open coast beaches, the *La-Niña* events, which are correlated to severe storms, may result in recession of the swash zone at the extreme northern ends of the beaches. This occurs rapidly following the SOI shift (a few months; Ranasinghe *et al*., 2004) and may result in reducing the available sand store on the beach that provides a buffer to the storm erosion demand. However, as the concomitant accretion at the southern end of the beach lags the SOI trend shift considerably (by up to and in excess of 1 year; Ranasinghe *et al*., 2004), this obviates any advantage that the accreted swash zone may accrue to supplying the storm erosion demand.

## 2.3.3 Sea Level Rise due to Climate Change

Another factor that may affect the long-term trends on beaches is a rise in sea level resulting from the *Greenhouse Effect*. A rising sea level may result in beach recession on a natural beach and an increased potential for dune erosion on a developed beach where the dune line may be being held against erosion by a seawall.

Figure 2.8 illustrates the concept of beach recession as a result of sea level rise.

Climate is the pattern or cycle of weather conditions, such as temperature, wind, rain, snowfall, humidity, clouds, including extreme or occasional ones, over a large area and averaged over many years. Changes to the climate and, specifically, changes in mean sea levels, wind conditions, wave energy and wave direction, can be such as to change the coastal sediment transport processes shaping beach alignments.

Climate change had been defined broadly by the Intergovernmental Panel on Climate Change (IPCC, 2001) as any change in climate over time whether due to natural variability or as a result of human activity. Apart from the expected climate variability reflected in seasonal changes, storms, *etc*., climate changes that are considered herein refer to the variability in average trends in weather that may occur over time periods of decades and centuries. These may be a natural variability of decadal oscillation or permanent trends that may result from such factors as changes in solar activity, long-period changes in the Earth's orbital elements (eccentricity, obliquity of the ecliptic, precession of equinoxes), or man-made factors such as, for example, increasing atmospheric concentrations of carbon dioxide and other *greenhouse* gases.

The signature of climate variability over periods of decades is seen in the Southern Oscillation Index (SOI), a number calculated from the monthly or seasonal fluctuations in the air pressure difference between Tahiti and Darwin. Sustained negative values of the SOI usually are accompanied by sustained warming of the central and eastern tropical

Pacific Ocean, a decrease in the strength of the Pacific Trade Winds and a reduction in rainfall over eastern and northern Australia. This is called an *El-Niño* episode. During these episodes, a more benign south-easterly wave condition is expected on the NSW coast. Positive values of the SOI are associated with stronger Pacific trade winds and warmer sea temperatures to the north of Australia, popularly known as a *La-Niña* episode. Waters in the central and eastern tropical Pacific Ocean become cooler during this time. Together, these give an increased probability that eastern and northern Australia will be wetter than normal and, during these episodes, severe storms may be expected on the Australian Eastern seaboard.

Over much longer time frames, the Intergovernmental Panel on Climate Change (IPCC 2001) has indicated that the global average surface temperature has increased over the 20$^{th}$ century by 0.6°C and that this warming will continue at an accelerating rate. The current consensus of scientific opinion is that such changes could result in global warming of 1.5° to 4.5°C over the next 100 years. This warming of the average surface temperature is postulated to lead to warming of the oceans, which would lead to thermal expansion of the oceans and loss of mass from land-based ice sheets and glaciers. This would lead to a sea level rise which, in turn, would lead to recession of unconsolidated shorelines.

### Historical Sea Level Rise

Tidal gauge data show that over the 20$^{th}$ century global average sea level rose between 0.1 m and 0.2 m; that is, at an average rate of between 1 mm/y to 2 mm/y (IPCC, 2001). Mitchell *et al.* (2001) summarised observed sea level rise in Australia and the Pacific. Analysis of data from Fort Denison in Sydney showed that, between 1914 and 1997, the underlying trend in sea level rise has been an average increase in relative sea level of 0.86 mm/year (and 1.18 mm/year in Newcastle). However, it was noted that there was considerable variation in the data, which was due to processes acting at inter-decadal scales, such as the *El-Niño* Southern Oscillation phenomenon. Part of this (25 mm) was due to isostatic rebound inducing a rise of the land mass, which is occurring at a rate of 0.3 mm/year. Mitchell *et al.* (2001) corrected sea-level changes at Fort Denison to an average increase of 1.16 mm/year to account for this rate of post-glacial rebound.

Satellite altimetry data has recently been employed to measure changes in global sea level – this has allowed a more accurate measurement of changes in Mean Sea Level around the globe since around 1993. From these measurements, it is apparent from Figure 2.9 that the rate of sea level rise has accelerated in the later part of the 20$^{th}$ century, with sea level in Australia rising by around 3.1 mm/year between 1993 and 2004 (White and Church, 2006).

### Projected Sea Level Rise

The National Committee on Coastal and Ocean Engineering of Engineers Australia has issued *Guidelines for Responding to the Effects of Climate Change in Coastal and Ocean Engineering* (NCCOE, 2004). These *Guidelines* indicated a range of engineering estimates for global average sea level rise from 1990 to 2100 of 0.1 m to 0.9 m with a central value of 0.5 m. The *Guidelines* indicated also that global average sea level rise scenarios must be converted to estimated local relative sea level movement for each site. In this regard, reference has been made to the IPCC projections for global and regional sea level change.

Using various climate models for different climate change scenarios, the Third Assessment Report (TAR) of the IPCC (2001) projected a range of sea level rises for the 21$^{st}$ century. It was projected that global average sea levels could rise from between

0.09 m and 0.88 m by 2100 (Figure 2.10; and from between 0.05 m and 0.30 m by around 2055). Mid-range scenarios gave "best estimates" of sea level rise of around 0.48 m for 2100 (and around 0.18 m for 2055).

From the IPCC Fourth Assessment Report (2007), the 5% to 95% confidence limit ranges of sea level rise predictions for the 21st century are shown in Figure 2.11 and summarised in Table 2.1, for the various scenarios and based on the spread of model results.

It can be seen from Table 2.1 that the 95% confidence interval for global average sea level rise in the worst case scenario (Scenario A1FI) is 0.59 m for a 100 year planning period. This is made up of various components, including thermal expansion of the oceans (the largest component), melting of the Greenland and Antarctic ice sheets and melting of land-based glaciers. There is considerable uncertainty also in the level of ice-sheet discharge, which could contribute, at a maximum, an additional 0.17 m to the worst-case scenario global average sea level rise (refer Table 2.2). This would give an upper bound sea level rise of 0.76 m for a 100 year planning period.

In addition to these impacts, there is also a local effect due to the East Australia Current, which could add around 10 – 14 cm to the global average sea level rise (McInnes *et al,* 2007).

In addition to the effects of climate change, there is also an existing underlying rate of sea level rise. Mitchell et al. (2001) quantified underlying rates of existing sea level rise at various tide gauge locations around Australia. Factors other than global warming that contribute to the underlying rate of sea level rise include (Walsh *et al*., 2004):

- geological effects caused by the slow rebound of land that was covered by ice during the last Ice Age (isostatic rebound);
- flooding of continental shelves since the end of the last Ice Age, which pushes down the shelves and causes the continent to push upwards in response (hydroisostasy);
- changes in land height in tectonically or volcanically active regions;
- changes in atmospheric wind patterns and ocean currents; and
- local subsidence due to sediment compaction or groundwater extraction.

Combining the relevant global and local information indicates that sea level rise on the NSW coast is expected to reach up to **0.90 m** for the year 2100. For 2050, the sea level rise benchmark advocated by the NSW Sea Level Rise Policy (2009) is **0.40 m**.

The NSW Department of Environment and Climate Change (DECC) has recently been advocating sensitivity analyses using a range of sea level rise scenarios for various planning horizons. As the 5% lower bound estimate from the IPCC report has a 95% probability of being exceeded for a 100 year planning period it is generally excluded from the sensitivity analysis for planning purposes.

The IPCC Fourth Assessment Report (2007) does not provide estimates of sea level rise for a 50 year planning horizon. However, the IPCC Third Assessment Report (2001) provides projections over the 21$^{st}$ century (Figure 2.10), with a median value of around 0.2 m and a maximum value of around 0.4 m for 2060.

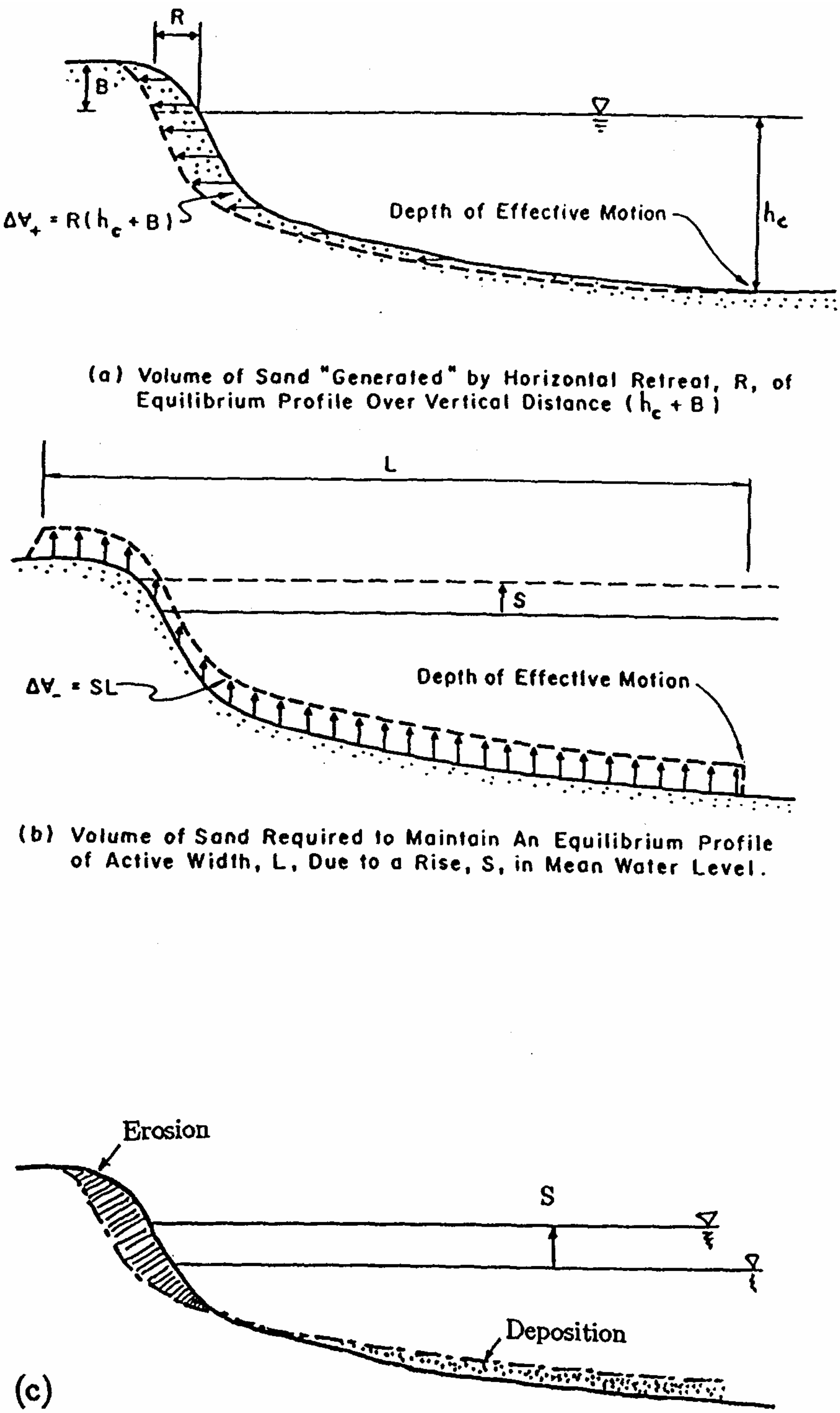



**Figure 2.8** - Concept of shoreline recession due to sea level rise

### Consequences of Sea Level Rise

Global warming may produce also a worldwide sea level rise caused by the thermal expansion of the ocean waters and the melting of some ice caps. According to the Intergovernmental Panel on Climate Change (IPCC, 2007), the upper range estimate for sea level rise for the 21$^{st}$ century is 0.59 m (Figure 2.11). This is made up of various components, including thermal expansion of the oceans (the largest component), melting of the Greenland and Antarctic ice sheets and melting of land-based glaciers. There is considerable uncertainty also in the level of ice-sheet discharge, which could contribute, at a maximum, an additional 0.17 m to the worst-case scenario global average sea level rise. In addition to this, there is a local component of sea level rise related to the East Australia Current, which amounts approximately to a further 0.1 m sea level rise along the NSW coast (Department of Environment and Climate Change, 2009a and 2009b).

The NSW Government has released the NSW Policy on Sea Level Rise. This Policy specifies the use of specific planning benchmarks for sea level rise, these being a 0.4 m sea level rise by 2050, and a 0.9 m sea level rise by 2100. These correspond approximately to the upper bound global average sea level rise values as presented in the IPCC's Fourth Assessment Report (2007), with additional allowances for ice melt and local effects. Appendix B documents the full range of sea level rise estimates adopted for the hazard assessment.

**Table 2.1 -** Range of Sea Level Rise Predictions (IPCC 2007)

| Scenario | 5% (lower bound) predicted sea level rise 1980-1999 to 2090-2099 (m) | 95% (upper bound) predicted sea level rise 1980-1999 to 2090-2099. (m) |
|---|---|---|
| B1 | 0.18 | 0.38 |
| B2 | 0.20 | 0.43 |
| A1B | 0.21 | 0.48 |
| A1T | 0.20 | 0.45 |
| A2 | 0.23 | 0.51 |
| A1F1 | 0.26 | 0.59 |

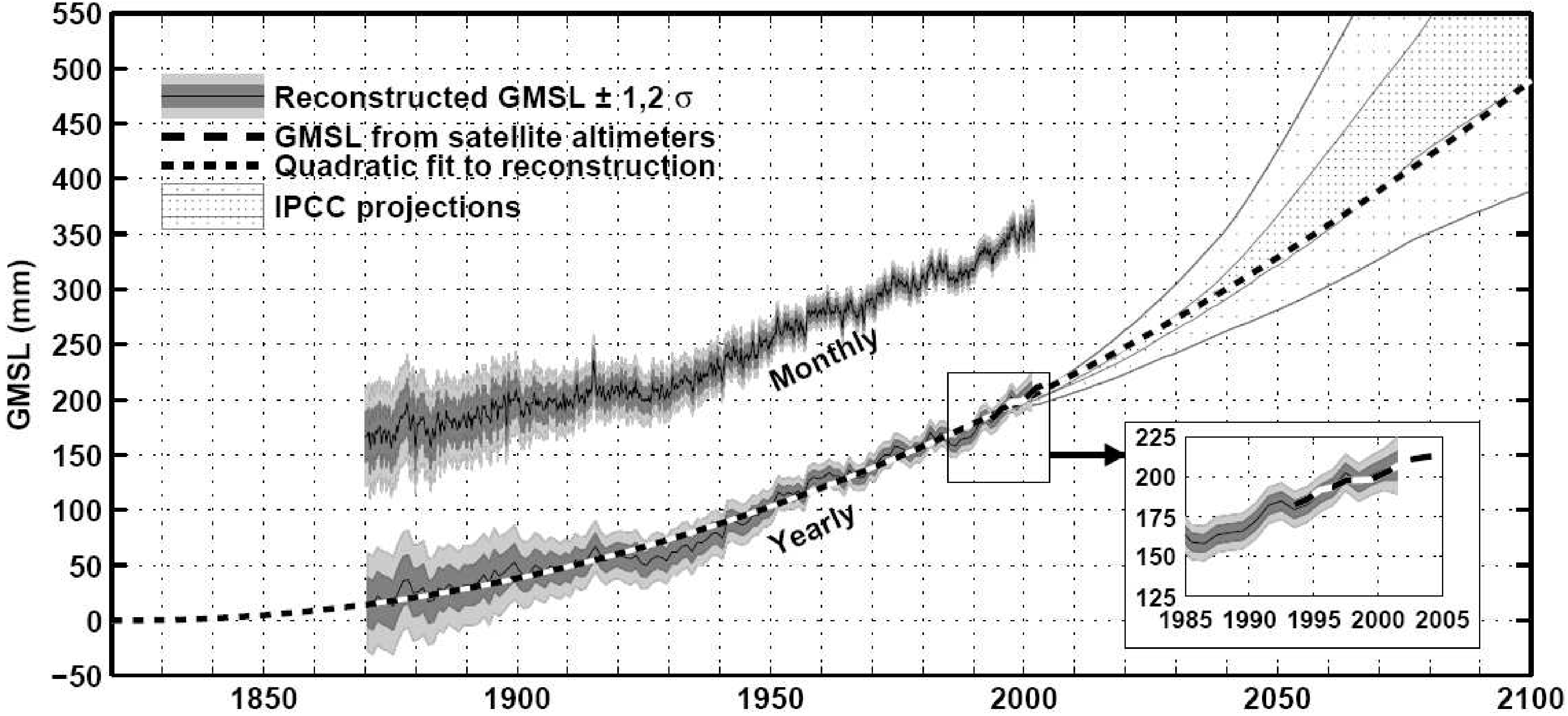



**Figure 2.9** – Measured global mean sea level 1870 – 2002 (White and Church, 2006)

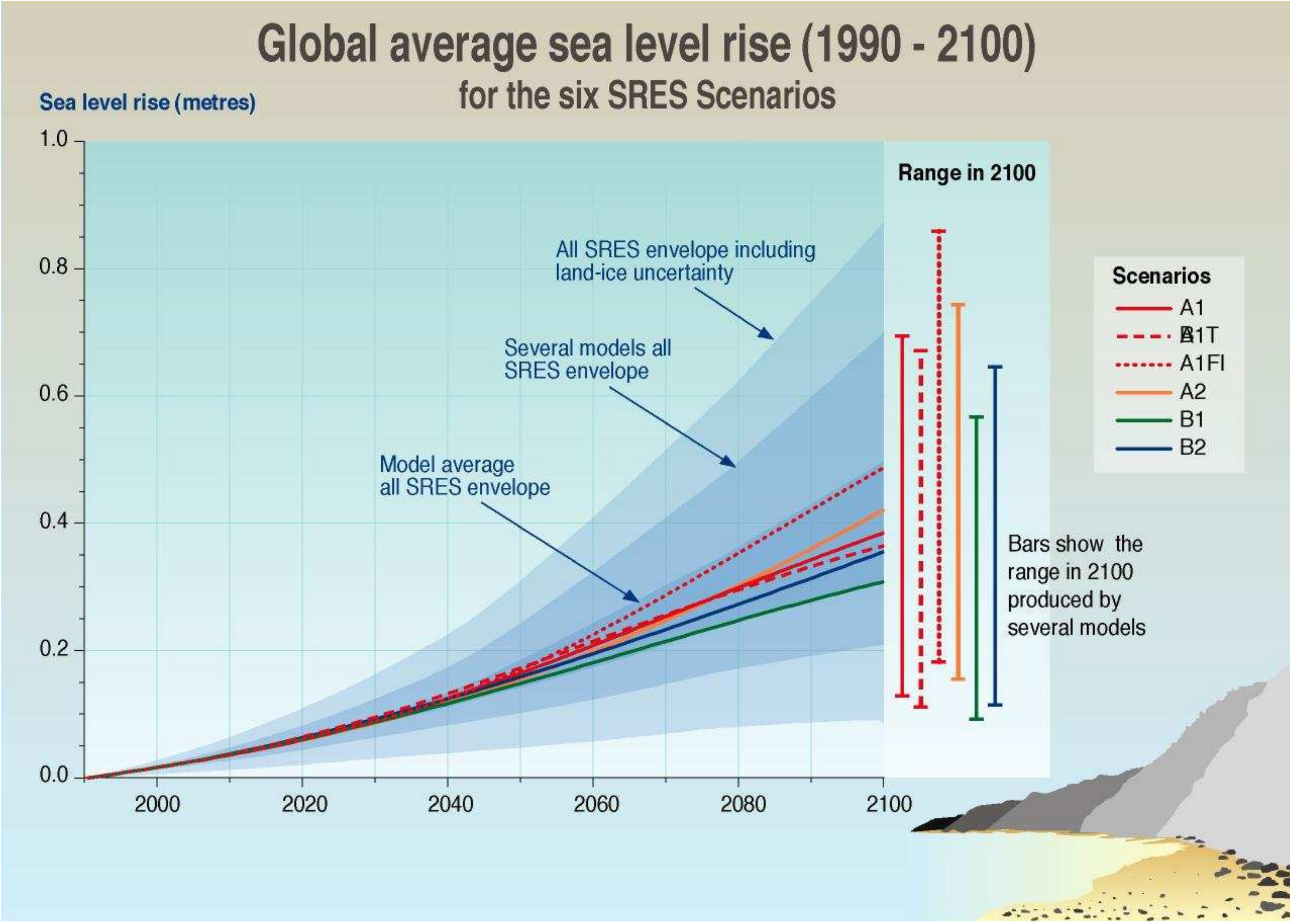



**Figure 2.10** – IPCC (2001) Sea level rise estimates

**Table 2.2** - Contributions to global average sea level rise for various scenarios, 1990 – 2095 (source: IPCC 2007).*

| | | B1 | | B2 | | A1B | | A1T | | A2 | | A1FI | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Thermal expansion | m | 0.10 | 0.24 | 0.12 | 0.28 | 0.13 | 0.32 | 0.12 | 0.30 | 0.14 | 0.35 | 0.17 | 0.41 |
| | mm yr-1 | 1.1 | 2.6 | 1.6 | 4.0 | 1.7 | 4.2 | 1.3 | 3.2 | 2.6 | 6.3 | 2.8 | 6.8 |
| G&IC | m | 0.07 | 0.14 | 0.07 | 0.15 | 0.08 | 0.15 | 0.08 | 0.15 | 0.08 | 0.16 | 0.08 | 0.17 |
| | mm yr-1 | 0.5 | 1.3 | 0.5 | 1.5 | 0.6 | 1.6 | 0.5 | 1.4 | 0.6 | 1.9 | 0.7 | 2.0 |
| Greenland Ice Sheet SMB | m | 0.01 | 0.05 | 0.01 | 0.06 | 0.01 | 0.08 | 0.01 | 0.07 | 0.01 | 0.08 | 0.02 | 0.12 |
| | mm yr-1 | 0.2 | 1.0 | 0.2 | 1.5 | 0.3 | 1.9 | 0.2 | 1.5 | 0.3 | 2.8 | 0.4 | 3.9 |
| Antarctic Ice Sheet SMB | m | -0.10 | -0.02 | -0.11 | -0.02 | -0.12 | -0.02 | -0.12 | -0.02 | -0.12 | -0.03 | -0.14 | -0.03 |
| | mm yr-1 | -1.4 | -0.3 | -1.7 | -0.3 | -1.9 | -0.4 | -1.7 | -0.3 | -2.3 | -0.4 | -2.7 | -0.5 |
| Land ice sum | m | 0.04 | 0.18 | 0.04 | 0.19 | 0.04 | 0.20 | 0.04 | 0.20 | 0.04 | 0.20 | 0.04 | 0.23 |
| | mm yr-1 | 0.0 | 1.8 | -0.1 | 2.2 | -0.2 | 2.5 | -0.1 | 2.1 | -0.4 | 3.2 | -0.8 | 4.0 |
| Sea level rise | m | 0.18 | 0.38 | 0.20 | 0.43 | 0.21 | 0.48 | 0.20 | 0.45 | 0.23 | 0.51 | 0.26 | 0.59 |
| | mm yr-1 | 1.5 | 3.9 | 2.1 | 5.6 | 2.1 | 6.0 | 1.7 | 4.7 | 3.0 | 8.5 | 3.0 | 9.7 |
| Scaled-up ice sheet discharge | m | 0.00 | 0.09 | 0.00 | 0.11 | -0.01 | 0.13 | -0.01 | 0.13 | -0.01 | 0.13 | -0.01 | 0.17 |
| | mm yr-1 | 0.0 | 1.7 | 0.0 | 2.3 | 0.0 | 2.6 | 0.0 | 2.3 | -0.1 | 3.2 | -0.1 | 3.9 |

*The additional 0.17 m sea level rise allowed for uncertainties in ice-sheet discharge is the upper bound range under the A1FI scenario, as indicated in the Table. This needs to be added to the sea level rise attributed to the other sources of sea level rise indicated in Table 2, which include thermal ocean expansion, melting of glaciers and ice caps, melting of the Greenland Ice Sheet and changes in the Antarctic Ice Sheet.

## River Entrance Response

Sea level rise is likely to cause an increase in the tidal prism of the Nambucca River and Deep Creek estuary entrances, leading to an increase in the volume of sand trapped in the ebb-tide and flood-tide deltas within the entrances (US National Research Council, 1987). This increased volume of sand trapped within the entrance is sourced from the adjacent beach, leading to erosion of the beach on the southern side of the river entrance at Nambucca, and on both sides at Valla. A larger ebb and flood tide delta means that longshore drift has a reduced capacity to bypass the entrance, and sediment infilling of the entrance occurs.

Further, an increased tidal prism would lead to the entrance offshore bar moving further offshore into deeper water, thus increasing the wave energy that can reach the beach and causing erosion. This has occurred at trained estuary entrances on the NSW coast, such as at Town Beach at Port Macquarie following construction of the breakwater on the northern bank of the Hastings River (SMEC, 2003). An increased tidal prism due to sea level rise could eventually send the estuary into an unstable scouring mode, which could lead to further beach erosion around the river entrances at Nambucca and Valla. This may be occurring at a number of estuaries along the NSW coast, such as Lake Macquarie and Wallis Lake, due to an increased tidal prism caused by construction of entrance training walls at these estuaries (Nielsen and Gordon, 2007).

Future breakthrough of the Deep Creek entrance further south along South Valla Beach is possible if the sand spit at the southern end of the entrance is eroded due to sea level rise. This could threaten the existing footbridge and change the nature of the coastline, whereby the existing foreshore of Deep Creek may become a future open coastline fully exposed to ocean waves.

The river entrance dynamics would likely also be influenced by changes in wave climate brought about by climate change, including changes in the frequency of *El-Niño* and *La-Niña* events.

### 2.3.4 Increased Storminess due to Climate Change

Hennessy *et. al.* (2004) predicts no increase in winter storm wind speeds for the NSW coast as a result of climate change. Mean wind-speed projections show a tendency for increases across much of the state in summer, with decreases in the north-east. In autumn, there is a tendency toward weaker winds in the south and east, and stronger winds in the north-west. The tendency in winter is toward increases in the far north-west and south and decreases elsewhere. A tendency for stronger winds is evident in spring, with greatest increases across central NSW.

Projected changes in extreme monthly winds (strongest 5%) showed similar patterns to the mean wind changes in summer and autumn, except that the magnitude of the increases and decreases tended to be larger. In winter, changes in extreme winds differed from changes in mean winds in that most of the state and the ocean in the far south showed a tendency for increasing extreme winds with, only the north-east indicating decreasing winds. However, as shown in Figure 2.12, for the north coast the tendency was for little change or decrease in extreme wind speeds. In spring, extreme winds tended to increase, except in a small area on the southern half of the coast where there was a tendency towards decreasing extreme winds.

In the winter half-year, the modelling has indicated that Tasman Lows contributing to extreme winds increased in frequency from 26% at present to 31% by 2070. Frontal systems also increased from 25% of extreme wind days at present to 29% by 2070.

There are no predictions for any increase in winter storm wind speeds and, hence, wave heights for this part of the NSW coast as a result of climate change (Figure 2.12). Foreshore recession resulting from a *Greenhouse*-induced sea level rise has been assessed using the *Bruun Rule* (Appendix B).

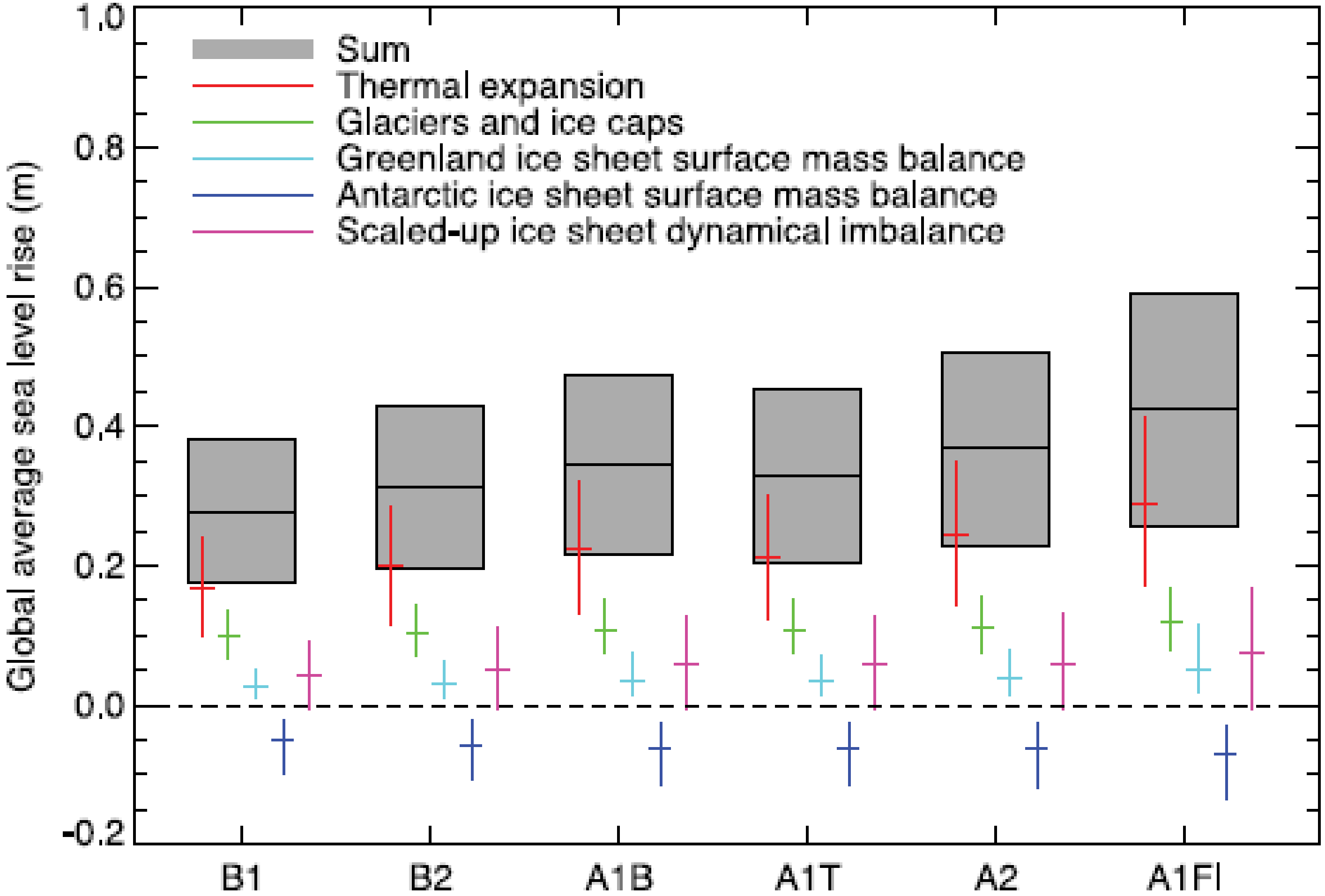



**Figure 2.11** – Projected sea level rise between 2000 and 2100 (after IPCC, 2007)

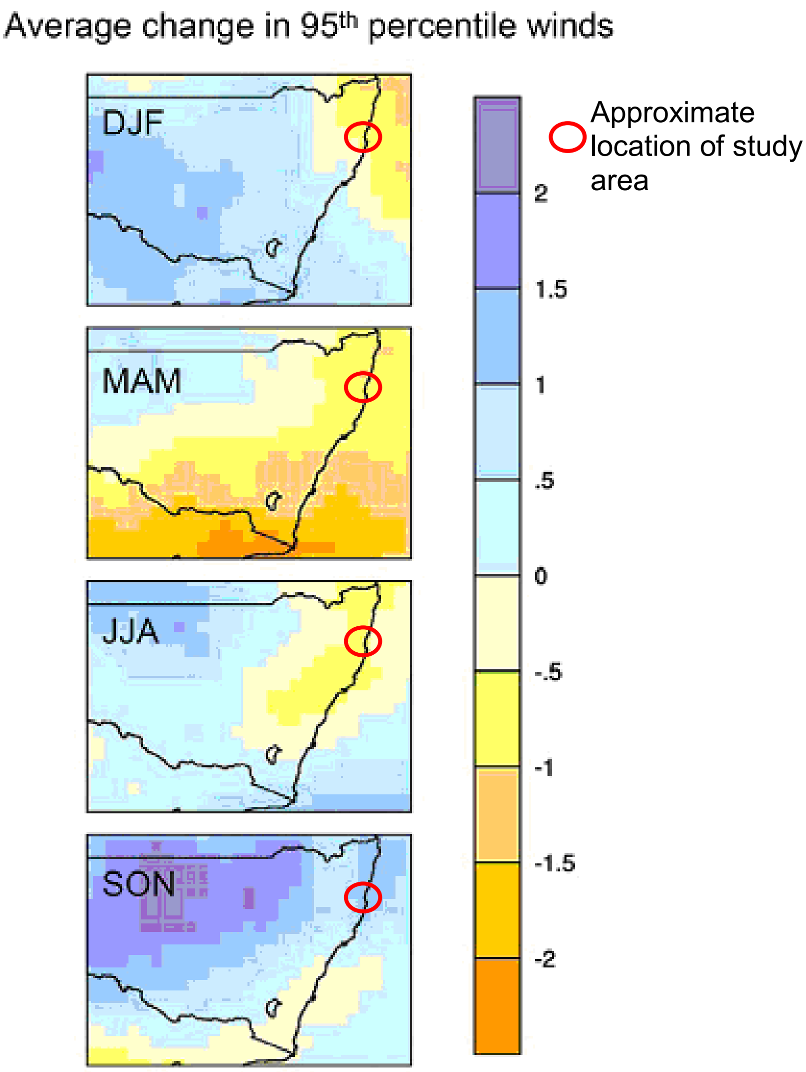



**Figure S3: The change in extreme monthly wind speed derived by averaging the 12 models results. Units are % change per °C of global warming. DJF = summer, MAM = autumn, JJA = winter, SON = spring.**

**Figure 2.12 –** Change in extreme monthly wind speeds for NSW coast (Hennessy *et al* 2004)

## 2.4 Coastal Inundation

An increase in water level at the shoreline results from the breaking action of waves causing what is termed wave setup and wave runup. Wave setup may be perceived as the conversion of part of the wave's kinetic energy into potential energy. The amount of wave setup will depend on many factors including, among other things, the type, size and periods of the waves, the nearshore bathymetry and the slope of the beach and foreshore. Typically, wave setup on an open-coast beach during severe storms can be around 1 m to 2 m.

The energy of a wave is dissipated finally as the water runs up the beach or shoreline. Wave run-up is the vertical distance the wave will reach above the level of the tide and storm surge and can be several metres. Wave run-up at any particular site is very much a function of the wave height and period, the foreshore profile and slope, surface roughness and other shoreline features on which the breaking waves impinge.

Should dune levels be low or the foreshore not protected by dunes, flooding and damage to structures can result from the coincidence of elevated ocean water levels and wave runup.

An assessment of coastal inundation due to wave runup for Scotts Head, Nambucca Heads and Valla Beach has been carried out in Appendix A.

## 2.5 Hydrodynamic Forcing

### 2.5.1 Introduction

Critical to a coastline hazard risk assessment is the definition and quantification of the waves and water levels that shape the beaches.

### 2.5.2 Wave Climate and Storms

Coastal processes along the coastline of Nambucca Shire are impacted greatly by intense tropical and non-tropical storms which occur along the NSW coastline at irregular intervals. These storms are responsible for episodic events of sand transport and erosion which are evident when examining data such as photogrammetry in detail.

It is important to document the history of storms along the Nambucca Shire coastline in order to ascertain whether the observed beach changes can be related to the specific occurrence of these storms. The ultimate goal is to delineate which observed changes are caused by episodic events such as large coastal storms and which changes have underlying causes which are due to long-term cycles, natural fluctuations or are caused by anthropogenic influences.

The drop in atmospheric pressure and the winds and waves which often accompany large coastal storms can cause the ocean to rise above its normal level and if this occurs concurrently with high astronomical tides, flooding of low-lying coastal land and beach erosion can result (Blain Bremner & Williams, 1985).

Storms which affect the NSW coast can fall under one of several categories – namely:

- Tropical Cyclones
- Easterly Trough Lows
- Inland Trough Lows
- Continental Lows
- Secondary Lows; and
- Anticyclonic Intensifications.

The majority of storms on the North and mid-North coasts are due to locally formed Easterly Trough Lows and tropical cyclones (NSW Government, 1990).

Blain Bremner and Williams (1985) documented all storms along the NSW coast between 1880 and 1980, with estimates of *significant* wave height made by examining synoptic charts from these dates, as well as historical shipping and press reports. Storms were assigned a severity rating based on a gradation of the *significant* wave heights. The storms were compartmentalised in terms of their severity and their location along the coast, whether they affected the far north coast, mid north coast, central coast or south coast. Nambucca Heads is considered to be affected by storms impacting on the north coast sector of NSW.

The categories of storms are illustrated in Table 2.3.

Further work was carried out by Lawson and Treloar (1986) expanding on the work of Blain Bremner and Williams to identify storms occurring between 1980 and 1985, using a combination of synoptic charts and Waverider buoy data.

Category X storms since 1985 were identified by examining Coffs Harbour and Crowdy Head Waverider buoy records from 1985 – 2007 obtained from the Department of Commerce Manly Hydraulics Laboratory. A representative *significant* wave height at Nambucca Heads was estimated from the combination of this data, and this enabled Category X storms (Hs > 6.0m) to be identified for the period from 1940 – 2007.

**Table 2.3 – Classification of Storms by Intensity**

**(Blain Bremner and Williams, 1985)**

| Category | Significant Wave Height (m) | Severity |
|---|---|---|
| X | > 6.0 m | Extreme |
| A | 5.0 m – 6.0 m | Severe |
| B | 3.5 m – 5.0 m | Moderate |
| C | 2.5 m – 3.5 m | Low |

Category A, B and C storms (*i.e. significant* offshore wave heights less than 6.0m) were not included in the analysis.

Figure 2.13 documents the extreme storm events and estimated *significant* wave heights for these events, and also plots the dates for which beach photogrammetry was available for analysis. Of particular note in the data is the occurrence of a major storm in June 1967 which caused severe erosion along the North Coast of NSW and had a peak *significant* wave height of around 10m. The synoptic chart for this storm is shown in Figure 2.14 (Bureau of Meteorology, 2008). The closely spaced isobars on the chart indicate strong wind speeds along the north coast of NSW. Other notable storms that may have caused beach erosion at Nambucca Heads occurred in 1942, 1954, 1974 and 1995.

Several cyclones affected the north coast of NSW during the 1970's, with cyclone Zoe coming within 200km from the study area in March 1974 with a central pressure of approximately 986hPa.

The storms of May-June 1974 caused widespread damage to coastal structures and beaches along the central coast of New South Wales (Foster *et al.,* 1975). These storms were associated with an intense low pressure cell adjacent to the coast near Sydney. Moreover, the 1974 storm event was coincident with maximum spring tides, with a maximum storm surge measured at Fort Denison of 0.59 m and a maximum ocean water level of 1.48 m on AHD (Kulmar and Nalty, 1997).

Following the storms of the 1970's, the region enjoyed a period of relatively low storm activity, and the beaches of the Nambucca were in fairly good condition at the time of SMEC's site visit in December 2008. However, an East Coast Low occurred in late May 2009, causing significant beach erosion at the beaches of Nambucca Heads. Loss of mature trees at Little Beach, Scotts Head and damage to the seawall at Main Beach was evident as a result of this storm, as documented in Figure 2.15.

The offshore swell wave climate (wave height, period and direction occurrences) has been recorded by the NSW Government Manly Hydraulics Laboratory with Waverider buoys located at Sydney, Crowdy Head and Coffs Harbour for many years. The Waverider buoy located at Sydney has measured also wave direction since 1992.

Summary wave statistics are available from the Manly Hydraulics Laboratory (*e.g.*, as published in Lord and Kulmar, 2000). The wave data show that the predominant swell wave direction is south-southeast (SSE) with over 70% of swell wave occurrences directed from the SSE quadrant. The average deep water *significant* wave height, as measured at Crowdy Head, is around 1.6 m (Figure 2.16) and the average wave period is around 10 s (Kulmar *et al.* 2005). Analysis of storms recorded at Coffs Harbour and Crowdy Head has provided wave height/duration data for various annual recurrence intervals.

Some large storms occurred during the period between 1973 and 1980, as shown in Figure 2.13. Several cyclones affected the north coast of NSW during the 1970's, with cyclone Zoe coming within 200km from the study area in March 1974 with a central pressure of approximately 986hPa.

Another significant storm was due to tropical cyclone VIOLET which occurred in March 1995. This cyclone lasted five days and had a central pressure of approximately 980hPa with wind speeds of around 54 knots, when it was less than 200 kilometres offshore from Scotts Head. The significant wave height reached 7.4 m during this period. Tropical cyclone NANCY came as close as 75km offshore from Valla Beach around the 3rd of February 1990 with a central pressure of 986 hPa and caused severe erosion along Valla Beach with a peak *significant* wave height of 6.7 m. At its closest point, Cyclone Nancy tracked to within 80 km of Valla Beach. The cyclone track is shown in Figure 2.17 (Bureau of Meteorology, 2008). Other notable storms that may have caused beach erosion at Valla Beach occurred in 1942, 1954, 1967 and 1995.

Some of the largest coastal storm events to have occurred in NSW included the storms of May-June 1974 whose impacts were greatest felt on the NSW central coast. The storms of May-June 1974 caused widespread damage to coastal structures and beaches along the central coast of New South Wales (Foster *et al.,* 1975). These storms were associated with an intense low pressure cell adjacent to the coast near Sydney. Because nearshore waves causing dune erosion are depth-limited, wave duration of moderate wave heights becomes a more important factor for dune erosion than peak offshore wave heights of short duration. It was the long duration of moderately high waves that made this particular 1974 storm so destructive. The 1974 storm event was coincident with maximum spring tides, with a maximum storm surge measured at Fort Denison of 0.59 m and a maximum ocean water level of 1.48 m on AHD (Kulmar and Nalty, 1997).

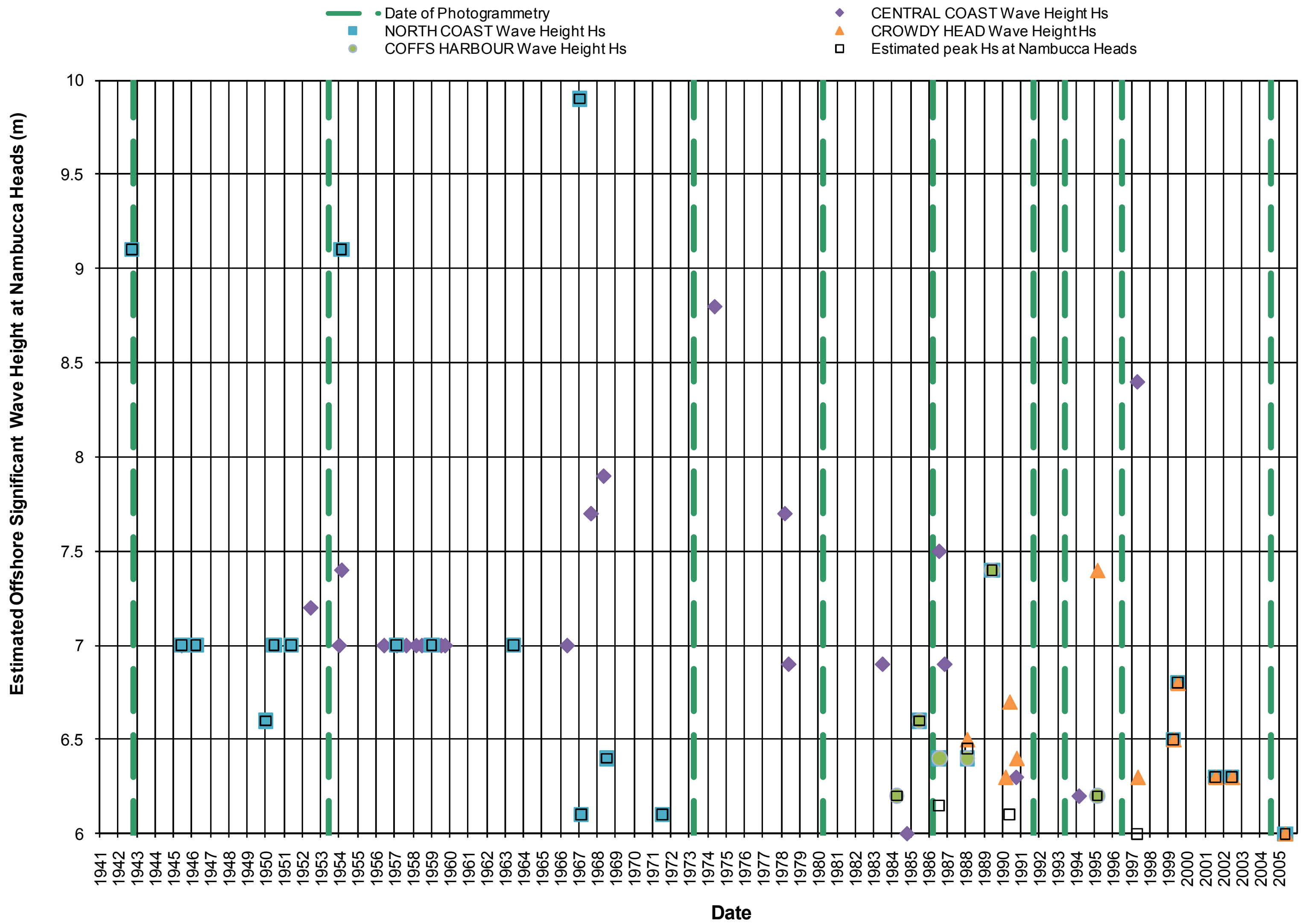



**Figure 2.13** – Extreme Storm events vs. Photogrammetry Dates

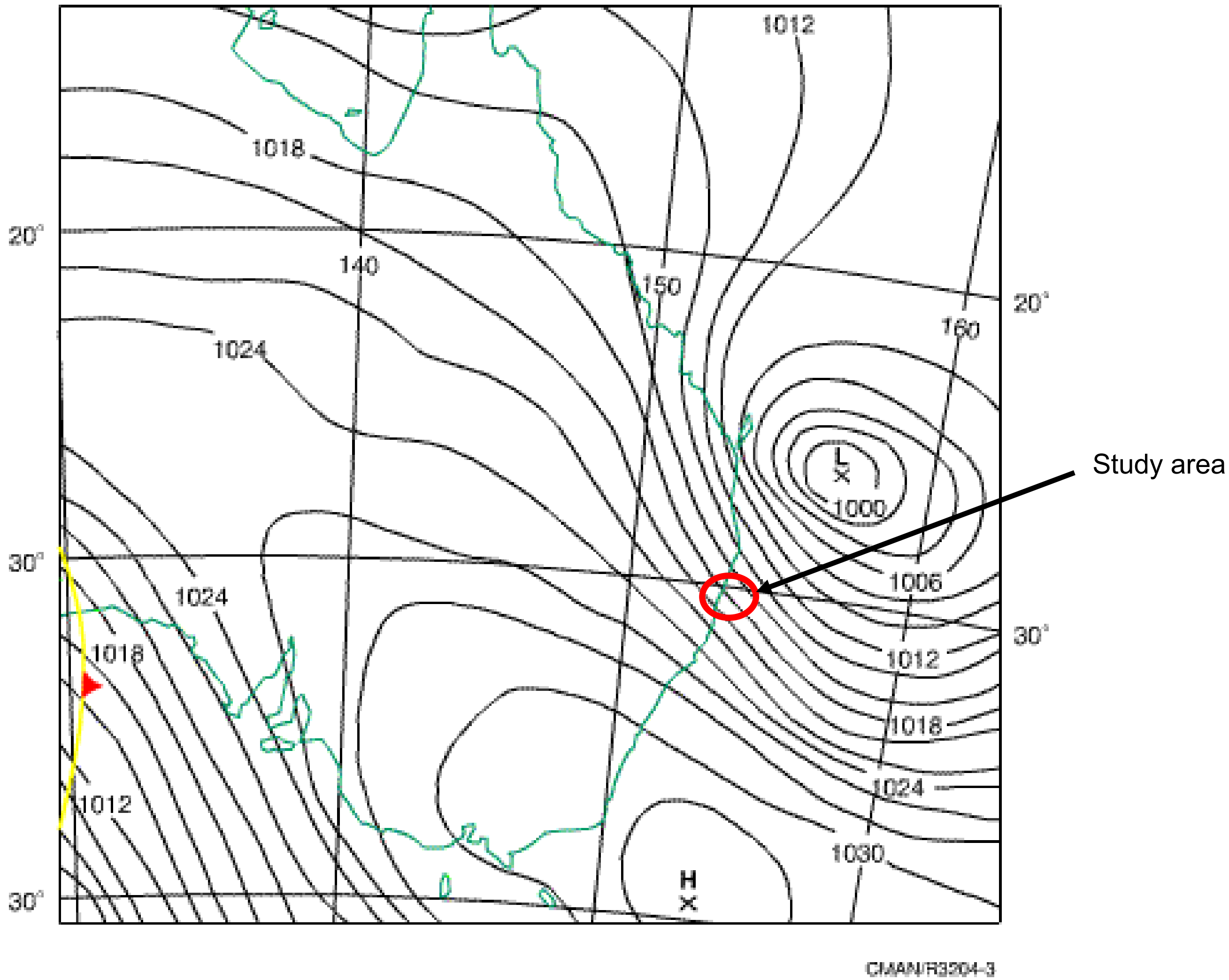
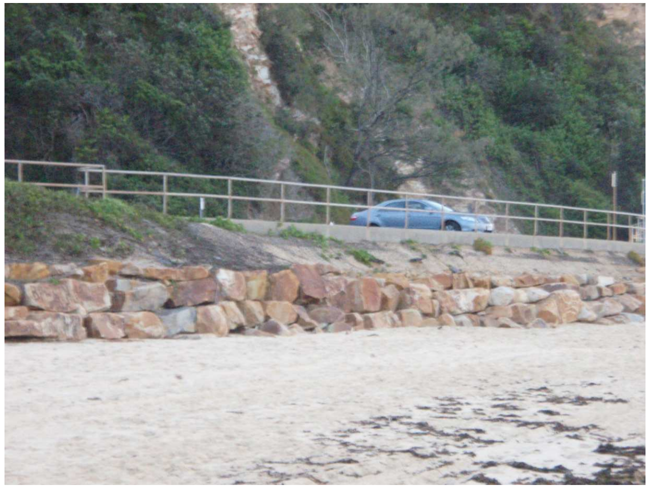



**Figure 2.14** - Synoptic Chart from the coastal storms of June 1967 (from Bureau of Meteorology, 2008).

Little Beach, Scotts Head December 2008

Little Beach, Scotts Head May 28 2009



Carpark seawall, Main Beach October 2008

Carpark seawall, Main Beach May 28 2009

**Figure 2.15** – Storm erosion and damage caused by East Coast Low, May 2009

These storm events had varying impacts on the beaches within Nambucca Shire, depending on the angle of approach of the storm waves and the state of the beaches prior to the storm. Depending on the dates of the available photogrammetry data, the signature of some of these storms could sometimes be seen more strongly for some beaches than for others. Where the effects of storm erosion were apparent from the photogrammetry and it could be attributed to a particular large storm event, that storm event was adopted as the design storm event for various parts of the Nambucca Shire coastline.

A significant storm event has also occurred along the NSW north coast in late May 2009. This event was the result of a complex East Coast Low pressure system which developed off the Queensland border. This system brought widespread rain and flooding to the mid north coast, as well as significant beach erosion to Nambucca's beaches. Significant wave heights as a result of this storm peaked at 6.4 m at Coffs Harbour at 10am on 23 May 2009 (Callaghan, 2009). Figure 2.18 provides a synoptic chart from the East Coast Low of May 2009.

Such storms, which occur along the NSW coastline at irregular intervals, are responsible for episodic events of sand transport and erosion, which are evident when examining photogrammetric data.

This study draws upon storm histories developed from synoptic charts, as well as historical data from the NSW Government Waverider buoys, to determine the dates and severity of the extreme storm events that have occurred over the period of the photogrammetry.

### 2.5.3 Extreme Water Levels

During storms, the ocean water level and that at the shoreline is elevated above the normal tide level. While these higher levels are infrequent and last only for short periods, they may exacerbate any storm damage on the foreshore. Elevated water levels allow larger waves to cross the offshore sand bars and reefs and break at higher levels on the beach. Further, they may cause flooding of low lying areas and increase tail water control levels for river flood discharges.

The components of these elevated water levels comprise the astronomical tide, barometric water level setup, wind setup, wave setup and runup (Figure 2.19). All of the components do not act or occur necessarily independently of each other but their coincidence and degree of inter-dependence, generally, is not well understood.

The tides of the NSW coast are semidiurnal with a diurnal inequality. This means that there are two high tides and two low tides each day and there is a once-daily inequality in the tidal range. The mean tidal range is around one metre and the tidal period is around 12.5 hours. Tides vary according to the phases of the moon. The higher spring tides occur near and around the time of new or full moon and rise highest and fall lowest from the mean sea level. The average spring tidal range is 1.3 meters and the maximum range reaches two meters. Neap tides occur near the time of the first and third quarters of the moon and have an average range of around 0.8 meters.

Storm surge is the increase in water level above that of the normal tide that results from the low barometric pressures, which are associated with severe storms and cause sea level to rise, and strong onshore winds that pile water up against the coast. Measured values of storm surge at Sydney include 0.59 m for the extreme storm event of 25–26 May 1974 and 0.54 m for the extreme storm event of 31 May – 2 June 1978, which were computed to have recurrence intervals of 77 and 39 years respectively (Haradasa *et al.*, 1991). Both of these extreme events were coincident with spring high tides with the water level in the 1974 event reaching the maximum recorded at Fort Denison of 1.48 m AHD. Return periods for ocean water levels comprising tidal stage and storm surge for Sydney, which are representative of the study region, are presented in Figure 2.20.

## 2.6 Tsunami

A tsunami is a series of ocean waves generated by a sudden displacement of large volumes of water (Gissing *et al.* 2007). Tsunami may be caused by vertical movement of the sea floor as a result of large earthquakes, or by submarine volcanic eruptions, meteor impacts, or coastal landslides.

Several small tsunami have been recorded on the coast of NSW, the largest occurring in 1868, 1877 and 1960. A tsunami generated by an earthquake in the Solomon Islands in April 2007 resulted in strong currents being measured at Coffs Harbour.

At present, no detailed tsunami hazard assessments have been carried out to assess which areas would be subject to the greatest hazard. The State Emergency Service, NSW Department of Environment, Climate Change and Water and Geoscience Australia have entered into a partnership to manage a tsunami risk assessment scoping study for the NSW coastline. This study will identify tsunami sources, summarise NSW tsunami history, estimate travel times for tsunami sources, assess coastal vulnerability and assess tsunami inundation through modelling.

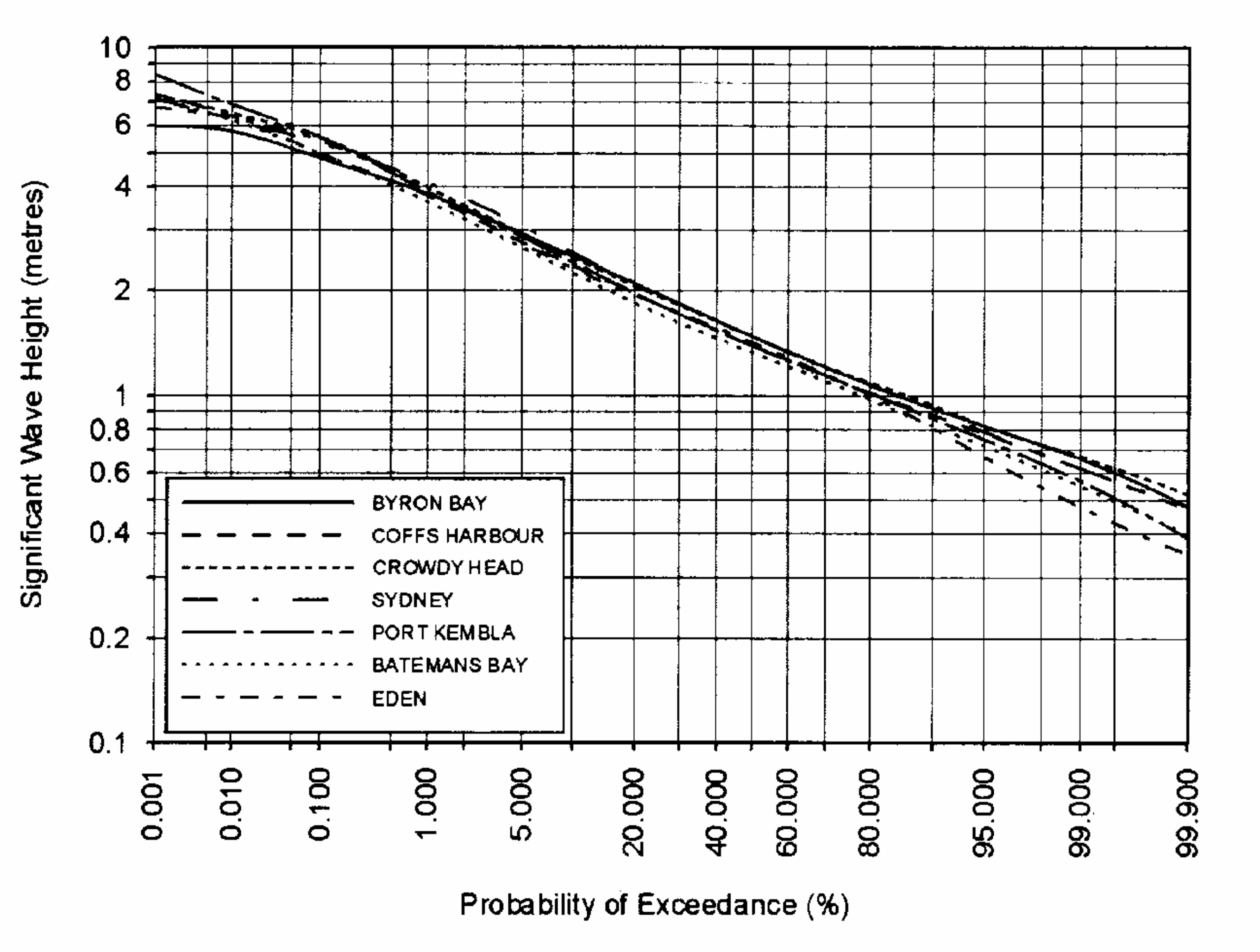
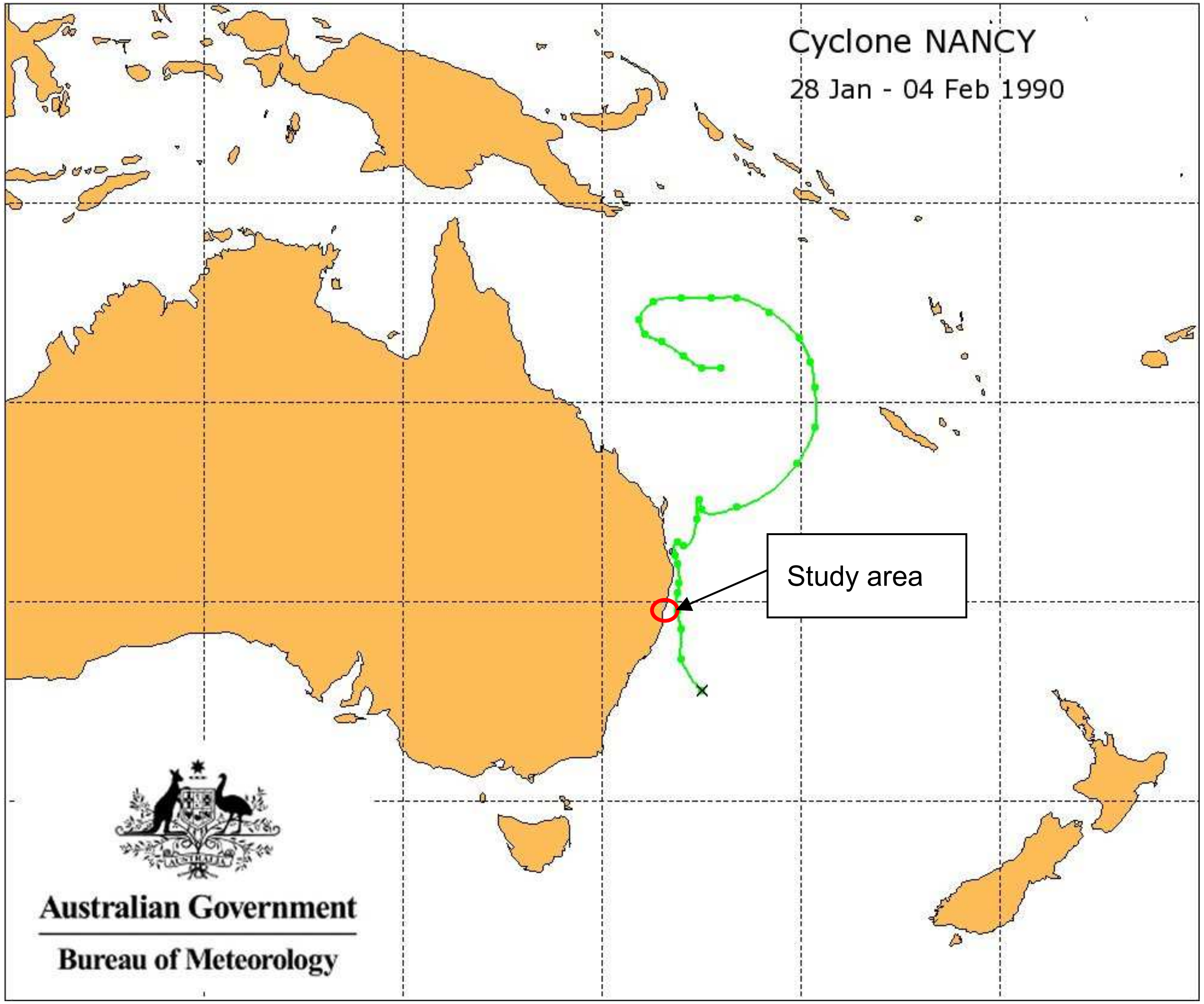



**Figure 2.16 -** Significant wave height exceedance for NSW coast (Lord & Kulmar, 2000)




| Date time (UTC) | Latitude (°S) | Longitude (°E) | Central pressure (hPa) | Wind speed (knots) |
|---|---|---|---|---|
| 28 Jan 1990 06:00 | 18.3 | 156.0 | 1000 | 11.7 |
| 28 Jan 1990 12:00 | 18.3 | 155.0 | 1000 | 11.7 |
| 28 Jan 1990 18:00 | 17.7 | 154.1 | 999 | 19.4 |
| 29 Jan 1990 00:00 | 17.0 | 153.0 | 998 | 29.2 |
| 29 Jan 1990 06:00 | 16.6 | 152.2 | 995 | 33 |
| 29 Jan 1990 12:00 | 15.9 | 151.9 | 995 | 33 |
| 29 Jan 1990 18:00 | 15.0 | 152.6 | 995 | 33 |
| 30 Jan 1990 00:00 | 14.8 | 154.0 | 995 | 33 |
| 30 Jan 1990 06:00 | 14.8 | 155.5 | 995 | 35 |
| 30 Jan 1990 12:00 | 14.8 | 156.8 | 991 | 36.9 |
| 30 Jan 1990 18:00 | 15.5 | 158.4 | 991 | 36.9 |
| 31 Jan 1990 00:00 | 16.8 | 159.9 | 990 | 40.8 |
| 31 Jan 1990 06:00 | 18.0 | 160.5 | 988 | 42.8 |
| 31 Jan 1990 12:00 | 19.3 | 160.7 | 988 | 46.7 |
| 31 Jan 1990 18:00 | 21.3 | 160.7 | 980 | 48.6 |
| 01 Feb 1990 00:00 | 23.1 | 159.8 | 980 | 50.5 |
| 01 Feb 1990 06:00 | 25.3 | 156.8 | 975 | 54.4 |
| 01 Feb 1990 12:00 | 25.4 | 155.0 | 980 | 48.6 |
| 01 Feb 1990 18:00 | 24.9 | 154.9 | 985 | 42.8 |
| 02 Feb 1990 00:00 | 25.9 | 154.8 | 985 | 42.8 |
| 02 Feb 1990 06:00 | 27.2 | 154.1 | 980 | 40.8 |
| 02 Feb 1990 12:00 | 27.0 | 153.8 | 980 | 40.8 |
| 02 Feb 1990 18:00 | 27.7 | 153.7 | 980 | 36.9 |
| 03 Feb 1990 00:00 | 28.1 | 153.8 | 980 | 36.9 |
| 03 Feb 1990 06:00 | 29.1 | 153.9 | 980 | 35 |
| 03 Feb 1990 12:00 | 29.6 | 153.8 | 985 | 33 |
| 03 Feb 1990 18:00 | 30.5 | 153.8 | 986 | 29.2 |
| 04 Feb 1990 00:00 | 31.4 | 154.0 | 989 | 27.2 |
| 04 Feb 1990 06:00 | 32.9 | 154.0 | 990 | 21.4 |
| 04 Feb 1990 12:00 | 34.5 | 155.0 | 995 | 15.6 |

**Figure 2.17** - Cyclone NANCY details - Cyclone NANCY track

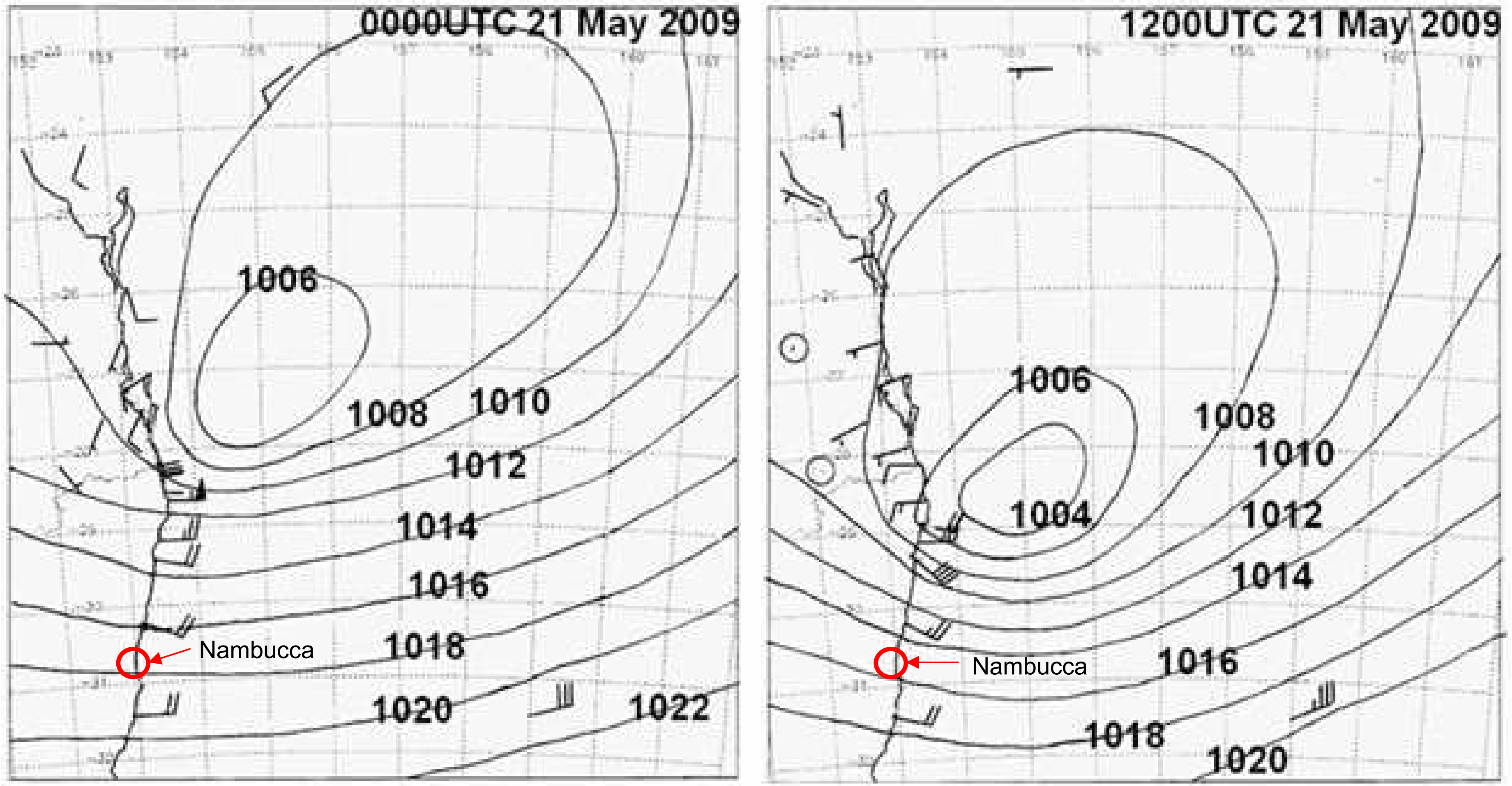



**Figure 2.18 –** Synoptic Charts from East Coast Low, May 2009 (Callaghan, 2009)

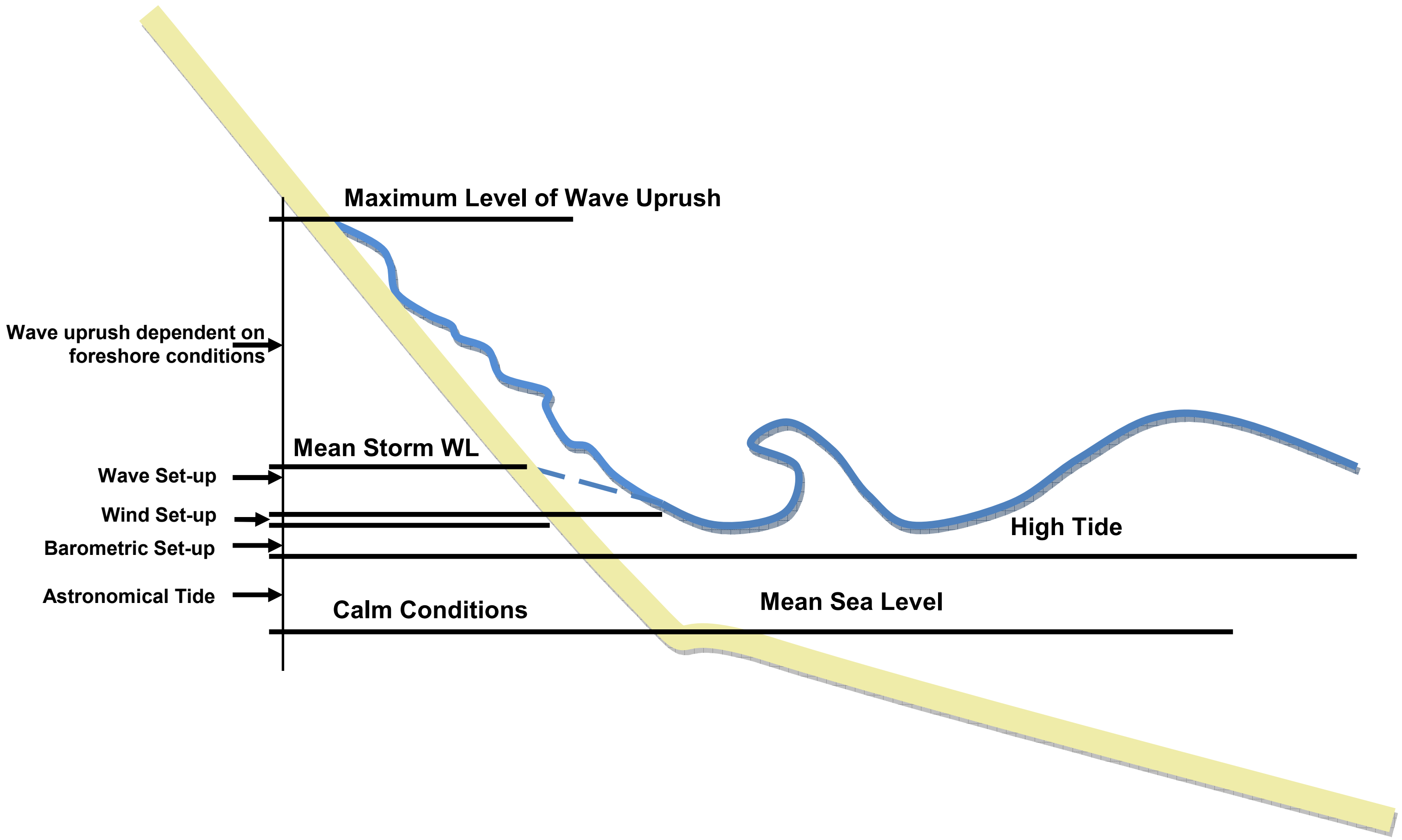



**Figure 2.19** - Components of elevated water levels on the coast (adapted from NSW Government, 1990)

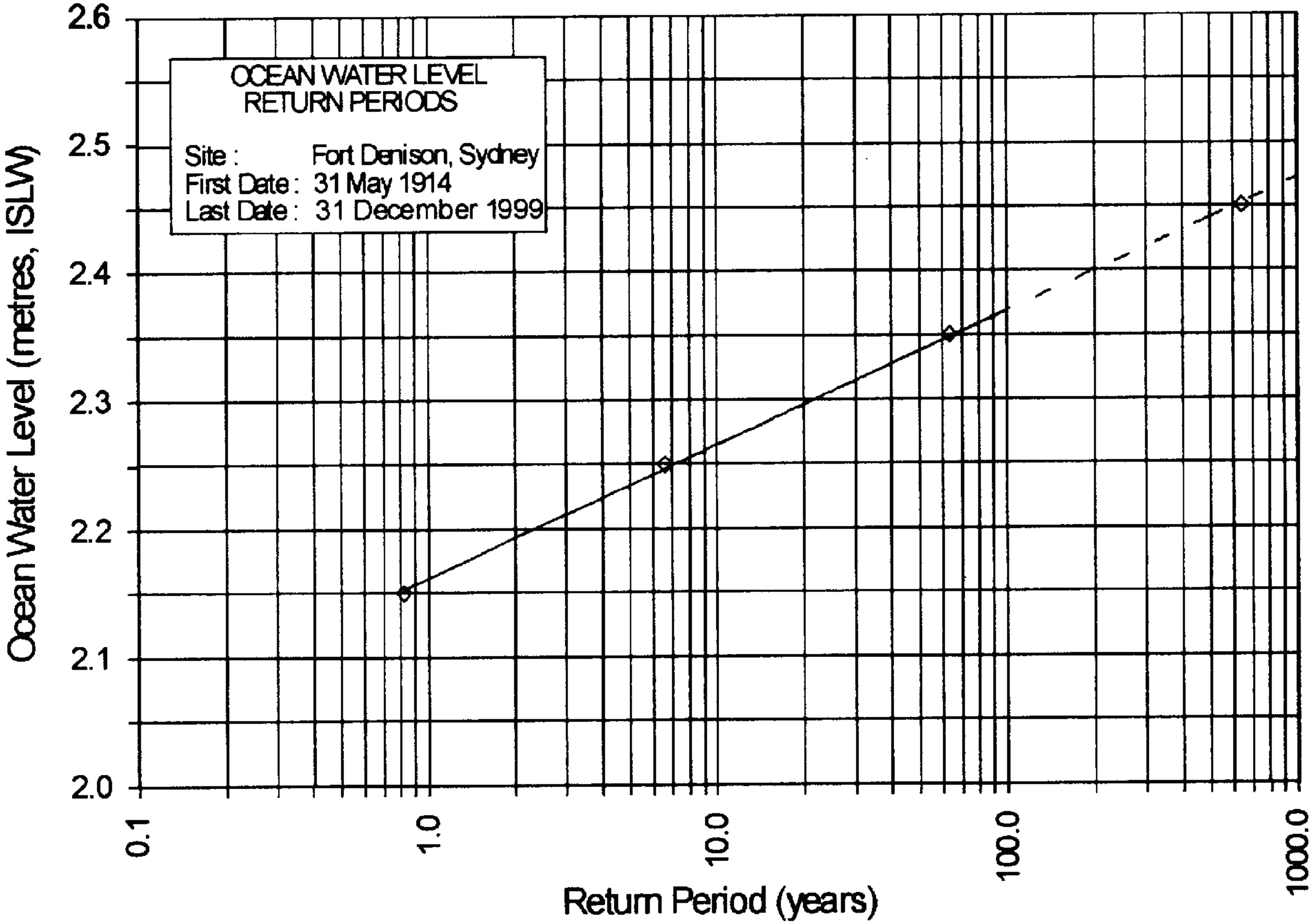



**Figure 2.20** - Sydney ocean level recurrence (Lord & Kulmar, 2000)

# 3 Site Observations

## 3.1 Site observations

In addition to the assessment of coastal hazards by analysis of the available photogrammetric data, site observations were made about the different beaches and characteristic places around Scotts Head, Nambucca Heads and Valla Beach. A site visit was conducted by SMEC's project team in December 2008. Notes from that site visit are provided below. Further site observations following the storm event of May 2009 are also provided for some locations.

## 3.2 Scotts Head

### 3.2.1 Little Beach

As described in the name, Little Beach is a small beach that extends approximately 300 metres in length and 100 metres in breadth, and is relatively well protected by two headlands with rock platforms that extend out to sea. Little Beach is north-east facing and appears stable with a well formed foredune and backdune. The dunes are stabilised by vegetation that becomes increasingly dense as it progress landward, ranging from sparse grasses (seaward) to bushes and trees (landward).

Little Beach suffered from significant erosion in the May 2009 storm event, with a significant storm cut and loss of mature vegetation, as shown in Figure 2.15.

### 3.2.2 Scotts Head SLSC, Stormwater Drain & Carpark

The SLSC is located directly behind the headland that separates Little Beach and Forster Beach (Figure 3.1). From what could be seen, the building appeared to be founded on a concrete slab with a low lying retaining wall placed several metres in front of the building facing towards Little Beach. The retaining wall was approximately 0.3m high and constructed from two planks of timber. In the history of the building, it has reportedly never been inundated from tidal flows or wave action resulting from severe storm events, although in the late 1990's there was a storm event which produced a large quantity of sea foam which flowed all the way up to the SLSC building.

The stormwater drain (Figure 3.2) is located north west of the SLSC building and is hidden underneath a wooden foot ramp which leads onto Forster Beach. While no erosion issues were observed with the design of the stormwater outlet, other issues included the invert being designed and constructed too low, which made it susceptible to sand filling and backwashing from tidal flow. The stormwater drain can sometimes create an incised morphology over the beach berm which can lead to loss of sand from the beach berm and scour along the toe of the seawall along the SLSC carpark. The incised morphology can lead to additional wave energy reaching the timber foot ramp and seawall. Outflow from the stormwater drain may at times trigger formation of a rip cell along the seawall, further increasing the beach berm erosion in this area.

A study of the regional drainage catchment leading to this stormwater outlet may be warranted, to define volumes and peak discharges for the stormwater drain. This would allow various options to be investigated which would reduce the stormwater erosion hazard at this outlet and allow the stormwater system to function more effectively. Such options could include:

- Stormwater detention within the upstream catchment to prevent flooding within the catchment area when the existing stormwater outlet is blocked with sand
- Diversion of stormwater into adjacent catchment areas to prevent erosion and the formation of a rip cell at this location
- Construction of a dissipation structure at the stormwater outlet or minor stabilisation works.

The state of Forster Beach was similar to that of Little Beach, whereby the dunal and beach system was observed to be stable with well developed foredunes and backdunes that were well vegetated. However, there was some evidence of dune erosion with exposure of tree roots evident within the foredune (Figure 3.3). The stability of the beach system has enabled the dune to be fenced off, and well constructed beach access ways to be provided.

Adjacent to the SLSC building, two carparks located on the north western face of the headland facing Forster Beach, were protected from wave action by a rock revetment. The first carpark, located further away from the SLSC building, was significantly more exposed to wave action although it had a relatively well constructed rock revetment with a heavy grade geotextile and rock diameters of 1.5 to 2 metres protecting it; this was constructed 8 years ago and is still in a relatively healthy state (Figure 3.4). The second carpark was located adjacent to the wooden foot ramp with a smaller seawall extending from the Forster Beach boat ramp to the stormwater drain. The seawall was made up of smaller armour stones ranging from 1 to 1.5 metres and appeared to be less well maintained with several rocks having been displaced from their original positions; in some areas, grouting that had been poured on top of the rock armour in an attempt to fix the rocks in place had broken up as rocks were loosened and dislodged (Figure 3.5).

It is suggested that the seawalls be reconstructed at the carpark to provide better protection against storm erosion. As the existing armour stones appear to be of sufficient size and quality to withstand the wave climate experienced at the site, they may be able to be re-used in the reconstruction. The carpark would be overtopped by storm waves, though the paving of the carpark would help prevent failure of the seawall due to overtopping. Construction of the wall at a slope of around 1:1.5 would assist in absorption of wave energy, and provision of a geotextile layer would prevent loss of fine sediment through the primary armour of the wall.

A typical concept design for reconstruction of the existing seawall is provided in Figure 3.6.

**Figure 3.1** – Scotts Head SLSC
Top – looking from Forster Beach, with car park and seawall in foreground
Bottom – rear of building as seen from Little Beach

**Figure 3.2** – Stormwater drain adjacent to carpark, southern end Forster Beach

**Figure 3.3** – Dune erosion, southern end Forster Beach

### 3.2.3 Scotts Head Caravan Park, Bowling Club & Christian Youth Centre

These facilities are situated directly behind the back dune of Forster Beach. While parts of the caravan park is expected to be impacted by coastal hazards with 50 years, the Bowling Club and Christian Youth centre are generally landward of the expected reach of the coastal hazards within the next 50 – 100 years. As the dune in front of these areas is well vegetated, it is considered stable and protected from wind erosion. Some of these areas are quite low in elevation, and could be affected by wave inundation after 2100 if the main dune were to completely erode as a result of future climate change.

The Scotts Head Sewage Treatment Plant was also inspected – this plant is located a long distance from the main beach and is also beyond the reach of coastal hazards within the next 100 years. 4WD access is provided to the beach within close proximity to the Sewage Treatment works.

**Figure 3.4** – Seawall adjacent to surf club, Forster Beach

**Figure 3.5** – Poorly built section of seawall, Scotts Head surf club

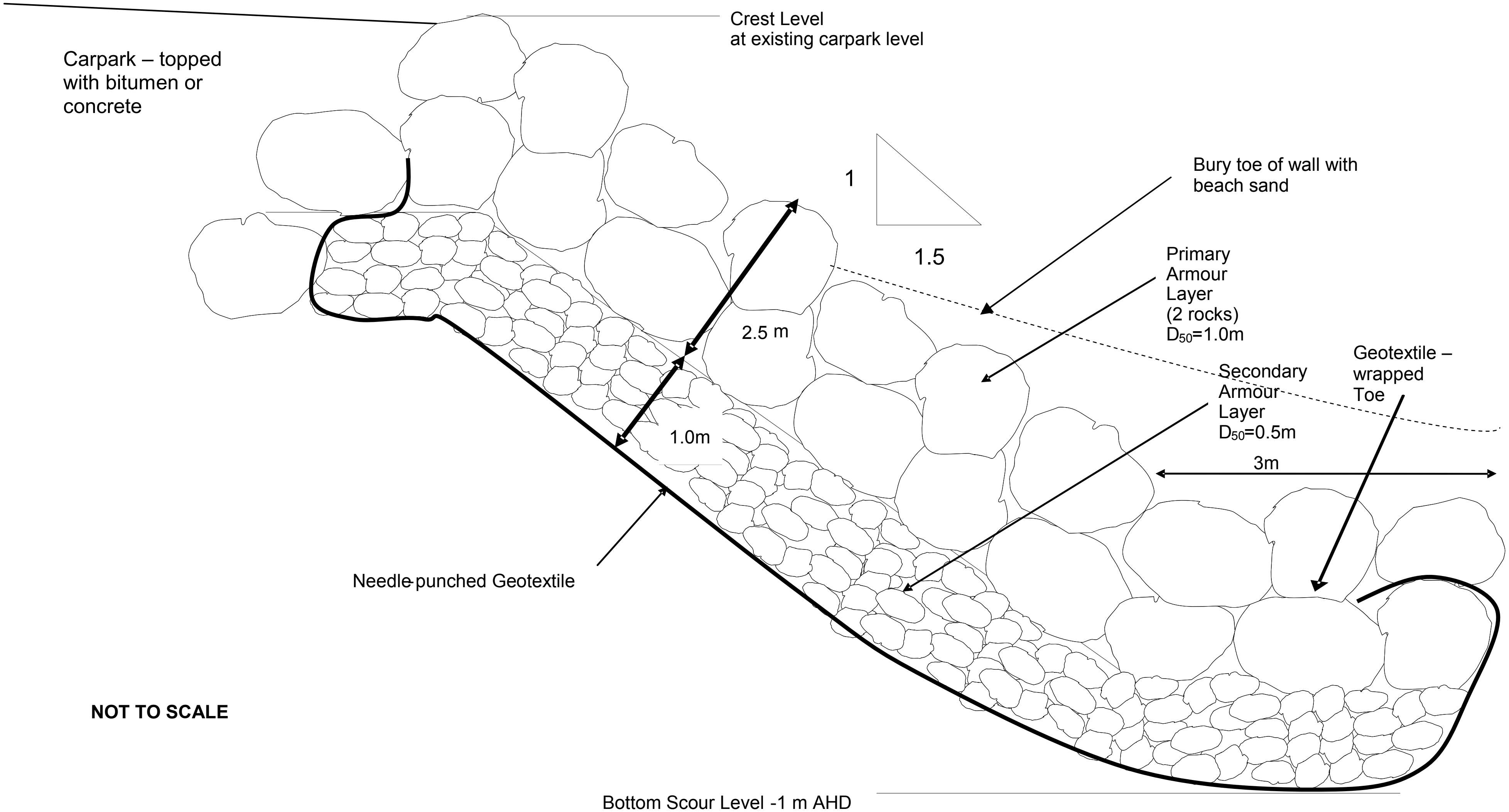



**Figure 3.6** – Typical seawall reconstruction design for open coast beaches within Nambucca Shire

## 3.3 Nambucca Heads

### 3.3.1 Seawall & V-wall

The seawall extends along the northern side of the lower estuary and follows through to the mouth of the estuary opening; these training walls were constructed from 1895 and 1918 (WBM Oceanics, 2004). A breach in the seawall, west of the vee-wall, is suspected to have resulted from the 1974 storm event (Figure 3.7).

### 3.3.2 Bellwood Park

Bellwood Park is located north east of Stuart Island, further upstream from the estuary mouth. This is a popular recreational park for families. There is evidence of a small seawall that previously surrounded the boundary edge of the park; however it has since been displaced and overtopped with some sections having rocks being sparsely dispersed, while other sections show signs of back scouring resulting from wave overtopping (Figure 3.8). No geotextile was seen to have been implemented to prevent fine sediment loss. The park may be vulnerable to inundation in king tides or large storms. In addition, when the river entrance is open, ocean waves can penetrate the river entrance, causing erosion of the small beach and picnic area.

Due to the popularity of this site, possible upgrades may include the reconstruction of a retaining wall along the boundary of the park where it could be impacted by wave action or tidal flows. Armour rock ranging from 0.3-0.5 m diameter may be used to construct the wall, underlain by a geotextile to prevent sediment loss. The wall should be high enough to prevent overtopping that could result to back scouring the undermining of the wall's structural integrity. Rock from the existing wall may be able to be utilised in the retaining wall's reconstruction.

A typical concept design for such a wall is given in Figure 3.9.

### 3.3.3 Shelly Beach

Shelly Beach is located on the northern side of the headland, north of the retaining wall and the estuary opening. It appears to be a relatively stable beach with the main assets being a parking lot and amenities block situated at the southern end of the beach. A boat ramp leading onto the beach is flanked by a seawall extending along the face of the carpark which decreases in height from approximately 2 metres to 0.5 metres northward. The wall is constructed as a near vertical face and from cube-shaped rocks approximately 0.5 – 1m in width (Figure 3.10). It was noted that the wall does not appear to have a geotextile lining to withhold fine sediment loss. A small scarp is evident at the foot of the foredune north of the boat ramp, possibly due to wave action from a previous storm event, although some light vegetation provides some form of stabilization. All access walkways to the beach have been fenced off on either side of the pathways.

**Figure 3.7 –** Gap in the northern breakwall, Nambucca Heads

**Figure 3.8 –** Remnants of seawall, Bellwood Park

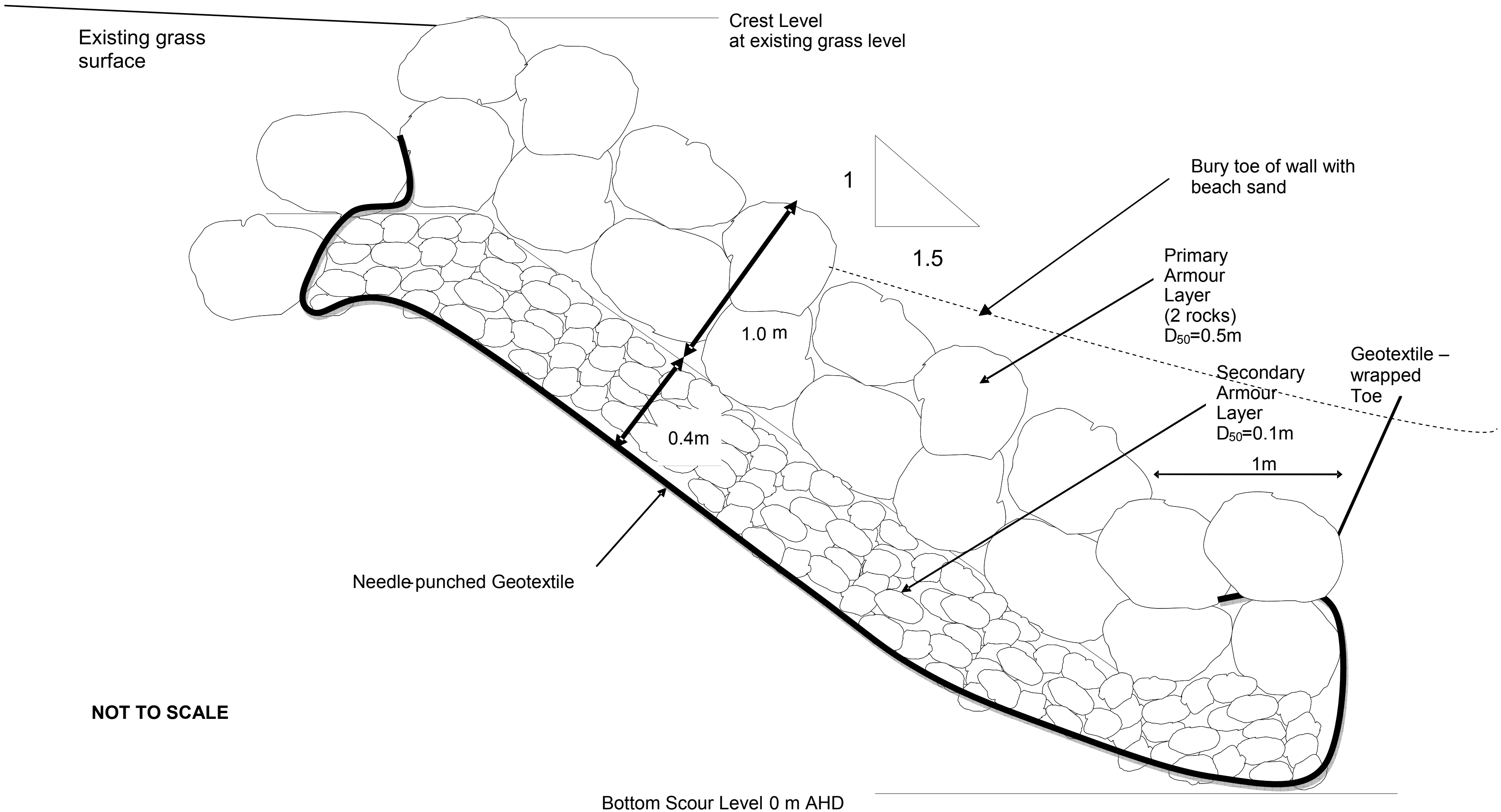



**Figure 3.9 – Potential seawall reconstruction design, Bellwood Park**

**Figure 3.10 –** Seawall and boat ramp, Shelly Beach

### 3.3.4 Beilby's Beach

Beilby's Beach is a northward extension of Shelly Beach and is also a relatively stable coastal system. The dune is high and steep here, with the foot of the seaward facing side of the foredune having a steep scarp approximately 1.5-2 metres high, although this too is covered in light vegetation. Along a section of the foredune at Beilby's Beach, a carpark is located at the top of the foredune with no edge protection. There has been some erosion evident here, possibly due to runoff over the edge of the road from the sloping ground behind (Figure 3.11). In some areas directly below the carpark, the vegetation has thinned and the dune suffers from wind erosion and destabilization.

### 3.3.5 Main Beach SLSC

Further north is Main Beach, separated from Beilbys and Shelly beaches by a small headland. The SLSC building is nestled in the southern end of the beach and is located in relatively close proximity to the swash zone. Some construction works have been carried out in placing concrete slabs at the foot of the foredune and in front of the SLSC building, which protrude approximately 0.3m out of the sand, to act as a retaining wall against wave run up in storm events. In some instances, the concrete blocks have been displaced, toppled or have been overgrown with grass or weeds. In severe storm events, the SLSC may be vulnerable to inundation on the ground floor. The carpark located north of the SLSC building is somewhat protected by a small seawall that extends along its base, rising to 3 rocks high in most places. A deficit in the seawall height results in a slight embankment between the top of the seawall and the base of the carpark, which is sparsely vegetated by weeds or grass. This seawall suffered damage in the storm event of May 2009, as illustrated in Figure 3.12. This beach was also observed to be a stable beach system.

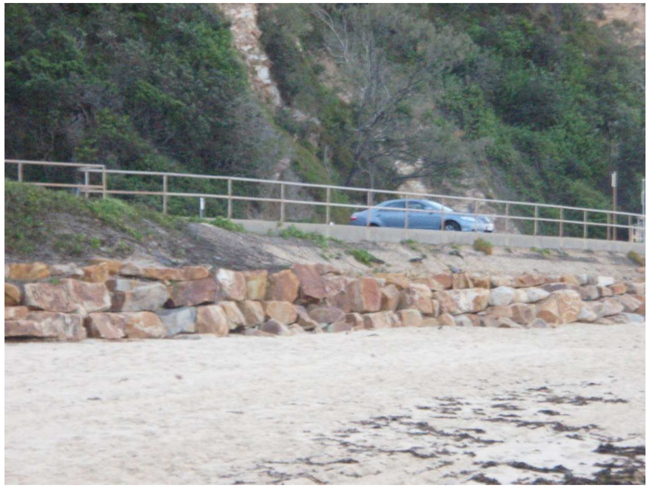
Upgrades may include the overhaul of the current concrete blocks used as a retaining wall and instead complete the reconstruction and development of a more substantial retaining wall if inundation from wave action is an issue. Stability of the existing seawall would be improved if it was constructed on a flatter slope (less than 1:1.5) and is backed by a geotextile layer to prevent fine material washing through the wall. Such a wall can follow the standard design schematic of Figure 3.6, but the armour size and dimensions would need to be larger and would need to be subject to detailed design. Rock from the existing wall may be able to be used in the seawall's reconstruction if necessary.

### 3.3.6 Swimming Creek & Nambucca Caravan Park

Swimming Creek has very low flows and remains largely stagnant for the majority of the year. In June 2008, the creek entrance required opening to lower water levels so that work could be done on the sewage pipes located near the caravan park. A small retaining wall built with small rocks (0.1-0.4m in diameter) has been placed on the southern side of the creek entrance that leads onto the beach (Figure 3.13). This retaining wall suffered damage during the East Coast Low of May 2009 (Figure 3.13).

The creek entrance is relatively small and does not have a major impact on beach stability.

**Figure 3.11 –** Erosion at Beilbys Beach carpark



Carpark seawall, Main Beach October 2008

Carpark seawall, Main Beach May 28 2009

Main Beach looking south, surf club in background

Main Beach surf club with concrete retaining wall in foreground

**Figure 3.12** – Main Beach

**Figure 3.13** – Swimming Creek – Top December 2008, Bottom July 2009