Coastal Hazard Study - Lot 1 DP 374315 & Lot 4 DP 615261 Ocean Drive Lake Cathie

For: King & Campbell Pty Ltd

MARCH 2010

Project Name:	Coastal Hazard Study - Ocean Drive Lake Cathie
Project Number:	3001718.003
Report for:	King & Campbell Pty Ltd

PREPARATION, REVIEW AND AUTHORISATION

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3 (FINAL)	22/3/10	C. Adamantidis M. Glatz L. Yeung	C. Adamantidis	C. Adamantidis

ISSUE REGISTER

Distribution List	Date Issued	Number of Copies
King & Campbell Pty Ltd:	22/3/10	1 (S)
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FOREWORD

As part of a Part 3A Environmental Assessment for the development of Lot 1 DP 374315 and Lot 4 DP 615261 Ocean Drive in Lake Cathie, King & Campbell Pty Ltd has commissioned SMEC Australia to prepare a Coastal Hazard Study in accordance with Section 6.1 of the Director General's Environmental Assessment Requirements. This report documents the technical studies undertaken for this project in addressing coastal hazards and the provisions in the NSW Government Coastline Management Manual, in particular considering the impacts associated with wave and wind action, coastal erosion, climate change, sea level rise and more frequent and intense storms.

Using a combination of worst-case scenario assessment parameters, it was found that there would be no impact on the proposed development as a result of coastal hazards, as the proposed development is located landward of the coastal hazard zones over a 100 year planning period.

REFERENCE

Glatz, M., Adamantidis, C., and Yeung, L. (2010). "Ocean Drive Lake Cathie Coastal Hazard Study", Report No. 3001718-003 prepared by SMEC Australia for King & Campbell Pty Ltd, March 2010.

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GLOSSARY

Accretion	The accumulation of (beach) sediment, deposited by natural fluid flow processes.
ACES	A computer program, developed by the US Army Corps of Engineers, that is used to determine, 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. (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
Inshore	(1) The region where waves are transformed by interaction with the sea bed. (2) In beach terminology, the zone of variable width extending from the low water line through the breaker zone.

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. (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.
SBEACH	A computer program, developed by the US Army Corps of Engineers, that is used to determine, among other things, wave transformation across the surf zone, beach and dune erosion and levels of wave runup on natural beaches.
Setup	Wave setup is the elevation of the nearshore still water level resulting from breaking waves and may be perceived as the conversion of the wave's kinetic energy to potential energy.

Shoal	(1) (noun) A detached area of any material except rock or coral. The depths over it are a danger to surface navigation. (2) (verb) To become shallow gradually.
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

Lake Cathie is located on the NSW north coast approximately 420 km from Sydney. The area of focus of this project is specifically the section of coastline owned by Milland and Seawide – Lot 1 DP 374315 and Lot 4 DP 615261 Ocean Drive.

The township of Lake Cathie is located on the open-coast beach of Lighthouse Beach, which is approximately 12 kilometres long between Middle Rock Point and Tacking Point. Extending immediately south of Middle Rock Point is the study area, which forms part of the embayment and is known as Rainbow Beach (See locality plan on Figure 1.1). The entire section of Rainbow Beach within the study area is flanked by littoral rainforest, which is identified and protected by SEPP 26. This strip of littoral rainforest and the foredune separates Lot 1 DP 374315 and Lot 4 DP 615261 Ocean Drive from the beachfront. A more detailed view of the study area and proposed development is given in Figure 1.2.

The coastline is subject to a high energy wave climate which has seen the gradual long term recession of Rainbow Beach, although to a lesser degree than the extent of erosion experienced by the beachfront north of Middle Rock Point.

A photograph of the study area following large storms which occurred in May 2009 is shown in Figure 1.3.

This report documents a detailed coastal hazard assessment of the section of beach adjacent to Lot 1 DP 374315 and Lot 4 DP 615261 Ocean Drive at Lake Cathie, which has been undertaken using photogrammetric and Aerial Laser Scan (ALS) data analysis and analytical assessments. It describes the coastal processes affecting the beach and the impact of these processes on the areas of the beach where future development areas may be at risk. The report quantifies the observed long-term beach change, 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, a 50 year planning period and a 100 year planning period.

This assessment has been carried out using conservative (worst-case scenario) parameters, in accordance with the NSW Coastal Management Manual (1990), the NSW Coastal Policy (1997) and the Coastal Protection Act (1979), which enshrine the need to consider the principles of Ecologically Sustainable Development (ESD) and the need to take a precautionary or "risk averse" approach to land use planning within the coastal zone.

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.

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

- short-term coastal erosion from severe storms and consequent slope instability;
- long term coastline recession resulting from imbalances in the sediment budget, such as aeolian (wind-driven) 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 Lake Cathie, the underlying strata consists of consolidated or *indurated* sands (coffee rock), which is more resistant to erosion than typical unconsolidated beach sand. This barrier is overlain by a layer of more erodible marine sand.

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.

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.

2.3 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.

2.3.1 Historical Beach Erosion

Historically Rainbow Beach, along with extensive sections of the north coast, has been subjected to large storms with some emanating from Queensland due to cyclonic events while others result from intense low pressure systems.

Some large storms occurred during the period between 1970 and 1983, as shown in Figure 2.3. These storms 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). This makes it suitable for use as a *design event* for Rainbow Beach.

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. It is important, therefore, to document the history of storms along the coastline at Rainbow Beach to ascertain whether the observed beach changes can be related to the specific occurrence of such storms. The aim is to delineate which observed changes are caused by episodic events, such as large coastal storms, and which changes have underlying causes that may be due to long-term cycles, natural fluctuations or are caused by anthropogenic influences.

2.3.2 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 2.4). This will result in an increasing potential for dune erosion during storms and long term beach recession (Figure 2.5).

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 Rainbow Beach using photogrammetric techniques.

2.4 Beach Rotation

Studies of embayed beaches on the NSW coast have identified a sensitivity of shoreline alignment to mean wave direction, which has been linked to the Southern Oscillation Index (SOI). 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).

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°.

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.

2.4.1 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.

Exposed open coast beaches 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.

2.4.2 Rotation And Longshore Drift

The application of the storm erosion hazard protocol herein (Nielsen *et al*., 1992) is to apply the design storm erosion demand to the most recent beach profile which is provided by detailed Aerial Laser Scan (ALS) topographic data from 2005. 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 is not seen at Rainbow Beach. This is because the ongoing long term erosion overrides any medium term oscillation of the sub-aerial beach sand store that may be induced by beach rotation of the swash zone.

There is little evidence of beach rotation taking place at the beach compartment immediately surrounding Rainbow Beach, with beach fluctuations generally correlated positively with changes along the entire region where photogrammetry is available. Examination of Rainbow Beach was carried out, by reviewing the photogrammetric investigations carried out at Bonny Hills/Lake Cathie by NSW Public Works (May 1990), and by reviewing the 2005 ALS data and comparing this with the previous photogrammetry. At the northern end of Rainbow Beach, the average movement of the 6m contour line was negligible between 1940 and 1988 (NSW Public Works, 1990), indicating that while the southern end of Rainbow Beach at Lake Cathie was receding, the northern end was relatively stable. This trend is confirmed by the ALS 2005, showing that the average movement of the 6.0m contour line is very low. This could be an indicator of beach rotation, but is more likely an indicator of a mean northerly longshore drift occurring.

There appears to be some anecdotal evidence of longshore drift, with the beach south of Middle Rock (Rainbow Beach) having a much wider berm than the beach north of Middle Rock, indicating that Middle Rock may be acting as a natural groyne by trapping northward longshore sediment transport. Wave crests have been observed in historical aerial photographs approaching obliquely to the beach from the south-east, which would also induce northward sediment transport (Figure 2.6).

Examination of wave data from Crowdy Head Waverider buoy between 1985 and 2005 was carried out to determine the change in mean offshore wave direction over time. It was found that mean wave direction was increasing over time on average, though the record is too short to remove the effects of inter-decadal variability. It was also found that mean wave direction was related to the Southern Oscillation Index (SOI), with mean wave direction being more southerly during *El-Niño* years and more easterly during *La-Niña* years (Figure 2.7). 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 2.8). A shift from dominant *La-Niña* to dominant *El-Niño* conditions caused by climate change would enhance northerly longshore drift.

A wave refraction analysis was undertaken for the Lake Cathie area to investigate the impact of change in offshore wave angle on mean wave angle in the nearshore area. This was undertaken using SWAN (acronym for **S**imulating **WA**ves **N**earshore – Cycle III version 40.11). SWAN is a numerical wave transformation program developed at the Delft University of Technology (Holthuijsen *et al.*, 2000). SWAN can be used to describe wave transformation in shallow water and to obtain realistic estimates of wave parameters in coastal areas, lakes and estuaries from given wind, bathymetric and current conditions. The background to SWAN is provided in Young (1999) and Booij *et al.*, (1999). SWAN has been validated using field data by Nielsen & Adamantidis (2003).

The range of offshore wave angles examined was from 127°TN to 140°TN, corresponding to the annual Mean Wave Direction (MWD) reported by Goodwin (2005). For this range of offshore wave directions, the variation in wave angle in the nearshore area of Rainbow Beach (at approximately the 5m depth contour, beyond the median wave breaking depth) is around 3° (see Figure 2.9). As the beach planform is typically normal to the MWD, the beach rotation that would be expected would be of the same order (±1.5°), with the effects seen most greatly at the extreme southern and northern ends of the beach. Assuming that the beach can be approximated by a straight line, the beach fluctuations due to rotation are estimated by the following formula:

$$R = dist \times \tan(r)$$

where *R* = beach fluctuation in metres at the location of interest

dist = distance in metres from the centre of the beach (for Rainbow Beach, this is 600-1300 m)

r = estimated change in nearshore wave angle in degrees.

Beach fluctuations over the 600-1300m distance for a ±1.5° beach rotation may reach 35m over the sandy portion of the beach – for a beach berm height of 2.0m AHD, this represents a sand volume fluctuation of approximately ±30 - 70 m^3/m. However, beach rotation at Rainbow Beach would be limited due to the presence of the Pleistocene indurated sand barrier, which cannot erode as readily as unconsolidated marine sands in response to changes in nearshore wave direction. In addition, beach rotation would be limited by the presence of the rock outcrops along the beach, such as at Middle Rock, which control the beach planform.

2.5 Enhanced *Greenhouse* Effect

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.

In the longer term, there may be global changes resulting from a postulated warming of the earth due to the accumulation in the atmosphere of certain gases, in particular carbon dioxide, resulting from the burning of fossil fuels (the *Greenhouse Effect*). 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. Such a warming could lead to a number of changes in climate, weather and sea levels. These, in turn, could cause significant changes to coastal alignments and erosion.

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 21st century is 0.59 m (Figure 2.10). 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 the effects of climate change, there is also an existing underlying rate of sea level rise which includes the effects of current local rates of isostatic and tectonic land movements. Mitchell et al. (2001) quantified underlying rates of existing sea level rise at various tide gauge locations around Australia. At Newcastle, this value was found to be 1.18 mm/year based on 32 years of record (Mitchell *et. al.* 2001). There are also local effects related to the East Australia Current. The sum total of these influences would give an upper bound sea level rise of approximately 0.90 m for a 100 year planning period. The NSW Government has released a Sea Level Rise Policy, which sets benchmarks for sea level rise for planning purposes of 0.4m for 2050 and 0.9m for 2100.

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 2.11). Foreshore recession resulting from a *Greenhouse*-induced sea level rise has been assessed using the *Bruun Rule* further in this report.

2.6 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 run-up.

2.7 Hydrodynamic Forcing

2.7.1 Introduction

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

2.7.2 Wave Climate And Storms

Coastal processes at Rainbow Beach 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.

The coastline at Rainbow Beach experiences high wave energy. 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 2.12) and the average wave period is around 10 s (Kulmar *et al.* 2005). Analysis of storms recorded at Crowdy Head has provided wave height/duration data for various annual recurrence intervals.

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.

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. Rainbow Beach is considered to be affected by storms impacting on the mid-north coast sector of NSW.

The categories of storms are illustrated in Table 2.1.

Table 2.1 – 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

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 Crowdy Head Waverider buoy records from 1985 – 2007 obtained from the Department of Commerce Manly Hydraulics Laboratory. A representative *significant* wave height at Rainbow Beach 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.

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

Figure 2.3 documents the extreme storm events that occurred between 1940 and 2005, with the estimated *significant* wave heights for these events. It plots also the dates for which beach photogrammetry was available for analysis. Some notable storms that may have caused beach erosion at Rainbow Beach occurred in 1954, 1967, 1974 and 1986.

2.7.3 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 2.13). 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 meter 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 2.14.

3 COASTAL HAZARD ASSESSMENT

3.1 Introduction

The coastal hazard assessment for Rainbow Beach comprised quantifying the three principal hazards, namely:

- short-term storm beach fluctuations;
- long term beach recession; and
- oceanic inundation.

For Rainbow Beach, the storm cut (or storm erosion demand) has been quantified empirically with data obtained photogrammetrically. An *equivalent* storm erosion volume has been derived empirically based on the schema presented in Nielsen *et al.* (1992) and storm erosion volumes derived from photogrammetry data between 1970 and 1983.

3.2 Short Term Beach Fluctuations

3.2.1 Design Storm Erosion

The design storm erosion demand has been based empirically on the measured erosion from the photogrammetry data between 1970 and 1983. Some large storms occurred during the period between 1963 and 1983, as shown in Figure 2.3. These storms included the June 1967 storms which impacted greatly on the NSW north coast, and the storms of May-June 1974 whose impacts were greatest felt on the NSW central coast. In the current investigation, photogrammetry data from 1967 or 1974 was not available. The impact of the 1967 storms is not noticeable on the photogrammetric data for Rainbow Beach. For this reason, volume changes between the photogrammetric data of 1970 and 1983 were analysed to estimate a storm erosion demand for the storms of May-June 1974.

An analysis of equivalent storm erosion volumes resulting from the 1974 storms followed the schema of Nielsen *et al.* 1992 (see Figure 3.1). The values were derived at the local maxima of the landward movement of the RL 6.0m contour, as measured between the 1970 and 1983 photogrammetric data and applied to the whole beach, to take account of the formation of rip-heads and to arrive at a conservative (worst-case scenario) estimate of storm erosion demand for the beach.

Equivalent storm erosion volumes were obtained from the analysis for the beachfront areas along the northern half of Rainbow Beach. Analysis of the photogrammetric data between 1970 and 1983 showed that up to 80 m^3/m of erosion had occurred over this time period, as shown on Figure 3.2. A previous study, “Rainbow Beach Hotel – Coastal Erosion Study” by Kinhill (July 1989) used a storm erosion volume of 200 m^3/m for Rainbow Beach. This value is equal to commonly reported storm erosion demand values at other open coast sandy beaches along the NSW coast (typically 200 – 250 m^3/m). This value is higher than the measured values along the beach and is therefore conservative due to the presence of indurated sands, which are relatively resistant to erosion when compared with typical unconsolidated beach sand. However, it should be noted that the indurated sands in the Lake Cathie area are generally only weakly consolidated, and they would still be subject to potential collapse during a storm event.

For our coastal hazard assessment, a value of 200 m^3/m was adopted, in line with previous assessments, and to ensure a conservative (worst-case scenario) assessment in line with the requirements of the precautionary principle.

AS4997-2005 “*Guidelines for the design of maritime structures*” (AS, 2005) recommends that a storm event having a 5% probability of being exceeded over a 50 year period be adopted for risk analyses. The lack of sufficient data immediately before and after storm events meant that it was not possible to perform a statistical analysis and assign a design encounter probability to the recommended storm erosion demand value. However, it is considered that a storm that would lead to the design storm erosion demand would have a very low risk of being exceeded over the next 50 years.

3.3 Long Term Recession

3.3.1 Introduction

Processes such as sea level rise, aeolian processes and the littoral drift of sediment are natural loss components of the sediment budget of a beach. Biogenic production of sand from the shells of benthic fauna, and sediment transported into the littoral zone from nearby estuaries are natural sources of sediment for a beach. If, in the long term, the losses of sediment from a beach are greater than the gains, then a gradual beach recession will result.

Detailed measurements of the sediment budget for Rainbow Beach were beyond the scope of this study. However, an assessment of the long term beach recession rate has been made empirically using photogrammetric data.

3.3.2 Measured Long Term Beach Recession

In addition to photogrammetric data from the report "Bonny Hills to Lake Cathie Coastal Study" from the NSW Public Works (1990), aerial laser scan data from 2005 and ground survey data were used to determine the rate of long-term beach recession. The photogrammetric profile locations are illustrated on Figure 3.3. In addition to this data, Kinhill (1989) carried out a ground survey of the beach dune which was synthesised with the photogrammetric and ALS data to obtain long-term rates of shoreline change.

The photogrammetric analysis indicated a very low rate of long-term erosion occurring along Rainbow Beach at Lake Cathie.

As the natural fluctuations of a beach and dune are large compared with any underlying long term trend in beach change, sometimes it can be difficult to quantify an accurate rate of erosion or accretion. Often it can be more accurate to measure beach recession by mapping the response of the dune erosion escarpment over time. This can be done by measuring the location of the dune face along each profile, for example, by measuring the chainage along each profile of the toe or the crest of the dune.

By inspection of the profiles, it was determined that from these data the location of the 6.0m AHD contour best represented the location of the front face of the dune along the beach. The locations of these contours were based on the Australian Map Grid (AMG) coordinates of the surrounding points in the photogrammetric profile data. This allowed the location of the front face of the dune to be plotted in the GIS and enabled an examination of the dune location over time. It was noted that this method is dependent also on the accuracy of the photogrammetry, as the spatial location of the 6.0m AHD contour will be dependent on the vertical resolution of the photogrammetric technique.

The location of the 6.0m AHD contour has been determined from the ALS data and compared with the previous location of the contour – in 1940, 1960, 1970, 1983 and 1988 – given in the PWD's report "Bonny Hills to Lake Cathie Coastal Hazard Study". These data were plotted on a graph and a general trend was determined from this data (Figure 3.4). In general, it was found that the locations of the 6.0m AHD contours were varying within 2 metres on average along most of Rainbow Beach. Therefore, it can be seen that the beach along the study area is relatively stable. While it may appear upper from Figure 3.4 that long term erosion is occurring at Profile 28 (at the centre of the study area), this trend has been exaggerated by a lowering of the foredune at this location, which forms a natural pathway for land-based runoff.

Averaged over the 65 years of photogrammetric data, the rate of dune face migration equates to a recession rate of around 0.01 m/year for the study area. For an average escarpment height of 8-9m, this equates to less than 0.1 m^3/m/year of volumetric erosion. The low rate of dune recession may be due to the exposure of the Pleistocene indurated sand barrier and the relative resistance of this material to erosion. It may also be due to the presence of Middle Rock, which acts as a natural groyne, trapping north-bound longshore drift.

3.4 Future Beach Recession – Sea Level Rise

3.4.1 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 21st century. It was projected that global average sea levels could rise from between 0.09 m and 0.90 m by 2100 (Figure 3.5; and from between 0.05 m and 0.30 m by around 2050).

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 2.10 and summarised in Table 3.1, for the various scenarios and based on the spread of model results.

It can be seen from Table 3.1 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 3.2). This would give an upper bound sea level rise of 0.76 m for a 100 year planning period.

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.

It should be noted also that sea level rise is subject to considerable regional variation, with the southern ocean in general forecast to undergo less sea level rise than the Arctic, due to regional climatic variations and local changes in salinity and ocean density. In the region off the east coast of Australia, the IPCC (2007) report indicates that the expected sea level rise would be close to the geographic global average. CSIRO (2007) reported on an investigation of the spatial pattern of projected sea level rise to 2070 for the Australian coast. Seventeen climate model results were examined and, of these, thirteen showed a positive thermal expansion along the east coast of Australia south of 30°S relative to the global average. This relates to a possible increase in the strength of the East Australian Current, leading to an additional sea level rise of around 10cm above the global average change.

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 21st century (Figure 3.5).

Current rates of relative sea level rise at Newcastle (1.18 mm/year), which take into account the local rates of isostatic and tectonic land movements, are reflected in the measured long term recession rate.

Table 3.1 – Range of Sea Level Rise Predictions (IPCC 2007)

Scenario	5% (lower bound) predicted sea level rise 1980-1999 to 2090-2099 (m)	Assumed median 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	0.28	0.38
B2	0.20	0.32	0.43
A1B	0.21	0.35	0.48
A1T	0.20	0.33	0.45
A2	0.23	0.37	0.51
A1F1	0.26	0.43	0.59

*The IPCC (2007) report does not provide median values for predicted sea level rise. Median values have been assumed by adopting the central value between the 5% and 95% confidence interval limits.

*Table 3.2 – 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.

The IPCC were unable to exclude larger values and there is emerging evidence in the current measurements and observations, suggesting the IPCC's 2007 report may have underestimated the future rate of sea level rise. Therefore, the NSW Government through the Sea Level Rise Policy Statement (DECC 2009) have set the NSW Sea Level Rise Planning benchmark at the upper bound levels of a 0.40 m increase above 1990 levels by 2050 and 0.90 m by 2100. The projections of future sea level rise for this coastal hazard study are based on this benchmark and are presented in Table 3.3.

Table 3.3 – Projected Greenhouse sea level rise scenarios for Rainbow Beach

Scenario Range\Year	2050	2100
Maximum	0.40 m	0.90 m

3.4.2 Impacts Of Sea Level Rise

3.4.2.1 Bruun Rule

The most widely accepted method of estimating shoreline response to sea level rise is the Bruun Rule (Bruun, 1962; 1983). Bruun (1962, 1983) investigated the long term erosion along Florida's beaches, which was assumed to be caused by a long term sea level rise. Bruun (1962, 1983) hypothesised that the beach assumed an *equilibrium profile* that kept pace with the rise in sea level without changing its shape, by an upward translation of sea level rise (S) and shoreline retreat (R).

Figure 3.6 illustrates the concept of the Bruun Rule. The Bruun Rule equation is given by:

$$R = \frac{S}{(h_c + B)/L}$$

where: *R* = shoreline recession due to sea level rise;

S = sea level rise (m)

h_c = closure depth

B = berm height; and

L = length of the active zone.

The Bruun model assumes that the beach profile is in an equilibrium state.

Berm height is taken to be the average height of the dune along the beach, and closure depth is the depth at the seaward extent of measurable sand movement. The length of the active zone is the distance offshore along the profile in which sand movement still occurs.

3.4.2.2 Determination Of Bruun Rule Parameters

Several schema exist, based on analytical and laboratory studies, to determine closure depth and length of the active zone, including those of Swart (1974) and Hallermeier (1981, 1983). Nielsen (1994) reviewed these, other analytical methods and a large body of field data to define subaqueous fluctuations of open coast beaches in NSW. Nielsen (1994) found that the absolute limit of offshore sand transport under cyclonic or extreme storm events occurred at a depth of 22m.

Bruun (1954) proposed a simple power law to describe the relationship between water depth, *h*, and offshore distance, *x*, measured at the mean sea level:

$$h = Ax^{\frac{2}{3}}$$

where *A* is a dimensional shape factor, mainly dependent on the grain size. Figure 3.7 (from Dean, 1987) gives an empirical relationship between *A* and grain size, D. This gives a value of *A* for Rainbow Beach, based on an assumed median grain size of around 0.2 mm, of approximately 0.1. Examination of data from the Admiralty Chart *Aus. 811 Crowdy Head to Smoky Cape* and digitised soundings on a 1 km grid as provided by Geoscience Australia (Petkovic & Buchanan, 2002) showed that the nearshore profile extended to a depth of 11.5 metres for a profile length of around 1190 metres. Beyond this depth there is a discontinuity in the profile indicating that it is not in equilibrium with the wave climate. Use of the Hallermeier (1981, 1983) formulation for estimating the closure depth gives an inner limit for the depth of closure of around 13 m.

A comparison plot of the shore-normal profile at Rainbow Beach and the estimated equilibrium profile is given in Figure 3.8. It should be noted that the nearshore profile is based on limited data. As the application of the Bruun Rule is limited to the portion of the profile in equilibrium with the wave climate, taking the nearshore slope out to a depth of 11.5 m for use with the Bruun Rule was considered appropriate. Addition of the average dune height of 8.3 m to the depth of closure gives a slope of around 1:60 for use with the Bruun Rule. The computed nearshore profile slope is within the range of 1:50 – 1:100 that is common to many of the world's coastlines (Ranasinghe *et al.* 2007).

For this application, therefore, the equilibrium profile for the application of the Bruun Rule was taken to a depth of 11.5 m (or the approximate depth of closure, h_c) for a profile length of 1190 metres (*L*).

The average of the dune heights along Rainbow Beach at Lake Cathie (*B*) is approximately 8.3 m, giving a profile slope of approximately 1:60 for analysis of recession due to sea level rise.

3.4.2.3 Beach Response

Sea level rise may lead to a shoreline response of coastal recession. Measurements of sea level rise show that there is considerable variation in the data. These variations are due to processes acting at inter-decadal scales, such as the El Niño Southern Oscillation (ENSO) phenomenon.

Figure 3.6 illustrates the concept of beach recession as a result of sea level rise. Table 3.4 provides estimates of the overall long-term recession expected at Rainbow Beach, Lake Cathie due to sea level rise. It is possible that these estimates are higher than what would actually occur, as the Bruun analysis does not take the reduced erosion potential of the indurated sand strata into account.

Table 3.4 – Predicted Future Beach Erosion and Recession due to Sea Level Rise at Lake Cathie

Total Predicted Sea Level Rise (m)			Total Beach Recession (m)		Total Beach Erosion (m^3/m)	
Scenario	**2050**	**2100**	**2050**	**2100**	**2050**	**2100**
High	0.40	0.90	24.2	54.4	198.9	447.5

For an upper-range sea level rise scenario, the total beach recession relative to 1990 levels expected would be **24.2 metres by 2050** and **54.4 metres by 2100**. This equates to an annual erosion rate as measured from 1990 of around **3.3 m^3/m/year to 2050,** increasing to **4.1 m^3/m/year by 2100**.

3.5 Oceanic Inundation

Design incident wave conditions for the assessment of wave runup were determined for a maximum deepwater offshore wave height corresponding to the 0.1% AEP (Annual Exceedance Probability). From long term wave statistics as measured at the Sydney directional Waverider buoy (which is representative of the study region), this corresponds to an offshore deepwater significant wave height of around 11 m. As Rainbow Beach is fairly exposed to swell waves, it can be assumed that the peak wave height reached offshore at Rainbow Beach would be similar to what could be expected at Sydney.

Wave runup levels at Rainbow Beach were estimated using the Automated Coastal Engineering Software (ACES). The wave runup module of ACES was used to determine the levels, which assumes a smooth slope, linear beach.

The nearshore boundary conditions for ACES that have been adopted for various locations along the beach are shown in Table 3.5. The assumed nearshore beach profile is measured from approximately 2 m below AHD to the top of the dune, to obtain a beach slope for use in the wave runup calculation. The runup was added to the nearshore water level, which included an allowance for wave setup and wind setup. The maximum expected wave runup and 2% wave runup (runup level exceeded by 2% of waves) is given in Table 3.5.

Table 3.5 – Maximum Wave Runup levels for Lake Cathie, 0.1% AEP storm event

Wave Period (s)	12.0
Deepwater significant Wave Height (m)	11.0
Nearshore Water Level (m AHD)	2.2
Nearshore Beach Slope	1:20
Maximum Wave Runup Level (m AHD)	5.1
2% Wave Runup Level (m AHD)	4.7
***Significant* Wave Runup Level (m AHD)**	4.2

From these results, it can be seen that the maximum expected wave runup level along the beach is around 5.1 m AHD. From the photogrammetric data and from the Aerial Laser Scan survey data provided by Port Macquarie-Hastings Council, this indicates that, at a maximum, wave runup would not overtop the existing dune embankment and there would be no impact on proposed dwellings or other infrastructure. Figure 3.9 shows the expected limit of maximum wave runup for the 0.1% AEP storm event.

3.6 Wind-Driven Dune Instability Hazard

Windborne sediment transport can result from destruction of the dune vegetation canopy – removal of dune vegetation can lead to areas of sand being destabilised by the wind, leading to a dune “blowout”. The study area is not affected by this phenomenon, as the dunes are well stabilised by vegetation.

4 HAZARD MAPPING AND RISK ASSESSMENT

4.1 Hazard Mapping

The derivation of the dune erosion hazard for the present day, 50 year and 100 year planning periods have been calculated. For each planning period, the erosion hazard has been defined as:

- a line delineating the limit of wave impact and dune slumping (*Zone of Wave Impact and Slope Adjustment*); and
- a line delineating the limit of the area behind the dune face where the capacity of the sand to support building foundations is reduced because of the sloping dune escarpment (*Zone of Reduced Foundation Capacity*).

In addition, the hazard lines have been determined using the upper-range sea level rise of 0.40m for a 50 year planning period and of 0.90m for a 100 year planning period, to be in accordance with the new *Sea Level Rise Policy Statement*.

4.2 Risk Assessment

A risk assessment for the present day, 50 year planning period and 100 year planning period has been carried out for the beach along the study area. The hazard lines are given on Figures 4.1, 4.2 and 4.3. This risk assessment was carried out with reference to the hazard mapping done for each of the three planning periods.

Despite the conservative (worst-case scenario) values of storm erosion volume chosen for the calculation of the hazard lines, the developed portion of study area would not be at risk nor be subject to reduced foundation capacity within a 100 year planning period. Only the littoral rain forest separating the study area and the ocean will be impacted, as would part of the revegetation area on the seaward side of the proposed development.

5 GENERAL ADVICE ON BEACH ACCESSWAY DESIGN

5.1 Description

5.1.1 Introduction

A beach accessway through the littoral rainforest area is proposed as part of the development of the area. This section of the report provides general design advice relating to the beach accessway, in accordance with the NSW Government Coastal Dune Management Manual (NSW Government, 2001). The primary design objective for the beach accessway design is to maintain continuity in the elevation of the dune surface to avoid the creation of a wind blowout. Material used in the construction of the accessway should be adjustable in order to accommodate sand accretion or erosion at the same rate as it would occur on the natural dune.

5.1.2 Position

The positioning is significant for pedestrian convenience and erosion limitation. The accessway should be constructed where the public usually crosses the dunes. If the seaward end of the accessway is too low, it could be damaged by wave action. However, if it is further back, sensitive areas would be more exposed to uncontrolled pedestrian movements. A compromise position should be determined.

5.1.3 Alignment

Ideally, the accessways should cross the dunes at right angles except if this direction is the one of the prevailing onshore wind. In this case, inclusion of a “dog leg” in the accessway could avoid the negative impact of wind erosion.

5.1.4 Gradient

The ideal slope of the accessway is the natural one of the dune. However, if the dune slope is steeper than 1V:4H, the construction of timber steps or switchback ramps may be necessary.

5.1.5 Surfaces

A surface cover is generally required in order to protect accessways from wind erosion and the physical movement of sand downhill by foot traffic.

Material should be chosen to have optimised safety and comfort for users. It could vary from wood chips in lower use areas to hardwood boards bound by chains in area of more intensive use. The material used should be adjustable in order not to impact the natural processes occurring within the dune environment.

In very sensitive areas, surface material should neither alter soil pH nor introduce toxins. Aesthetics should also be considered. The different options of accessway materials are listed below:

- Board and chain (Figure 5.1);
- Woodchip, mulch and sawdust;
- Crushed sandstone (Figure 5.2);
- Conveyor belt (Figure 5.3); and
- Asphalt, concrete and paving stone (Figure 5.4 and 5.5).

Woodchip, mulch and sawdust are short-lived and ideal for low traffic areas. As there would be one beach accessway only in the study area, the traffic would be relatively high and this option may not be appropriate. Asphalt, concrete and paving stone can be used in very high traffic area but should not be used in exposed or sloping areas to avoid damage due to wind and waves. Moreover, concrete and asphalt paths are not always aesthetic. Hence, this option should also be avoided for the seaward face of the accessway. The three other options are described in more detail below:

- *Board and chain accessways*: Board and chain is the most commonly used method on active dune surfaces. These walkways have been designed to adjust to the changes in dune profile. They are flexible and the spaces between the boards act as sand traps. With proper maintenance, they can accommodate accretion and erosion. Fencing that adjoins board and chain walkways needs to be installed as closely as practicable to the walkway so that tracks are not worn along the fence. A continuous line of closely spaced board provides the most comfortable walking surface but is expensive, has a long construction time and is difficult to raise if sand starts to bury it. The most commonly used method is to omit every third board as it fits to adult and juvenile feet and pace length. Planing of the top surface and bevelling of the top edges of the boards is recommended for a better safety and user comfort. Hardwood is preferred to other wood which could warp. Construction details are illustrated in Figure 5.6 extracted from the Coastal Dune Management Manual (NSW Government, 2001).
- *Crushed sandstone*: It can be used to provide a reasonably erosion resistant track surface on low gradient accessways. It should not be used on steep dune faces, as rainstorms will wash the fines away, leaving a very rough surface unacceptable to bare footed pedestrian traffic. Maintenance costs could often be high.
- *Conveyor belt*: This material could be obtained in widths up to 1.4 metres. Holes are stamped through it prior to use, to facilitate drainage and maintenance lifting. It is flexible, cheap, easy to lay and accessible for wheelchairs. However, it is only suitable for pedestrians on grades up to 1V:14H, as it could become slippery when wet. Moreover, its 1.4m maximal width is a little narrow to allow two people to pass readily and two strips would be needed.

5.1.6 Steps And Stairs

These should be avoided if possible as they are generally not favoured by users and can become relatively expensive structures, both to construct and to maintain. Risers are constructed with sleepers. In these situations sand or other material is placed behind the timber to act as a step. Risers should be anchored firmly, preferably by driving reinforcing rod or galvanised pipe through them into the ground (as shown on Figure 5.7 NSW Government, 2001). Round treated logs should be avoided, as they become slippery when covered with sand.

Stairways may be used to control potential environmental damage (provide access across a steep foredune or protect vegetation). Stairs are usually constructed from timber and ideally they should be founded at a depth that will continue to provide safe and comfortable beach access if the beach surface is lowered by storm waves.

It is preferable to locate such stairways at the more protected end of the beach where there is less erosion and there are opportunities to base the steps on bedrock without interfering with the sand movement along the beach.

5.1.7 Elevated Walkways

These structures are relatively expensive and could only be used in highly trafficked areas where access is to be provided across particularly sensitive environments (Figure 5.8), which is the case in the study area. They can also have a positive aesthetic aspect. These walkways require careful design incorporating hand rails for public safety.

5.1.8 Fencing

Fencing is highly recommended to avoid pedestrians diverting from the defined route and damaging vegetation. Fences along board and chain accessways should allow enough room between the end of the board and the fence to be lifted (around 100-150mm each side) but should be close enough to avoid pedestrians walking between the fence and the walkway, which could lower the sand level and create some sand drift problems along the accessway.

5.1.9 Maintenance

Regular maintenance of any kind of walkway is required to avoid any safety problems and to keep the path functioning correctly.

Minimising the length of the accessways would reduce installation and maintenance cost. The choice of the material should take into account the resistance to salt erosion or vandalism.

In the sand accumulation area, regular lifting is required to avoid the board and chain being buried too deeply, leading to expensive and time consuming maintenance works. Crowbars may be suitable for minor lifting work and a suitable lifting hook may be needed if the burial is more widespread. Accumulated sand should be spread out evenly to make lifting easier. The board and chain is then lifted and shaken. This could be efficiently done by two people using the hook on either side of the accessway. After severe erosion under the accessway or sudden burial by wave action, action should be taken as soon as possible after the event, using a tractor or front-end loader to push up the removed sand or to remove the sand from the buried board. The non-boarded lengths of chain at the seaward end of the walkway would facilitate the lifting.

5.2 Recommendations

Given the steepness of the front face of the dune (1V:4H or steeper) and the relatively high traffic that would occur on the accessway at Rainbow Beach (as there would only be one accessway for all beach users), the best option would be to use a board and chain walkway (as described on Figure 5.6) for the seaward face of the dune. The stairway is to be avoided if possible according to Standards Australia (1999) and most of the other options would not accept a dune slope as steep as Rainbow Beach dune.

Concerning the landward part of the accessway, given the gentler slope and still considering the high traffic which would occur on this pathway, options like pavers or elevated walkways would be appropriate.

All these pathways should be fenced to avoid damage to the vegetation around the path and pedestrians diverting from the walkway. The fences should be located at a distance allowing the maintenance of the path but should also be located close enough to avoid people walking between the pathway and the fences, which could lead to some sand drift and other vegetation damage.

6 SUMMARY AND CONCLUSIONS

Detailed technical studies using an updated empirical database have allowed for the quantification of the coastal hazards at Lot 1 DP 374315 & Lot 4 DP 615261 Ocean Drive at Lake Cathie. The assessment has been made on the basis of detailed photogrammetric survey data and Aerial Laser Scan (ALS) survey data provided by King & Campbell.

Using a combination of worst-case scenario assessment parameters, it was found that there would be no impact on the proposed development as a result of coastal hazards, as the proposed development is located landward of the coastal hazard zones over a 100 year planning period.

AS4997-2005 "*Guidelines for the design of maritime structures*" (AS, 2005) recommends that a storm event having a 5% probability of being exceeded over a 50 year period be adopted for risk analyses. A large storm event occurred over the period of the photogrammetric data record in May-June 1974. The exceedance probability of this storm at Rainbow Beach is not known, but as it is one of the largest storms to have occurred over the period of the photogrammetric record, it was adopted for analysis. The signature of this storm could not be clearly seen in the photogrammetric data. However, the maximum measured erosion between 1970 and 1983, which encompasses this large storm event, was found to be 80 m^3/m. An adopted storm erosion value of 200 m^3/m was used, however, in line with previous assessments and to ensure a conservative (worst-case scenario) assessment.

The available photogrammetric data has indicated that Rainbow beach at Lake Cathie is undergoing low long term recession at a rate of around 0.01 m/year. Consequently, an allowance has been made for historic long term recession of 0.01 m/year.

The natural channel which might be created by land-based runoff around the middle of Rainbow Beach, should be monitored to avoid any increase in dune erosion.

The prognosis for a future sea level rise, as a result of global warming, could increase the rate of long term recession. Estimated sea level rise scenarios in line with the NSW Sea Level Rise Policy Statement, indicate a potential sea level rise of 0.40 m by 2050, and 0.90 m by 2100. This led to an assessment of beach recession of 25.2 m by 2050 and 54.4 m by 2100. It is possible that these estimates are high, as the Bruun analysis does not take the reduced erosion potential of the indurated sand strata into account.

Despite the conservative (worst-case scenario) values of storm erosion volume chosen for the calculation of the hazard lines, the developed portion of study area would not be at risk nor be subject to reduced foundation capacity within a 100 year planning period.

Wave runup analysis for the design storm has indicated that maximum runup levels of 5.1m would not pose an inundation hazard to the two lots of the study area as the embankment height is above 7.5m AHD.

General advice on design of a beach accessway has been provided. Given the steepness of the dune (1V:4H or steeper) and the relatively high traffic that would occur on the accessway at Rainbow Beach (as there would only be one accessway for all beach users), the best options would be to use a board and chain walkway on the seaward face of the dune and pavers or an elevated walkway on the landward half of the dune. Fences should be placed all along the pathways for safety and environmental reasons.

7 REFERENCES

AS (2005). “Guidelines for the design of maritime structures”, Australian Standard 4997-2005, Standards Australia, 2005.

Department of Environment and Climate Change NSW (2009). “Sea Level Rise Policy Statement”.

Department of Environment and Climate Change NSW (2009). “Scientific basis of the 2009 sea level rise benchmark, Technical Note”.

Department of Land and Water Conservation NSW (2001), “Coastal Dune Management – A Manual of Coastal Dune Management and Rehabilitation Techniques”, October 2001.

Foster, D.N., Gordon, A.D., Lawson, N.V. (1975) “The Storms of May-June 1974, Sydney, N.S.W.”, Second Australian Conference on Coastal and Ocean Engineering, Gold Coast Queensland, April 27 – May 1 1975.

Goodwin, I.D. (2005). A mid-shelf, mean wave direction climatology for south-eastern Australia, and its relationship to the El Nino – Southern Oscillation since 1878 A.D. Int. J. Climatol. 25, (2005).

Haradasa, D., S. Wylie & E. Couriel (1991). “Design Guidelines for Water Level and Wave Climate at Pittwater”, Australian Water and Coastal Studies Pty Ltd Report 89/23, March, 1991.

Hennessy, K., K. McInnes, D. Abbs, R. Jones, J. Bathols, R. Suppiah, J. Ricketts, T. Rafter, D. Collins* and D. Jones* (2004). “Climate Change in New South Wales Part 2: Projected changes in climate extremes” Consultancy report for the New South Wales Greenhouse Office by Climate Impact Group, CSIRO Atmospheric Research and *National Climate Centre, Australian Government Bureau of Meteorology, November 2004

IPCC (2007). “*Climate Change 2007 – The Physical Science Basis, Fourth Assessment Report of Working Group 1 of the Intergovernmental Panel on Climate Change*”, Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA. 2007.

Kinhill Engineers Pty Ltd, “Rainbow Beach Hotel Coastal Erosion Study”, July 1989.

Kulmar, M. and Nalty, C. (1997), “New South Wales Coast, May 1997 Storm Analysis” Report MHL886, December 1997.

Kulmar, M., D. Lord and B. Sanderson (2005), “Future Directions for Wave Data Collection in New South Wales”, Proceedings of Coasts and Ports Australasian Conference, September 2005, Adelaide South Australia.

Lord, D.B. & M. Kulmar (2000). “The 1974 storms revisited: 25 years experience in ocean wave measurement along the south-east Australian coast”, Proc. 27th ICCE, ASCE, Sydney, July, 2000, 559-572.

Mitchell, W., Chittleborough, J., Ronai, B. and Lennon, G. 2001, 'Sea Level Rise in Australia and the Pacific', in Proceedings of the Pacific Islands Conference on Climate Change, Climate Variability and Sea Level Rise, Linking Science and Policy, eds. M. Grzechnik and J. Chittleborough, Flinders Press, South Australia.

Nielsen, A.F., D.B. Lord & H.G. Poulos (1992). “Dune Stability Considerations for Building Foundations”, IEAust., Aust. Civ. Eng. Trans., Vol. CE 34, No. 2, 167-173.

NSW Government (1990). “Coastline Management Manual”, ISBN 0730575063, September 1990.

NSW Public Works (1984). “Lake Cathie Flood Study”, Report no. 84010, September 1984.

NSW Public Works (1990). “Bonny Hills – Lake Cathie Photogrammetric Analyses”, Contract 89022, May 1990.

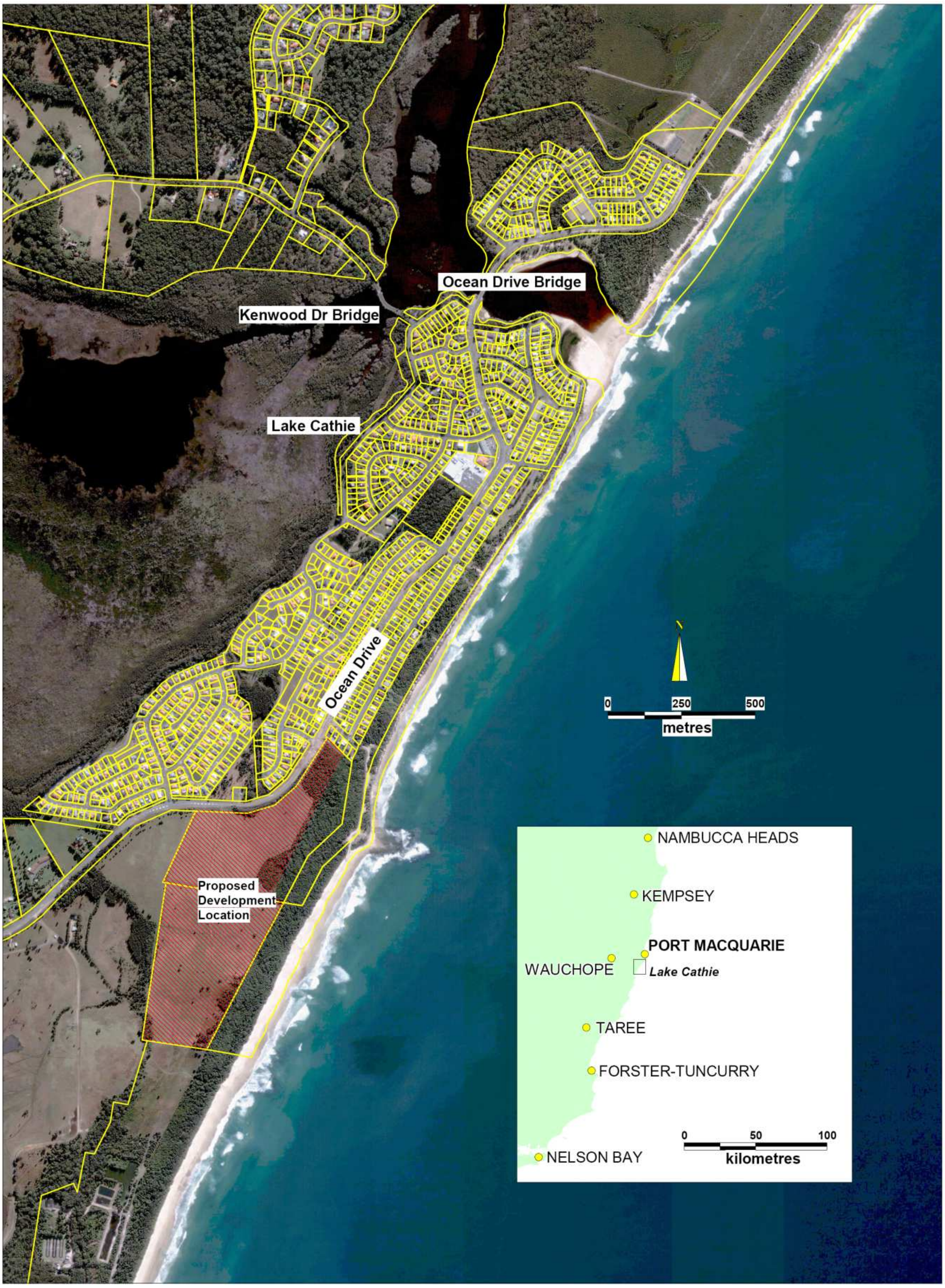
NSW Public Works (1991). “Lighthouse Beach (north) Photogrammetric Analysis”, Contract 89023, February 1991.

Ranasinghe, R., R. McLoughlin, A. Short & G. Symonds (2004). “The Southern Oscillation Index, wave climate, and beach rotation”, Marine Geology 204, 273−287.

Short, A.D., A.C. Trembanis & I.L. Turner (2000). “Beach oscillation, rotation and the Southern Oscillation, Narrabeen Beach, Australia”, Proc. 27th ICCE, ASCE, Sydney, July, 2000, 2439−2452.

Standards Australia (1999). “Walking Tracks Part 2: Infrastructure Design, Draft Australian Standard 99196”, as referenced in NSW Govt. Coastal Dune Management Manual, 2001.

FIGURES



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LOCALITY PLAN

COASTAL HAZARD STUDY
OCEAN DRIVE - LAKE CATHIE

Figure 1.1 – Lake Cathie Locality Plan

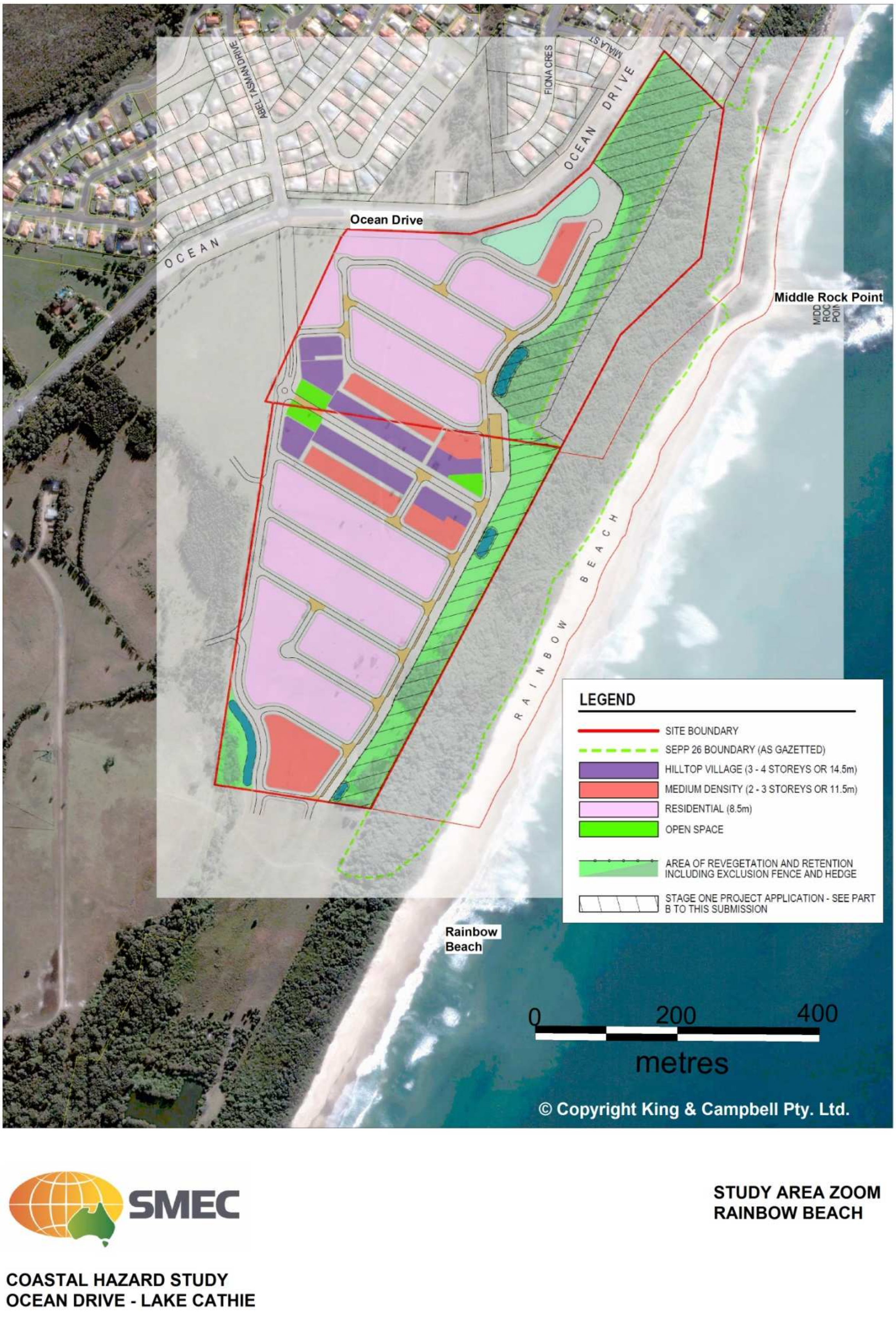


Figure 1.2 – Proposed development location, Rainbow Beach

Figure 1.3 – Rainbow Beach, looking south from Middle Rock (June 2009)

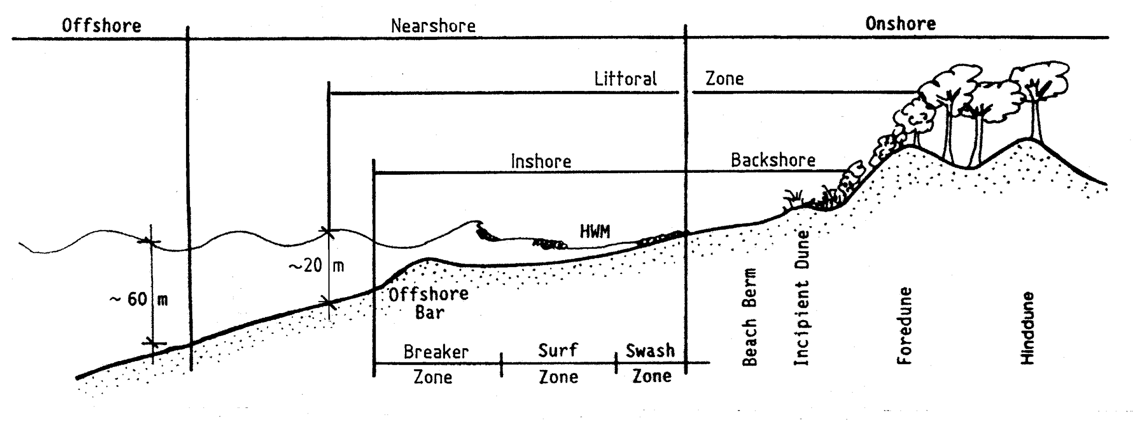


Figure 2.1 – Beach definition sketch (open coast beaches)

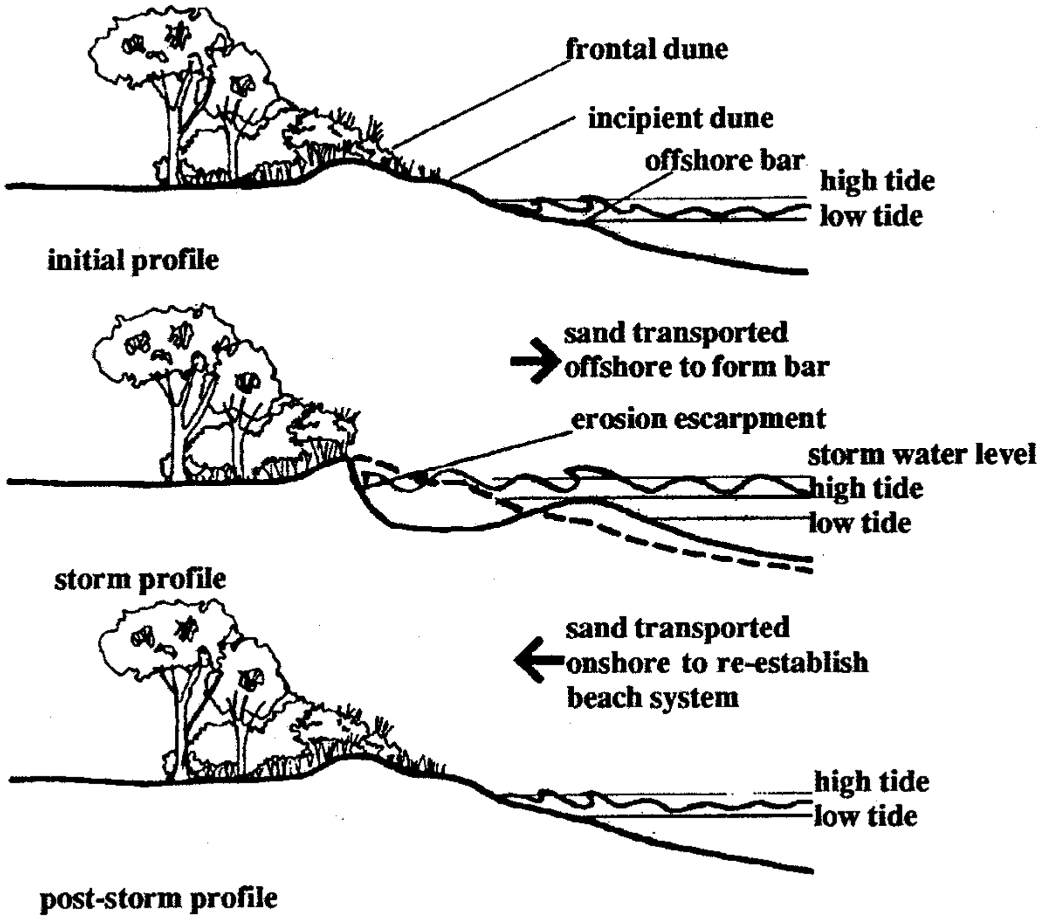


Figure 2.2 – Beach storm erosion/accretion cycle

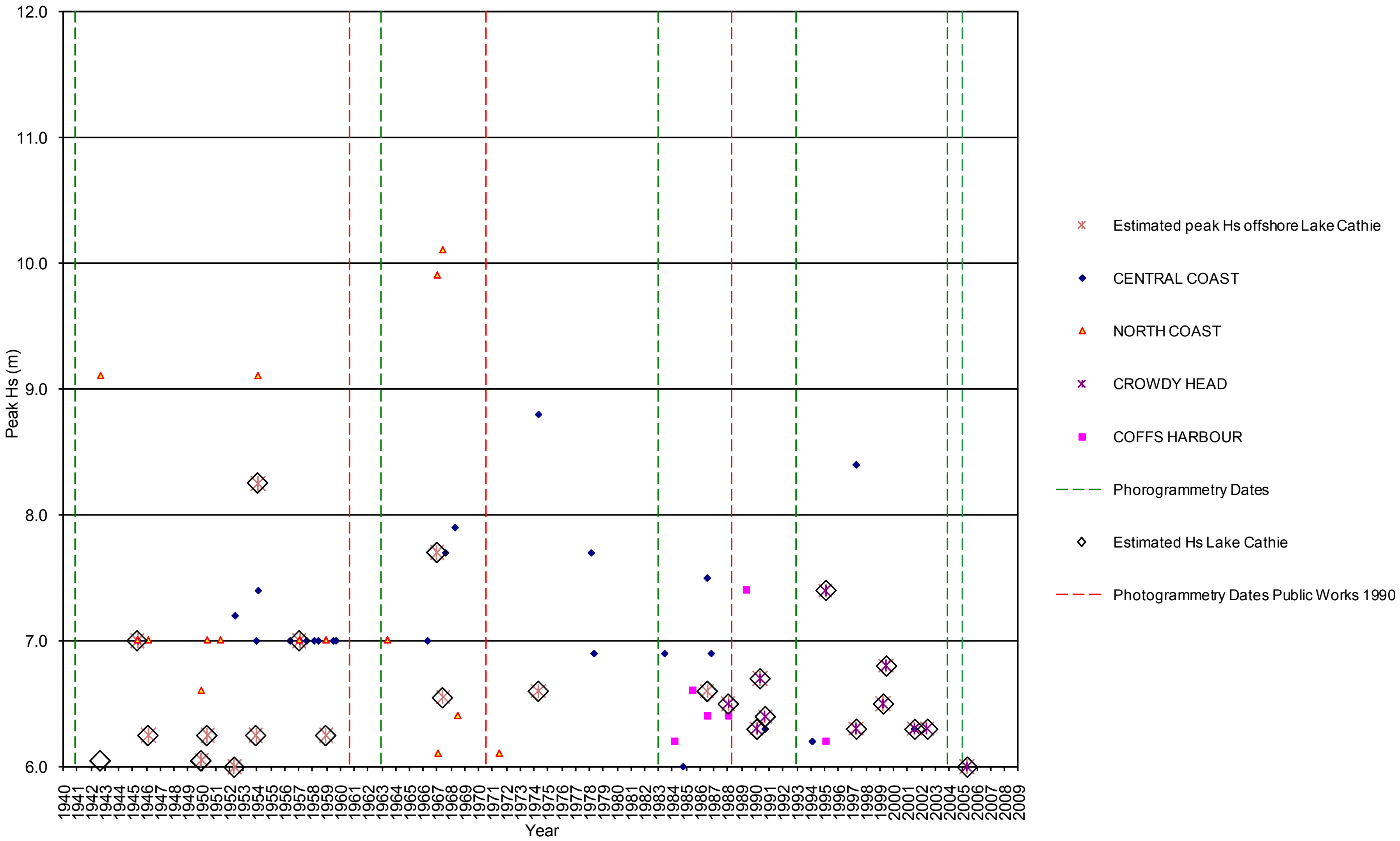


Figure 2.3 – Extreme Storm events vs. Photogrammetry Dates

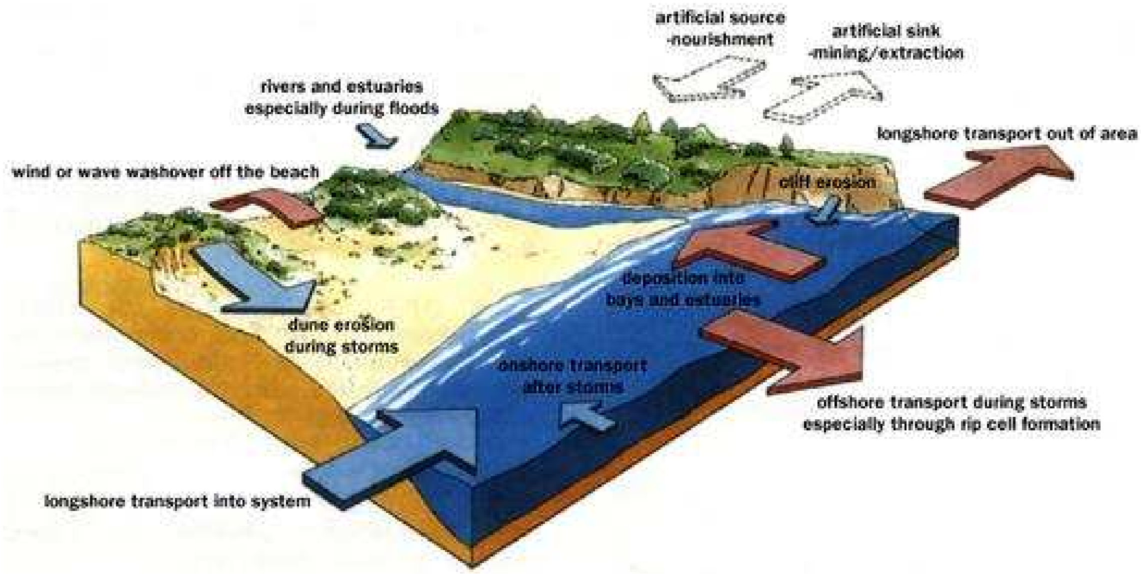


Figure 2.4 – Sediment budget schema (NSW Government, 1990)

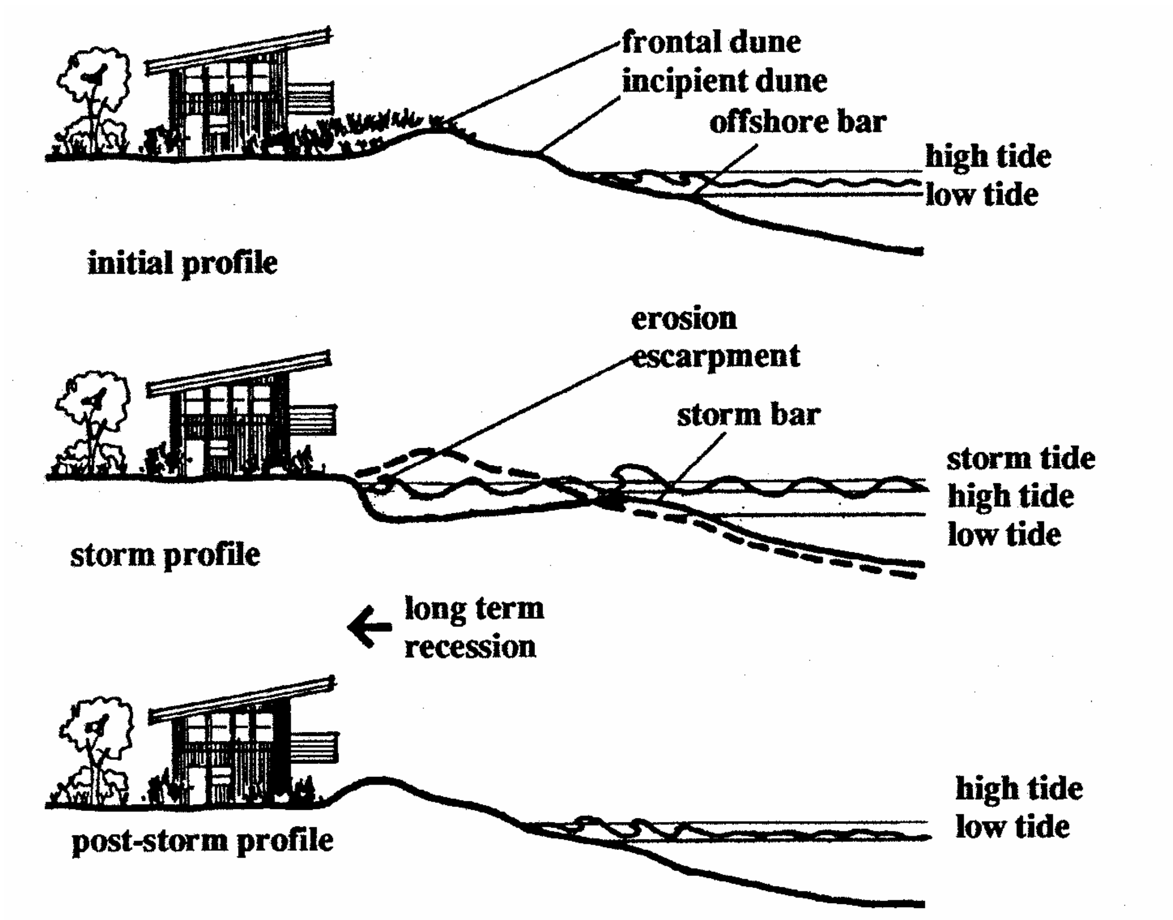


Figure 2.5 – Long term erosion schema

Figure 2.6 – Approaching wave crests, Lake Cathie (1963 aerial photography)

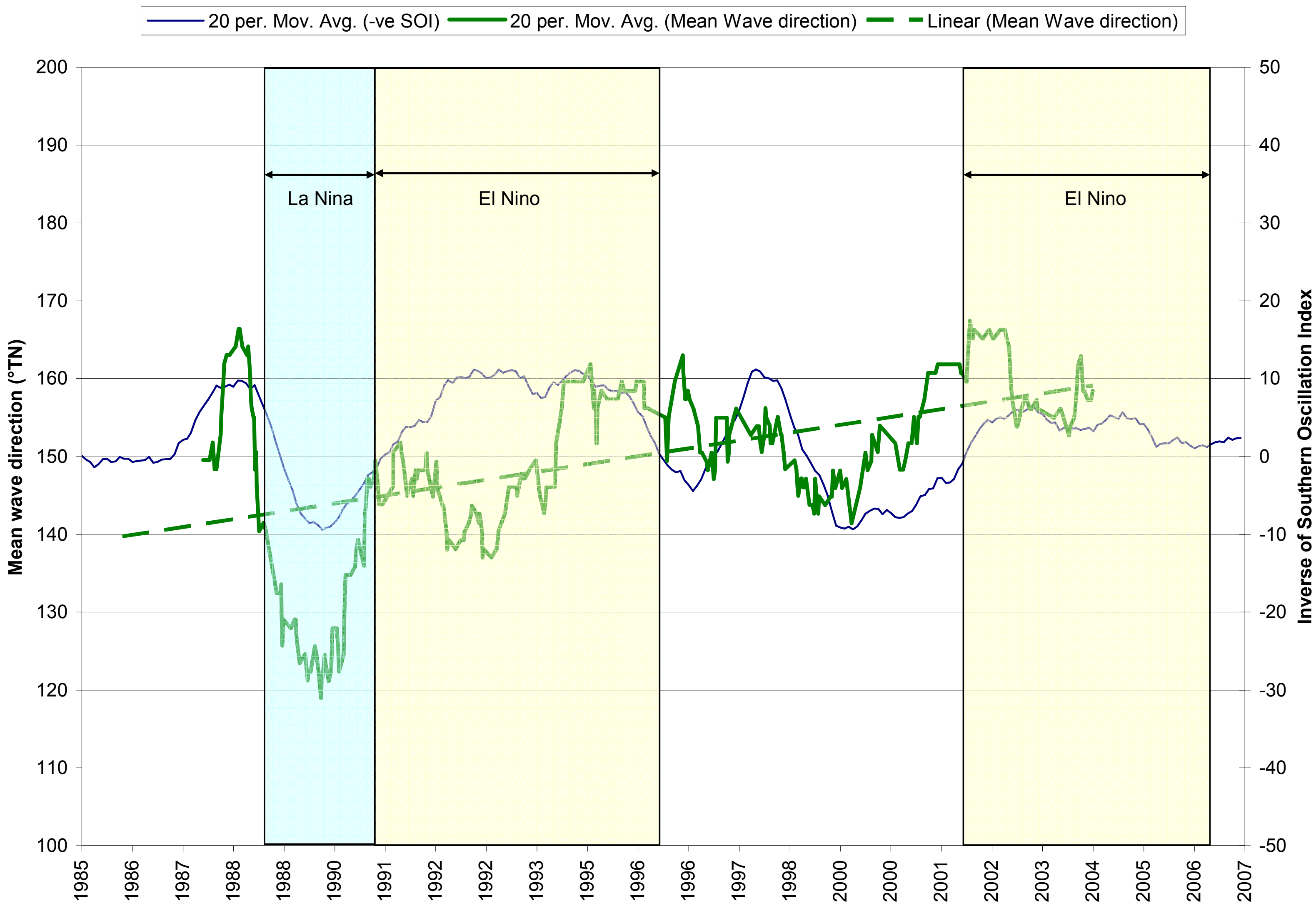


Figure 2.7 – Mean Wave direction vs. mean SOI, Crowdy Head wave data

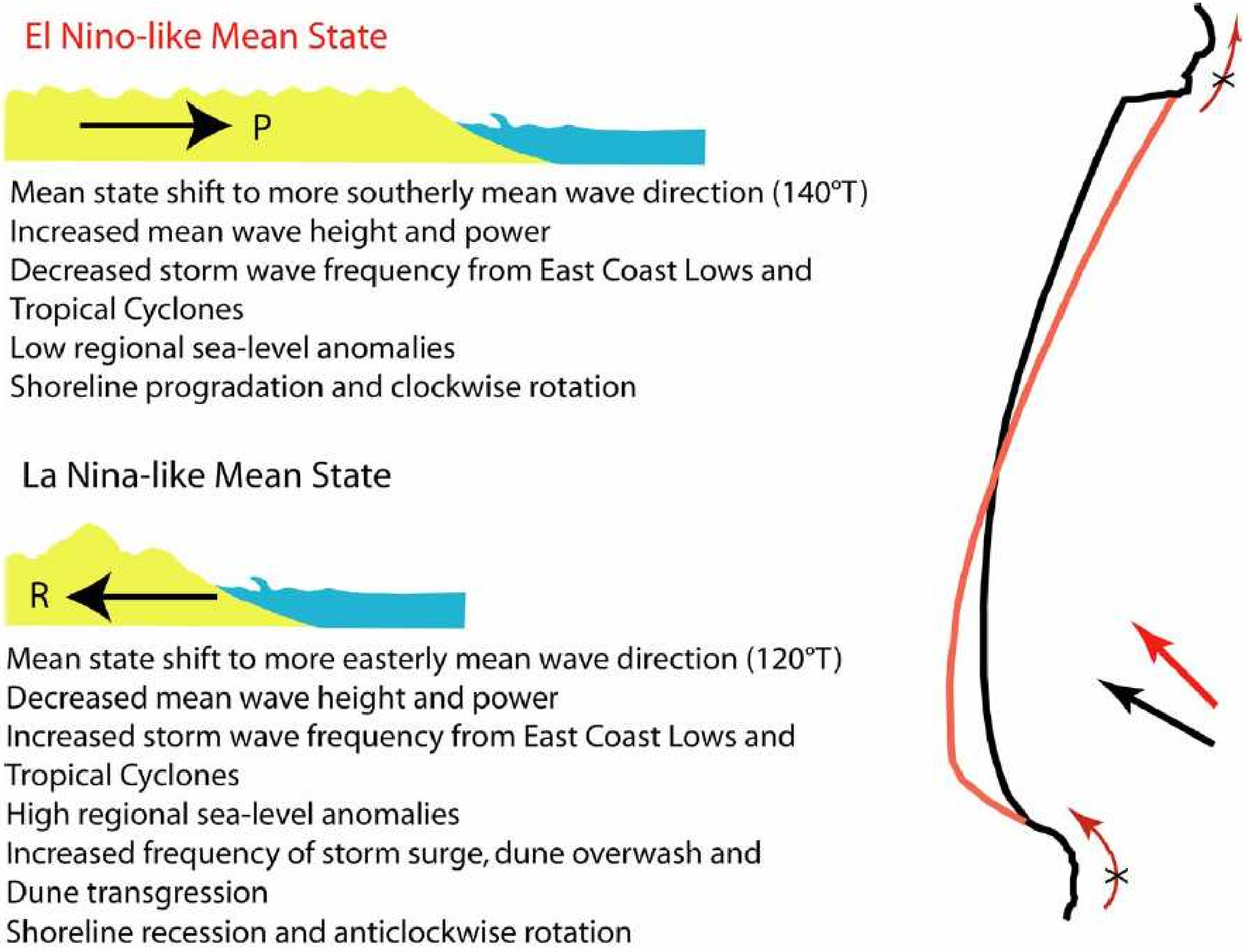
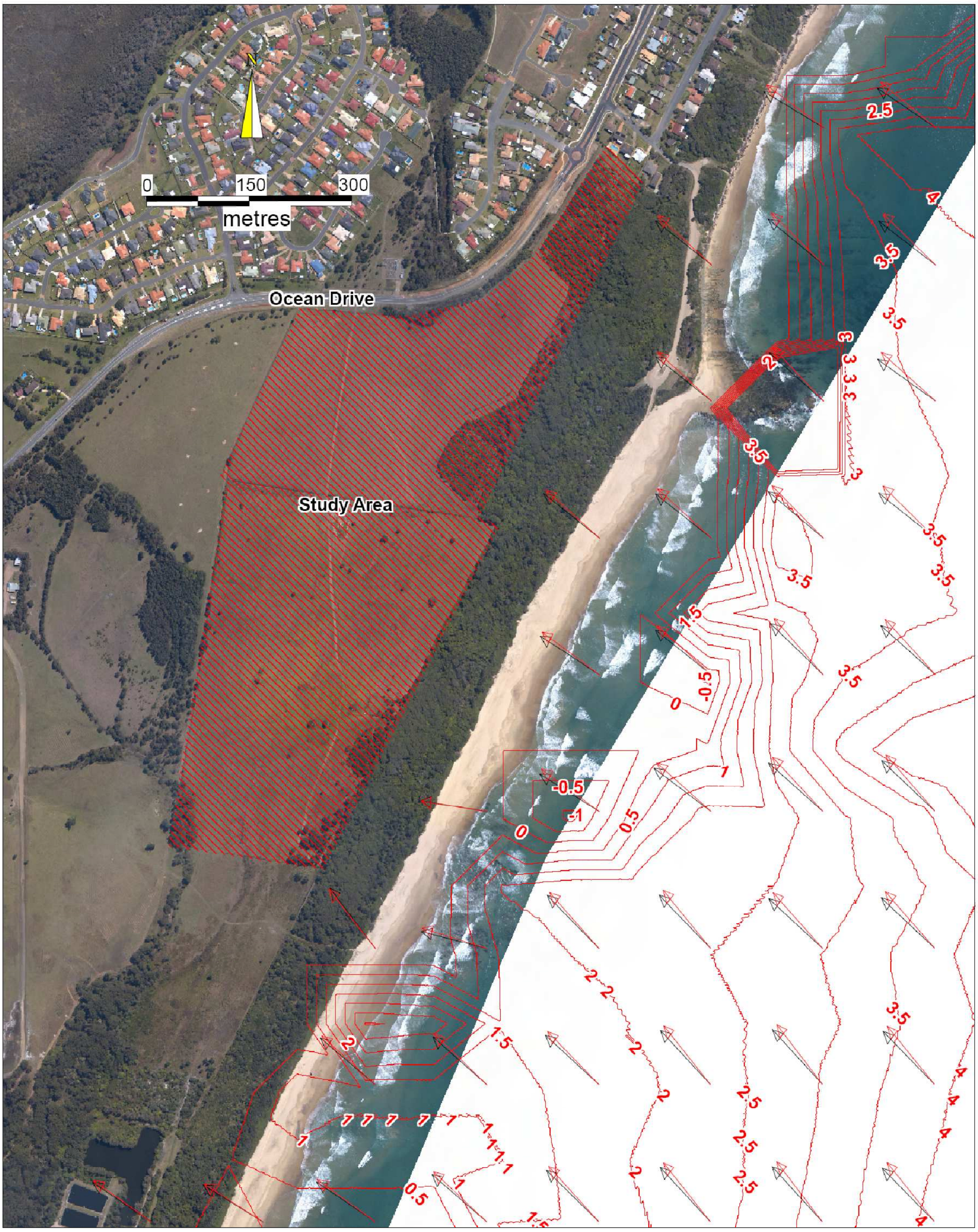


Figure 2.8 – Wave rotation caused by El-Niño or La-Niña mean states (after Goodwin et al. 2007)



Change in nearshore angle caused by change in offshore wave approach angle from 127°TN to 140°TN

COASTAL HAZARD STUDY
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Figure 2.9 – Change in nearshore angle caused by change in offshore wave approach angle from 127°TN to 140°TN

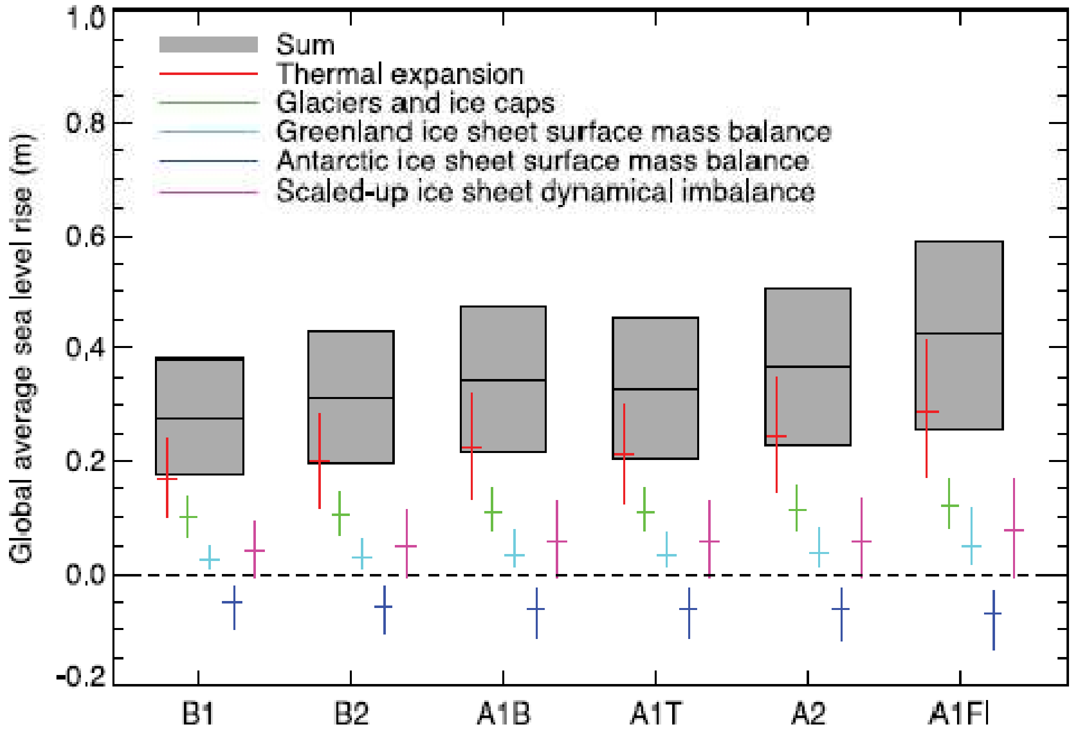


Figure 2.10 – Projected sea level rise between 2000 and 2100 (after IPCC, 2007)

Average change in 95th percentile winds

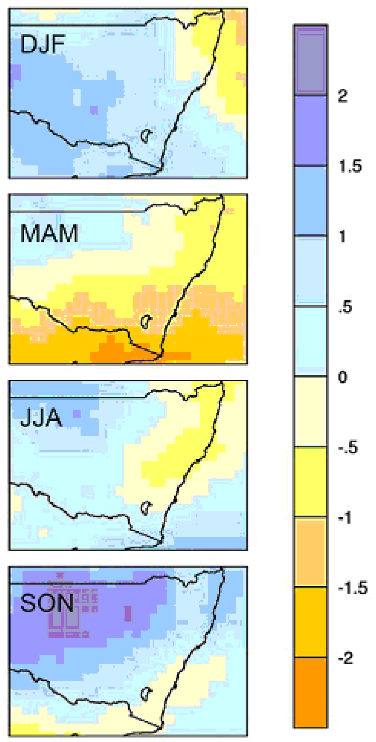


Figure S3: The change in extreme monthly wind speed derived by averaging the 12 models results. Units are % change per °C of global warming. DJF = summer, MAM = autumn, JJA = winter, SON = spring.

Figure 2.11 – Change in extreme monthly wind speeds for NSW coast (Hennessy et al., 2004)

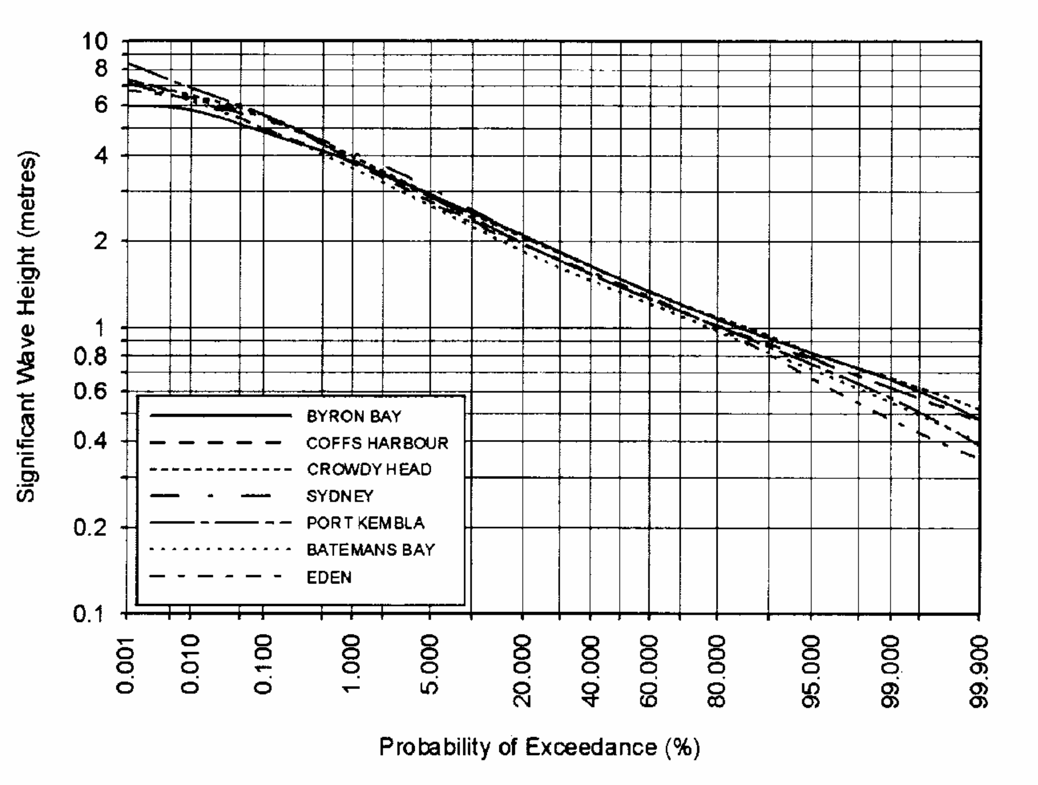


Figure 2.12 – Significant wave height exceedance for NSW coast (Lord & Kulmar, 2000)

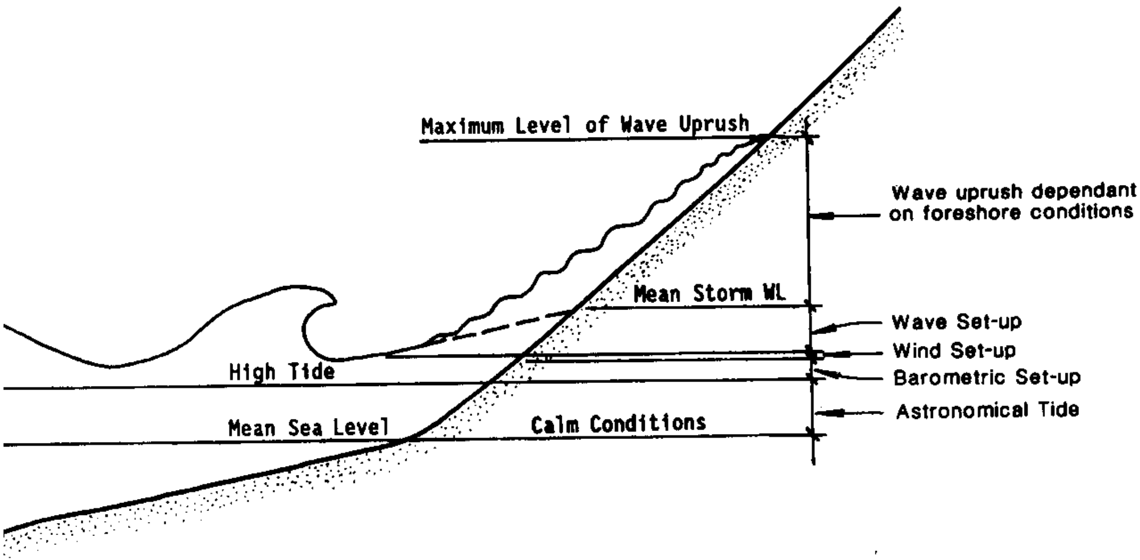


Figure 2.13 – Components of elevated water levels on the coast (NSW Government, 1990)

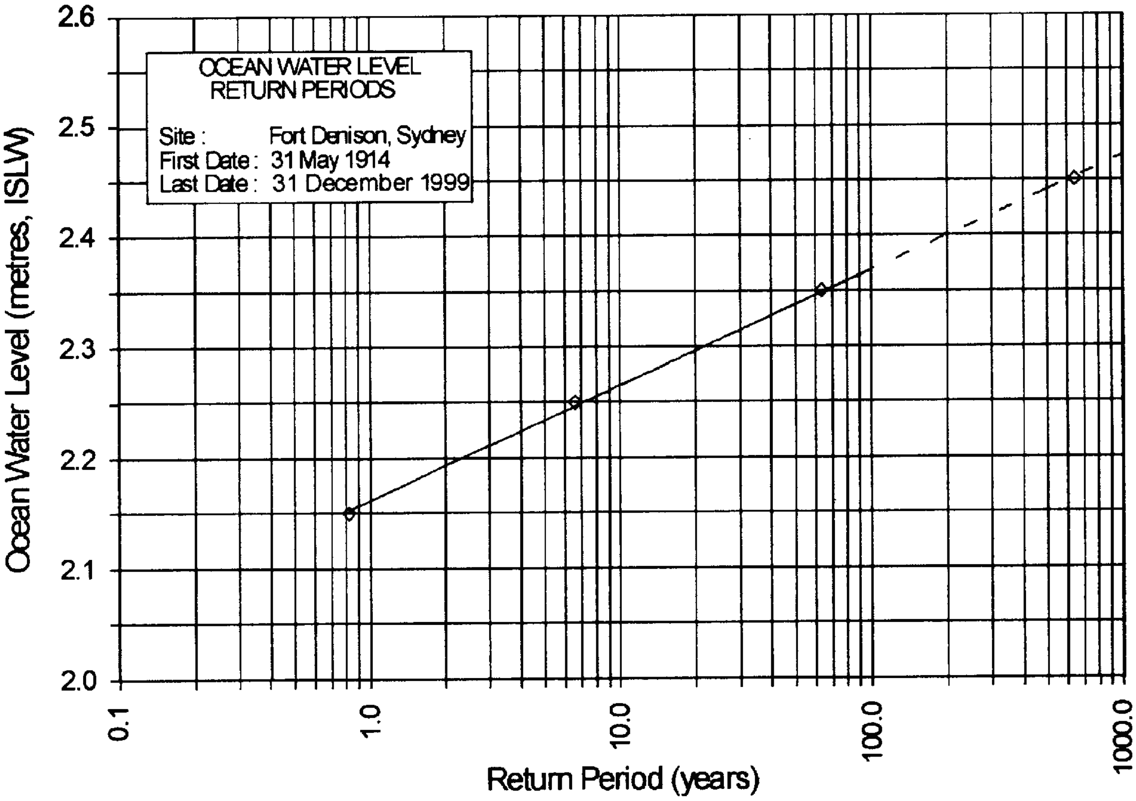


Figure 2.14 – Sydney ocean level recurrence (Lord & Kulmar, 2000)

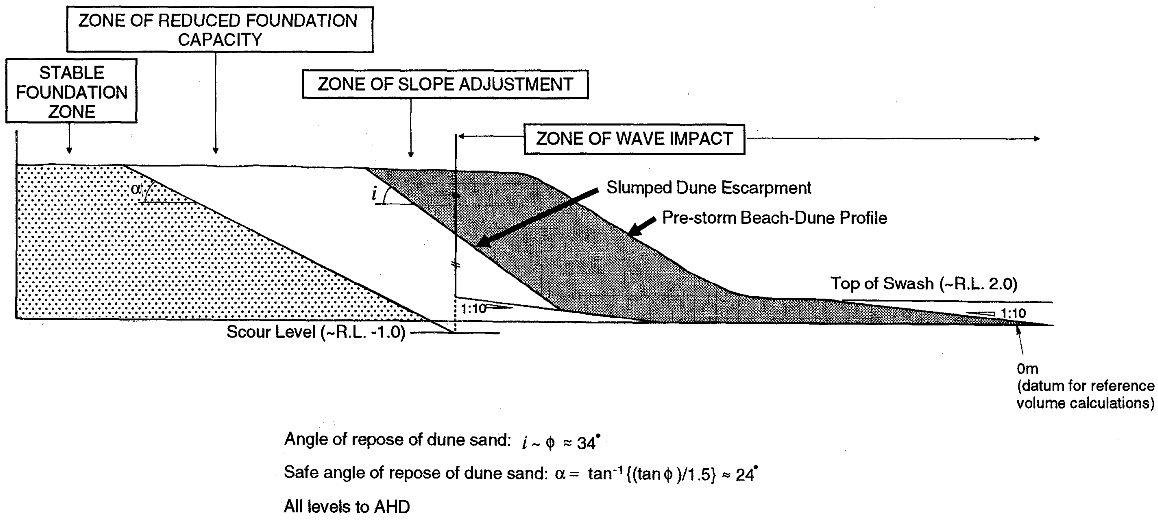


Figure 3.1 – Dune stability schema (after Nielsen et al., 1992)

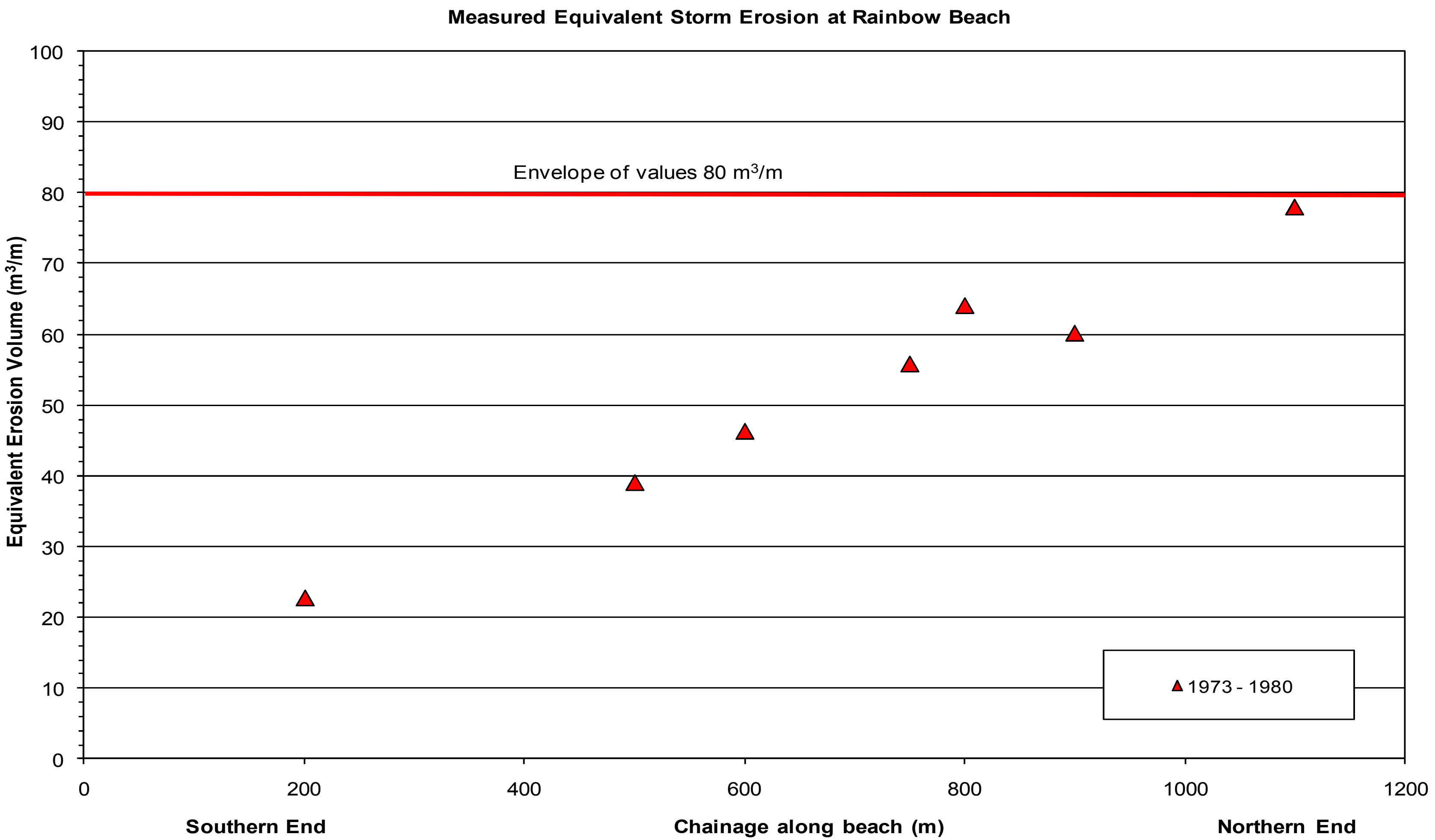
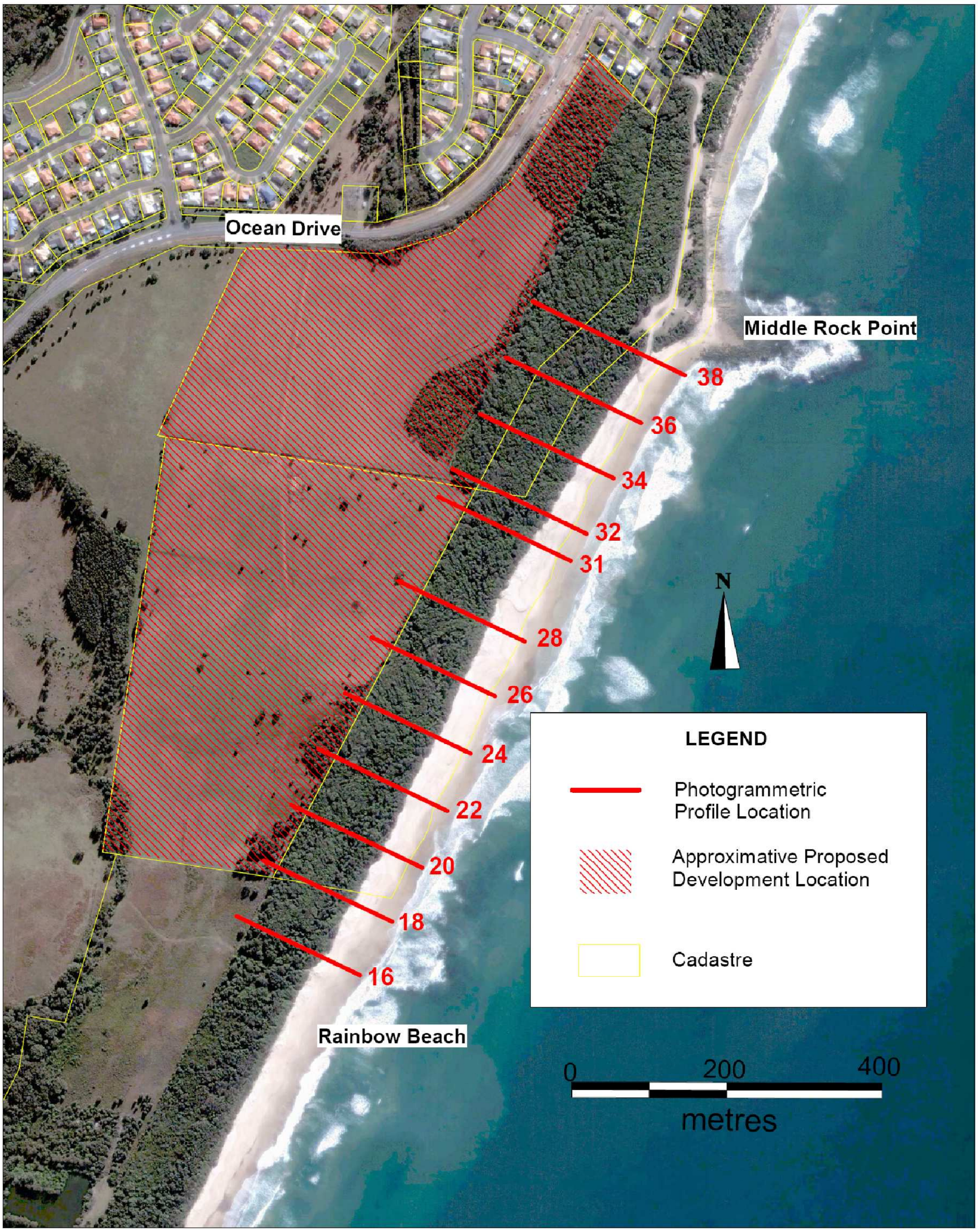


Figure 3.2 – Equivalent Storm Erosion volume for the 1974 storms along the proposed development area at Rainbow Beach



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PHOTOGRAMMETRIC PROFILES LOCATION

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OCEAN DRIVE - LAKE CATHIE

Figure 3.3 – Photogrammetric profiles locations at Rainbow Beach

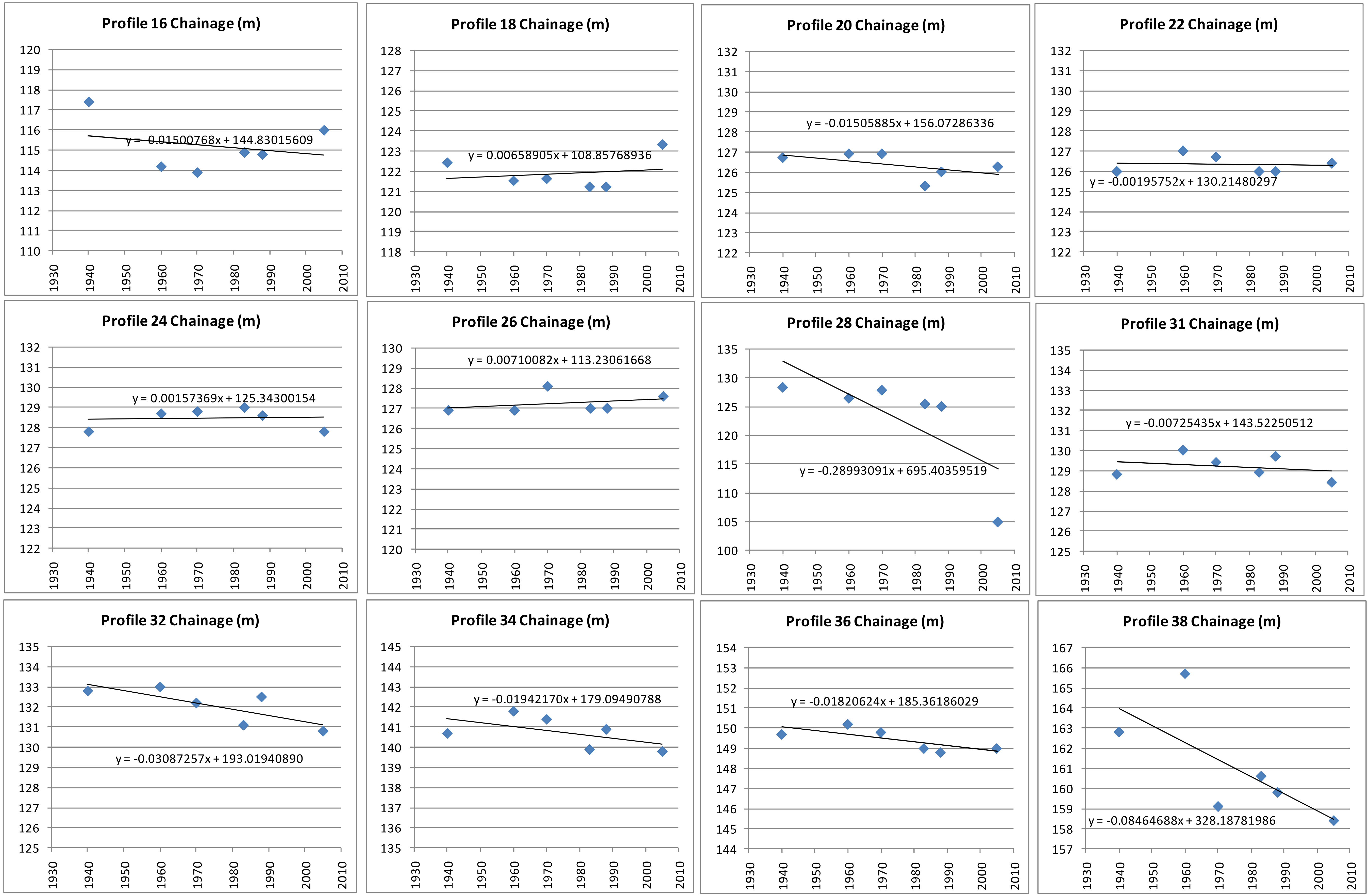


Figure 3.4 – Location of the 6.0m AHD contour between 1940 and 2005 for the different profile fronting the proposed development area at Rainbow Beach

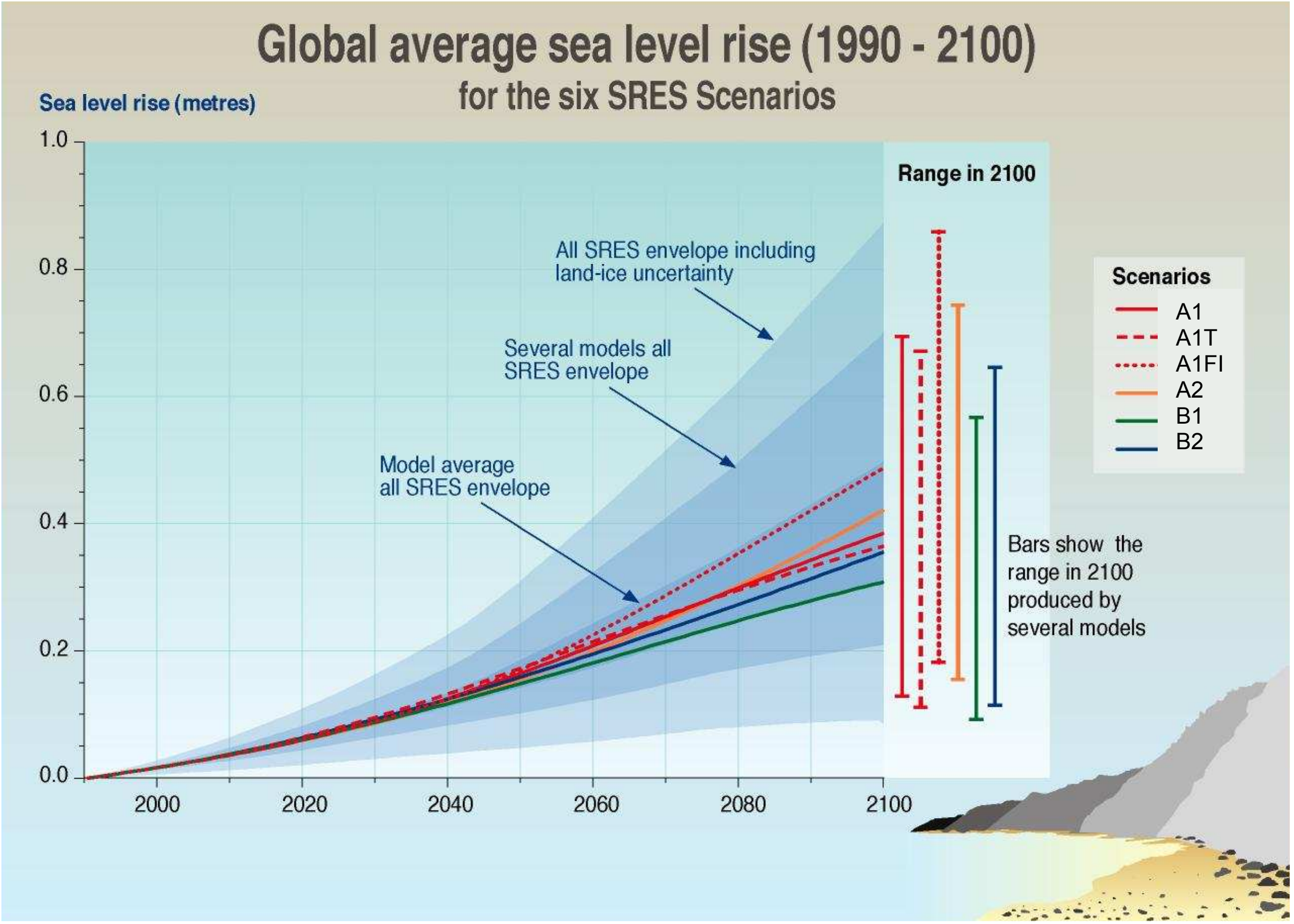


Figure 3.5 – IPCC (2001) Sea level rise estimates

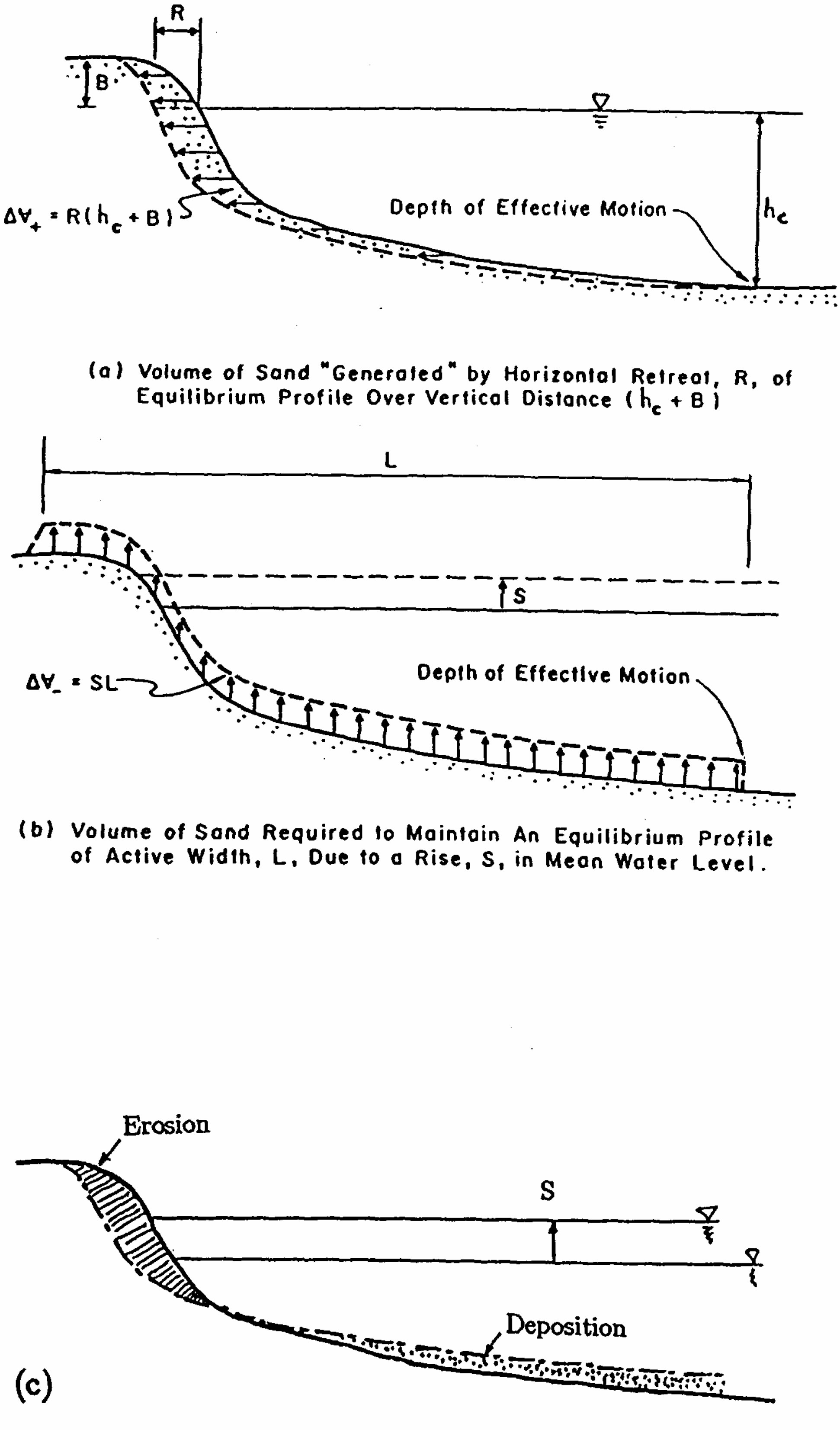


Figure 3.6 – Concept of shoreline recession due to sea level rise

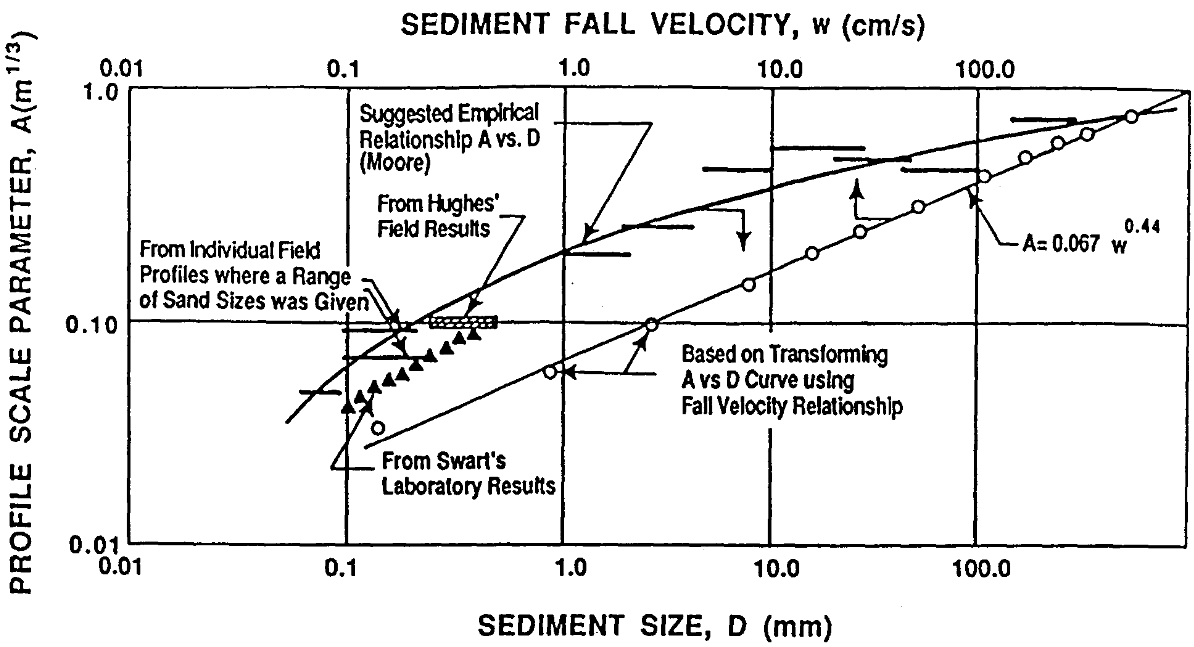


Figure 3.7 – Suggested relationship for shape factor A vs. grain size D

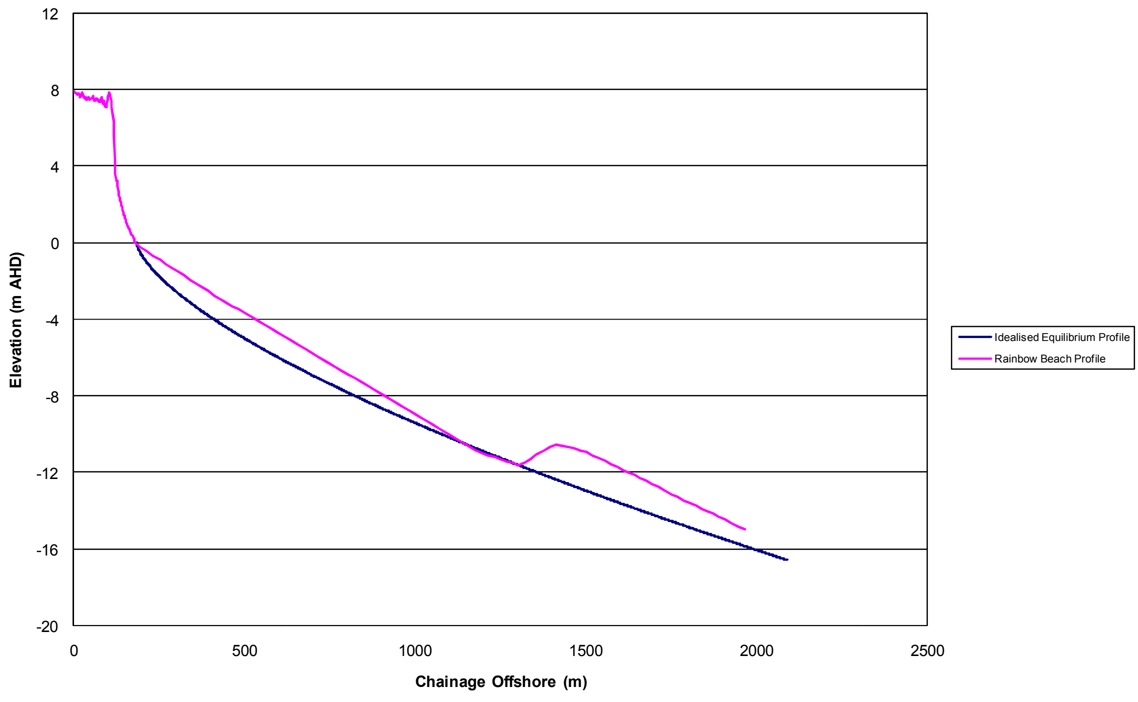
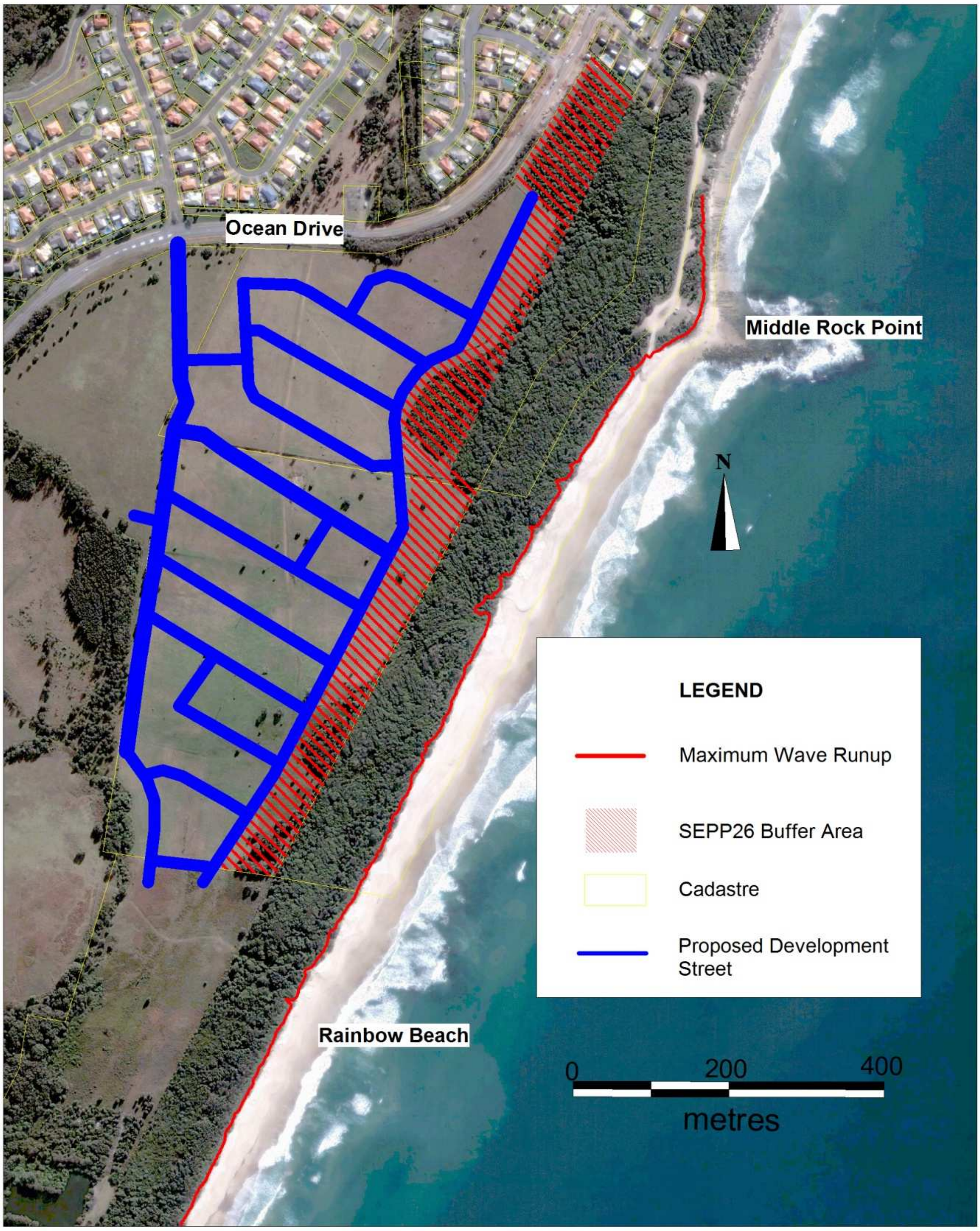


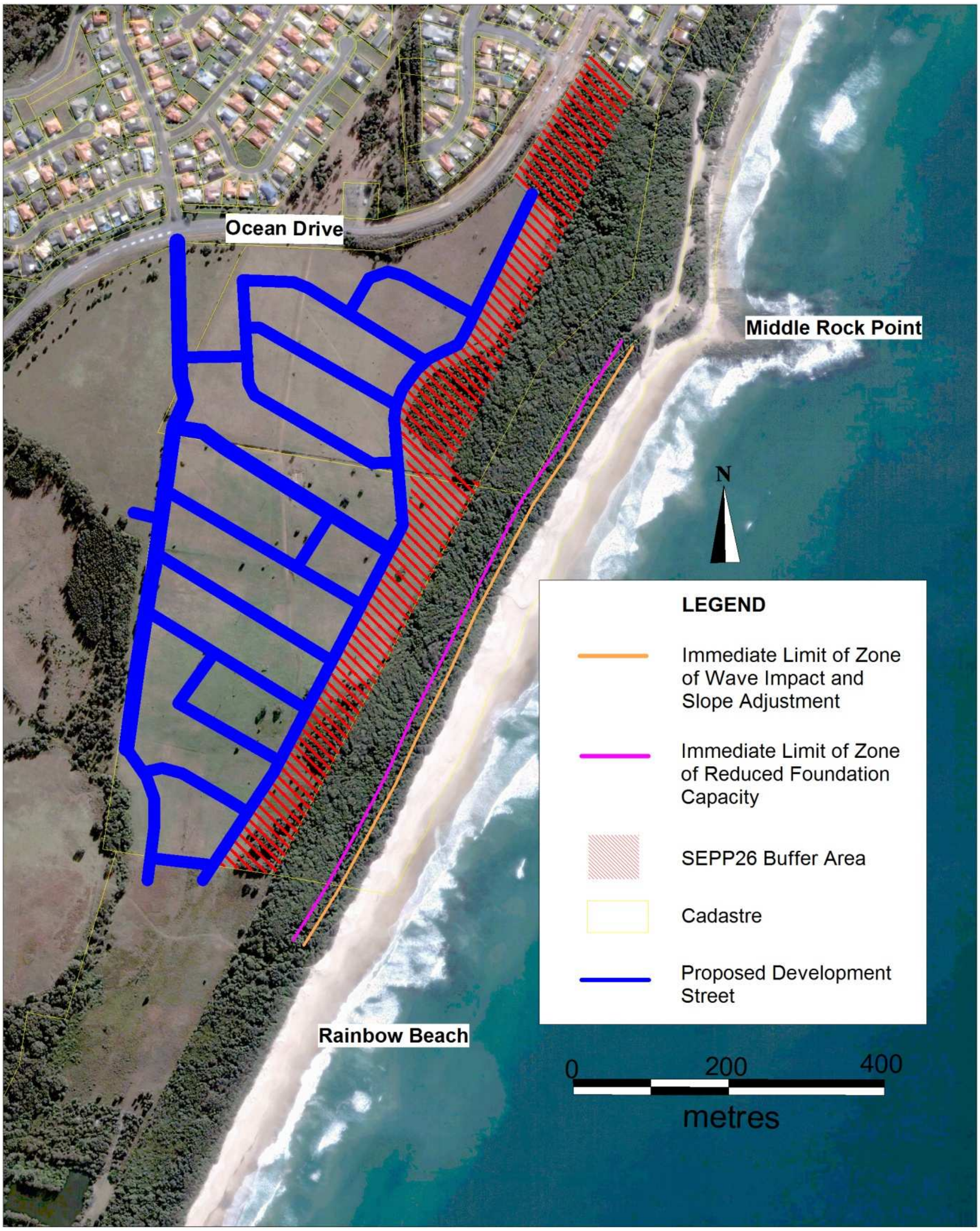
Figure 3.8 – Nearshore profile at Rainbow Beach vs. idealised equilibrium profile



MAXIMUM WAVE RUNUP

COASTAL HAZARD STUDY
OCEAN DRIVE - LAKE CATHIE

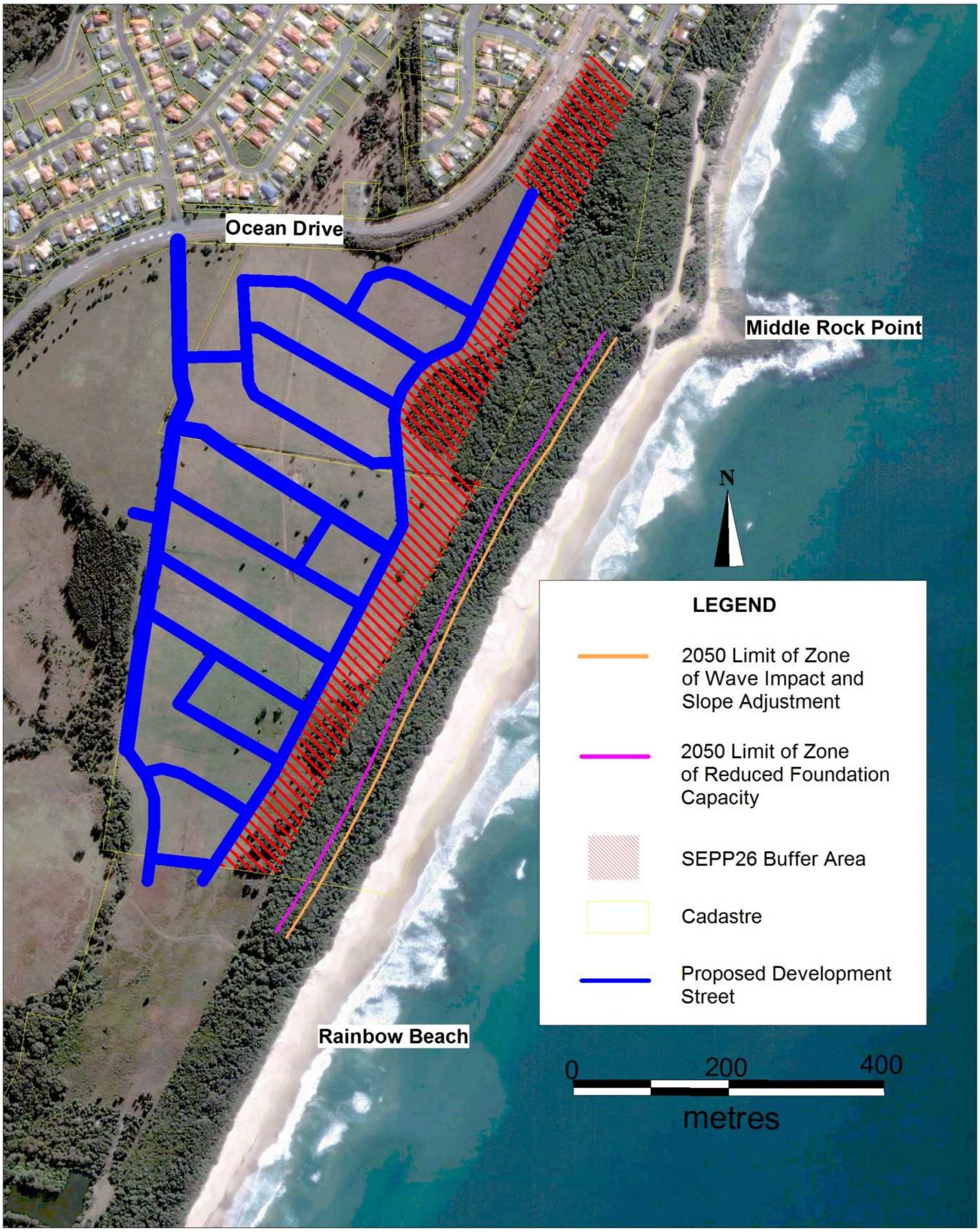
Figure 3.9 – Maximum wave runup



IMMEDIATE HAZARD ZONE

COASTAL HAZARD STUDY
OCEAN DRIVE - LAKE CATHIE

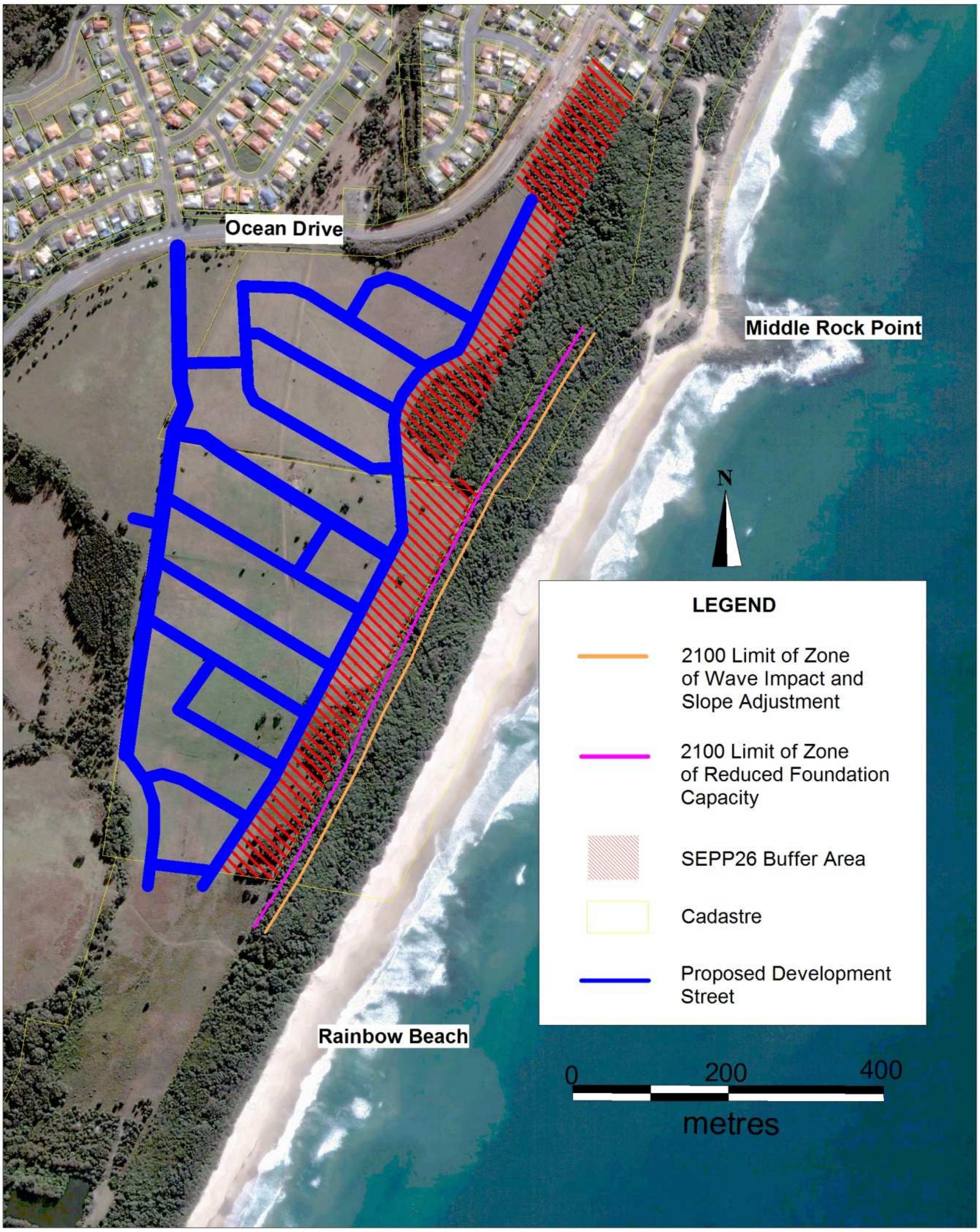
Figure 4.1 – Immediate Hazard Zones



2050 HAZARD ZONE

COASTAL HAZARD STUDY
OCEAN DRIVE - LAKE CATHIE

Figure 4.2 – 2050 Hazard Zones



2100 HAZARD ZONE

COASTAL HAZARD STUDY
OCEAN DRIVE - LAKE CATHIE

Figure 4.3 – 2100 Hazard Zones

Figure 5.1 – Board and chain accessway (Coastal Dune Management, NSW Government, 2001)

Figure 5.2 – Crushed sandstone accessway (Coastal Dune Management , NSW Government, 2001)

Figure 5.3 –Conveyor belt pathway (Coastal Dune Management , NSW Government, 2001)

Figure 5.4 – Pavers pathway (Coastal Dune Management , NSW Government, 2001)

Figure 5.5 – Asphalt accessway (Coastal Dune Management , NSW Government, 2001)

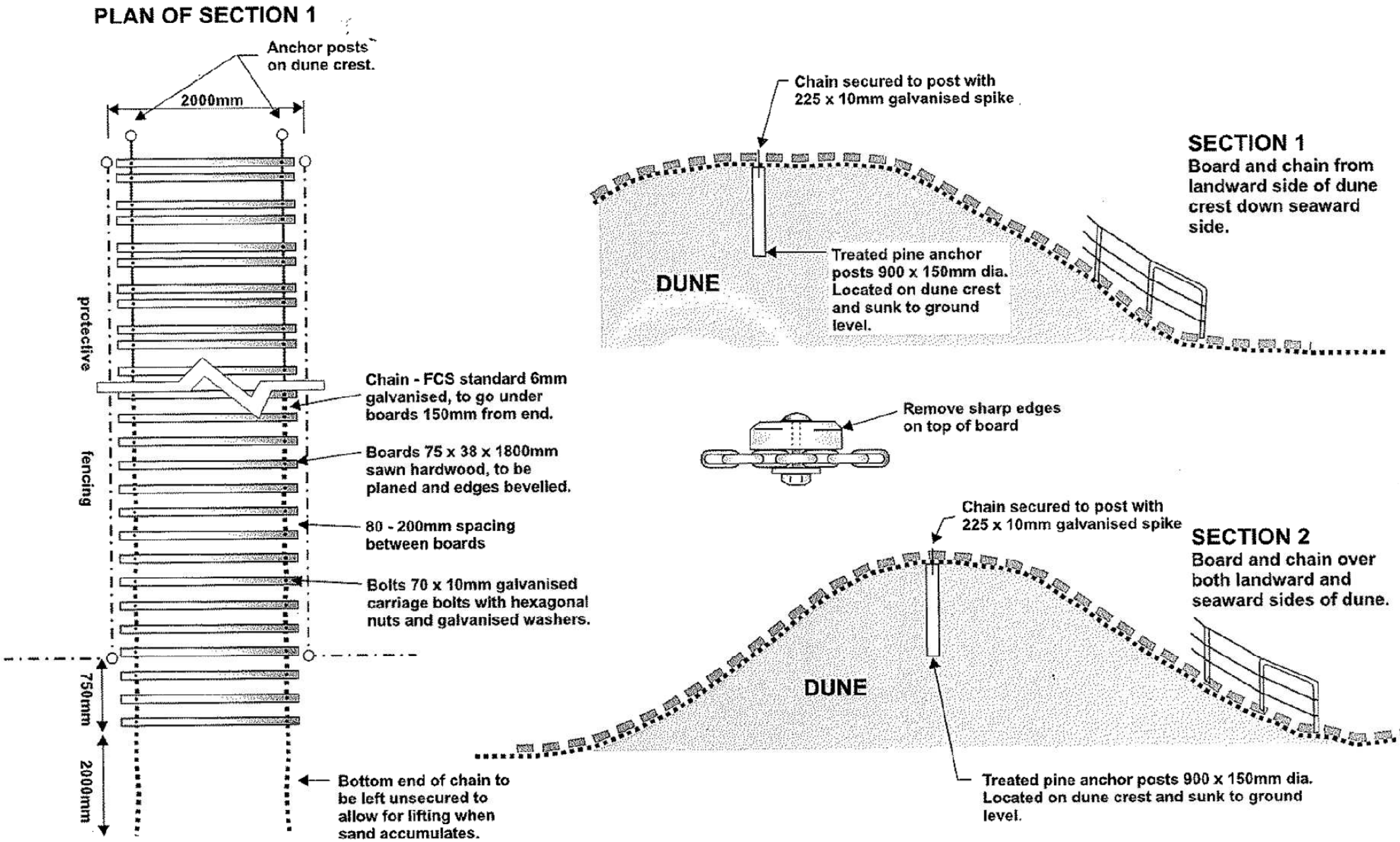


Figure 5.6 – Pedestrian board and chain characteristics (Coastal Dune Management , NSW Government, 2001)

DIMENSIONS FOR RISERS AND TREADS

SLOPE	HEIGHT OF RISER	DEPTH OF TREAD
1 in 5	100	475
1 in 4	115	450
1 in 3.5	125	425
1 in 3	135	400
1 in 2.5	150	380
1 in 2	165	330
1 in 1.5	175	280

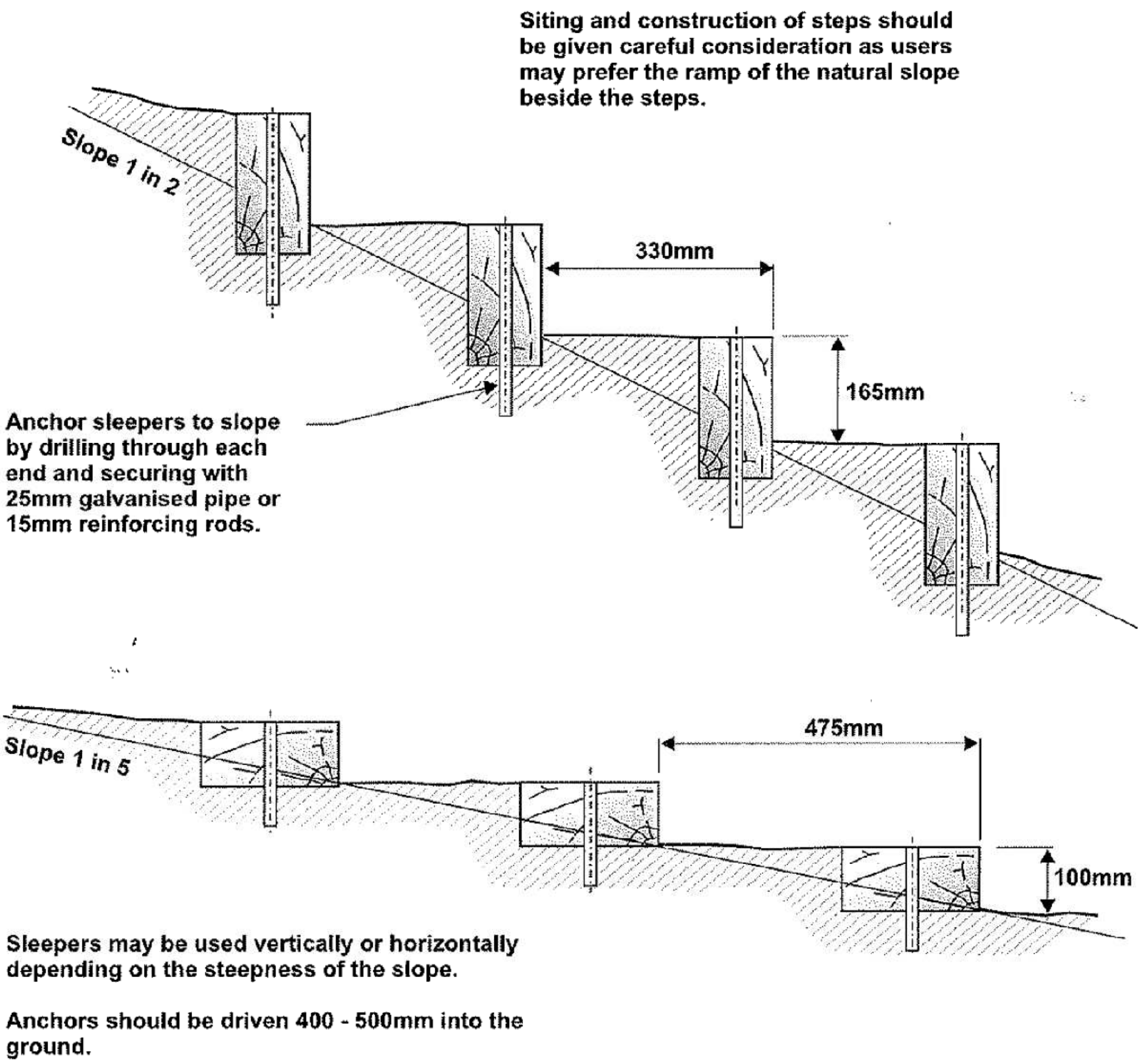


Figure 5.7 – Dimensions for riser and treads for a stairway design (Coastal Dune Management , NSW Government, 2001)

Figure 5.8 – Elevated walkway (Coastal Dune Management , NSW Government, 2001)