Coffs Harbour Coastal Processes and Hazards Definition Study
Volume 1: Final Report

Offices

Brisbane
Denver
Mackay
Melbourne
Newcastle
Perth
Sydney
Vancouver

Prepared For:	Coffs Harbour City Council
Prepared By:	BMT WBM Pty Ltd (Member of the BMT group of companies)

DOCUMENT CONTROL SHEET

BMT WBM Pty Ltd BMT WBM Pty Ltd 126 Belford Street BROADMEADOW NSW 2292 Australia PO Box 266 Broadmeadow NSW 2292 Tel: +61 2 4940 8882 Fax: +61 2 4940 8887 ABN 54 010 830 421 003 www.wbmpl.com.au	***Document :***	R.N1440.002.02.CoastalHazards_Final.doc
	Project Manager :	Philip Haines
	Client :	Coffs Harbour City Council
	Client Contact:	Martin Rose, Malcolm Robertson
	Client Reference	

Title :	Coffs Coast Coastal Processes and Hazards Definition Study Volume 1: Final Report
Author :	Verity Rollason, Philip Haines
Synopsis :	This Coffs Coastal Processes and Hazards Definition Study Report presents a summary of coastal processes (from the Coffs Coastal Processes Draft Progress Report), and then provides the methodology and outcomes for the definition of the eight coastal hazards on the Coffs regional coastline. The likelihood (‘almost certain’, ‘unlikely’ and ‘rare’) of beach erosion and shoreline recession, and separately, coastal inundation have been mapped for the immediate, 2050 and 2100 horizons. Detailed hazard maps are contained in the Figures Compendium volume of this report.

REVISION/CHECKING HISTORY

REVISION NUMBER	DATE OF ISSUE	CHECKED BY		ISSUED BY	
0	14/05/10	PEH / DCP		PEH	
1	18/09/10	PEH		PEH	
2	15/02/11	PEH		PEH	

DISTRIBUTION

DESTINATION	REVISION			
	0	1	2	3
CHCC	3 + elec	1 elec	4 + elec	
BMT WBM File	1	1	1	
BMT WBM Library	1	1	1	

CONTENTS

LIST OF FIGURES

LIST OF TABLES

FIGURES COMPENDIUM

Refer to Volume 2 of this Report series.

1 INTRODUCTION

This Coffs Harbour Coastal Processes and Hazards Definition Study project investigates the coastal processes occurring on the Coffs Harbour Local Government Area (LGA) coastline (the Coffs coastline) and the extent of the coastal hazards arising from these processes. This report documents a summary of coastal processes, methodology used to assess the coastal hazards, approach to hazards definition mapping, and a detailed beach by beach summary of analyses and outcomes.

A more detailed assessment of the coastal processes is presented in the Coffs Harbour Coastal Process Progress Report (Progress Report) (BMT WBM, 2009c). A summary of the Progress Report is given within this report, to provide the background knowledge required to understanding coastal hazards at the Coffs coastline. The summary includes regional geology and geomorphology, wave climate and variability, climate change projections, water levels, and the interaction of these resulting in longshore and cross shore transport to shape the coastline evident today.

The methodology used to assess the eight coastal hazards as defined in the Coastline Management Manual (CMM) (NSW Government, 1990) is detailed within this report. This includes our approach to beach erosion incorporating wave climate variability, and most notably, the use of the “world’s best practice” Shoreline Evolution Model to assess shoreline recession due to sea level rise and shoreline structures (e.g. headlands, breakwaters).

The definition and mapping of coastal hazards in this study adopts a ‘probability of occurrence’ or ‘likelihood’ of hazard extent. Following the Australian Standard for Risk Management (AS/NZS ISO 31000:2009), the likelihood scale of ‘almost certain’, ‘likely’, ‘possible’, ‘unlikely’ and ‘rare’ was adopted (although only ‘almost certain’, ‘unlikely’ and ‘rare’ have been mapped). Risk assessment is now the prescribed framework for assessing and evaluating coastal hazards and their associated risk by the NSW Government (DECCW, 2009a, 2009b, 2009c) whereby risks are determined giving consideration to both ‘likelihood’ and ‘consequence’ of occurrence. Within this risk assessment framework, the definition of the “consequences” from each of the coastal hazards would be undertaken during the subsequent Coastal Zone Management phase for the Coffs coast. This approach has distinct advantages for Council, most notably, the ability to undertake land use planning appropriate to the level of risk from coastal hazards in each beach compartment.

The mid north coast is expected to experience a population growth rate of ~ 1.1% per year over the next 25 years. This growth rate is amongst the highest in regional NSW, with Coffs Harbour expected to support a high proportion of this North Coast population growth (DP, 2009). Residential growth to accommodate the increasing population in the Coffs region is to occur within mapped urban areas, with Coffs Harbour as a regional centre and Woolgoolga as a major town in the Mid North Coast region (DP, 2009). Existing and future development (residential and recreational) within the coastal zone will require careful consideration of the likelihood and consequence from coastal hazards, including climate change impacts, to ensure development is undertaken as appropriate to the level of risk at present and in the future, thereby reducing the liability of Council from poorly planned or inappropriate development.

This Coffs Harbour Coastal Processes and Hazards Definition Study report is set out as follows:

Chapter 2 provides a summary of coastal processes operating along the Coffs coastline;

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

Chapter 4 details for each beach compartment the hazards analyses and outcomes utilised to define the likely extents of hazards over each planning timeframe (immediate, 2050 and 2100);

Figures Compendium provides the full suite of hazard maps for the combined beach erosion and shoreline hazards and for coastal inundation along each section of coastline at the immediate, 2050 and 2100 timeframes; and

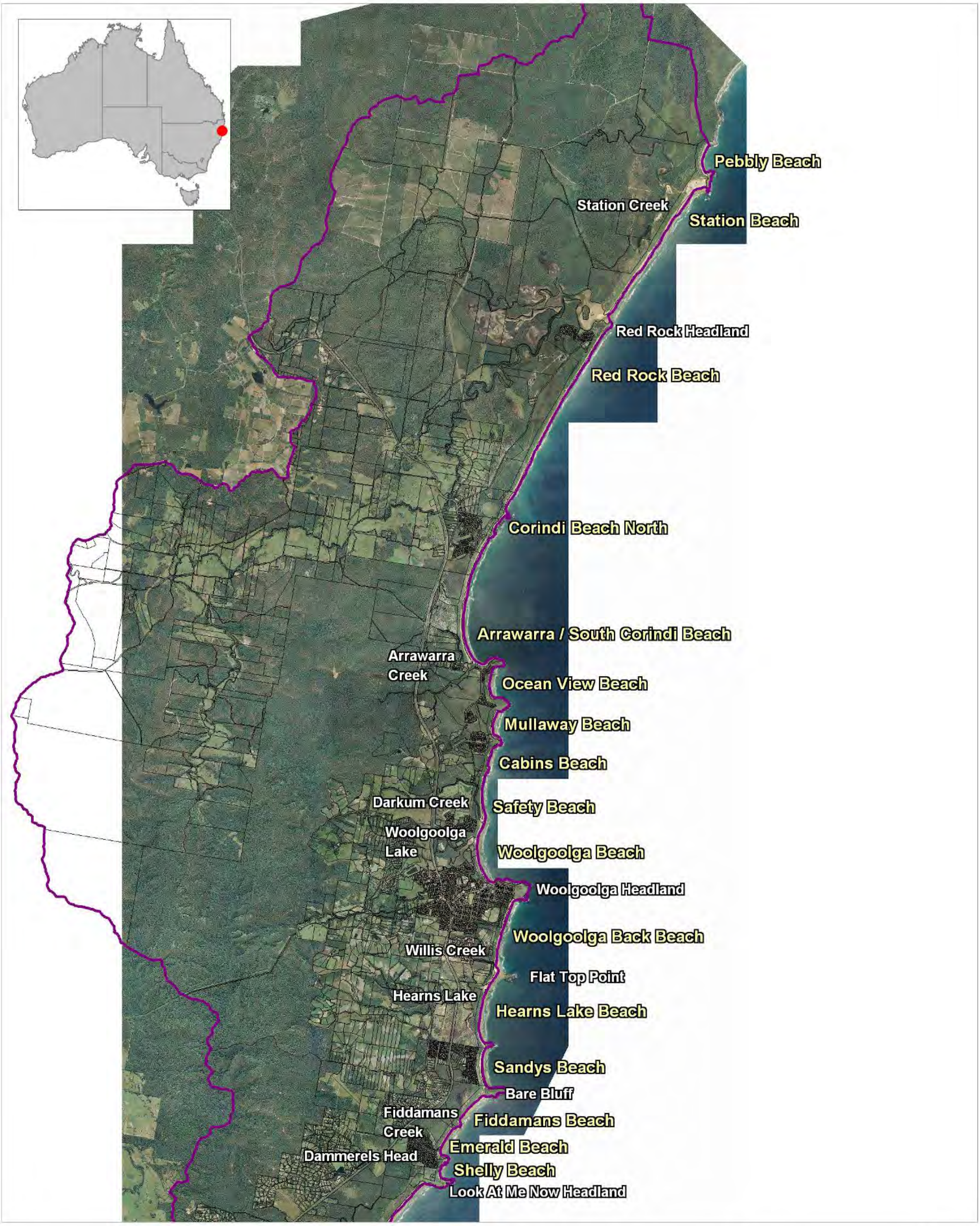
Appendices provide supplementary information for this report, most notably, the Progress Report in full which provides a detailed discussion of coastal process for the Coffs coastline.

1.1 Study Area

The Coffs Harbour Local Government Area (LGA) is situated on the NSW north coast approximately mid way between Sydney and Brisbane. The Coffs Harbour LGA coastline and its beaches are illustrated in Figure 1-1 and Figure 1-2.

The Coffs coastline is 79 km in length, which includes 38 beach embayments (Short, 2007). Of these, 31 beach embayments lie within the Solitary Islands Marine Park (SIMP), which extends from Muttonbird Island at Coffs Harbour to Plover Island at Sandon River, north of the Coffs LGA.

Many of the Coffs Harbour beaches also lie within land based reserves, namely: Bongil Bongil National Park which covers Bongil Beach and North Beach; Muttonbird Island Nature Reserve, which includes Muttonbird Island (but no beaches); Coffs Coast Regional Park, which incorporates beaches from Charlesworth Bay to Woolgoolga Back Beach; Moonee Beach Nature Reserve, which includes Moonee Beach and Fiddamans Beach; and Yuraygir National Park which includes Pebbly Beach and Station Beach.



Title:

Coffs Harbour LGA Study Area North

Figure:

1-1

Rev:

A

N

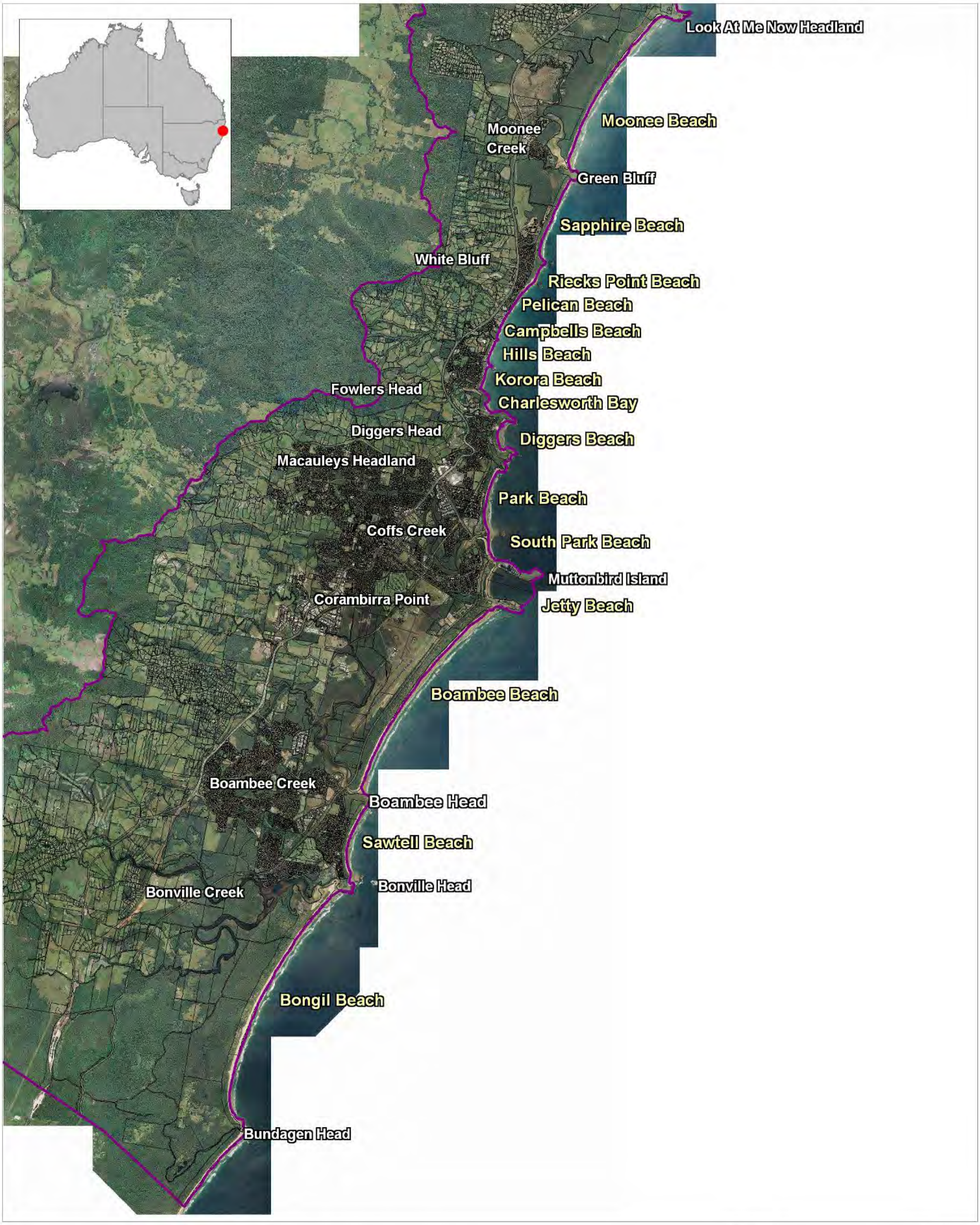
0 2.5 5km

Approx. Scale

BMT WBM

www.wbmpl.com.au

Filepath : K:\N1440 Coffs Coastal Process Hazard Definition Study\MapInfo\Workspaces\StudyArea_Figure_N.WOR



Title:

Coffs Harbour LGA Study Area South

Figure:
1-2

Rev:
A

N

0 2.5 5km
Approx. Scale

BMT WBM
www.wbmpl.com.au

Filepath : K:\N1440 Coffs Coastal Process Hazard Definition Study\MapInfo\Workspaces\StudyArea_Figure_S.WOR

2 COASTAL PROCESSES SUMMARY

2.1 Introduction

In this section, the coastal processes that have shaped the morphology of the Coffs regional coastline are described. Each of the coastal processes are related to or interact with each other to some degree and such interactions are described as required.

A detailed discussion of coastal processes is given in the Progress Report (BMT WBM, 2009c), included as Appendix A to this document.

2.2 Regional Geology and Geomorphology

Regional geology determines the orientation of the coastline, the width and slope of the continental shelf, the type and location of headlands, reefs and other structures, embayment width and sediment grain size and type. The interaction of waves, tides and sea level changes with regional geology, and determines the shape of past, present and future shorelines and coastal barriers.

Broadly, the NSW coast is described as being strongly controlled by bedrock, which outcrops as headlands, rock platforms and cliffs. From south to north along the NSW coastline there is a general increase in the embayment length as there are fewer bedrock outcrops / headlands, and so, an increase in the length and width of Quaternary barrier deposits (i.e. beaches and dunes).

The Coffs region differs from the coastline of the surrounding north coast region by being more embayed due to the type of bedrock geology. Coastal embayments in Coffs are described as small and narrow to medium sized, while either side of this area, coastal embayments are described as medium to large and broad (Troedson *et al*., 2004). This is because Coffs lies within the New England Fold Belt province and bedrock outcrops (headlands, cliffs, rock platforms, low relief rock reefs) spur outward from the nearby coastal ranges in the west towards the coastline, to form the (relatively narrower) beach embayments. The bedrock geology is typically composed of highly deformed paleozoic meta-sedimentary rock (Troedson *et al.,* 2004).

North of Red Rock there is an obvious change in the coastline character, in line with a change in geology, moving out of the New England Fold Belt. North of Red Rock there are very few headland protrusions, and instead the coastline is of low relief and comprises long stretches of sandy beach and coastal dunes (Short, 2007).

The age and extent of coastal barrier formation reflects sea level rise from the past to present. A prior sea level high stand occurred during the Pleistocene around 120,000 years ago (the Last Interglacial period, 117,000 to 133,000 yr BP). At this time, sea levels were around 5 m above their present levels (Troedson *et al.*, 2004). The last glacial period between 25,000 and 15,000 years ago saw sea levels around 110-130 m below their present level. After this, sea levels rose rapidly and reached the present level around 6,500 years ago, in the Holocene period. Sea levels have remained within 1 to 2 m of their present levels since this time (Troedson *et al.,* 2004).

Coastal barriers evident on the coast today have formed in response to the Pleistocene and Holocene sea level high stands. Barriers formed during the Pleistocene are termed inner barrier deposits, having formed during higher sea levels than present, and are still evident in some locations along the NSW coast. The more recent Holocene beach barriers systems are typically termed the outer barrier (Troedson *et al.,* 2004).

The Coffs regional geomorphology is therefore summarised as follows (as given in the Progress Report, Appendix A):

- A multiple sand barrier and estuary type coastline with extensive outcrops of rock reef offshore from the headlands between Bundagen Headland and Coffs Harbour;
- Smaller pocket or embayed beaches, with an increase in offshore rock reefs north from Coffs Harbour to Arrawarra Headland; and
- Between Arrawarra Headland and Station Creek, the longer sand barrier and estuary type coastline is again dominant.

2.2.1 Shoreface Bathymetry

The continental shelf of NSW is the narrowest continental margin along the entire Australian coast (Short, 2007), up to only 50 km in width (Troedson *et al*., 2004). The width of the continental shelf widens towards the northern border of NSW. The width of the shelf affects the dissipation and shoaling of waves as they are transformed from deep water into the nearshore zone (Troedson *et al.*, 2004).

The active shoreface, or nearshore zone, extends from the shoreline to water depths of 20 – 30 m and is divided into three zones:

- Surf zone from 0 to 5 m water depth, extending from the beach berm to the outer sand bar;
- Inner nearshore zone from 5 to 12 m depth; and
- Outer nearshore zone from 12 to between 20-30 m depth.

The boundary between inner and outer nearshore sands is commonly stated to be the “depth of closure”. That is, cross shore sediment transport processes, particularly during storms, that may supply sediment to the beach face essentially ceases beyond this boundary. Other studies both around Coffs and regions immediately north and south (Lennox Head, Evans Head) note this boundary to be at ~ 11 m water depth (PBP, 2004).

Seawards from depths of 20-30 m is the boundary between nearshore and inner shelf sediments. This boundary is said to be the boundary between the active and relict shoreface.

The slope of the nearshore zone from Sawtell to White Bluff has been described by Lord and Van Kerkvoort (1981) to be flatter than in other regions of similar exposure and orientation in NSW. The Campbells Beach nearshore zone between the 0 and 20 m contour has slopes of 1:100 to 1:175, and is one of the flattest nearshore zones in NSW (WP Geomarine, 1998). Other studies in the region have utilised steeper slopes, of around 1:50 (PWD, 1995, PBP, 2004). Analysis of nearshore slopes based upon the hydrographic survey maps of the region for use in the Shoreline Evolution Model (Section 3.4.1) determined a slope of ~ 1:60 to be appropriate in the Coffs region.

2.2.2 Nearshore Sediments

The inner nearshore sediments may provide a sediment source to the upper beach face, via cross-shore transport processes. Available supplies will affect the recovery of beaches and response to sea level rise.

Between Bundagen Head and Coffs Harbour, Holocene dune barrier sands are more extensive and sand deposits in the nearshore zone are said to be semi-continuous. The nearshore sediment source is thought to have supplemented accretion upon these beaches over the Holocene period (refer Progress Report, Appendix A).

North of Coffs Harbour, it is thought that the inner nearshore sand unit does not continue across Coffs Harbour mouth and is also restricted around Macauleys and Diggers Headlands (Lord and Van Kerkvoort, 1981). The nearshore bathymetry at least to White Bluff contains extensive offshore reefs and prominent headlands (Lord and Van Kerkvoort, 1981). The entire nearshore sand unit is described as a thin mobile cover over a coarse grained, light brown shelly inner shelf sand, as well as bedrock, gravels and clay (Lord and Van Kerkvoort, 1981; Stephens and Roy, 1980). The inner shelf deposits may outcrop in the nearshore zone as patches of gravel and sandy gravel. Holocene beach, and dune deposits are also minimal in width and volume North of Coffs Harbour at lease to White Bluff (refer Progress Report, Appendix A).

The presence of exposed rock reefs, gravels and shell lags in the nearshore zone immediately north of Coffs Harbour suggests sediment supplies in the nearshore zone are limited, as prior wave action has mobilised and transported available sand landwards and alongshore, leaving heavier fractions (gravel, shell lags) behind in the nearshore zone. In addition, the cessation of littoral transport past the harbour breakwaters (as discussed in detail in Section 2.8.2.2) has resulted in increased demand upon available nearshore sediment supplies, further depleting the supplies in the nearshore (in addition to dune supplies) and causing overall shoreline recession. Gravel and coarser sediments upon beaches north of the harbour have been supplied from the nearshore gravel and shell lags. BMT WBM personnel noted the beaches between Sawtell and White Bluff to have extensive coverage of gravels, which are consistent with the nearshore and inner shelf sediments described. The northern beaches have additionally become coarser as finer sand is winnowed from beach sediments, as part of the shoreline recession due to the harbour construction.

North of Moonee Beach to Red Rock, observations from aerial photography suggest that rock reefs are extensive in the nearshore zone along this section of shoreline. This may suggest lesser nearshore sediment supplies along this coastline section also. The impact of the rock reefs to the upper beach face in relation to wave dissipation, sediment supplies and sea level rise is discussed throughout this report.

The surf zone and inner nearshore sand unit is fine to coarse grained (0.27 to 0.20 mm), occasionally gravelly, fawn coloured, ranging from angular to rounded. The sands comprise 0 to 5% shell, 0 to 1% heavy minerals, and 1 to 3% rock particles. The outer nearshore unit comprises fine grained (0.19 to 0.18 mm), grey coloured sand (Stephens and Roy, 1980).

2.2.3 Headlands, Reefs and Coastal Structures

As noted above, Coffs Harbour differs from the regions immediately north and south by having a greater number of headland outcrops, which separate the coastline into smaller embayments. The coastline also has numerous rock reefs, some of which lie adjacent to the shoreline (forming tombolos behind) and some of which are located further offshore. In addition, Coffs Harbour breakwalls were completed in 1946, which have had a significant impact upon the coastline character of the Coffs region both up drift (south) and down drift (north) of the structure.

Notable headlands from south to north that are likely to have a strong control on sediment transport include Bonville Head, Macauleys Head, Diggers Head, Look At Me Now Headland, Woolgoolga Head and Arrawarra Headland, in addition to Coffs Harbour. The numerous other small headlands and shoreline rock reefs also affect the character of the coastline to a lesser and more local degree. The effect of headlands, reefs and the harbour upon longshore sediment transport and beach character is outlined in greater detail in Section 2.8.2.

2.2.4 Beach State

Wright and Short (1984) developed a beach classification system for wave-dominated coasts, based on wave energy exposure, beach and surf zone morphology and sediment grain size. The classification system is useful as it describes the exposure of beach embayments to the existing wave climate, particularly wave height, and the response of the beach embayment depending upon the existing beach sediments and geology.

Short (2007) has classified all of NSW's beaches into their respective beach types. Coffs coast beaches are typically intermediate beaches that oscillate between up to four beach states, depending on the wave height conditions. Intermediate beaches are typified by one to two roughly parallel sand bars cut by beach rips at regular intervals, medium to fine grained sand, and experiencing moderate to high wave conditions. The beach state classification system of Wright and Short (1984) with example beaches in the Coffs Region is given in Table 2-1. The typical state of individual beaches in Coffs Harbour is discussed in Chapter 4.

2.2.5 Sand Mining

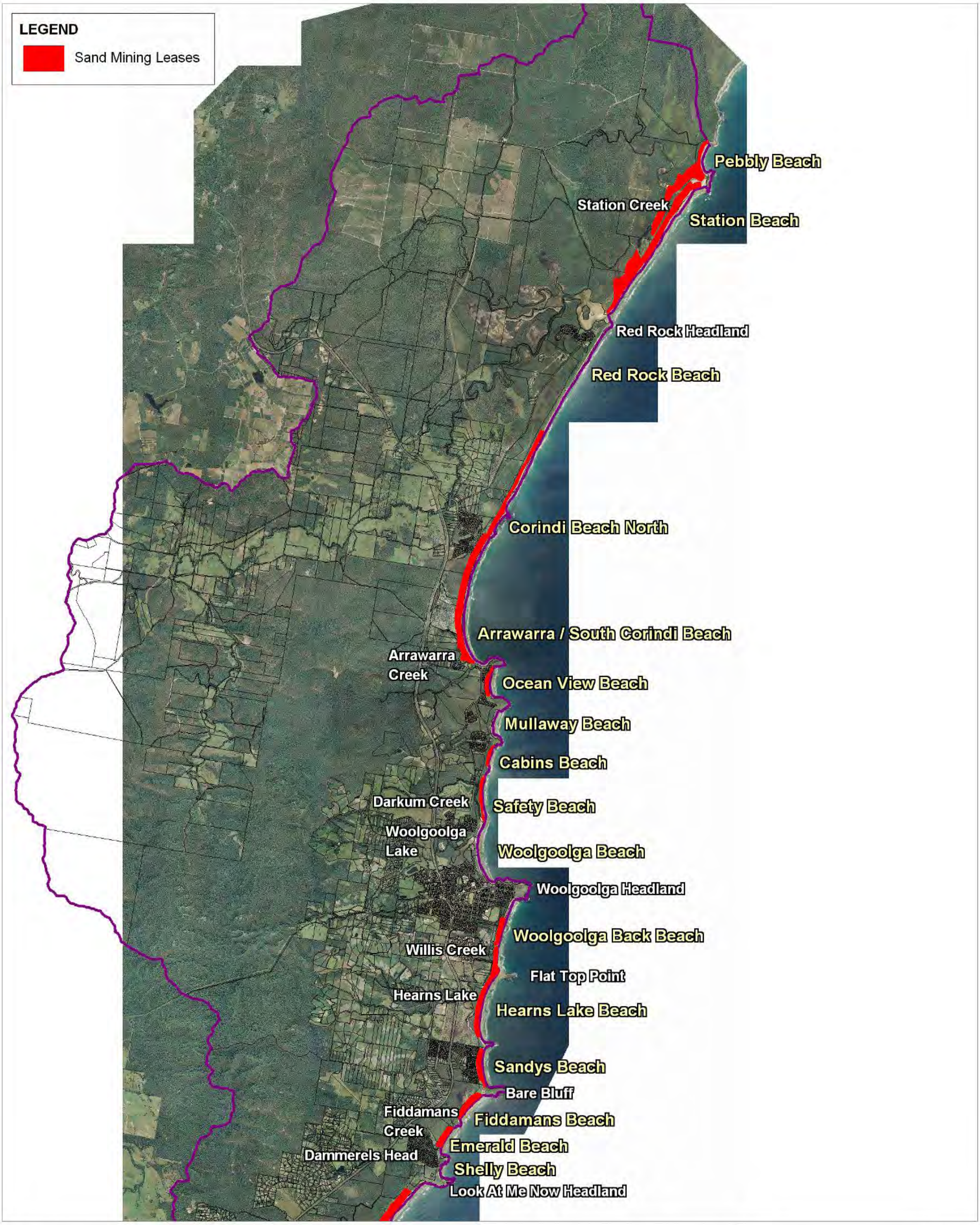
Sand mining for mineral sands occurred extensively along the NSW coast including the Coffs region over the 1950s, 1960s and 1970s. Maps of the location of former sand mining leases are shown in Figure 2-1 and Figure 2-2. Sand mining was typically undertaken in the foredune region, and in some cases hind dunes. In some places, extraction of sand from the incipient / active beach face also took place (likely for building / other purposes).

Sand mining involved substantial relocation of dune sand and removal of the heavy mineral component. Typically, 1-3% of the sand volume within the mined area was removed. In some cases, entire foredunes were removed and not reformed to previous profiles (i.e. dunes may have been re-established in different locations and shapes).

The impacts of sand mining are particularly relevant to the interpretation of photogrammetric data. Care has been taken in interpreting the photogrammetry, to identify where mining obviously took place and, wherever possible, avoid inclusion of these areas in data analysis. For some beaches, however, certain dates of photogrammetry had to be excluded because the mining impact to foredunes and incipient beach regions was too significant. Discussion of the quality of photogrammetric data with respect to mining impacts is given for each beach in Chapter 4.

Table 2-1 Beach State Classification and Coffs Beaches

Beach State	Identifier	Description / typical conditions	Example Coffs Beach
Reflective	**R**	Steep upper beach face which reflects waves, no sand bars, deeper water immediately offshore, Low wave energy (0-1 m height), coarser grain sizes	Korora Beach, Charlesworth Bay
Low Tide Terrace (Intermediate)	**LTT**	Single shallow bar or terrace exposed at low tide, Low wave energy (0.5 – 1 m height), possible weak rips at high tide	Woolgoolga Beach, Arrawarra Beach
Transverse Bar Rip (Intermediate)	**TBR**	Attached bars cut by frequent beach rip troughs/channels (150 – 300 m spacing) which can have strong currents, Moderate wave energy (1 – 1.5 m height)	Emerald Beach, Diggers Beach
Rhythmic Bar & Beach (Intermediate)	**RBB**	Undulating (rhythmic) sand bars separated by a trough from shoreline which feeds into strong rips, often heavy shore break due to troughs, Moderate wave energy (1.5 – 2.0 m height)	Woolgoolga Back Beach.
Longshore Bar & Trough (Intermediate)	**LBT**	Shore parallel sand bar(s) with deep trough inshore and moderately steep beach face causing heavy shore break. Typically strong currents in trough feeding widely spaced, strong rip currents. Moderate to High wave Energy (1.5 – 2.0 m height)	Red Rock Beach (North Corindi)
Dissipative	**D**	Wide surf zone with multiple shore parallel bars and troughs, High wave energy (2 – 3 m) generating wave set up/set down and undertow currents	None in Coffs Harbour



Title:

Sand Mining Leases, Northern Coffs Study Area

Figure:
2-1

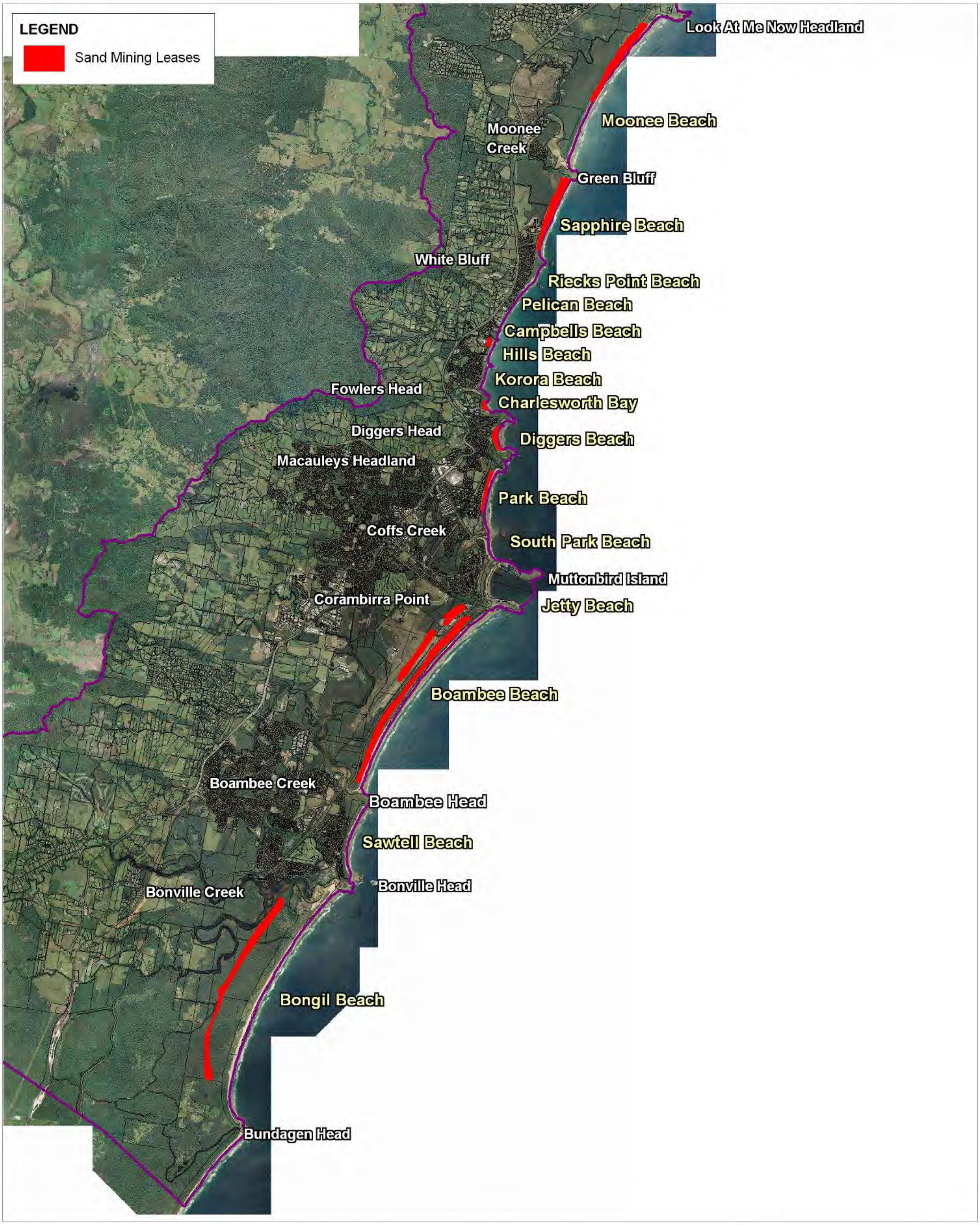
Rev:
A

N

0 2.5 5km
Approx. Scale

BMT WBM
www.wbmpl.com.au

Filepath : K:\N1440 Coffs Coastal Process Hazard Definition Study\MapInfo\Workspaces\SandMining_FigureN.WOR



Title:

Sand Mining Leases, Southern Coffs Study Area

Figure:

2-2

Rev:

A

N

0 2.5 5km

Approx. Scale

www.wbmpl.com.au

Filepath : K:\N1440 Coffs Coastal Process Hazard Definition Study\MapInfo\Workspaces\SandMining_FigureS.WOR

2.3 Climate Change Parameters

Our scientific understanding of the hazards relating to climate change has changed greatly since the Coastline Management Manual was released in 1990. Climate change projections relevant to coastal assessments now include wave height and direction, storm surge and wind speed and direction (as described in McInnes *et al.,* 2007; Macadam *et al.,* 2007; CSIRO, 2007) and sea level rise, as given in Table 2-2. These climate change parameters will affect each of the individual coastal processes that generate coastal hazards.

We have integrated the assessment of climate change into the analysis of each coastal hazard in terms of its future extent, using the most current theories and analytical approaches. That is, a 'climate change hazard' has not been defined explicitly, rather climate change impacts have been included in our analysis of the 2050 and 2100 extent of each coastal hazard.

McInnes *et al* (2007) and Macadam *et al*. (2007) have compiled various climate change predictions for Batemans Bay and Wooli Wooli Estuary. Predictions for Wooli Wooli Estuary have been used as this is the closer location to Coffs. The climate change predictions of McInnes *et al*. (2007) are based upon the output of two CSIRO models, CCM2 and CCM3 as the two models exhibited distinctly different climate change responses with respect to wind speeds, providing useful output to investigate predictions for wave heights/directions and storm surg. Both CSIRO models are forced with the same emission scenario, A2, where CO_2 rises from 370 parts per million (ppm) at present to 880 ppm by 2100, which is typically taken as the highest emission scenario, which current trends are tracking.

Below is a summary of the climate change parameters that are relevant to assessing climate change impacts upon coastal hazards.

Sea Level Rise

The NSW Sea Level Rise Policy Statement (DECCW, 2009a) has adopted levels of 0.4 m by 2050 and 0.9 m by 2100 to be used in planning and associated assessments in the coastal zone of NSW. DECCW (2009b) has based these levels upon the most recent IPCC (2007) projections for sea level rise (0.18 – 0.59 m by 2090-99), the IPCC's (2007) assumed linear trend in global ice melt causing 0.2 m sea level rise by 2100, plus up to 0.14 m regional sea level rise by 2100 associated with the East Australian Current on the NSW Coast (CSIRO, 2007; McInnes *et al.*, 2007). The projections for 2100 were compared with the sea level rise trend projections to derive a 2050 sea level rise estimate of 0.4 m. The projections for 2100 were rounded (to 0.9 m and 0.4 m) to acknowledge the uncertainty in projection estimates (DECCW, 2009a).

From a risk perspective, it is important to consider changes beyond that given within the current predictions. Thus, we have analysed a potential higher than predicted sea level rise, of 1.4 m by 2100, representing 0.5 m higher than the prescribed NSW Government levels (or, 0.7 m by 2050, assuming the same rate of increase as given in predictions). The use of the higher than predicted sea level rise levels does not override the use of current predictions, but rather provides for an extreme or very unlikely scenario impact. Greater discussion of the use of these levels is outlined in Section 3.4.

It is widely acknowledged that sea level rise will result in the recession (or transgression) of sandy shorelines, such as described by the Bruun Rule (1962). This assessment utilises world's best practice Shoreline Evolution Modelling to determine the extent of recession due to sea level rise in the Coffs region, as discussed in detail in Section 3.4.

Oceanic inundation of low lying and back beach areas may also increase in frequency with sea level rise. Potential impacts of elevated water levels and thus the coastal inundation hazard are outlined in detail in Section 2.5 and Section 3.5.

Wave Climate

CSIRO (2007) has predicted an increase in storm intensity and frequency under a future climate. McInnes *et al.* (2007) have provided predictions for future wave heights (mean and maximum) and future wave directions due to climate change for Wooli Wooli Estuary (closest location to Coffs). The CCM2 and CCM3 modelled wind speeds and directions were converted by McInnes *et al.* (2007) to significant wave height (H_s) and wave period (T_p) using empirical relationships, to provide predicted changes to wave height and direction. Winds near to the coast were used to generate storm waves and winds further offshore to generate swell waves. The projected changes are given in Table 2-2.

An increase in storm intensity or wave height means that beaches may experience greater erosion of sand during individual storms, while increased storm frequency means that beaches have less time to recover and accrete sand upon the upper beachface before the next storm occurs. Any increase in storm intensity or frequency due to climate change will be coupled with a rise in sea level, further intensifying potential storm erosion.

Wave direction is also an important component for consideration in determining future beach state. A sustained shift in the wave climate (even if not combined with a change in wave height) may impact upon coastlines, because it is the wave direction relative to the orientation of the shoreline that is a key determinant for longshore sediment transport.

Projections by McInnes *et al*. (2007) are still somewhat unclear if and to what extent changes in wave direction and / or wave height may occur in the future. The resolution of the climate change models (CCM2 and CCM3) is not sufficiently fine scaled to provide more detailed projections at the present time. Thus, we find the projections for changes to wave direction and wave height are within the natural range of variability of the existing wave climate.

However, it is still valid to investigate the potential impact upon the shoreline from a sustained shift in wave direction towards the east (e.g. from the average 135° wave direction at present to that of the summer wave climate, of 120° in the future). The rationale for this investigation is given in more detail in Section 2.4.5.

Storm Surge

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

Table 2-2 Climate Change Projections of Interest for Coastal Hazards

Prediction	**Year**	**2030**	**2050**	**2070**	**2100**	**Reference**
Sea Level Rise			**0.40 m**		**0.90 m**	NSW Government (2009)
Storm Maximum Wave Height (Hmax)	S + SE direction	0% to +3%		-15% to +9%		McInnes *et al*. 2007. Ranges based upon output from CCM2 & CCM3 models
Storm Wave Frequency	S + SE direction	-8% to +13%		-20% to + 48%		McInnes *et al*. 2007. Ranges based upon output from CCM2 & CCM3 models
	NE Direction	-40% to +100%		-73.3% to 0%		
	E Direction	-49.5% to +2.7%		-54.5% to +35.1%		
	SE Direction	-35.6% to -23.6%		-34.4% to +50%		
	S Direction	+3.9% to +34.1%		-13.7% to +46.3%		
Swell Waves SSE direction (135-180 ^{o} TN)	Mean Direction	158.6-159.6 ^{o} TN		159.4-160.6 ^{o} TN		McInnes *et al*. 2007. Ranges based upon output from CCM2 & CCM3 models
	Change in direction	-0.8 to +0.3 ^{o}		+0.1 to +1.2 ^{o}		
Swell Waves from 10-190 ^{o} TN	Mean Direction	101.3-106.1 ^{o} TN		99.4-105.9 ^{o} TN		McInnes *et al*. 2007. Ranges based upon output from CCM2 & CCM3 models
	Change in Direction	-3.1 to +0.6 ^{o}		- 3.3 to -1.3 ^{o}		
Storm Surge	100 yr ARI	+/- 1%		-3% to +4%		McInnes *et al*. 2007. Actual change is 1 - 3 cm
Changes to percentage of wind direction days with average wind speed:	**4 - 8 m/s Annual** SE (112.5 – 157.5°)	-2 to +1 %		-1 to +2 %		Macadam *et al.* 2007 for ocean near Wooli, based on McInnes *et al*. 2007 output from CCM2 & CCM3 models
	8 - 12 m/s Annual SE (112.5 – 157.5°)	-1 to +2 %		-1 to +2 %		
	12 - 16 m/s Annual SE (112.5 – 157.5°)	0 to +1%		0 to +1%		
	>16 m/s Annual SE (112.5 – 157.5°)	*No change*		*No change*		
Extreme rainfall events		-10 % to 0 %		-10% to +10%		Macadam *et al*. 2007
Average total Rainfall		-6 % to 0 %		-19% to 0%		Macadam *et al*. 2007

McInnes *et al* (2007) have provided predictions for the likely change in storm surge due to climate change. Projected sea level rise and wave set up need also be added when assessing future elevated water level events, as has been done in Section 2.5 and Section 3.5.

Rainfall

Macadam *et al* (2007) have provided recommendations for percent changes in annual and extreme rainfall events for Wooli Wooli Estuary. The projections suggest that an increase in extreme rainfall in concurrence with an overall decrease in annual average rainfall may occur. This would impact upon lagoon entrance behaviour of coastal lagoons and intermittently opening coastal creeks.

A reduction in annual rainfall is likely to result in more frequent closure of estuary entrances, as the reduced outflow cannot scour marine sediments delivered by waves to build an entrance berm. An increase in frequency and intensity of extreme rainfall events would result in an increase in the frequency and extent of inundation of upstream areas. This would be exacerbated by closed entrance conditions, until such time that a breakout occurs.

There may also be minor effects upon erosion occurring at stormwater outlets on beaches. Increased flow velocities (from larger rainfall events) may cause increased scour at outlets that are inadequately designed for such velocities.

These impacts are investigated within the coastal entrance hazard and stormwater erosion hazard, in Section 3.6 and Section 0.

Wind

Macadam *et al.* (2007) have provided advice relating to future wind directions and speeds at Wooli Wooli Estuary. Future changes in wind speeds or directions may have an effect on windborne (aeolian) sand transport from the beach and dune systems. While the volume of aeolian sediment transport is controlled by grain size, the number of days during which appropriate wind conditions occur may modify future volumes of sediment transported. The impact from predicted changes to wind regimes is discussed within the sand drift hazard (Section 3.8).

2.4 Wave Climate

2.4.1 Wave Generation Sources

The wave climate of the south east Australian coastline has some seasonality due to the seasonal dominance of the major wave generation sources. While there is some seasonality to the timing of the wave generation sources, it is important to note that storm(s) of sufficient magnitude to cause erosion may occur at any time during the year at Coffs Harbour. The wave generation sources are outlined below (Short and Trenaman, 1992; Short, 2007).

- Tropical cyclones may occur from November to May, but are most frequent during February and March. Tropical cyclones tracking towards the Tasman Sea (usually well offshore of the coast), may generate north easterly swell directions arriving at the coast.
- East coast cyclones may occur at any time of the year, but are most likely to occur in May, June and July. These systems are said to generate the strongest winds, heaviest rainfall and largest waves experienced on the NSW Coast. East coast cyclones tend to form towards the middle of the NSW coast, generating waves which arrive from south easterly to easterly directions.
- Mid-latitude cyclones occur throughout the year, particularly March to September, and these systems generate the predominant south easterly swell experienced along the coast. Mid-

latitude cyclones tend to form closer to the southern Australian continent in winter and further south in summer. Thus during winter, when they are closer to the coastline, higher waves may be expected from these systems, which may directly impact NSW weather (i.e., wind and rainfall on land).

- The subtropical anticyclone produces fine, warm weather on the NSW coast, and particularly during summer, may generate weak north east to easterly swells. The anticyclone moves from west to east over the Australian continent throughout the year, and is located further south in summer and further north in winter. In summer, on clear warm/hot days the land heats faster than the ocean, causing hot air to rise over the land and cooler air from the ocean to move in to replace it, forming onshore sea breezes along the coast (and the opposite may occur over night during winter, causing morning offshore breezes). The onshore winds arrive from the NE rather than directly E due to the Coriolis effect (which deflects air and water movement to the left in the southern hemisphere). When such NE to E onshore winds are persistent over days, they may generate a weak wind swell on the coast.

2.4.2 Measured Wave Climate

Wave data for Coffs Harbour, Bryon Bay and Sydney was provided by the Department of Commerce Manly Hydraulics Laboratory (MHL), with data collection funded by the Department of Environment, Climate Change and Water (DECCW). The wave rider buoys are moored in ~ 85 m water depth, ~ 10 km offshore.

The Coffs Harbour wave rider buoy measures wave height and period, but not wave direction. The data recording period at Coffs Harbour spans 31 years from May 1976 to December 2007. Mean wave direction data for the Coffs Harbour region has been interpreted from the Sydney and Byron Bay data. The record length for wave direction at Sydney (540 km south) spans 15.5 years from March 1992 to December 2007. At Byron Bay (240 km north) the data record length is only 8 years, from October 1999 to December 2007.

The shorter record length for wave direction at Byron Bay may have impacted the statistical analysis. The Byron Bay directional buoy has also experienced occasional long periods of missing data, some of which occurred during storms. The missing data have been repaired and validated to some degree, for the purpose of statistical analyses (pers. comm., Mark Kulmar, MHL, 28/07/2008).

2.4.2.1 Significant Wave Height

The mean significant wave height (H_s) experienced at Coffs Harbour is 1.57 m. This is slightly lower than the mean for Bryon Bay of 1.65 m, and 1.61 m at Crowdy Head. The north coast sector of NSW (Smoky Cape to the NSW-Queensland Border) has been described as having generally lower storm activity than other parts of the NSW coastline (BBW, 1985; Lawson and Treloar, 1986). Statistics for H_s percentage exceedance statistics can be reviewed in the Progress Report, Appendix A.

With regard to seasonality at Coffs Harbour, H_s is largest in autumn, then winter, summer and the lowest wave heights occur typically in spring. All of the major storm generation sources have the potential to occur in the autumn months, and this may explain the higher wave heights experienced over autumn. Tropical cyclones do not occur between May and October and mid latitude cyclones are more prevalent in winter than spring, thus the lowest wave heights would be expected during spring.

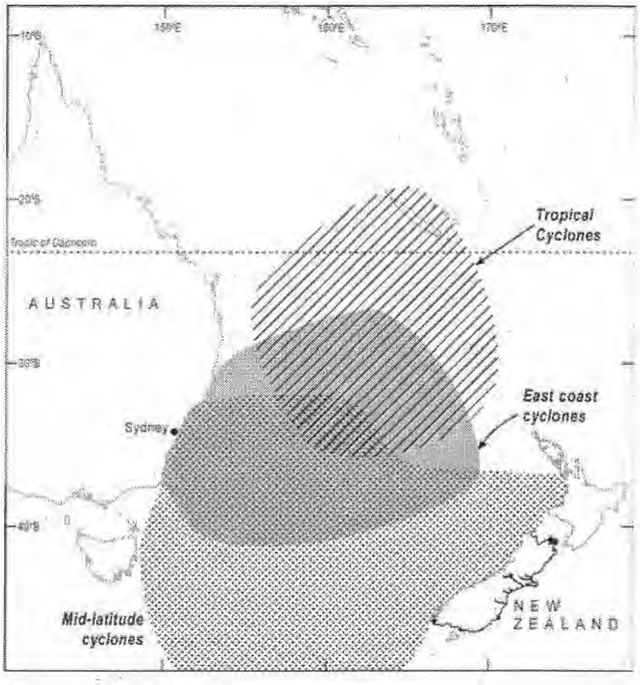


Figure 2-3 Wave Generation Sources on the South East Australian Coast (Short 2007)

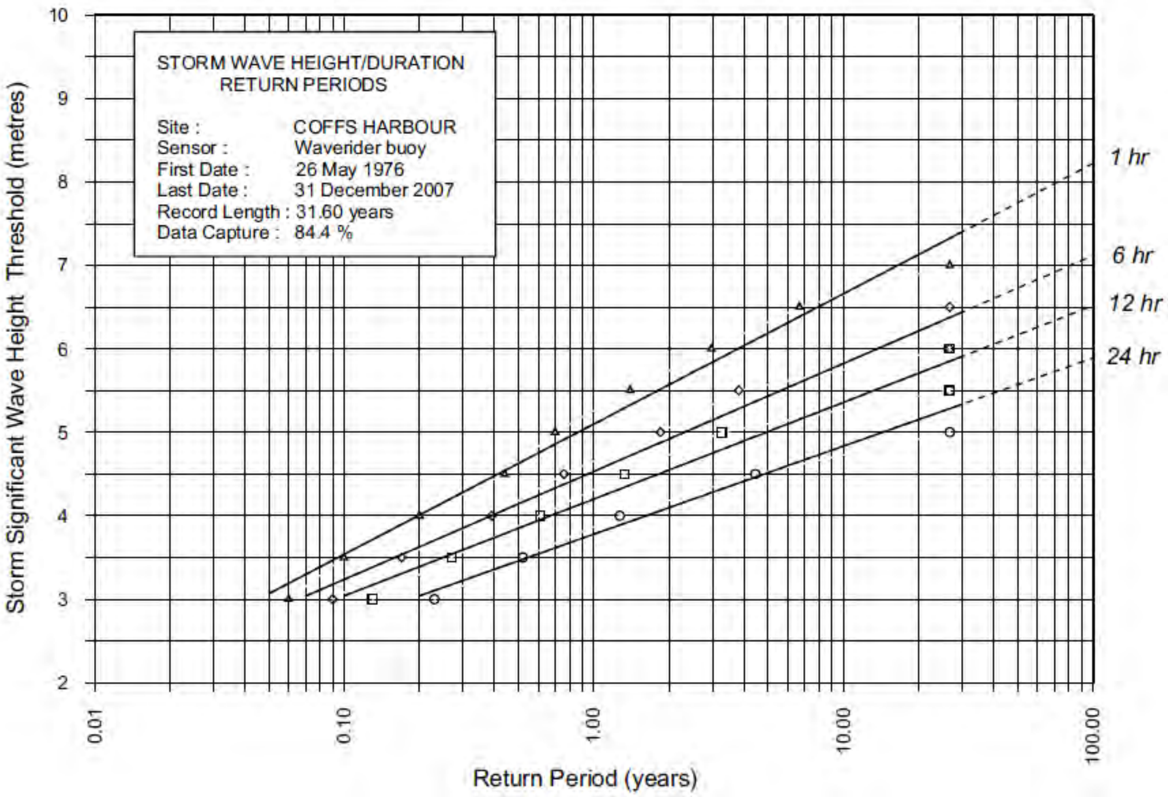


Figure 2-4 Storm Wave Height / Duration Curves for Coffs Harbour

The highest measured H_s of 7.36 m at Coffs Harbour was recorded in the month of June, during which east coast low cyclones or mid-latitude cyclones may occur. Analysis of storm wave height/duration return periods for Coffs Harbour between May 1976 and December 2007 has been provided by MHL, as illustrated in Figure 2-4. The analysis indicates a 1 in 100 year H_s of 8.2 m for a 1 hour duration storm may occur at Coffs Harbour.

2.4.2.2 Wave Direction

Wave direction statistics data from the directional buoy at Byron Bay and Sydney may be used to infer likely direction at Coffs Harbour. Tabulation of monthly percentage occurrence of wave direction, and percentage joint occurrence statistics for wave height and direction at Byron Bay and Sydney are found in the Progress Report, Appendix A.

The average annual wave direction is south east (135 ° TN) at both Byron Bay and Sydney, with the single most dominant wave direction at both locations being south-south-east (SSE). At Byron Bay and Sydney respectively, 60% and 65% of waves arrive from the south east to south sector and 27% and 30% from the SSE alone. Wave direction at Coffs Harbour is thus assumed to be dominantly south east.

Seasonally, average seasonal wave direction reflects the dominant wave generation mechanisms as discussed in Section 2.4.1. During winter and spring, south east sector waves are dominant at Sydney and Byron Bay, as consistent with the dominant occurrence of mid-latitude cyclones during winter and spring when other generation sources are less prevalent.

Over the summer to early autumn months in both Sydney and Byron Bay, wave direction shifts north slightly. At Byron Bay, east and east-south-east waves are the dominant wave directions during January to April. At Sydney, the waves are more northerly in direction than at Byron Bay, however south east sector waves remain the dominant wave direction. The shift in wave direction at Byron and Sydney is consistent with occurrence of east coast low cyclones and tropical cyclones from summer through autumn. The wave record will also be more easterly due to summer north-easterly sea breezes and associated wind waves on the coast. We would expect then that Coffs Harbour wave direction shifts to more easterly waves during summer to autumn.

Percentage joint occurrence statistics for wave height and direction provide insight into the generation sources for storms. At Byron Bay the statistics indicate that storm waves (i.e. H_s > 3 m) most commonly arrive from the south east sector (the SSE in particular), however, storm waves do occur from east-north-east to east-south-east directions, such as would be generated by tropical cyclones. The statistics at Sydney also demonstrate a dominance of south east sector storm waves, with the occurrence of storms from the east-north-east to east-south-east directional region far less common than at Byron Bay.

The statistics suggest east coast low cyclones and mid-latitude cyclones to be the dominant storm generation mechanism on the NSW coast, which generate east to south east waves. Tropical cyclones are also evident in the storm record, more so in the record at Byron Bay as this is closer to the tropics. Likewise at Coffs Harbour storms are expected to arrive from the east-north-east to south, generated by east coast low cyclones, mid-latitude cyclones and tropical cyclones.

2.4.3 Storm History

For the period prior to 1977 when wave data measurements commenced, the storm history provided in sources such as BBW (1985, 1986) and in other hazard studies in the region has been evaluated. The number of storms and some characteristics for each year taken from BBW (1985; 1986) prior to 1977 has been summarised in the Progress Report, Appendix A.

Most of the storm activity and the largest wave heights are said to be produced by east coast low cyclones, then tropical cyclones to a lesser degree on the NSW north coast (BBW, 1986).

1967 was the stormiest single year in the historical data (BBW, 1985) with the highest number of storms and of the largest wave height. This included two category X storms in February and March 1967 (tropical cyclones), followed by a larger storm generated by an east coast low cyclone in June 1967. In addition to the extreme wave heights, the June storm is expected to have caused the greatest damage as it occurred in conjunction with spring high tides and when the beach was already in an eroded state.

The year 1954 also experienced a Category X storm during a tropical cyclone in February of that year. Other regional reports (WBM, 2003) have described this as a notable year for storminess on the north coast, although unfortunately there is only limited data in BBW (1985) on storms in this year.

The years 1929, 1942, 1955 and 1971 are also noted as being stormy years from the BBW (1985) storm history, and regional reports describe 1974 (WBM, 2003) to also be a relatively stormy year.

The May-June period of 1974, during which numerous storms occurred and produced significant beach erosion particularly on the south, Sydney and central NSW coasts, was not reported by BBW (1985) to be as significant, with only one event reported on the north coast. However, this year is still thought to have been particularly erosive on the Coffs Harbour coastline, due in part to the water levels associated with these storms (Foster *et al.,* 1975) and which followed tropical cyclones occurring earlier in 1974.

A number of the storm events are known to have coincided with high water levels on the NSW coast. While wave heights may have been lower, the elevated water levels are likely to have resulted in greater damage from these storms than may be anticipated from wave height alone. The known events are listed below:

- Storms in February 1954, February 1974 and June 1967 (as noted above) coincided with the occurrence spring high tides (PBP, 2004).
- The May 1974 storm coincided with the highest water level recorded on the NSW coast, of 2.37 m (above ISLW) measured at Fort Denison (May 25, 1974), which included 0.24 m of unpredicted astronomical tide on top of 0.23 m of storm surge and 1.9 m of predicted tide (Foster *et al.,* 1975).
- The May 1997 storm (peak H_s of 5.6 m) coincided with an elevated water level 0.7 m higher than the predicted tide. Water levels during the May 1997 storm were found to be 1.2 - 1.9 m higher than three other storms of greater wave height (August 1986, June 1989 and April 1989), and so, the storm was described as more damaging. When storm duration was also accounted for, this storm was considered the 7th largest between 1976 and 2001. The storm caused damage to the eastern breakwater of Coffs Harbour (PBP, 2004).

2.4.4 Variability in the Wave Climate

Throughout the wave record, the predominant wave direction has remained south east along the NSW coast. However, there may be subtle shifts in the wave climate (wave height, wave direction) between years and even decades that relates to the intensity and frequency of storms (affecting wave height) and storm generation sources (affecting wave direction). Such shifts in wave climate may manifest on the shoreline as a period of erosion or accretion, and longshore movement of sand volumes (rotation).

Periods (years and decades) of high storm activity have been found to generate the largest extents of beach erosion. For example, the high storm activity during the decade of the 1970s is typically associated with the greatest beach erosion extents in the historical record on NSW beaches (Forster, *et al.*, 1975; Thom and Hall, 1991; McLean and Shen, 2006). The higher frequency of storms during this period suggests that the recovery of the beach between storms (or lack thereof) was significant in the resulting extent of beach erosion, in addition to the impact of the individual storms (Short *et al*., 2000; Ranasinghe *et al*., 2004; McLean and Shen, 2006).

Climate variability at greater than decadal time scales (10-30 years) is also an intrinsic characteristic of the Australian regional climate (Power *et al.*, 1999). This is reflected in the wave climate, with a period of dramatic erosion and shoreline retreat reported to have occurred between 1954 and 1974, after which a relatively calmer period of beach recovery and lower storminess has persisted to the present (WBM, 2003). The period since the late 1970s is typically stated to have been less stormy with wave direction remaining more persistently south east (see Goodwin, 2005 and Appendix A for more detail). A number of researchers have found there to be some correlation between the south east Australian wave climate and the El Nino Southern Oscillation (ENSO), which is discussed further in the Progress Report, (Appendix A). Generally, there is observed to be an increase in the occurrence of tropical cyclones and east coast low cyclones during the La Nina phase (Goodwin 2005; Phinn and Hastings, 1992; Hemer *et al.,* 2008, CSIRO, 2007). Relating to this, the La Nina phase has been associated with more northerly (easterly) wave directions (Short, *et al.,* 2000; Goodwin 2005; Ranasinghe *et al.,* 2004). Mean wave power has also been found to be higher during the La Nina phase, likely due to the greater frequency / intensity of tropical and east coast cyclones, in addition to the predominant mid-latitude cyclones (e.g. refer Phinn and Hastings, 1992; Ranasinghe *et al*., 2004; You and Lord, 2008). Hopkins and Holland (1997) found a strong tendency for east coast low cyclones to occur when an El Nino is followed by a La Nina year. During the El Nino phase there are generally fewer tropical and east coast cyclones and mid-latitude cyclones remain dominant, resulting in a more southerly mean wave direction (Ranasinghe *et al.*, 2004; Goodwin, 2005).

Some of the climate variability on decadal scales is believed to be related to the Inter-decadal Pacific Oscillation (IPO) (Power *et al*., 1999). This is an oscillation in sea surface temperatures across the entire Pacific Ocean (further description is given in the Progress Report, Appendix A). Power *et al*. (1999) illustrated that when the IPO is in its La Nina-like phase, the year to year variability in the Australian climate is closely associated with year to year variability in ENSO. Goodwin (2005) found that NSW wave climate is also more closely correlated with ENSO during the IPO La-Nina-like phase. That is, the correlations between wave height and direction for the El Nino and La Nina phases become more reliable.

There is some correlation observed between ENSO, IPO and the wave climate, however, the interrelationships between ENSO, IPO and other climatic drivers (Southern Annular Mode, Indian Ocean Dipole) and how such climatic processes affect wave climate is not yet fully understood. It is therefore not possible to use the interrelationships between such climatic indicators to either hindcast or forecast the NSW wave climate. The use of ENSO and / or IPO indicators alone is not adequate to describe or predict the extent of variability we observe in the wave climate (height and direction), or the shoreline response.

In this study, the key message is that natural variability in the wave climate is observed to occur over longer periods (years and decades). Variability in wave height and direction that persists for years to decades will affect the extent of erosion / accretion and rotation (longshore sediment movement) observed at the shoreline. A series of storms (and associated water levels) over months to years and even decades will have a cumulative effect upon the shoreline. Periods of higher or lower storminess in the wave climate (and subsequent shoreline response) can be expected to continue in the future.

2.4.5 Future Wave Climate Due to Climate Change

Current climate change predictions suggest the future wave climate will be similar to the present. Predictions given by McInnes *et al.* (2007) are within the variability of the existing wave climate. That is, the historical shifts in wave climate that occurred naturally are greater in range than the predicted shifts in the future climate. It was noted that the climate models used to generate such predictions (CCM2, CCM3 by McInnes *et al.* 2007) are too coarse to adequately describe the NSW wave climate.

Thus, it is possible that the predictions do not represent the future wave climate adequately. For this reason, the theoretical possibility of a permanent shift from the existing south easterly wave climate (135°) to a more easterly wave climate (120°) has been considered, with average wave height remaining the same. The aim of this is to represent a change in the relative dominance of tropical cyclones and east coast low cyclones compared with mid-latitude cyclones that would result in a minor change in *average* wave height, but notable change in wave direction. In the Progress Report (Appendix A), 120° was found to represent the average wave direction in summer during which these wave generation mechanisms are more dominant. The potential impacts of a more easterly wave climate at 2050 and 2100 have been investigated as part of the long term recession hazard (refer Section 3.4).

2.5 Water Levels

2.5.1 Tides

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

Coffs Harbour tidal water levels are given in Table-2-3, as provided by MHL using data from 1987 – 2007. Coffs Harbour has a maximum tidal range of 2.04 m. The highest predicted tidal level, or highest high water solstice spring tide (HHWSS), is 1.084 m AHD. Indian Spring Low Water tide (ISLW) is -0.955 m AHD, which is the lowest predicted tidal level.

The ocean tidal regime is uniform along the NSW Coast which means high tide occurs close to simultaneously at all locations along the coast. As such, shore-parallel tidal currents along the coastline are negligible. Near the larger entrances of estuaries, creeks, harbours and lakes/lagoons, tidal driven currents may be generated by the tidal volume flowing through such entrances on the falling and rising tide, resulting in local currents in the surf zone.

Table-2-3 Coffs Harbour Tidal Levels*

	HHWSS	**MHWS**	**MHW**	**MHWN**	**MSL**	**MLWN**	**MLW**	**MLWS**	**ISLW**
Level (m AHD)	1.084	0.695	0.547	0.399	0.009	-0.381	-0.529	-0.677	-0.955
Level (m ISLW)	2.040	1.651	1.503	1.355	0.965	0.575	0.426	0.278	0.000

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

2.5.2 Elevated Water Levels

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

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

It is generally considered that the highest elevated water levels would occur for a limited time only (several hours) around the high tide.

DECCW (2009c) advises that for coastal assessments the still water level return periods for Fort Denison in Sydney be used, until such time as location specific analyses are available. The Fort Denison values include barometric pressure set up, (some) wind set up and astronomical tide and tidal anomalies, but do not include wave set up. Extreme still water levels for Fort Denison are given in Table 2-4.

Wave set up in the surfzone has been measured as proportional to the wave height (Nielsen, 1988). As a general rule of thumb, wave set up is taken to be ~ 15 % of the offshore significant wave height (WBM, 2003; WP Geomarine, 1998), with some authors suggesting up to 20 % (Masselink and Hughes, 2003).

The 1 hour duration storm wave heights, as given in Figure 2-4, have been used to assess wave set up, because wave heights are greater over the shorter duration, giving the highest potential wave set up values that may occur at the coastline during a storm. The 1 hour storm duration wave heights and associated wave set up values at 15 % of wave height are given in Table 2-4, and summed with the extreme still water levels.

Future elevated water levels in 50 and 100 years will include the predicted increase in sea level. There may also be small changes in water levels in relation to the predicted minor changes to storm surge height and to the maximum (storm) wave height in the future due to climate change (from McInnes *et al.* (2007). Any reductions in storm surge and wave height predicted in the future have not been utilised because from a risk perspective, increases in water level are of greater consequence. Potential future water levels including climate change factors for 2050 and 2100 are given in Table 2-5 and Table 2-6.

In considering risk, it is important to consider factors that may induce greater water levels than are predicted. We have determined two components that may contribute to higher than predicted water levels. First, there is the potential for a higher than predicted sea level rise, which has been adopted as 1.4 m by 2100, representing 0.5 m greater than predicted (0.9 m) sea level rise (and an equivalent 0.7 m rise by 2050). This is also included in predicted water levels in Table 2-5 and Table 2-6.

Second, there is the potential for storm surge levels greater than predicted from the historical data, as a result of extreme climatic conditions, for example, a tropical cyclone in proximity to Coffs Harbour, or a 1 in 1000 year east coast low cyclone. In terms of risk, given the relatively short record of measured weather data in Australia, there is the potential for storms of greater intensity to occur under an existing climate. It is worth considering therefore the potential for tropical cyclones or storms of greater intensity to occur at Coffs Harbour under a hotter climate.

The 1 in 1000 year tropical cyclone storm surge plus tide water level at Surfers Paradise is the same as the 1 in 50 year water level at Fort Denison. For sites in southern Queensland (Rainbow Beach, Scarborough, Surfers Paradise) that have a similar highest astronomical tide to Coffs Harbour (1.06 – 1.24 m AHD) the difference in surge level between a 1 in 100 year event and a 1 in 1000 year event was 0.2 to 0.3 m. Furthermore, the predicted 1 in 1000 year still water level event at Fort Denison has been calculated at 0.14 m higher than the 1 in 100 year event (pers. comm., Phil Watson, DECCW July 2010). Thus, the 1 in 100 year water level has been increased by 0.2 m, to represent the possibility of an extreme climatic condition, for example, an estimated 1 in 1000 year water level event (excluding wave set up) at Coffs Harbour, as given in Table 2-5 to Table 2-6.

The adopted likelihood of various water levels and resultant coastal inundation is discussed in Section 3.5.

Table 2-4 Elevated Water Levels for the Immediate Timeframe

Immediate				
Recurrence Interval (years)	**Still Water Level (Fort Denison) (m AHD)**	**1 hr duration wave height (m)**	**Wave Set up (m) (15% of wave ht)**	**Extreme Water Levels (m AHD)**
20	1.38	7.1	1.07	**2.5**
100	1.44	8.2	1.23	**2.7**
100 (extreme storm conditions)	1.64	8.2	1.23	**2.9**

Table 2-5 Elevated Water Levels for the 2050 Timeframe

Recurrence Interval (years)	**Still Water Level (Fort Denison) (m AHD)**	**Predicted increase in storm surge due to CC (m AHD)**	**1 hr dur'n wave height (m)** (includes increase due to CC)	**Wave Set up (m)** (15% of H_s)	**Sea Level Rise**	**Extreme Water Levels (m AHD)**
20	1.38	0.01	7.31	1.10	0.4	**2.9**
100	1.44	0.01	8.45	1.27	0.4	**3.1**
100 (extreme storm conditions)	1.64	0.01	8.45	1.27	0.4	**3.3**
100 (extra SLR)	1.44	0.01	8.45	1.27	0.7	**3.4**

Table 2-6 Elevated Water Levels for the 2100 Timeframe

Recurrence Interval (years)	**Still Water Level (Fort Denison) m AHD**	**Predicted increase in storm surge due to CC (m AHD)**	**1 hr dur'n wave height (m)** (includes increase due to CC)	**Wave Set up (m)** (15% of H_s)	**Sea Level Rise**	**Extreme Water Levels (m AHD)**
20	1.38	0.03	7.74	1.16	0.9	**3.5**
100	1.44	0.03	8.94	1.34	0.9	**3.7**
100 (extreme storm conditions)	1.64	0.03	8.94	1.34	0.9	**3.9**
100 (extra SLR)	1.44	0.03	8.94	1.34	1.4	**4.2**

2.5.3 Wave Run Up

The wave run up mechanism can result in the overtopping of coastal barriers (e.g. dunes), with overwash typically extending for 10 – 30 m behind the barriers. In some locations along the Coffs coast, such as Campbells Beach, wave uprush already reaches the foredune crest during king high tide or high wave conditions. Wave run up contributes to beach erosion.

Wave run up is highly variable between storms and locations, and will depend on factors including wave height, wave period, beach slope, shape and permeability, the roughness of the foreshore area and wave regularity. The largest measured wave run-up level is 7.3 m (AHD) at Narrabeen in 1986 (given in Table 2-7). This measurement was based on debris lines and so includes the elevated water levels during the storm in the measurement. Other levels assessed by WP Geomarine (1998) using the steepest and flattest photogrammetric profiles in the Coffs Region were 7.0 to 10.3 m AHD, as given in Table 2-7. As noted previously, these levels are not certain due to the constraints of calculating wave run up. There may also be impacts upon these levels from climate change induced shifts in storm surge and wave height, as given by the predictions of McInnes *et al.* (2007).

The climate change impacts upon sea level, storm surge and wave height have been used to calculate potential increases in wave run up height by 2050 and 2100. However, it has been assumed that impacts of wave overtopping of dune barriers (i.e. wave run up) will be encompassed by the beach erosion hazard.

Table 2-7 Wave Run Up for the Existing, 50 and 100 Year Planning Periods

Planning Period (years)	Wave Run up Level (m AHD)		
	Lower	Measured	Upper
Existing	7	7.3	10.3
50 (inc. 0.4 m SLR)	7.4		10.7
100 (inc. 0.9 m SLR)	7.7		11.3

2.6 Wind Climate

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

Assessment of 30 years of wind data from Coffs Harbour Airport indicated there to be a diurnal variation in wind direction during warmer months (November to March) (MHL, 1983). Winds are generally offshore in the morning (due to the cooler land mass relative to the sea), and onshore from the east to north east direction in the afternoon, as the land mass is heated during the day and the overlying air is heated and rises causing cool air to flow in from the sea to replace it. During the cooler months, winds tend to originate from the west to south directions. Occasional afternoon sea breezes occur during cooler months, however, these are of lesser strength than those in summer months (MHL, 1983; Binnie and Partners, 1987).

2.7 Regional Rainfall and Runoff

The Coffs regional climate is humid sub-tropical, and Coffs typically experiences warm to hot summers, and generally mild winters. Average annual rainfall is 1800 mm, of which, around 60% occurs between December and April. Coffs annual rainfall is one of the highest in the state (Binnie and Partners, 1987). Rainfall typically falls as occasional high intensity bursts, and the creeks and lagoons are noted to respond rapidly to rainfall (WP Geomarine, 1998).

The major rivers and creeks of the Coffs regional coastline are: Bonville Creek, Boambee Creek, Coffs Creek, Moonee Creek, Woolgoolga Creek, Arrawarra Creek, and the Corindi River.

2.8 Sediment Transport

2.8.1 Longshore Sediment Transport

Waves approaching the shoreline from an oblique angle generate a current alongshore which transports sediment. Depending on the prevailing wave direction, the longshore sediment transport may be directed either north or south. On NSW beaches, the net longshore sediment transport is to the north, due to the predominant south east wave climate relative to the general north to south orientation of the coastline. The net northerly transport is considered to be more pronounced in northern NSW because headlands are less common.

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

There will naturally be differentials in the longshore transport rate along a coastline at any one time. This is because the rate of transport is dependent upon the shoreline alignment relative to the prevailing wave direction and the presence of control features or structures such as headlands, reefs, breakwaters or groynes that may interrupt the sediment transport.

Lord and Van Kerkvoort (1981) estimated the regional longshore sediment transport rate to be 75,000 m^3/yr. The rate of accretion upon the northern half of Boambee beach from 1969 to 2007 has been calculated as part of this study to be ~ 30,000 m^3/yr. When this is combined with the rates of infilling of the harbour (from Carley *et al.*, 2006) of up to 50,000 m^3/yr, the rates are consistent with numbers provided by Lord and Van Kerkvoort in 1981. The Coffs regional longshore sediment transport rate is thus taken to be 75,000 m^3/yr on average, however, the rate will increase or decrease depending upon wave climate conditions in any one year.

Accretion and erosion may occur on a beach over extended periods of time (years, decades) in response to extended periods of wave climate that enhance or reduce the longshore transport rate. Medium term (eg. decades) phases of different beach behaviour have been noted in other regional studies, such as at Ballina (WBM, 2003). The wave climate may impact upon the longshore transport rate in terms of average transport along the beach and sediment bypassing of headlands and other control features, which typically only occurs during storm conditions. The impact of headland and other controls on longshore and cross shore transport are discussed in greater detail in Section 2.8.2

The average regional transport rate of 75,000 m^3/yr represents transport accounting for the perturbations and differentials in the rate of transport in response to wave climate variations over time impacting upon different beach geomorphologies (length, orientation, headlands / structures etc). The decades prior and during the 1970s were observed to result in enhanced erosion of beaches in the region, and typically, photogrammetric analyses during this period suggested the beaches were receding. Photogrammetry analyses for this project indicate there has been strong accretion over recent decades particularly on the long, sandy coastline stretches that face south-south-east, namely Bongil, Moonee and Station Beach (Boambee is also accreting, although in part due to the harbour).

Accretion on these beaches is a response to the persistent south east wave climate over recent decades. Accretion has been less prevalent or not occurred at all on those Coffs beaches that are more east facing and / or affected by headland or other control features (e.g. where storms are required to initiate bypassing of the headlands and supply sediment into the beach, refer Section 2.8.2).

For coastal planning purposes it is important to consider that a period of wave climate producing enhanced erosion on beaches such as occurred during the 1970s may occur again in the future. Coastal works (such as breakwaters, groynes and seawalls) will also interrupt littoral transport, resulting in long term responses on updrift and downdrift beaches.

2.8.2 Longshore and Cross Shore Transport at Headlands, Reefs and Coastal Structures

While the average net longshore flow of sand may bypass a headland over a period of years, thus maintaining beach stability, in the short term there is potential for temporary perturbations in the pattern of supply past natural headlands to downdrift beaches. These perturbations are typically greater at the more prominent headlands (eg. Woolgoolga), but can also effect downdrift beaches at relatively minor headland or groyne structures.

Sediment movement past headlands / structures tends to occur as episodic ‘slugs’ of relatively large quantities of sand, requiring short term storm events (hours to days) with high wave energy to activate sand transport past the headland. Longshore transport along beaches (particularly longer embayments) tends to be more continuous over the longer period (months, years).

For the shorter and more embayed beaches such as Diggers, Ocean View and Mulloway, bypassing of sediment is a key in supplying sediment into these beaches. Lord and Van Kerkvoort (1981) noted that longshore sediment transport into Campbells Beach to be dependent on storm events to activate bypassing around the headlands.

Rip currents, which commonly occur adjacent to headlands, assist to facilitate the removal of sand from the updrift compartment. The increased wave energy of the storm and accelerated longshore currents associated with wave reflections enable sand transport in the deeper water adjacent to rocky headlands. Wave direction is also important as oblique waves enable the transport to be directed into the adjacent downdrift compartment.

The ‘slug’-like movement of sand past major headlands / structures is important for longshore transport, but may also have short term erosion / accretion effects upon the shoreline, as follows (WBM, 2003):

- Periods of considerable temporary loss of sand from the updrift beach, after which there is slow accretion against the headland trapping longshore transport of sand;
- Large accumulations of sand to the immediate downdrift side of the headland during major storms, forming lobes at the shoreline, widening the beach and at time extending some distance seaward, beyond the normal surfzone;
- Extensive erosion upon the downdrift beach where there is a short term mis-match in the sediment budget, as potentially large quantities of sand moved away by longshore transport during the storm are not immediately replaced by sand bypassing of the updrift headland; and

- Erosion upon the beach may be further exacerbated if the downdrift beach has also lost sand via bypassing to its adjacent downdrift beach, or likewise if the updrift beach has not had sediment bypassing replaced by sediment bypassing from its adjacent updrift beach, in which case, there is a short term starvation of sediment from this beach, which may have short term effects upon the shoreline.

What this highlights is that, in relation to storm events, at any one time a beach may be left in a more eroded state, depending upon the stage in the process of sand transport around headlands.

Lord and Van Kerkvoort (1981) reported findings of a sand tracer experiment at Diggers Head. Diggers Head was selected for the experiment as it is one of the major protruding headlands in the Coffs region. The experiment involved placing sand tracer in a rip current on the southern side of the headland (i.e. at Diggers Beach) under ~ 4 m wave heights. The offshore water depths were noted to be ~ 2 - 3 m around the headland. The experiment indicated significant bypassing of Diggers Head, with tracer collected at Campbells Beach within two days of placement at Diggers Beach.

At headlands with deeper water offshore (Look At Me Now, Woolgoolga) the dominant mechanism driving currents was found to be wind, typically generating currents in the same as the wind direction. However, during storm events, waves break further from the shore throughout the beach region, and significant currents may be generated at the deeper water headlands (MHL, 1987).

Perturbations along the shoreline in relation to episodic movement of slugs of sand and rip currents are evident in the photogrammetric record. This is important in understanding that areas of far greater erosion may occur at any location along a single beach, and will be different under different storm wave scenarios for locations along a beach. Adequate planning for beach erosion set backs must account for this process.

Nearshore reef outcrops may also affect shoreline evolution as they affect the dissipation and propagation of waves to the shore. Reefs act to attenuate and refract the waves, reducing wave energy at the shoreline behind. As such, accretion of shorelines in the lee of the reefs is often observed (e.g. tombolos and salients). The reef and adjacent shoreline may act similarly to a groyne, with a more stable alignment updrift and shoreline retreat downdrift of the reef structure.

2.8.2.1 Artificial Structures

Headlands and rock reefs are structures around which the shoreline and natural sand bypassing has evolved over the geological time-frame. The natural coastal bedrock features have provided controlling influences on the movements of sand and the coastline shape throughout the past 6,500 years of Holocene shoreline evolution.

Artificial structures such as breakwaters, seawalls and groynes introduced into the natural system generally cause significant perturbations of the beach processes. Most notably:

- Breakwaters (e.g. at Coffs Harbour) and groynes act as shore-normal barriers to the longshore transport of sand, trapping sand and building out the beach/dune on the updrift (southern) side and eroding an equivalent quantity of sand from the downdrift (northern) side; and

- Seawalls protect the land behind and detach the beach dunal system from the active beach processes, which otherwise would contribute to the transport of sand both alongshore and cross-shore, hence seawalls may result in exacerbated erosion at adjacent shorelines.

2.8.2.2 Effects of the Construction of Coffs Harbour Breakwaters

Carley *et al*. (2006) provides a history of the construction of Coffs Harbour and the effects of the harbour breakwaters upon northerly littoral transport. Prior to the construction of the harbour breakwaters, the northerly sediment transport rate was estimated at 75,000 m^3/yr (Lord and Van Kerkvoort,1981). Sediments travelled both behind (via wave and wind processes) and around South Coffs Island / Corambirra Point, along Jetty Beach, then between Muttonbird Island and the shoreline into Park Beach and beyond (Carley *et al.*, 2006). It is not known if bypassing of the ocean side of Muttonbird Island occurred.

The northern breakwater is approximately 1 km long, joining with Muttonbird Island. It commenced in 1914 and was completed in 1924. The channel between South Coffs Island (Corambirra Point) and the mainland was reclaimed between 1915 and 1927. The reclamation closed off the main sand pathway between Boambee Beach and Jetty Beach. The eastern breakwater (off South Coffs Island) was commenced in 1919 and completed in 1946 (Carley *et al.*, 2006).

The breakwaters and land reclamation have resulted in the interception of virtually all of the northerly littoral transport past the harbour Similar littoral drift barriers (e.g. Tweed River breakwaters) are reported to affect beach processes and literal drift for up to 10 km downdrift (Carley *et al*., 2006).

Analysis of photogrammetric data to 2007 gave an average of 3.4 m/yr accretion along Boambee beach, with up to 4 m/yr at the northern end. Sand is periodically removed from the intertidal zone at the far northern end of Boambee Beach (under licence with Dept of Lands). A total of 151,000 m^3 has reportedly been removed over the last 10 years, equivalent to ~ 16,000 m^3/yr (pers. comm., Robert Kasmarik, DECCW, February, 2009). If the intertidal sand mining data is included, the northern end of the beach may be accreting by up to 5 m/yr.

There is some bypassing of sediment from Boambee around the eastern breakwater and into the harbour. A tidal shoal has developed inside the harbour and is moving landward, slowly decreasing water depths between the eastern breakwater and Muttonbird Island. The harbour requires periodic dredging due to the shallowing of water depth. Based upon the 1999 hydrographic survey, there was an increase in the infilling rate of the harbour from 25,000 m^3/yr (given by Lord and Van Kerkvoort in1981) to up to 50,000 m^3/year (Carley *et al.*, 2006).

Park Beach has been periodically nourished with sand (taken from dredging within the harbour) to offset downdrift recession processes. Between 1988 and 1998, nourishment totalled 116,000 m^3 (or 11,600 m^3/yr) (RDM, 1998). Other nourishment events have occurred since 1998 although specific volumes are unknown.

It is possible that in the longer term infilling of the harbour will reach a point whereby sand is bypassed on the ocean side of Muttonbird Island and onto Park Beach.

Carley *et al.* (2006) used recession rates calculated by PWD in 1995 (and which are based upon photogrammetry up to 1988/89) to estimate littoral losses for the beaches north of the harbour. Via this method, the overall rate of loss from beaches north of the harbour to Moonee Beach (but not including Moonee and Korora, as they had not been assessed by PWD at that time) was calculated to be ~ 73,000 m^3/yr. This rate supports the cessation of littoral drift around the harbour, as it is similar to the measured net littoral transport of 75,000 m^3/yr given by Lord and Van Kerkvoort (1981).

Analysis of photogrammetry for this study indicated that the coastline from South Park Beach to Moonee Beach (inclusive) has not receded but has remained roughly stable, with overall accretion of ~ 5,000 m^3/yr in total. The general stability of the beaches north of the harbour, particularly since the time of the assessment by Carley *et al* (2006), suggests that a small amount of bypassing may have commenced. Nearshore sediments are reported to be depleted north of the harbour (refer Section 2), and this further supports the likelihood of sediment bypassing of the harbour.

Shoreline response modelling was conducted as part of this study (refer Section 3.4). The model results suggest that by 2000 – 2010, harbour bypassing would commence resulting in the stabilisation of the northern beaches. Modelling results and the harbour impact are discussed in greater detail as part of the shoreline recession hazard in Section 3.4.

2.8.2.3 Sea Level Rise and Headlands, Structures and Reefs

Sea level rise tends to exacerbate the interruption effect on littoral drift of natural headlands and man-made structures (breakwaters). Erosion at the southern end of beaches would be enhanced as it requires greater wave activity to bypass intervening headlands and man-made structures. Likewise, accretion at the northern ends of the beaches occurs, as additional sediment would be trapped by the headland.

At reefs in the nearshore zone, sea level rise will result in impacts at the shoreline in lee of the reefs. The wave dissipation and refraction at the reefs would be lessened due to the greater water depths with sea level rise. The result is enhanced wave activity at the shoreline and subsequent erosion of tombolos, salients and sand lobes that had formed previously in lee of the reef. This may have significant impact upon the shoreline alignment in the lee of nearshore reefs. Numerous reefs exist in the nearshore zone of the Coffs Region, as discussed further as part of the long term recession hazard (Section 3.4).

2.8.3 Cross Shore Sediment Transport

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

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

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

In their assessment of storms and ENSO, Ranasinghe *et al*. (2004) found that storm wave heights during an individual storm could be equally large during a La Nina or El Nino period. However, the beach is more or less able to withstand storm attack depending on whether it is in a relatively accreted or eroded state. The relative state of the beach (eroded or accreted) is related to the frequency of storm events, not simply the wave height during one storm, as this modifies the length of time between storms during which the beach may recover.

Throughout the first half of 2009, significant beach erosion has been observed along the Coffs coastline. Erosion escarpments have been estimated to be at or close to the erosion extents experienced during the highly stormy decade of the 1970s. There is no wave data or beach survey data to fully analyse this recent erosion event. However, it is known that there was no single storm (e.g. 1 in 100 year wave height) linked with the observed erosion. Instead there were a number of storm events during the January to July period, at least one of which coincided with a high spring high tidal phase. In this case, it is likely that the frequency of storm events, the incident directions of the waves, coupled with high tide water levels has resulted in the significant extent of beach erosion observed.

Wave climate variation over longer time frames is noted throughout this report. This is an extension of the short term erosion concept, such that, where a coastline is stable and longshore and cross shore transport rates are constant on average, the longer term wave climate periods may promote accretion or result in a typically eroded beach state over the same period. The historical beach response given in the photogrammetry demonstrates the effect of longer periods of wave climate variation, which produce enhance periods of accretion, erosion or stability on the Coffs beaches. This is discussed in greater detail as part of the beach erosion hazard (Section 3.3).

2.8.3.1 Rip Currents

The main cross shore current of interest within the surf zone is rip currents (other cross shore currents tend to be small in comparison). Rip currents facilitate the offshore flow of water from the surf zone, which has been delivered by onshore breaking waves. Rip currents are dominant upon high energy single to double barred beaches, the most common beach state along the Coffs Coast. The spacing of rips is dependent upon the wave energy conditions, such that during large waves, fewer rips will form at greater distance apart, however, the currents are wider and stronger. Feeder currents and troughs into the rips will also increase in width and strength during high waves.

Rip currents contribute to the extent of beach erosion during severe storms both in terms scarping of the upper beach face, as well as the offshore transport of sand mobilised by wave breaking. On the open beach, rips may form at any location along the beach. Their formation at any potential location needs to be considered when planning set backs for the beach erosion hazard.

Topographically constrained rip currents form at headlands or along reefs, to facilitate the offshore flow of water from breaking waves at headland constrained beaches. Topographic rips at headlands assist in the bypassing of sediment around headlands, delivering sediment beyond the headland during high waves.

On heavily embayed beaches, under very high wave height and energy conditions, “mega rips” may form, typically along one of the headlands, as the wave energy precludes the formation of beach rips. Mega rips can export sand up to 1 km offshore. The water depths at 1 km offshore are likely too deep to enable sand to be reworked back onshore during calm conditions, and thus this sediment can be lost from the system.

2.8.3.2 Beach Rotation

The phenomenon of beach rotation will also form a component of the observed extent of “erosion” on beaches. Beach rotation is the anti-clockwise to clockwise shift in beach orientation in response to shifts in wave direction and height over seasons and years (Short *et al.*, 2000; Ranasinghe *et al.* 2004). It manifests as an increase in beach width at one end while the opposing end experiences a decrease in width. Rotation is particularly evident on embayed beaches where headlands constrain the transport of sediment within the embayment.

Beach rotation can be a response to wave direction during storms and during the intervening calm periods. Under typical south easterly wave conditions experienced along the NSW coast, the southern ends of beaches tend to recede. This is due to northerly directed longshore sediment transport driven by the modal south easterly waves. Where the modal south easterly wave conditions are persistent for years to decades, significant erosion of the southern ends of beaches may occur (Short *et al*., 2000; Ranasinghe *et al*., 2004). In contrast, periods of high storm activity associated with more easterly to north easterly wave conditions may generate southerly sediment transport (Short *et al*., 2000; Ranasinghe *et al*., 2004), in addition to the erosive impacts (at northern beach ends) from increased storm activity.

For the longer beaches, the response to predominant wave climate conditions results in “zeta-form” embayments as described by Stephens *et al.* (1981). Under predominant south easterly waves we observe ongoing retreat at the southern ends (or hooks) of the embayment is observed. Sediment slugs from headland bypassing events, which occur during storms, may also bypass the southern end of the embayment depending upon wave direction. Easterly wave conditions allow for longshore transport into the southern hooks of long embayments.

2.8.4 Aeolian (windborne) Sediment Transport

Aeolian or windborne sediment transport originates from the dry sub-aerial upper beach face and berm and unvegetated incipient dunes and foredunes, supplying sediment to landward foredunes. Aeolian transport is specific to particular sediment grain sizes, such that sediments which are too coarse or heavy are not able to be transported by the wind.

Aeolian transport is the key builder of foredunes particularly where vegetation enables the windblown sediment to be captured and stabilised. The sediment is thus stored within the beach system, rather than lost via further windborne transport. In the Coffs Region, aeolian transport typically contributes positively to the growth of incipient foredunes and storage of sediment in vegetated foredunes.

Between Fiddamans Beach and Sandys Beach, across Bare Bluff, Aeolian transport may also form part of the mechanism for sediment transport between these beach compartments. In recent years dune care groups have undertaken measures to attempt to stabilise the dune blowout across Bare Bluff. While stabilisation may be of use for reducing drift into nearby properties, it is unknown what effect stabilisation has had upon sediment transport into Sandys Beach.

Aeolian transport is likely to be insignificant on those beaches (e.g. Charlesworth Bay, Campbells, Korora, Hills) with coarse or gravel sediments, or where the upper beach face is typically inundated during high tide which hampers the transport by wind (Aeolian processes only apply to dry sand).

Loss or damage to vegetation on sand dunes,(e.g. the creation of informal tracks by walkers or four-wheel drive vehicles), may initiate sand blowouts and subsequent destabilisation of the dune system. This may have consequences for the retention of sediment within foredunes and therefore, the protection available to beaches during periods of erosion by waves and high water levels. Windblown sediment may also present a net loss of sediment from the active beach and dune system.

It is unknown what effect predicted changes to future wind regimes with climate change (refer Table 2-2) may have upon Aeolian transport volumes. However, while ever dunes are vegetated, windblown sediment is more likely to be captured and retained within the beach system.

3 HAZARDS DEFINITION METHODOLOGY

3.1 Hazard Probability Zones

The definition of coastal hazards inherently involves uncertainty relating not only to limited data and assessment methods but also to the uncertainties involved with climate change. Cowell *et al* (2006) describe uncertainty in climate change and coastal processes assessments due to “uncertainty about climate change itself; uncertainty about its effect on sea levels and wave climates; and process uncertainty in modelling beach responses on timescales relevant to climate change (decades or longer)”.

Cowell *et al* (2006) also note that in spite of uncertainty, we must make decisions to plan for future population and development pressures on our coast, and to preserve biophysical systems vital to our coastal communities. In this case, a method for accommodating uncertainty and allowing for transparency in estimates of beach response is required.

A risk assessment approach is a powerful methodology for dealing with uncertainty in processes and information. Rather than attempting to provide a single answer with absolute and potentially unfounded accuracy, the risk assessment approach allows us to consider a range of events, their likelihood, consequence and thus the overall level of risk. The use of a risk assessment framework for managing coastal hazards is prescribed by the NSW Government in its *Sea Level Rise Policy Statement*, *Draft NSW Coastal Planning Guideline: Adapting to Sea Level Rise* and *Draft Coastal Risk Management Guide*, all released in October 2009.

An accepted process for identifying and managing risks is outlined in the Australian Standard for Risk Management (AS/NZS ISO 31000:2009). A risk is considered to be the probability of an event occurring and the consequential impact of the event upon the asset or value. Under the Australian Standard, risks are analysed in terms of their ‘likelihood’ and their ‘consequence’.

Coastal hazards are considered to be the event that is to be analysed through risk management. In this case, both ‘likelihood’ and ‘consequence’ of the hazards needs to be analysed. The Hazards Definition phase of the NSW coastal management process is suited to defining the ‘likelihood’ or probability of occurrence of coastal hazards, through the analysis of coastal processes and historical beach responses. Based upon the Australian Standard for Risk Management (AS/NZS 4360:2004; AS/NZS ISO 31000:2009) and its companion document (HB 436:2004), the scale of ‘likelihood’ or probability of occurrence for a hazard impact is given in Table 3-1. The timeframes over which coastal hazards probability has been assessed is defined in Table 3-2, namely the immediate, 2050 and 2100 planning horizons.

The consequences of coastal hazards should then be analysed using a risk assessment as part of the Coastal Zone Management phase of the NSW coastal management framework. For example, the consequence of ‘almost certain’ beach erosion at one beach may involve the loss of one or many houses, but at another beach it may be the loss of national park lands or foreshore reserves. Clearly the resulting ‘risk’ is different based on what is exposed to the hazards. During the coastal management stage, combining consequence and likelihood, will allow the determination of a level of risk from coastal hazards at various locations along the coastline. Management responses may then be developed and tailored appropriately to the level of risk, such that areas at highest risk are prioritised for treatment.

Table 3-1 Risk Likelihood / Probability

Probability	
Almost Certain	There is a high possibility the event will occur as there is a history of periodic occurrence
Likely	It is likely the event will occur as there is a history of casual occurrence
Possible	There is an approximate 50/50 chance that the event will occur
Unlikely	There is a low possibility that the event will occur, however, there is a history of infrequent and isolated occurrence
Rare	It is highly unlikely that the event will occur, except in extreme circumstances, which have not been recorded historically.

Table 3-2 Timeframes for Coastal Planning

Timeframe	
Immediate	Present day conditions (2010)
2050	Expected conditions by circa 2050
2100	Expected conditions by circa 2100

During this study, it has been found that the historical beach response and other data was not comprehensive or detailed enough to be able to differentiate between the five likelihood categories given in Table 3-1. Rationalisation of these categories has thus been required, with focus given to ‘almost certain’, ‘unlikely’ and ‘rare’ probabilities for the immediate, 2050 and 2100 planning horizons. It has been presumed that these categories will provide a sufficient level of detail for coastal planning purposes. Our understanding of coastal processes and potential for hazards impacts has improved in recent years and will continue to improve, allowing for improvements in determination of probabilities of hazard occurrence into the future. Council is encouraged to continue and expand their data collection (e.g. beach surveys following consequential storms), in order to have ongoing datasets with which to refine the hazard zones into the future.

There are a number of advantages to providing hazards in this format, as follow:

- Defining the likelihood enables transparency about the uncertainty involved with developing hazards lines, such as relating to assessment methods and assumptions, the accuracy and coverage of available historical data, and climate change predictions and potential impacts.
- The approach makes explicit the likelihood or possibility of hazard impacts within various zones. Past hazard studies have typically defined a single hazard line for each planning period, which may have been based on the best available information and assessment methods, but were always stated to be an estimate. In practise however, the hazard lines were interpreted to have a very high level of accuracy such that it was assumed that immediately landward of a line there was zero risk of hazard impact. In reality and as observed in some locations, the hazard line was only a best estimate and there was always a risk of impact landward of the line.
- The approach is consistent with and falls neatly into a risk based management framework, as recommended by the NSW Government for coastal planning (noted above).

- Defining hazard probabilities provides better advice to planners on land use planning and zoning. For example, temporary structures (surf clubs and amenities) would be appropriate seaward of an ‘unlikely’ zone, while critical infrastructure and development (sewage pump stations, hospitals etc) may be better sited landward of the ‘rare’ hazard zone.

The methodology adopted to define the hazards and their likelihood is outlined herein.

3.2 Photogrammetric Data Analyses

Photogrammetric data provides the only source of information on changes to beach volume and the position of dunes over time. It involves the analysis of aerial photography with a stereoscope to measure elevation along a horizontal chainage line (profile). The use of photographs means that the data represents individual ‘snap-shots’ that describe beach state at one particular time.

The dates and coverage of photogrammetry data for beaches along the Coffs Harbour LGA coastline varies. The accuracy of the data also varies because of the altitude at which particularly older dates of aerial photography was flown, thus typically, older dates have a lower vertical and horizontal accuracy. The available dates of photography, vertical / horizontal accuracies and photogrammetric data quality are outlined for each of the beaches in Appendix B.

Photogrammetric data can be processed to calculate volumes along a profile cross section (in m^3/m), cumulative volumes (in m^3) of a set of profiles (a block) and to measure the horizontal distance to a particular elevation, for example, the 4 m AHD contour position. The advantages and disadvantages of each of these calculations were reviewed by Hanslow (2007). Hanslow (2007) conducted a statistical review of the photogrammetric assessment options, including sub-aerial beach volume calculation and horizontal movement of a selected dune contour position. Both of these measures were considered to have statistical significance and to be appropriate for use in beach assessments.

The dune position measurement was found to have a slightly lower standard error and slightly greater statistical significance than the sub-aerial volume calculation. The dune position measurement is also said to be vulnerable to rare events, rather than short term variability, which is useful for defining rarer or longer term beach erosion responses. However this measurement has been criticised by some authors because it does not account for vertical changes in the beach profile (PBP, 2004). Sub-aerial beach volume calculations include the vertical component of the beach profile, providing a more complete picture of beach change, but may be more susceptible to short term variability.

For this project, sub-aerial beach volume data (cumulative block volumes, individual profile volumes) and dune contour position movement have been used in assessments of both beach erosion and long term recession.

3.2.1.1 Limitations

There are limitations to the use of photogrammetric data when determining beach erosion and recession hazards, as discussed below.

The dates of the photography relative to the occurrence of storms may give a misleading account of recession over the long term because the short term erosion of beach volume skews the long term trend. The use of linear regression may assist to reduce the effect of the short term variation. Block volumes along a beach are also analysed, as the storms may impact different beach sections to a lesser or greater degree. Longer data sets, that is, more dates of photography, also assist to reduce the variation caused by individual storms periods within the data set.

In determining short term “storm bite”, the timing of the photography relative to the timing of the storm will affect the calculation of how much sediment is mobilised from the sub aerial beach face during a single storm. However, the approach to beach erosion assessment that has been adopted avoids this problem to a large degree. As explained in Section 2.4.4, it has been observed by a number of authors that the greatest extents of beach erosion, that is the greatest cutback into protective foredunes that may threaten development, are the product of a series of closely spaced storms (such as over a few months) combined high water levels (e.g. tidal anomalies additional to the high water levels caused by the storms).

At any one location on a beach, a single storm may have more or less impact in relation to the wave direction, wave height and local geomorphology that dissipates this wave energy, the water levels during the event, and the preceding beach state (eroded, accreted, average). A comparison of the day, month and year of photography against storm events (i.e. H_s > 3 m for more than 1 hour duration) in the preceding days, months and years was undertaken (refer Table B-2, Appendix B). A consistent correlation between the beach state (eroded, average, accreted) and the timing, number and duration of storms could not be found. This is largely because of the varying impact of storms upon the shoreline as explained above, as well as the inherent inaccuracies of the photogrammetric data itself.

The adopted approach to defining the extents of potential beach erosion was thus to consider the most eroded beach and dune position given in the photogrammetric data, rather than attempt to define the erosive capacity of a single storm. In addition to the fact that attempting to use photogrammetry to define the impact of a single storm is highly problematic, this approach is also insufficient for deriving zones within which beach erosion may occur and be a hazard to back beach development.

Another limitation in the use of the photogrammetric data is the occurrence of sand mining during the 1950s, 1960s and 1970s along the NSW coast. Mapping of the location of mining leases is given in Figure 2-1 and Figure 2-2. Careful observation of photogrammetric cross sections in combination with sand mining lease mapping was undertaken, and data were excluded from assessment where mining was clearly apparent. Documentation of the photogrammetric data quality for each beach is given in Chapter 4.

3.3 Beach Erosion

The beach erosion hazard probabilities have been defined based upon the most eroded profiles recorded in the photogrammetric data. A range of probable erosion extents have been determined, which encompasses the uncertainty in deriving beach erosion extents, due to climate variability and data limitations. Exact wave conditions (or water levels) that may produce the erosion extents have not been defined. It is assumed that the eroded profiles are formed by a series of storms over a period of months. The series of storms may be part of a longer (decadal) period of enhanced storminess, with various wave directions and heights during the storms. It has been assumed that the conditions that produced the most eroded profiles in the past will occur again in the future. The changes in beach position are not part of the shoreline recession hazard because even if changes occur over decades, they are a response to wave climate periods, not a permanent change in sediment supplies (e.g. a decrease due to harbour construction etc).

The same storm period may manifest differently upon each beach, as this is controlled by beach geomorphology. Geomorphology (beach orientation, headlands, reefs and other structures, pre-existing beach state such as eroded or accreted, pre-existing rip current location, grain size) affects the refraction and dissipation of waves, and the resulting erosion or accretion upon the beach. Even within a beach embayment, a storm may impact upon either end of the beach to more or less degree depending upon the incident wave direction (and which can result in a transfer of sand from one end of the beach to the other, typically termed ‘rotation’).

Use of the most eroded profile to define probable beach erosion extents is not representative of one ‘design’ storm. The occurrence of a ‘design’ storm and calculation of a ‘storm bite’ is not necessarily representative of the most eroded beach condition, which is of key interest to planners and managers in utilising areas behind the beach. It is recognised in the literature that a series of storms produce greater extents of erosion because the beach does not have time to recover (accrete) between storms (e.g., CMM, 1990; Ranasinghe *et al.*, 2004). The ‘design storm’ concept cannot adequately represent a series of closely spaced storms within a period of enhanced storminess. Furthermore, beach erosion is influenced by too many variables, including wave height, wave direction, water levels, storm duration, sediment grain size, beach geomorphology and beach state prior to the storm, which prevent specific ‘design storm’ criteria being determined.

Likewise, there are limitations in the extent, coverage and accuracy of historical data that make the ‘design storm’ approach potentially unreliable. It is reasonable to assume that not all periods of beach erosion are recorded for every beach because there are relatively few dates of photogrammetric data at each beach. For example, at Bongil Beach there are only six photogrammetric dates between 1964 and 2007, while Sawtell Beach has nine dates between 1967 and 2007.

Defining a range of probable erosion extents rather than a single erosion line or ‘storm bite’ captures the uncertainty in beach erosion estimates due to climate variability, data limitations and assessment techniques. Further, it enables previously unrecorded erosion events to be estimated, along with an indicative likelihood of occurrence. As used here, the ‘rare’ erosion hazard provides further information for both landuse planners and the general public about extreme coastal processes, which may be worse or more extensive than has been recorded in the data or observed historically. Even though the probability of such events is very low, the potential impacts may need to be managed.

The approach adopted was to review the historical data to derive the likelihood for the occurrence of beach erosion extents. Using the most eroded conditions of the past encompasses the existing wave climate variability, which may manifest over monthly, seasonal, annual and even decadal scales. The likelihood of erosion occurring again is based upon its occurrence in the past, regardless of the wave and water levels conditions that produced this erosion. As noted in Section 3.2.1.1, both the historical beach behaviour information and the historical wave and water level information are not sufficient to provide detail on wave and water level conditions. Furthermore, estimating a range of ‘probable’ beach erosion extents considers the uncertainty involved in estimating beach erosion. It also enables consideration of conditions for which there is no recorded data.

The process utilised in deriving hazard probability zones from the historical data is outlined below. The process for defining ‘almost certain’, ‘unlikely’ and ‘rare’ beach erosion is summarised in Table 3-3. Definition of the probabilities is given in Table 3-1. Detailed explanation of the derivation of beach erosion hazard extents is given for each beach in Chapter 4.

Photogrammetric data was interrogated in a number of ways to determine the most eroded beach profile in the past. This included visual interrogation of profile cross sections to observe the location of most eroded profiles and potential changes in beach width. The movement of the 4 m AHD contour position was then derived from the photogrammetric data. The 4 m AHD contour is within the area of active surfzone processes during storms and is also the region of active contemporary dune building processes during beach recovery, but this position is relatively unaffected by short term (daily) beach changes. It is thus an appropriate bench mark to observe movements of the beach position. Profile volumetric data (m^3/m) was also considered in determining the probable beach erosion extents. To compare dune position change and beach volume change, the volumetric data was converted to a movement of the shoreline position. The dune (4 m AHD) contour calculations and profile volume calculations were compared with the photogrammetry profile cross sections in order to ensure consistency with changes in beach morphology over time. Examples of such calculations at Bongil Beach and Sawtell Beach are given in Figure 3-1 and Figure 3-2.

For each photogrammetric profile along a beach, the most eroded (landward) position of the 4 m AHD contour was measured from the 2007 position, as shown in Figure 3-1 and Figure 3-2. Data was processed relative to the 2007 position because aerial laser survey data was available for this date, from which hazard extents can be spatially measured and mapped. The subtraction between most eroded and 2007 dates was repeated for the profile volume data (m^3/m), and after subtraction, the volumetric data was converted to a horizontal movement (m) based upon the dune height of the profile.

The average erosion value (m movement of the 4 m contour) was adopted as the ‘almost certain’ probability of occurrence of beach erosion, as shown in Figure 3-1 and Figure 3-2. Given that the erosion extents are derived from historical data, it is very likely that the conditions which produced such extents in the past will occur again in the future.

The maximum erosion value at any point along the beach was adopted as the ‘unlikely’ probability of occurrence of beach erosion for the whole beach, such as shown in Figure 3-1 and Figure 3-2. This encompasses the possibility that rips (and their associated erosion scarps) may form at any location along a beach, and that waves may affect any section of the beach.

It is also possible that the most eroded beach state has not been recorded by the historical (photogrammetric) data. In this case, a ‘rare’ probability beach erosion extent has been derived. The simplest approach (in lieu of measured data that would enable a more refined approach) was to calculate the difference between the average and maximum beach erosion extent, and then add this to the maximum beach erosion extent. This is shown in Figure 3-1 and Figure 3-2. The ‘rare’ probability accounts for extreme conditions that have not been measured previously, but that may occur in the future and therefore need to be considered for future planning.

The values adopted for the beach erosion probabilities were rounded up from the average and maximum values. This aims to clearly recognise the uncertainty and assumptions used in determining the estimates. That is, using exact numbers implies a level of accuracy in the assessment that is not consistent with the photogrammetric data coverage and quality.

Each of the beach erosion probabilities (‘almost certain’, ‘unlikely’ and ‘rare’) have been adopted across the length of the beach embayment. All locations along a beach have the potential to be affected, depending upon the wave height, direction and water level of storms. Headland bypassing events occur during storms, resulting in episodic movement of slugs of sand around headlands. This can manifest as severe erosion of the updrift or downdrift coast, depending upon the timing of the bypassing. In addition, rip currents may potentially form at any location along the beach. The shoreline behind a rip current will typically experience greater erosion, due to the deeper water and outflowing current within the rip. In large storms, the number of rips reduces, but the size and strength of the individual rips increases, causing greater impact on the shoreline.

There were additional considerations when processing the photogrammetric data and applying the hazard zones, as follows.

Where the beach was known to be considerably affected by the harbour construction (e.g. Park, Diggers, Campbells etc) values from beaches known to be unaffected by the harbour (Sawtell, Bongil) were adopted, as appropriate to the beach geomorphology. As shown in Figure 3-1 and Figure 3-2, the erosion extents at Bongil and Sawtell Beaches are quite different, as is dependent upon the beach geomorphology.

Photogrammetric profiles across creek mouths and drainage lines were not included in the assessment of beach erosion extents, because these areas are additionally affected by runoff and creek outflow which may also cause erosion, such as demonstrated in Figure 3-1 (e.g. Bonville Creek, Bundageree Creek). Including photogrammetric data from creek mouths would give an overestimate of beach erosion extents, which would be inappropriate particularly along the remainder of the beach. The extent of erosion at creek mouths and drainage lines however, was included within the beach erosion hazard zones. The origin line from which beach erosion extents were measured was taken on the landward side of drainage points and creek entrance berms. In all cases, the photogrammetric data showed that entrance berms were eroded away frequently in the past, and so, we have assumed that under an open entrance condition, waves may attack and cause erosion of areas behind the entrance berm. In this manner, erosion of coastal entrances and stormwater drainage lines is included within the beach erosion hazard, rather than defined separately.

Future Beach Erosion due to Climate Change

Detailed analysis of a future potential wave climate was undertaken for this project. Detailed analysis of historical wave climates prior to the period of wave measurement was also undertaken (refer Progress Report, Appendix A).

In the case of future wave climates (height, direction), the analysis indicated that any future change is within the existing variability that has occurred during the historical past. In particular, the period of enhanced storminess of 1970s is more extreme than that given in wave climate projections for the future.In this case, we may consider the historical beach response, which represents the effects of wave climate of the past, to be representative of the potential impact of future wave climate variability. Utilising erosion profiles of the past is very likely to capture future erosion events, due to natural or climate change induced variability.

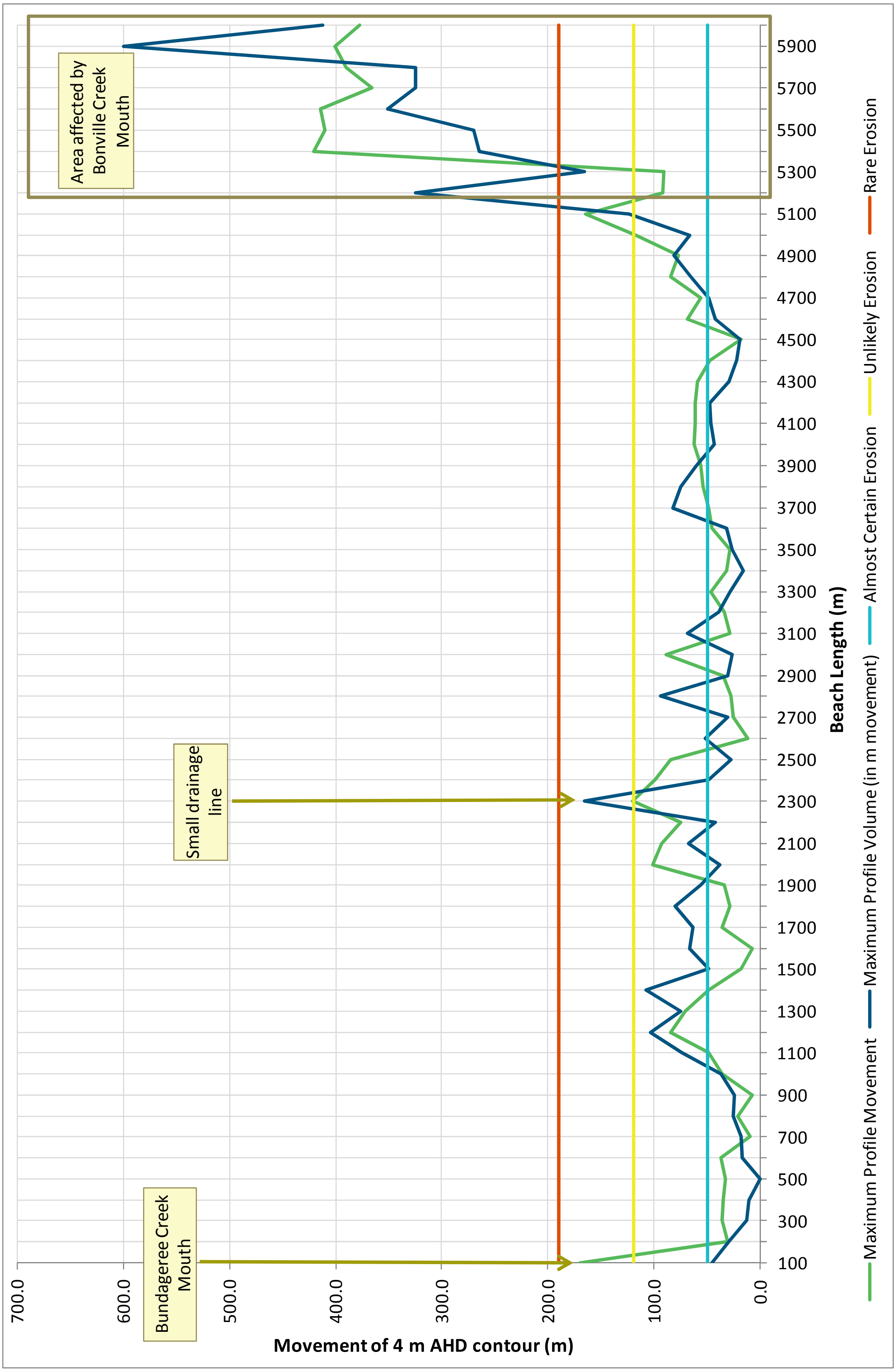


Figure 3-1 Beach Erosion Calculation, Bongil Beach Example

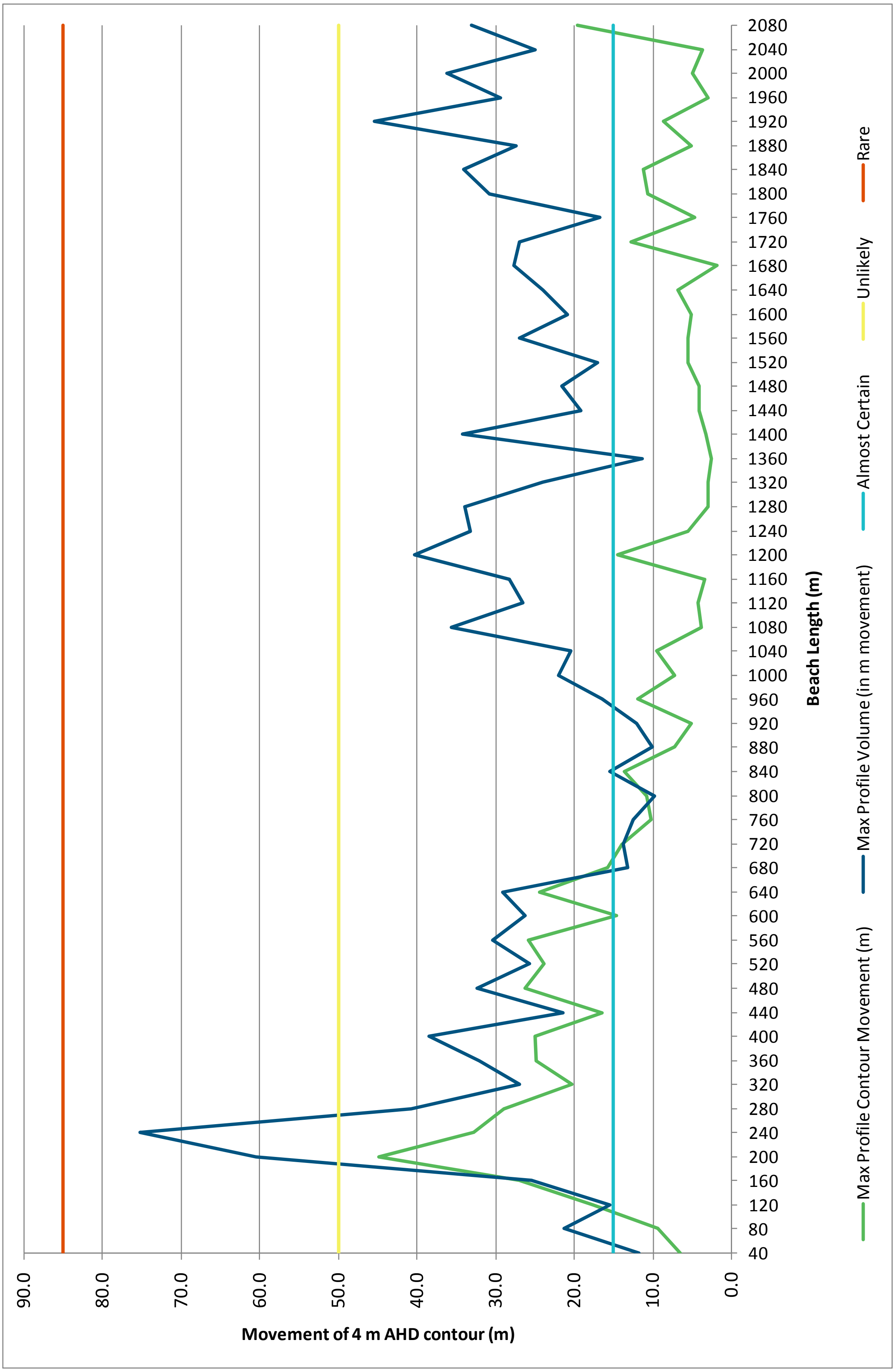


Figure 3-2 Beach Erosion Calculations, Sawtell Beach Example

3.4 Long Term Recession

Shoreline recession, or long term recession, is defined in the Coastline Management Manual (1990) as the permanent landward movement of the shoreline position. Unlike beach erosion, the recession impacts are permanent. An ongoing and permanent loss of sediment from the beach system, such as may occur due to the interruption of littoral transport by a harbour or groyne, is one cause of permanent landward shift in the shoreline. The landward movement of the shoreline also occurs in response to sea level rise, illustrated typically with the Bruun Rule (1962) concept, in Figure 3-3. The concept demonstrates the two-dimensional response of the shoreline to reach a new equilibrium with the new sea level position. This results in an upward and landward translation of the entire beach and dune profile.

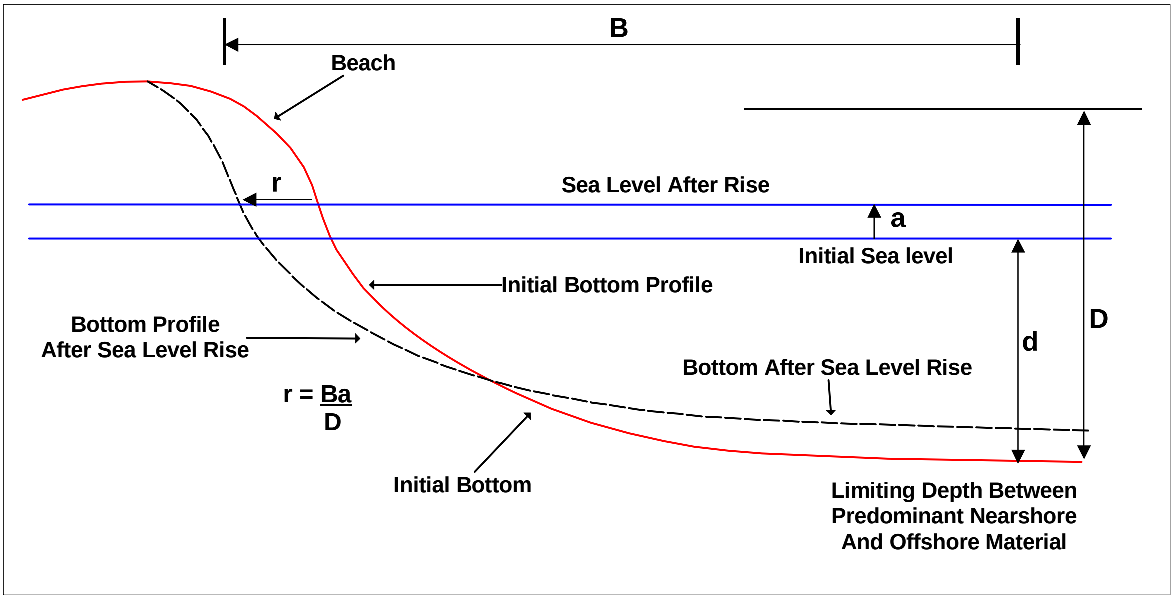


Figure 3-3 Brunn (1962) Concept of Recession due to Sea Level Rise

BMT WBM (Dean Patterson) has developed a Shoreline Evolution Model which is capable of reproducing the response of the shoreline to sea level change, and / or structural changes (e.g. harbour breakwaters or groyne construction). The adopted approach to assessing long term recession utilised this modelling tool in addition to available historical data, as follows:

- An assessment of the photogrammetric data to determine historical trends was undertaken. As documented in Section 2.8.2.2, the construction of Coffs Harbour breakwaters has had a considerable impact on beaches updrift and downdrift of the harbour.
- Shoreline evolution modelling using world class techniques was conducted to replicate historical trends, particularly the impacts of harbour construction upon the shoreline. The model results were compared with historical data to confirm the validity of outputs.
- An assessment of long term recession in the future due to sea level rise and local impacts (e.g. Coffs Harbour, natural headlands and reefs), using world class modelling techniques was

performed. Model results were utilised as appropriate at the beaches, depending upon the comparison with historical data.

Each of these tasks and regional findings are explained below, in particular, the significant advance in predicting future long term recession with modelling compared with use of the Bruun Rule (1962).

3.4.1 The Shoreline Evolution Model

BMT WBM's Dean Patterson has developed a Shoreline Evolution Model as part of his part-time PhD studies. The model is the first of its kind able to predict shoreline change in response to large scale changes in sea level (e.g. 0 to 100 m) and changes in shoreline structure, e.g. due to the installation of harbour breakwaters that may affect longshore sediment transport.

The model uses a time stepping approach to drive shoreline evolution in response to deep water wave time series data (rather than input from a wave model) and sea level. The model internally refracts waves from deep water into the near shore zone, calculates longshore transport to match the regional transport rate and includes an onshore transport rate (based upon annual average rates derived from beach profile data) to account for supply from nearshore and inner shelf sands to the upper beach face as sea level rises. A schematic of the two-dimensional model domain is given in Figure 3-4 (Patterson, 2009).

This world-class model is a significant advance from the Bruun Rule (1962), as it is able to account for the three dimensional nature of the coastline (refer to Ranasinghe *et al*. (2007) for limitations of the Bruun Rule). The model accounts for the interaction between waves (refraction, dissipation), headlands, reefs, rock platforms, groynes, breakwaters and other coastline features and shoreline slope in generating longshore and cross shore sediment transport. As a result, the model is able to predict the different responses to sea level rise along a section of coastline in response to headland and reefs, and structures such as groynes and harbour breakwaters.

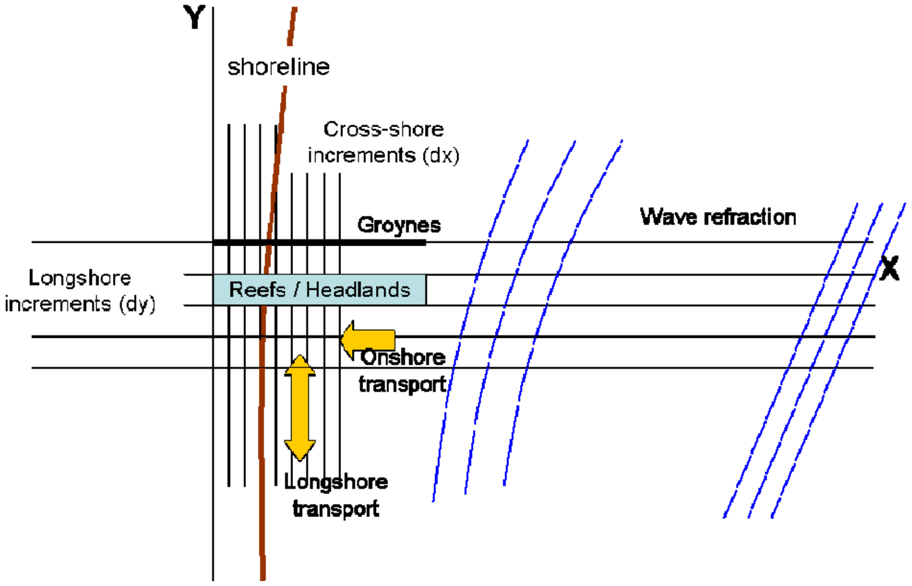


Figure 3-4 Modelling Software Schematisation (Patterson, 2009)

BMT WBM recognises that modelling is a tool for understanding long term recession, rather than an absolute outcome. Model results provide an estimation of likely impact, but must be consistent and verifiable against the physical constraints of coastal processes and coastal geomorphology, as described in the historical (photogrammetric) data. Therefore, careful analysis of photogrammetry data for long term beach trends was compared with model outputs to verify results.

The modelling procedure involved the following stages:

- Modelling for a 'base' case shoreline without Coffs Harbour breakwaters or sea level rise, but including all natural features such as headlands and reefs. The 'base' case was simulated for a period of 2000 years (at zero sea level rise) to stabilise the regional longshore transport into, along and out the Coffs coastline, prior to structural changes.
- Modelling of a 'harbour' case, that is, the construction of the harbour breakwaters at the northern end of Boambee and Coffs Harbour. This scenario was run for 200 years from 1930 (assuming the complete construction of the harbour) to 2130, without change in sea level.
- A verification process to compare model results with the historical data was undertaken, to determine if results were consistent with actual beach changes. Modification to the structural representation of the harbour within the model was conducted as required, to ensure consistency between model output and historical beach response.
- Modelling of a 'harbour and sea level rise' case, simulated for 200 years from 1930 to 2130. Sea level rise was kept constant until the year 2000, after which a linear rise to 0.4 m by 2050 then to 0.9 m above present by 2100 was simulated.
- Modelling of a second theoretical 'harbour and sea level rise' case, to investigate the impact of a 0.5 m greater than predicted rise in sea level to 2100. Again, the simulation was run for 200 years from 1930 to 2130, with sea level rise remaining constant until 2000, then rising linearly to 0.7 m by 2050 then 1.4 m by 2100.
- Where model results performed well compared with the historical results for the harbour construction, the model results for sea level rise and the harbour impact were adopted (with rounding to account for uncertainty), as explained in detail below.
- In the rare case where model results from impact of harbour construction alone were inconsistent with the historical results, the results for sea level rise were adjusted to better reflect the likely future impact.

Discussion of the historical data, modelling results and verification for the harbour impact and sea level rise in the past and future is given in detail below.

3.4.2 Historical Long Term Recession

The assessment of long term recession first involved analysing the photogrammetric data to determine the rate of recession or accretion along the beach. Analysis of the photogrammetric data involved calculating cumulative block volumes and average dune position in blocks. Linear regression of volumes were then converted (using dune height) into a metres per year (m/yr) movement of the shoreline position. For comparison, linear regression of the movement of dune position was also conducted. Based upon the results, the rate of change representing either recession or accretion was determined within blocks and on average for each beach.

The analysis carefully considered the quality of the photogrammetric data (as evident in profile cross section diagrams), particularly for potential mining impacts in the data. Our assessment and comparison of photogrammetric data and model results has been careful to account for wave climate variability that may modify the historical beach response. Further, the response to wave climate variability is captured within the beach erosion hazard.

The historical response of each beach (recession, accretion or stability) as evident in historical data has been documented in Chapter 4. In general, beaches south of Boambee (Sawtell, Bongil) are unaffected by the harbour construction. Boambee Beach has experienced significant accretion particularly at its northern end due to the capture of littoral drift sediment by the harbour breakwaters. Likewise, the harbour mouth has experienced accretion and a reduction in depth, as it collects sediment bypassing around the eastern breakwater. The beaches immediately north of the harbour (South Park and Park, Diggers, Korora, Campbells to White Bluff) have clearly experienced significant recession in the past. Impacts from the harbour construction are more recently beginning to occur on Sapphire and Moonee Beaches.

In recent years the rates of recession on these northern beaches have slowed, and even stabilised at the majority. The exception is Diggers Beach, which continues to demonstrate significant recession. In addition to sand mining impacts in the past, Diggers is heavily embayed by large bounding headlands and requires storms to bypass and supply sediment into the beach. The less stormy wave climate conditions from 1970s to 2007 may have thus exacerbated sediment starvation of Diggers Beach.

Wave climate conditions may enhance or reduce the trends evident in the historical data. In particular, the period of lower storminess and slightly enhanced southerly wave climate since the late 1970s has been observed to have promoted a period of accretion particularly on beaches facing south-east to east-south-east in Coffs Harbour, as discussed in detail in Chapter 4. On certain northern beaches such as Moonee, this may have dampened the recessionary effects of the harbour. The photogrammetric assessment confirms that recession has slowed or stabilised at a number of the beaches north of the harbour, which is due in part to the wave climate conditions and a likely resumption of some sediment bypassing around the harbour.

Beyond Look At Me Now Headland (at the northern end of Moonee Beach) impacts from the harbour are not evident, with recession and accretion on beaches north of this headland in response to wave climate variability, rather than a permanent change. Look At Me Now Headland appears to be a significant boundary to longshore sediment transport in the region, which was confirmed in the model results.

The shoreline modelling results were found to replicate the historical results very well. Shoreline modelling (verified with the trends apparent in the photogrammetric data) has provided useful insight into the effect of the harbour construction upon longshore sediment supply and long term recession at Coffs Beaches. The impact of the harbour construction is evident in Figure 3-5 and Figure 3-6, which illustrates the change in longshore transport rate along the coastline from 1930 to 2030. This figure illustrates the initial cut off of longshore transport by the harbour as a sharp drop in the longshore transport rate immediately north of the harbour. Over time the reduction in longshore transport rate progressively moves northwards.

The effect of the reduction in longshore transport rate recession of the beaches is felt first on beaches in closest proximity to the harbour (i.e. Park Beach, Campbells Beach), as demonstrated in Figure 3-9, which shows the change in shoreline position over time from the Harbour impact only. As time continues, the beaches in closest proximity are receded to a point where longshore transport is relatively impeded by bounding headlands. The impact of the harbour transfers to beaches further north, to supply the natural longshore transport rate, as demonstrated in the model results in Figure 3-5, Figure 3-6, Figure 3-9 and Figure 3-10 and confirmed in historical data, described above.

At the same time, sediment is progressively built up along the southern boundary of the harbour (Boambee Beach), eventually reaching a point that bypassing of the harbour resumes. The model results suggest harbour bypassing is expected to resume by around 2000, supplying beaches in closest proximity first enabling stability and minor (1-2 m) recovery. This was confirmed in the photogrammetric data for Park to Campbells Beaches (except Diggers) as noted above.

One difference of note between the shoreline modelling and the photogrammetric data is that of the rates of recession at the extreme southern ends of beaches. The modelling suggests that the extreme southern ends would experience the highest recession extents. However, the photogrammetric data indicated that the highest extents of recession did not occur at extreme southern ends, but rather at the shoreline just north of the extreme southern end.

It is likely that the refraction of waves into the Coffs Coastline is not always replicated exactly in the model. In actuality, south easterly waves refracting around the larger headlands into the Coffs Coastline will arrive at the shoreline slightly north of the extreme southern end and this is where longshore sediment transport will be initiated. The result is greater recession at the location where waves meet the shoreline (i.e. slightly north of the southern end) and shadowing of the extreme southern ends from the full effect of the incoming waves and longshore transport. This has been accounted for in the adoption of recession rates due to sea level rise at the southern end of the beaches.

3.4.3 Future Long Term Recession

Beyond 2000 without sea level rise, the modelling results indicate that the recessionary effect of the harbour continues to migrate northwards, causing recession on Moonee Beach in particular by 2100, and eventually more minor recession to beaches north of Look At Me Now Headland after 2050 to 2100 (refer Figure 3-9 and Figure 3-10). This is because, even though bypassing has resumed by 2000, it has not yet matched the sediment supply required to maintain stability of the beaches, that is, the regional longshore transport rate. As noted above, beaches such as Park and Campbells would be expected to stabilise without sea level rise by 2100.

The shoreline evolution model was also utilised to model the impact of predicted sea level rise, in addition to the harbour impacts. The outcomes of the shoreline modelling *without* sea level rise were consistent with the extents of recession described by the photogrammetry for the majority of beaches. Thus, there is confidence in the use of modelling results to predict the beach response to projected sea level rise and the harbour impact in the future.

The change in the shoreline position due to the combined impact of sea level rise and the harbour is illustrated in Figure 3-11 and Figure 3-12. The recessionary impact of sea level rise alone is shown in

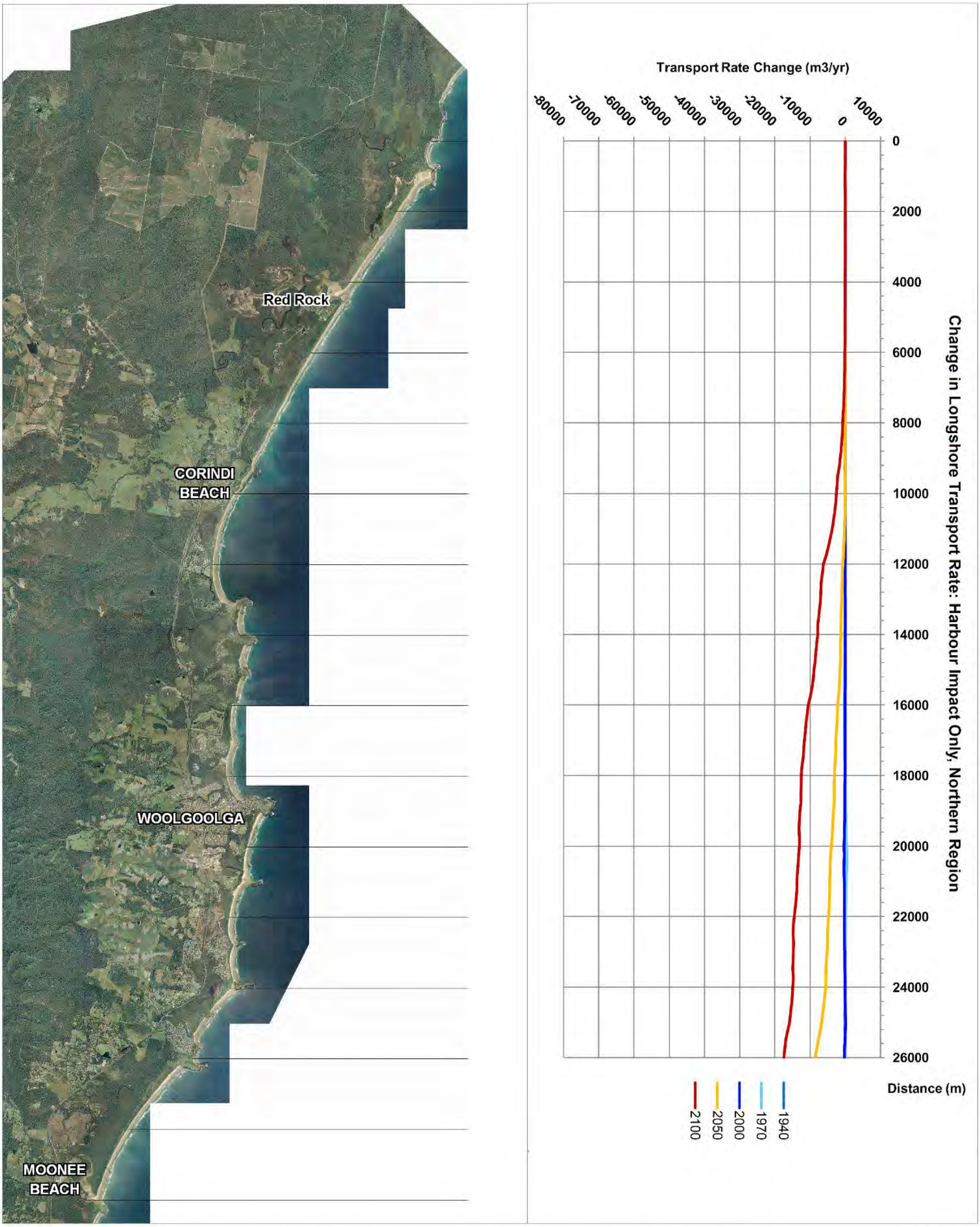
Figure 3-13 and Figure 3-14, with the change in longshore transport rates in relation to sea level rise shown in Figure 3-6 and Figure 3-7.

The modelling results demonstrate that the extent of recession due to sea level rise is considerably greater at the southern end of the beach, while the northern end of the beach experiences minimal recession. This is an important finding of the shoreline model, as it differentiates alongshore response, which the Bruun Rule is incapable of doing. The south easterly wave climate generates a northerly longshore sediment transport. As the sea level rises, headlands further separate transport from beach to beach, due to the increased water depths. The northerly transport within an embayment acts to supply sediment to the northern end of the beach, mitigating recession to some degree. However, the southern end of the beach is the source of this supply and, without supply from beaches to the south into the compartment, there is enhanced recession at the southern ends of beaches due to sea level rise.

There are many locations in Coffs which have reefs attached to or immediately offshore of the shoreline, behind which lobes or tombolos of accumulated sand have formed (e.g. Riecks Point Reef north of Campbells Beach). The modelling demonstrates the impact of sea level rise upon shorelines in the lee of reefs. The increased water depth with sea level rise reduces dissipation and refraction of incoming waves by the reef. The enhanced wave energy in the lee of the reefs will act to erode the previously accumulated sediment behind the reefs.

The model results for predicted sea level rise demonstrate that, in addition to the expected recession, the sea level rise acts to ‘re-initiate’ the impact of the harbour on Coffs northern beaches. As we have discussed, the Coffs coastline to some degree will have started to reach an equilibrium with the harbour construction by 2000. With sea level rise, the harbour construction has a similar but enhanced effect as headlands on the coastline. The sea level rise constricts accretion upon Boambee Beach as it responds to the sea level rise, reducing the accumulation of sediment and bypassing into the harbour. In turn, this limits accretion in the harbour and the increasing water depths at the harbour mouth further limit the potential for sediment transport into South Park and Park Beaches (as greater wave heights are required to mobilise the sediment). The result is that recession on South Park and Park Beaches due to the harbour will re-commence. This will be in addition to the general recessionary effects of sea level rise on these beaches. Given the lack of sediment within the beach systems adjacent to the harbour, the migration of the harbour impact to Sapphire, Moonee and beyond will also continue and is in addition to the recession due to sea level rise alone.

The Shoreline Evolution Model is an extremely powerful and informative tool in predicting the impacts of sea level rise on the Coffs coastline, as it is able to account for the interaction of the south east wave climate with headlands, reefs and structures such as the harbour in generating longshore transport and ultimately, the extent of recession in response to sea level rise.



Title:

Modelled Change in Longshore Transport Rate due to the Harbour Construction Only, Northern Region

Figure:

3-5

Rev:

A

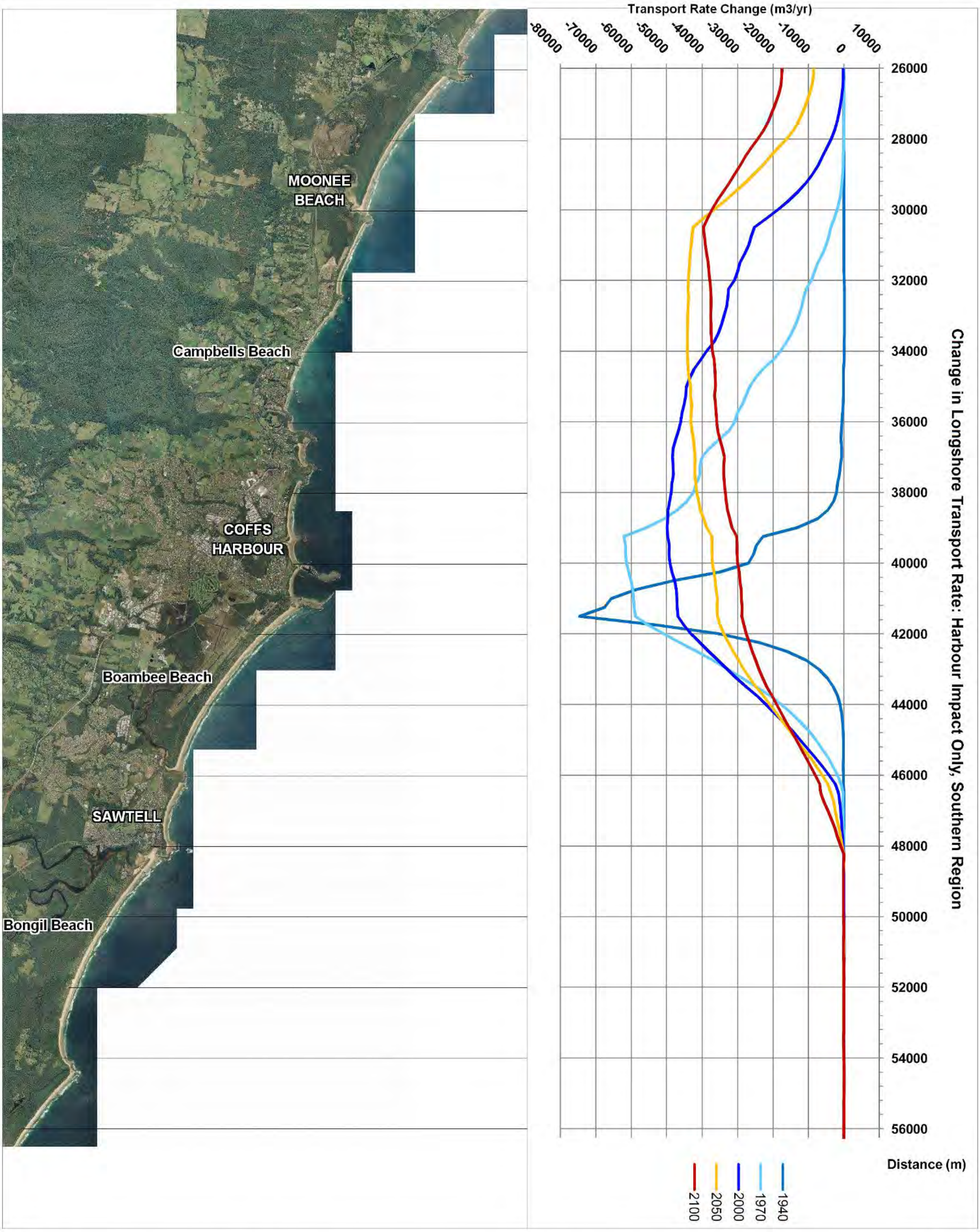
N

0 2.5 5km

Approx. Scale

BMT WBM
www.wbmpl.com.au

Filepath : K:\N1440 Coffs Coastal Process Hazard Definition Study\MapInfo\Workspaces\DRG_023_100511 Longshore Harbour Impact North.WOR



Title:

Modelled Change in Longshore Transport Rate due to the Harbour Construction Only, Southern Region

Figure:

3-6

Rev:

A

N

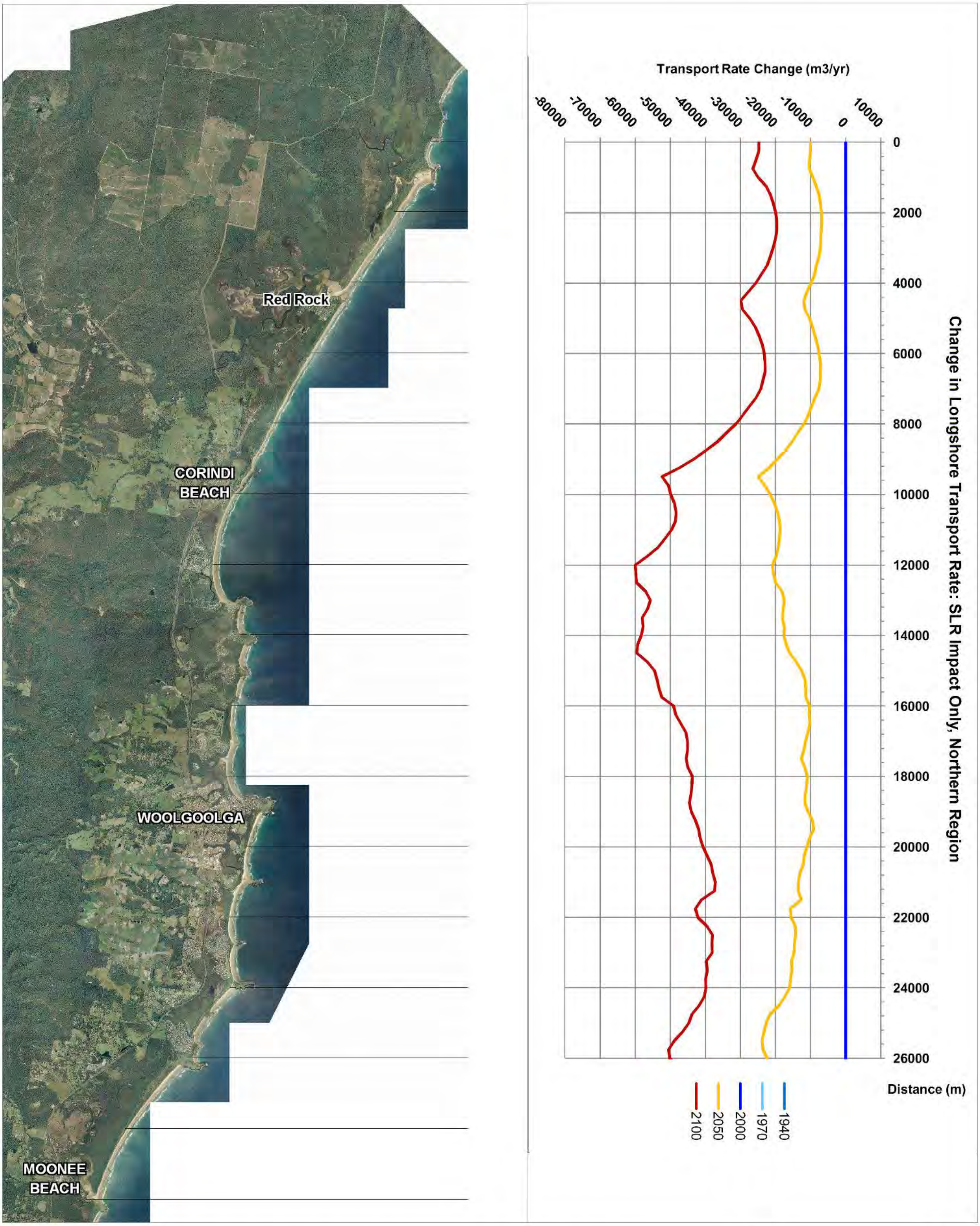
0 2.5 5km

Approx. Scale

BMT WBM

www.wbmpl.com.au

Filepath : K:\N1440 Coffs Coastal Process Hazard Definition Study\MapInfo\Workspaces\DRG_026_100511 Longshore Harbour Impact South.WOR



Title:

Modelled Change in Longshore Transport Rate due to Sea Level Rise Only, Northern Region

Figure:

3-7

Rev:

A

N

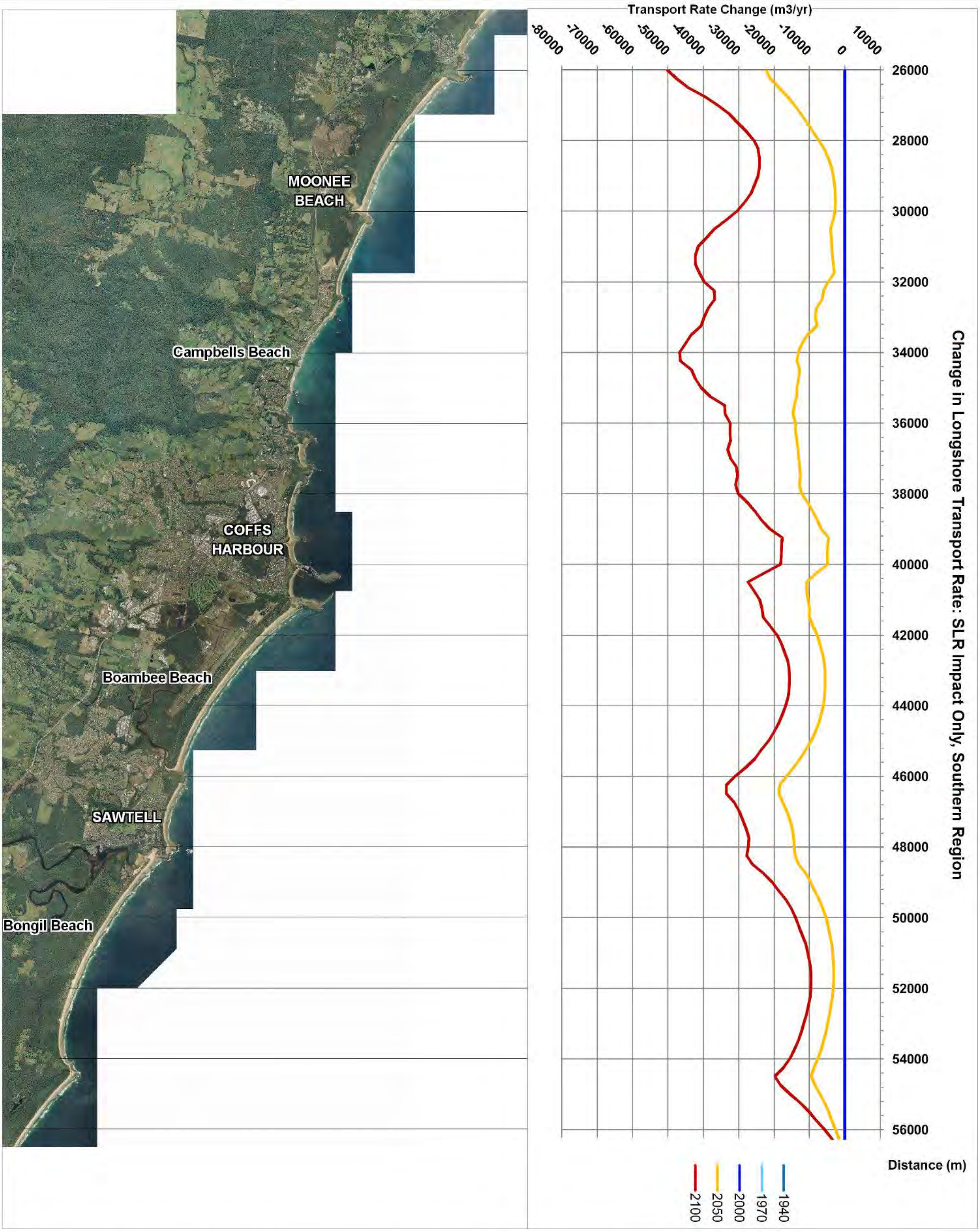
0 2.5 5km

Approx. Scale

BMT WBM

www.wbmpl.com.au

Filepath : K:\N1440 Coffs Coastal Process Hazard Definition Study\MapInfo\Workspaces\DRG_024_100511 Longshore SLR Impact North.WOR



Title:

Modelled Change in Longshore Transport Rate due to Sea Level Rise Only, Southern Region

Figure:
3-8

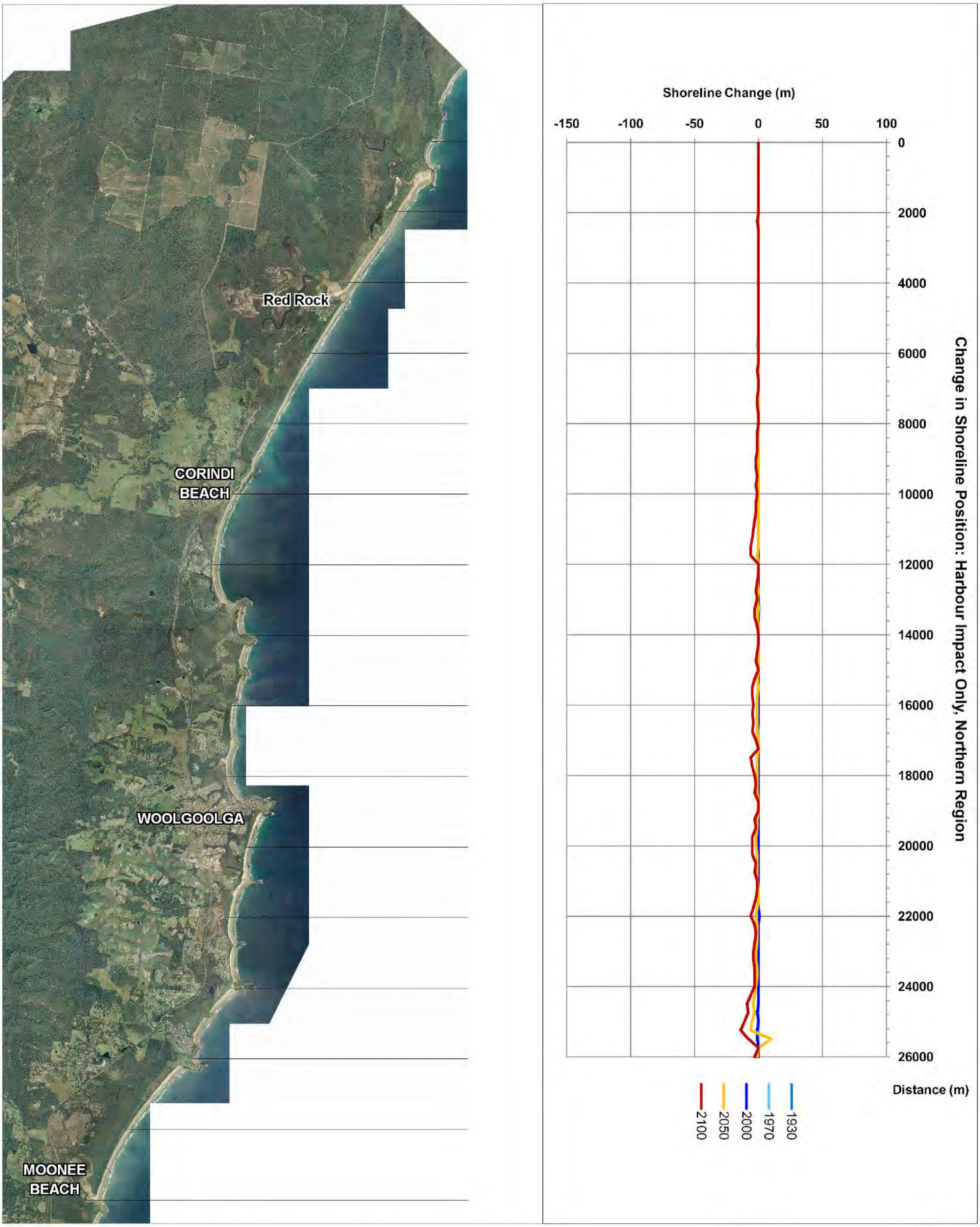
Rev:
A

N

0 2.5 5km
Approx. Scale

BMT WBM
www.wbmpl.com.au

Filepath : K:\N1440 Coffs Coastal Process Hazard Definition Study\MapInfo\Workspaces\DRG_027_100511 Longshore SLR Impact South.WOR



Title:

Change in Shoreline Position due to Harbour Only, Northern Region

Figure:
3-9

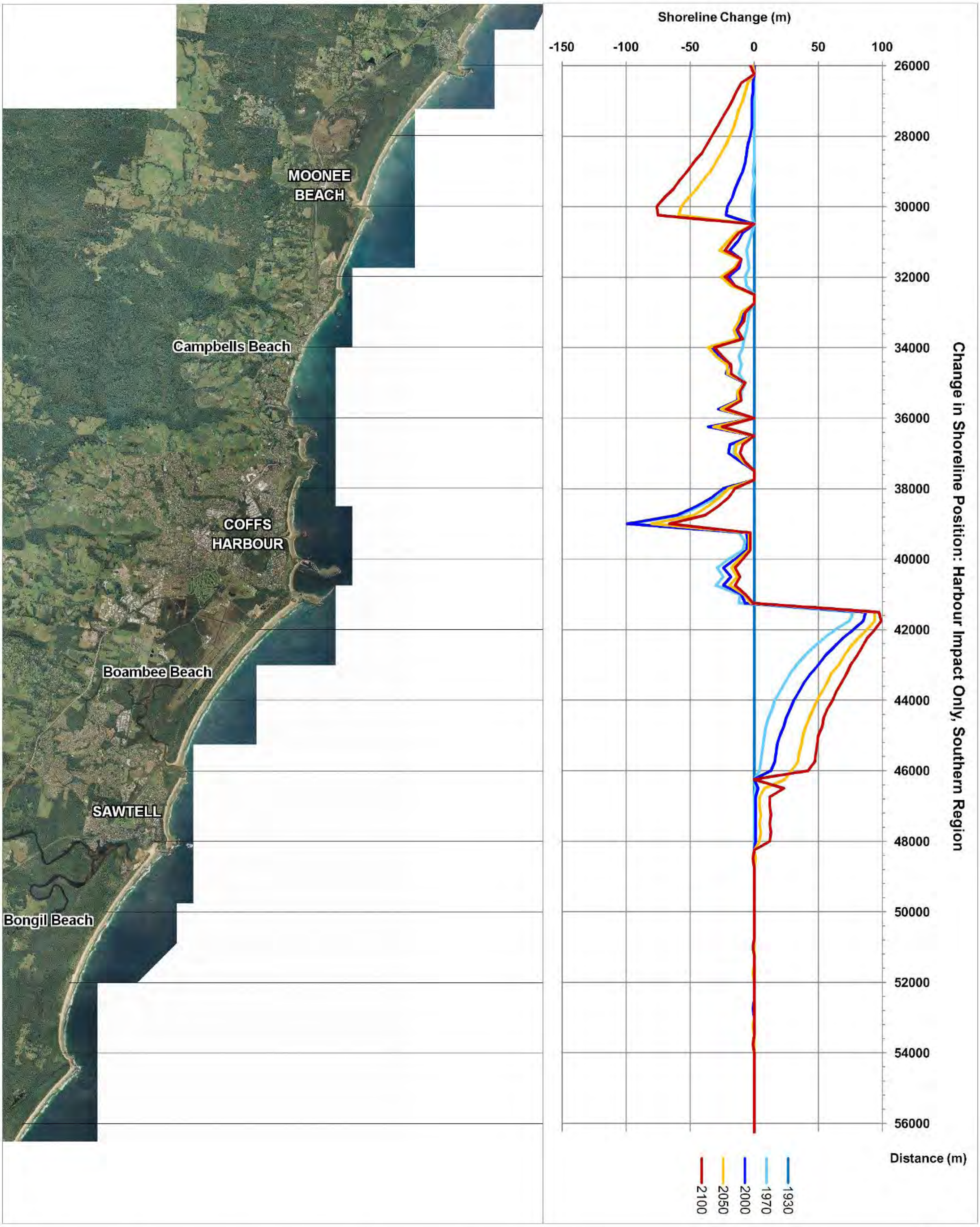
Rev:
A

N

0 2.5 5km
Approx. Scale

BMT WBM
www.wbmpl.com.au

Filepath : K:\N1440 Coffs Coastal Process Hazard Definition Study\MapInfo\Workspaces\DRG_018_100511 Shoreline Harbour Impact North.WOR



Title:

Change in Shoreline Position due to Harbour Only, Southern Region

Figure:
3-10

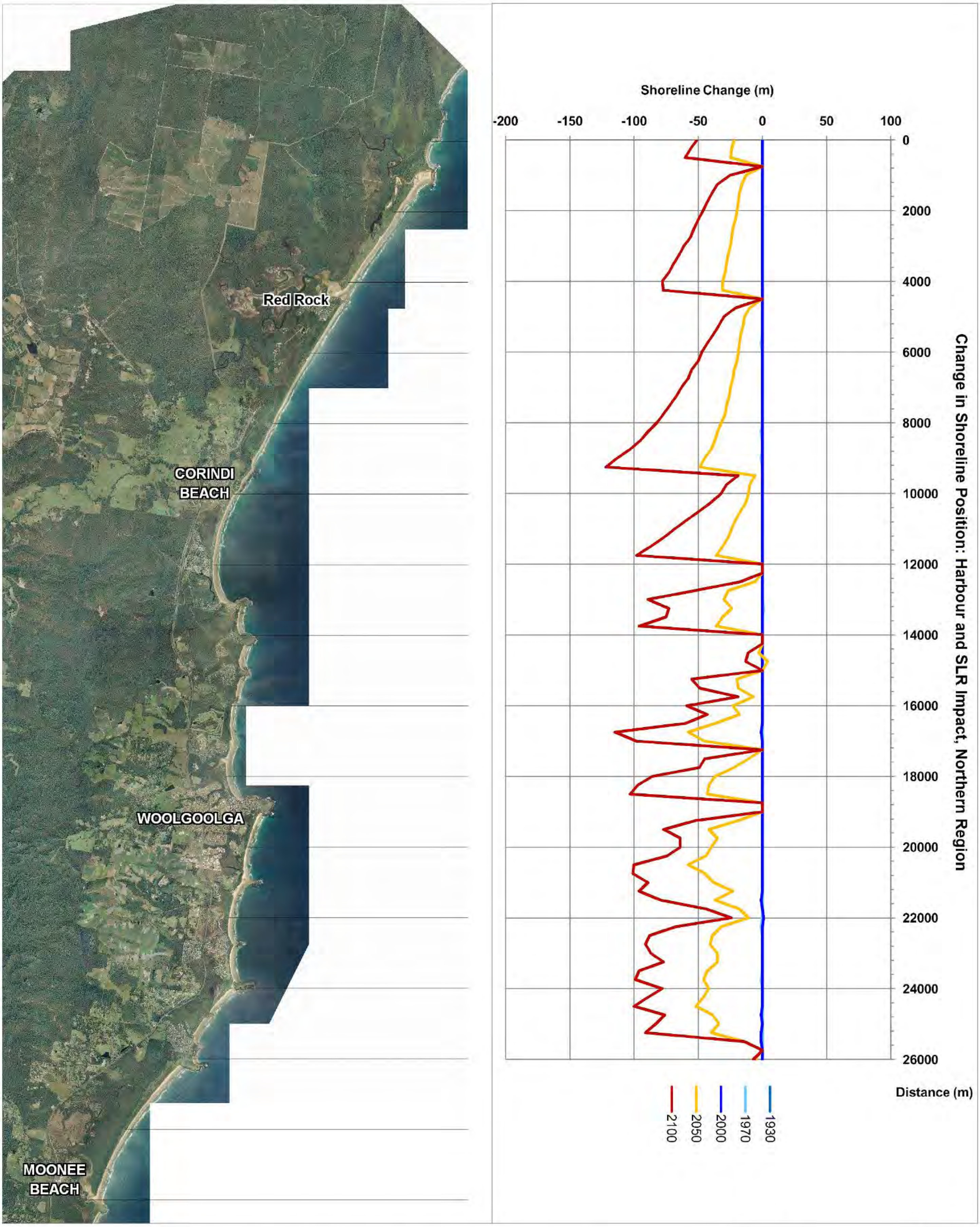
Rev:
A

N

0 2.5 5km
Approx. Scale

BMT WBM
www.wbmpl.com.au

Filepath : K:\N1440 Coffs Coastal Process Hazard Definition Study\MapInfo\Workspaces\DRG_025_100511 Shoreline Harbour Impact South.WOR



Title:

Change in Shoreline Position due to Harbour and Sea Level Rise, Northern Region

Figure:
3-11

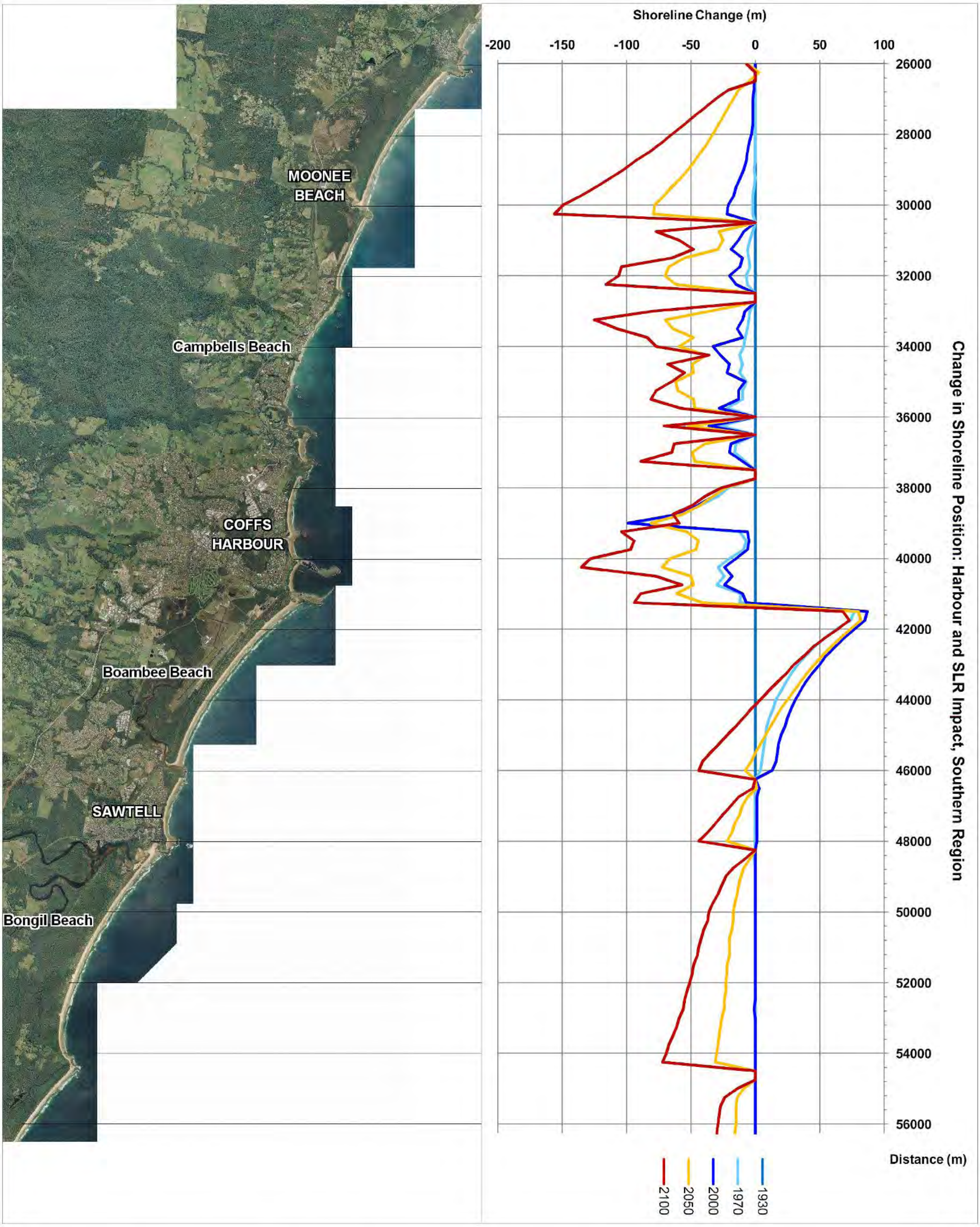
Rev:
A

N

0 2.5 5km
Approx. Scale

BMT WBM
www.wbmpl.com.au

Filepath : K:\N1440 Coffs Coastal Process Hazard Definition Study\MapInfo\Workspaces\DRG_021_100511 Shoreline Harbour and SLR Impact North.WOR



Title:

Change in Shoreline Position due to Harbour and Sea Level Rise, Southern Region

Figure:

3-12

Rev:

A

N

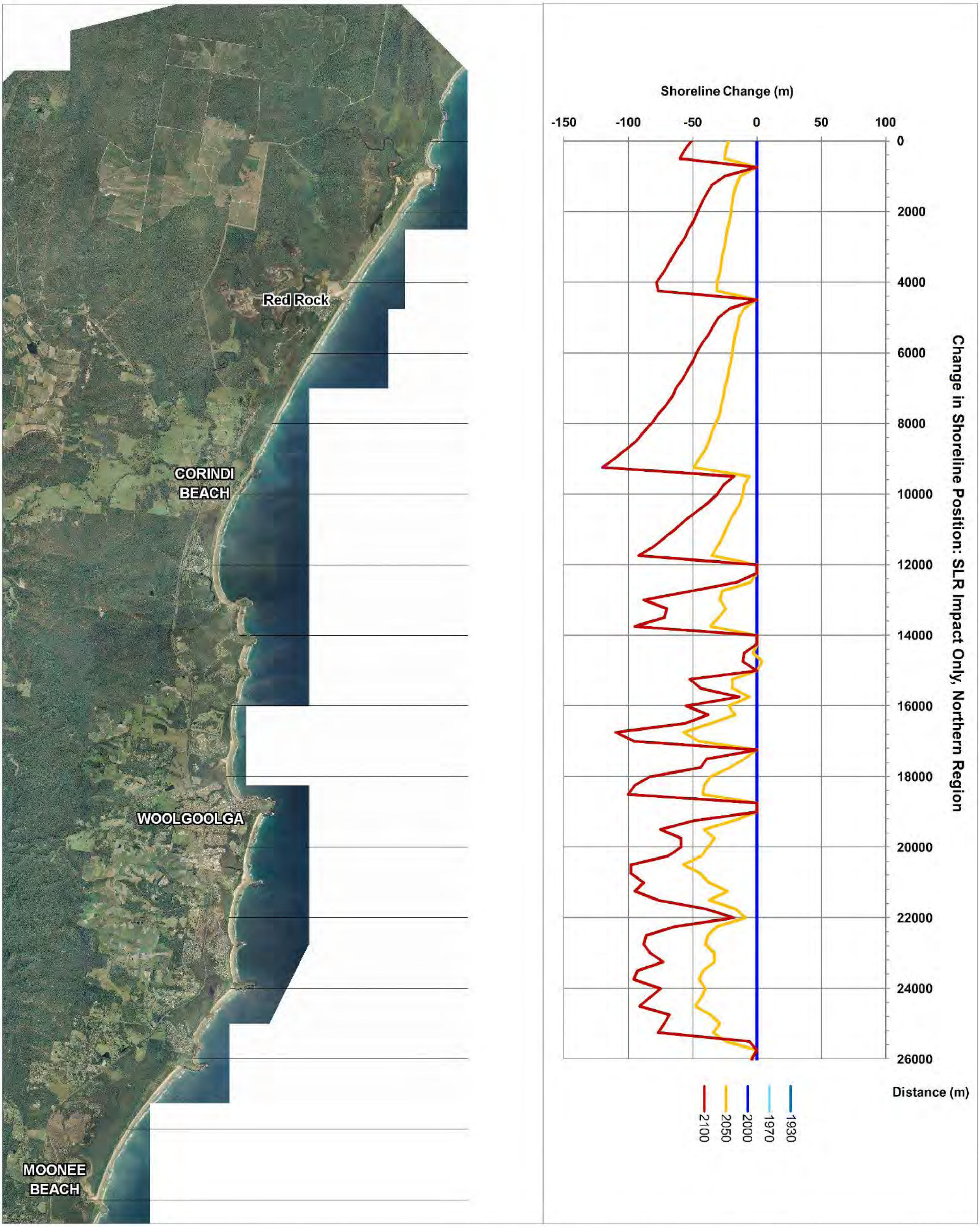
0 2.5 5km

Approx. Scale

BMT WBM

www.wbmpl.com.au

Filepath : K:\N1440 Coffs Coastal Process Hazard Definition Study\MapInfo\Workspaces\DRG_020_100511 Shoreline Harbour and SLR Impact South.WOR



Title:

Change in Shoreline Position due to Sea Level Rise Only, Northern Region

Figure:

3-13

Rev:

A

N

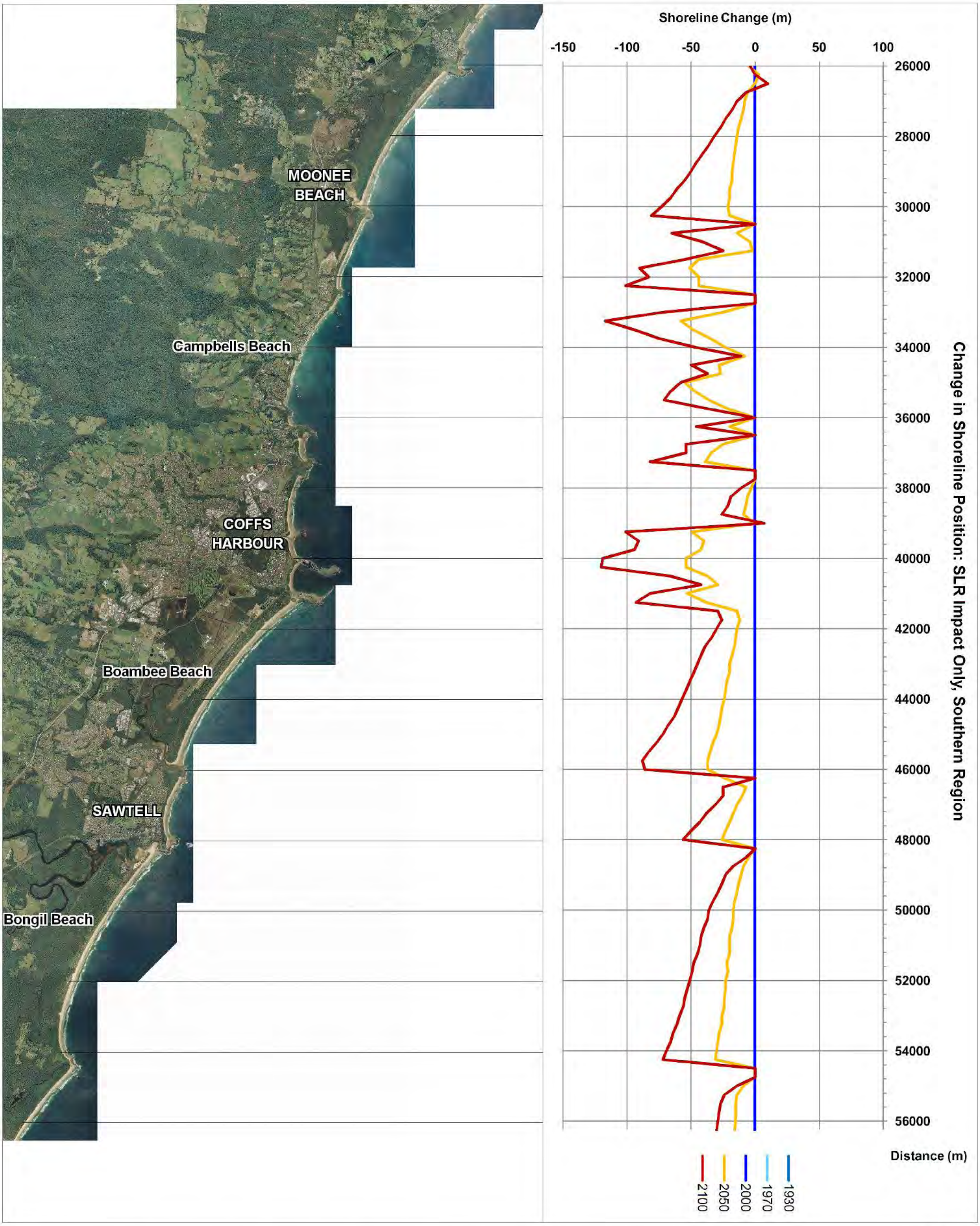
0 2.5 5km

Approx. Scale

BMT WBM

www.wbmpl.com.au

Filepath : K:\N1440 Coffs Coastal Process Hazard Definition Study\MapInfo\Workspaces\DRG_022_100511 Shoreline SLR Impact North.WOR



Title:

Change in Shoreline Position due Sea Level Rise Only, Southern Region

Figure:

3-14

Rev:

A

N

0 2.5 5km

Approx. Scale

BMT WBM

www.wbmpl.com.au

Filepath : K:\N1440 Coffs Coastal Process Hazard Definition Study\MapInfo\Workspaces\DRG_019_100511 Shoreline SLR Impact South.WOR

3.4.4 Hazard Mapping for Beach Erosion and Long Term Recession

This section outlines how the modelling results for future long term recession have been combined with the future beach erosion hazard extents to derive the 2050 and 2100 hazard probability zones.

The derivation of the beach erosion hazard accounts for the existing and future wave climate variability, for example an enhanced period of storminess such as observed during the 1970s. The 'immediate' beach erosion hazard is carried forward to 2050 and 2100 as there is currently no reliable or reasonable data that would justify assuming a different extent of erosion in the future. Combining the long term recession due to sea level rise (as derived from model results) at 2050 and 2100 with the immediate beach erosion hazards ensures that both wave climate variability and long term permanent change are captured within the hazard mapping.

The 'almost certain' line at 2050 and 2100 accounts for future long term recession without sea level rise, that is, due to the harbour impact only, plus 'almost certain' (average) beach erosion (refer Section 3.3). The advice given by the NSW Government (DECCW, 2009c) is that coastal risk planning areas should consider a zero sea level rise scenario. While many would argue that sea level rise is very likely to occur, the 'almost certain' zone becomes a planning benchmark irrespective of uncertainty associated with climate change. What is certain is that the Coffs Harbour coastline will continue to evolve in response to the construction of Coffs Harbour in the 1920s. The derivation of the 'almost certain' hazard likelihood zones at all planning periods is summarised in Table 3-3.

The 'unlikely' hazard likelihood zone is the addition of future long term recession due to predicted sea level rise of 0.4 m and 0.9 m by 2050 and 2100, the harbour impact over this timeframe, plus the 'unlikely' (maximum) beach erosion hazard extent (refer Section 3.3). Once again, sea level rise may be considered to be highly likely however, there is uncertainty relating to the extent of sea level rise and the timeframe over which it may manifest. The shoreline modelling has provided greater certainty as to how sea level rise impacts may manifest along the shoreline, and this is incorporated into this hazard zone. The derivation of the 'unlikely' likelihood zones at all planning periods is summarised in Table 3-3.

The 'rare' hazard probability zone was derived as the maximum extent of recession due to either:

- Future long term recession due to a higher than predicted sea rise (including the harbour impact) plus the immediate 'unlikely' (maximum) beach erosion extent;
- Future long term recession due to projected sea rise (including the harbour impact) and a sustained easterly shift in average wave direction, plus the immediate 'unlikely' (maximum) beach erosion extent; or
- Future long term recession due to projected sea rise (including the harbour impact) plus 'rare' (extreme) beach erosion extent.

From a risk perspective, it is important to consider the impact of a higher rise in sea level than that currently prescribed by the NSW Government (DECCW, 2009a). As such, the impact of a 1.4 m sea level rise by 2100, and to a 0.7 m rise in sea level by 2050 has also been modelled. The outcomes of this modelling for 2050 and 2100 have been combined with the 'unlikely' (maximum) beach erosion extent, to form one of the conditions for the 'rare' hazard probability zone.

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

Probability	Immediate	2050	2100
Almost Certain	'average' beach erosion [1]	Immediate 'average' beach erosion + Harbour Impact	Immediate 'average' beach erosion + Harbour Impact
Likely	NM [2]	NM	NM
Possible	NM	NM	NM
Unlikely	'maximum' beach erosion at any position along the beach [1]	Immediate 'maximum' beach erosion + Harbour Impact + 0.4 m SLR	Immediate 'maximum' beach erosion + Harbour Impact + 0.9 m SLR
Rare	'extreme' beach erosion [3]	**Worst Case of either**: Immediate 'maximum' beach erosion + Harbour Impacts + 0.7 m SLR **OR** Immediate 'extreme' beach erosion + Harbour Impacts + 0.4 m SLR **OR** Immediate 'maximum' beach erosion + Harbour Impacts + 0.4 m SLR + more easterly wave climate	**Worst Case of either**: Immediate 'maximum' beach erosion + Harbour Impacts + 1.4 m SLR **OR** Immediate 'extreme' beach erosion + Harbour Impacts + 0.9 m SLR **OR** Immediate 'maximum' beach erosion + Harbour Impacts + 0.9 m SLR + more easterly wave climate

[1] *Measured over the past 3 - 5 decades*

[2] *NM = Not Mapped*

[3] *Assumed to be 'maximum' erosion plus difference between 'maximum' and 'average' beach erosion*

At the present time the existing wave climate remains predominantly south easterly in direction, even during phases of enhanced storminess and alternate phases of ENSO or IPO. However, from a risk perspective, it is important to consider a permanent climate change induced shift to a more easterly wave direction (e.g., the average summer wave climate of ~120°). A sustained shift to a more easterly wave climate would have a significant effect upon longshore sediment transport rates and so, upon how recession in response to sea level rise may manifest upon the shoreline.

Climate change projections for wave climate are still relatively coarse as described in Section 2.3, and uncertainty remains regarding how and to what extent climate change may affect our wave climate. In this case, it was considered prudent to investigate the 'rare' scenario of a permanent shift to a more easterly wave climate of 120°, compared with the existing 135° average wave climate.

Unfortunately it was not possible to assess the impacts of changed wave directions using the Shoreline Evolution Model directly. Instead the CERC (1984) equation was used to calculate the change in longshore transport rates under the different wave direction regimes. For beaches facing more south east (Boambee, Moonee) the effect was significant, with a reversal of transport direction for easterly wave conditions compared with south easterly direction. In contrast, there was very little change in longshore transport rates at easterly facing beaches such as Sawtell and Park Beach. At beaches of east-south-east orientation such as Bongil, Sapphire and the Korora to White Bluff coastline (including Campbells Beach), the effect was a reduction of northerly transport rates by around 50%.

In the CERC (1984) equation, the difference in longshore transport rates is driven purely by the orientation of the shoreline relative to the incoming wave direction. The length of the beach, headlands and reef impacts that will refract and dissipate waves into the shorelines is not considered. Reefs and headlands are particularly important in areas such as Campbells and Diggers Beach. The longshore transport rate calculations have only be used as a guide to the likely shift in recession extents and not to set extents of recession. The recession extents generated by the shoreline model are still used as the basis for recession along the beach, with the longshore transport calculations used to guide the ‘rotation’ of shoreline recession particularly at the ends of the beach. Furthermore, the known response of the beach as captured by photogrammetric data was used to clarify the adopted shifts in recession extents. Likely shifts in recession extents due to a more easterly wave climate with predicted sea level rise and the harbour impact were combined with ‘unlikely’ (maximum) beach erosion extents as part of the ‘rare’ hazard probability zone at 2050 and 2100.

For the ‘rare’ hazard likelihood zones, the maximum landward shift in shoreline position from each of the three investigations (as outlined above) at 2050 and 2100 was adopted as the final ‘rare’ hazard extent. It was typically found that a higher than predicted sea level rise caused the greatest potential for recession, and thus was mostly adopted as defining the ‘rare’ hazard.

For all scenarios, the results of the shoreline modelling have been used with caution. Model results have not been adopted exactly, as this implies a level of certainty and accuracy that is not appropriate. The shoreline model is considered to be a tool, used to assist the derivation of recession hazard zones. The values have typically been rounded (up) to reflect the uncertainty involved in using model results. More importantly, the model results for sea level rise have been applied at locations along the beach and adjusted to reflect the actual response of the beach evident in the historical data (e.g. maximum erosion just north of the southern end of the beach compartment, as described previously).

Detailed discussion of the photogrammetric data, the shoreline modelling results with and without sea level rise, and the application of the recession hazards are given for each beach in Chapter 4.

In mapping hazard extents areas of known or “assumed” bedrock that would constrain erosion and recession extents have been identified as best as possible. The manner in which areas of “assumed” bedrock have been applied is described below:

- A comparison was made between back beach areas of high elevation (> 10 m AHD) and the Quaternary geology mapping, provided by DII (then DPI, as part of the Comprehensive Coastal Assessment Dataset) and described in Troedson *et al.* (2004).
- Areas of high elevation that were assumed to be bedrock, as based on field observation (e.g. headlands) or the Quaternary geology mapping are displayed on the hazard maps.
- Where the hazard lines intersect with the assumed bedrock zones (e.g. headlands), the hazard lines have been clipped to the boundary of the assumed bedrock, as beach erosion or shoreline recession processes will not significantly recede bedrock within the 100 year planning timeframe.

- Where the areas of high elevation were suggested in the geology mapping to be sediment, it has been assumed that these areas may be affected by beach erosion and shoreline recession hazards (e.g. high dunes at Sapphire and Moonee).

All regions of assumed bedrock and assumed sediment should be confirmed through a detailed geotechnical investigation, especially in areas where hazard lines coincide with development (e.g. at Emerald Beach etc).

The suite of beach erosion and shoreline recession hazard maps for all sections of the Coffs Coastline for the immediate, 2050 and 2100 planning timeframes are given in the Figures Compendium at the end of this report.

3.4.5 Dune Scarp Slope Adjustment and Reduced Foundation Capacity

Immediately following storm erosion events on sandy beaches, a near vertical erosion scarp of substantial height can be left in the dune or beach ridge. Over time this near vertical scarp will slump through a zone of slope adjustment to the natural angle of repose of the sand (approx. 1.5 Horizontal to 1.0 Vertical). Also, a zone of reduced bearing capacity, due to soil slip or undermining, for building foundations exists adjacent to and landward of the dune scarp (see Figure 3-15).

Nielsen *et al.* (1992) outlined the zones within and behind the erosion escarpment on a dune face that are expected to slump or become unstable following a storm erosion event, namely:

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

The defined zones are added to the immediate, 50 and 100 year beach erosion hazard (i.e. taken to occur in a landward direction from the edge of the beach erosion extent). Climate change is not expected to modify soil stability, and thus the hazard extents remain relevant at the 50 and 100 year planning period.

Amongst other factors, the width of the zone of reduced bearing capacity behind the top of an erosion escarpment is dependent upon the angle of repose of the dune sand and the height of the dune above mean sea level (refer Figure 3-15). Table 3-4 provides an indicative guide to the width of the zone of reduced bearing capacity measured landward from the top of the erosion escarpment for homogeneous sand with no water table gradients, for various dune heights.

The allowances in Table 3.4 are provided for indicative planning purposes only. These allowances assume a dunal system made up entirely of homogeneous sands (with an assumed angle of repose of 35 degrees) and makes no allowance for the presence of more structurally competent stratums, for example indurated sands and bedrock that exist within the study area. Nor do these allowances take account of water table gradients that may be present within the dunal system. Expert geotechnical engineering assessment is recommended to establish the structural stability of foundations located (or likely to be located) within the zone of reduced bearing capacity on a case by case basis.

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

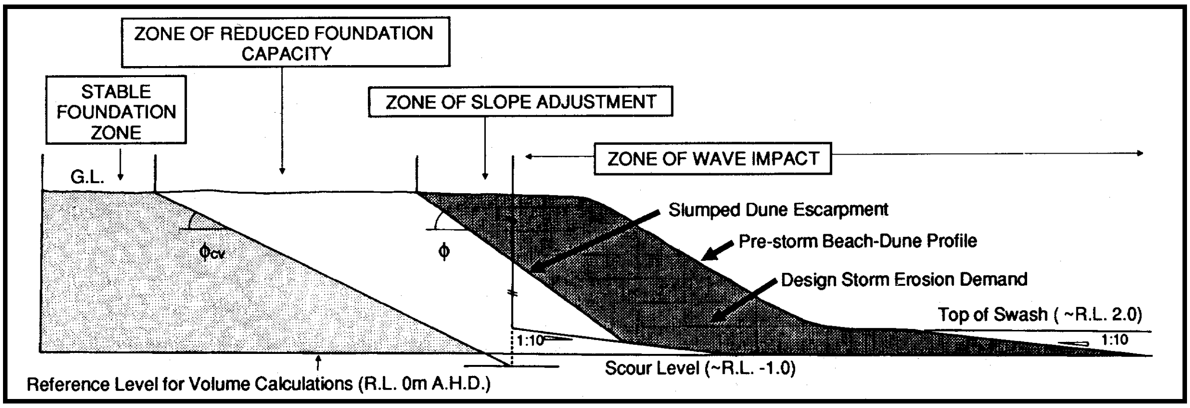


Figure 3-15 Design Profile and Zones of Instability for Storm Erosion (From Nielsen *et al.*, (1992)

Table 3-4 Width of Zone of Reduced Bearing Capacity

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

1 *Assumed that surface of dunal system is approximately level (see Figure 3-15).*

2 *Distance measured landward from the top of the erosion escarpment following slope readjustment (see Figure 3-15).*

3.5 Coastal Inundation

The main impact of the coastal inundation hazard refers to the inundation of low-lying areas near and behind coastal barriers and coastal entrances during high ocean water levels. Elevated ocean water levels during a storm may result in the inundation of estuary foreshores, lake and lagoon foreshores (closed or open) and low lying back beach areas hydraulically connected to the ocean (NSW Government, 1990). The elevated ocean levels cause inundation by either propagating into entrances or acting as a tailwater level precluding outflow from the creeks and so elevating the water levels within the creeks/lakes/lagoons.

Elevated water levels during a storm, which may result in coastal inundation, comprise of: barometric pressure set up; wind set up; astronomical tide; and wave set up, as defined in Section 2.5.2. Table 2-4 to 2-6 provide elevated water level predictions for each of the immediate, 2050 and 2100 timeframes. A summary of the rationale behind the coastal inundation levels and their probability for all planning periods is given in Table 3-5, and explained below.

For the purpose of defining the likelihood of coastal inundation within the immediate timeframe, it was considered 'almost certain' would be equivalent to a 1 in 20 return interval event, 'unlikely' would be equivalent to a 1 in 100 year event and 'rare' would be equivalent to a 1 in 100 year event with the addition of an extreme climatic condition. As detailed in Section 2.5.2, the extreme climatic condition represents the occurrence of an event of sufficient rarity, for example a tropical cyclone tracking south to Coffs Harbour or extreme east coast low cyclone, resulting in still water levels (excluding wave set up) roughly equivalent to a 1 in 1000 year average recurrence. Such an event was estimated to add 0.2 m to the 1 in 100 year water level. Given the potential for tropical cyclones to track further southwards due to climate change or more extreme storms due to climate change or natural variability over the immediate to 2100 period, it is reasonable to plan for greater than expected water levels in the future. The adopted inundation levels for the immediate timeframe are given in Table 3-6.

For the 2050 planning period, as discussed in Section 2.5.2, extreme water levels will additionally include sea level rise, as well as minor projected changes to storm surge and wave height (as given by McInnes *et al*., 2007). The inundation levels are thus: an 'almost certain' probability of a 1 in 20 return interval event, without sea level rise; an 'unlikely' probability of experiencing a 1 in 100 yr event plus predicted sea level rise of 0.4m by 2050, and increased wave set up and increased storm surge due to climate change; and a 'rare' probability of a 1 in 100 yr event plus greater than predicted sea level rise of 0.7 m by 2050, or an extreme climatic condition (e.g. a 1 in 1000 year still water level event, excluding wave set up) plus predicted sea level rise of 0.4 m by 2050, whichever was the higher. The adopted inundation levels for the 2050 timeframe are given in Table 3-6.

Similarly, the 2100 planning period coastal inundation extents will additionally include sea level rise and minor changes to wave set up and storm surge due to climate change. The 'almost certain', 'unlikely' and 'rare' probability levels are thus the same as 2050, but with the additional sea level rise and wave height and storm surge change predicted by 2100. The adopted inundation levels for the 2100 timeframe are given in Table 3-6.

Wave breaking processes on the shoreline will cause wave run-up onto the beach face and over dune crests during elevated water level events. A small component of the inundation hazard refers to overtopping of dune barriers by wave run-up. This typically occurs during a storm, and so, wave overtopping occurs in combination with the processes that cause beach erosion. Typically once a dune or barrier has been breached, the waves spread out in the 10 – 20 m behind the barrier. Overtopping is almost certainly of less consequence than the more hazardous impact of beach erosion during such a storm (and likely contributes to the erosion). Wave overtopping at an extreme level is likely to occur for a limited time (several hours) around the high tide. Thus, we have assumed that the hazard of wave overtopping is captured within the beach erosion assessment.

Our analysis of coastal inundation of back beach areas, particularly lakes, lagoons and estuaries assumes that all components of elevated water levels (storm surge, sea level rise, tide, wave set up) are included when determining inundation extents using a 'bath-tub' approach. We recognise that elevated ocean levels will not always penetrate into estuaries and lakes to the same maximum height, given attenuation through entrances and along channels. However, elevated ocean levels of this magnitude occur during storm conditions, and so it is probable that there would be rainfall on the catchments associated with the storm. In this case, the elevated water levels in the ocean act as a higher tailwater level for catchment flooding.

Table 3-5 Coastal Inundation Likelihood Summary

Probability	Immediate	2050	2100
Almost Certain	1 in 20 yr storm surge and wave set up	As per immediate	As per immediate
Likely	NM[1]	NM	NM
Possible	NM	NM	NM
Unlikely	1 in 100 yr storm surge and wave set up	1 in 100 yr storm surge and wave set up + 0.4 m SLR and climate change impacts	1 in 100 yr storm surge and wave set up + 0.9 m SLR and climate change impacts
Rare	1 in 100 yr storm surge and wave set up + extreme climatic conditions (e.g. tropical cyclone, 1 in 1000 year east coast low)	**Worst Case of either:** 1 in 100 yr storm surge and wave set up + extreme climatic conditions + 0.4 m SLR and climate change impacts **OR** 1 in 100 yr storm surge and wave set up + 0.7 m SLR and climate change impacts	**Worst Case of either:** 1 in 100 yr storm surge and wave set up + extreme climatic conditions + 0.9 m SLR and climate change impacts **OR** 1 in 100 yr storm surge and wave set up + 1.4 m SLR and climate change impacts

[1] NM = Not Mapped

Table 3-6 Adopted Inundation Levels

Adopted Inundation Levels	Immediate (m AHD)	2050 (m AHD)	2100 (m AHD)
Almost Certain	2.5	2.5	2.5
Unlikely	2.7	3.1	3.7
Rare	2.9	3.4	4.2

The impacts of elevated ocean levels on flooding extents associated with catchment runoff would need to be determined explicitly for each waterway using a hydraulic flood model. However, in the first instance it is reasonable to assume that flooding levels would reach a comparable level to ocean tailwater conditions within the estuaries. The coastal inundation extents we have provided should be considered in light of existing flood extent mapping. That is, inundation (be it from ocean or catchment) would be the higher of the coastal inundation extents or any flood modelling extents.

Ultimately, the flood extents should be assessed / reassessed using the new ocean tailwater conditions.

The suite of coastal inundation hazard maps for all sections of the Coffs Coastline for the immediate, 2050 and 2100 planning timeframes are given in the Figures Compendium at the end of this report.

3.6 Coastal Entrances

The coastal entrance hazard refers to existing and future berm height and closure characteristics of coastal creeks, lagoons, lakes and estuaries, which may modify the extent of inundation in back beach areas during closed entrance conditions. Future berm heights and closure characteristics may be modified by sea level rise in particular. The occurrence of back beach inundation through open / partially open coastal entrances is discussed within the coastal inundation hazard (Section 3.5), and erosion of coastal entrances is incorporated within the beach erosion and shoreline recession hazards (Section 3.3). As such, these aspects are not included within the definition of the coastal entrance hazard herein.

The coastal entrance hazard for typically closed and typically open entrances is discussed separately. At the present time, Bongil, Boambee, Coffs, Jordans, Moonee, Fiddamans, Arrawarra, Corindi and Station Creeks typically remain open to the ocean. The remaining creeks and lagoons (Bundageree, unnamed creek on Hills Beach, Pine Brush Lagoon, South, Hayes, Hearnes Lake, Willis, Woolgoolga Lake, Darkum, Pipe Clay Lake and the unnamed creek on Station Beach) are typically closed, with breakouts occurring during infrequent rainfall events. Arrawarra is known to have closed in the past and based on existing conditions, closure of Jordans and Fiddamans Creeks may occur in the future, thus these creeks have been included in the assessment of closed entrances.

The potential extent of inundation is dependent upon the height of the entrance berm, as water is stored behind the closed entrance. For typically closed entrances, the probable inundation extents due to entrance closure may be derived from the measurement of berm heights in the past, given in the photogrammetric data. Unfortunately, photogrammetric profiles covering the entrance berm region are only available for five of the 14 typically closed entrances (namely Hayes, Fiddamans and Arrawarra Creeks, unnamed creek on Station Beach and Hearnes and Woolgoolga Lakes). For those locations with data, the berm height given in available profiles along an entrance berm was averaged, while the maximum value was also calculated over the years of available data. The outcome of the assessment is given in Table 3-8.

Hanslow *et al.* (2000) suggested that the worst case (or extreme) scenario berm height at coastal entrances would occur during a period of little rainfall and runoff into the creeks / lagoons that resulted in prolonged entrance closure. In this extreme scenario, the berm heights may reach the level of adjacent dunes. The incipient dunes formed by wind and wave processes over the last 20 – 30 years on beaches in the Coffs region typically reach a maximum height of 4 – 5 m AHD. The height of incipient dunes is assisted by the growth of Spinifex vegetation that captures sediment within the dune. However, on a typically unvegetated entrance berm, wind allows for the transport of sediment off the top of the berm and into the creek / lagoon behind. This process would limit the height of the entrance berm until such time as vegetation colonises the entrance to assist the capture and vertical accretion of the berm. Considering these factors, an extreme berm height of 3.5 m AHD has been adopted.

For the typically closed entrances without available data, the potential impacts of future sea level rise described below should be considered by Council in future planning and in flooding / inundation assessments. It is recommended that berm height measurements (both from historical aerial photographs and with future beach survey) be collected, to derive probable berm heights for planning and flood / inundation assessment purposes. The extreme scenario of 3.5 m AHD may be adopted at these locations.

For future planning periods of 2050 and 2100, sea level rise is an important consideration for the coastal entrance hazard. For those creeks which typically remain closed, it is widely noted (Hanslow *et al.*, 2000; Haines and Thom, 2007; Wainwright and Baldock, 2010) that berm heights will increase by a roughly equal amount as the rise in sea level. That is, it may be expected that berm heights will increase by 0.4 m by 2050 and 0.9 m by 2100. Similar to the Bruun Rule concept of the movement upward and landward of the beach profile, coastal entrances will also increase in height to reach equilibrium with the new mean sea level and wave processes. Wainwright (in prep.) has found that, with an increase in berm height at typically closed entrances, there is a corresponding increase in available storage volume within the lagoon or creek (behind the entrance). Entrance breakouts would thus become less frequent because more rainfall volume would be required to overtop the berm.

From a risk perspective, it is also important to consider a higher than predicted increase, for example a 0.5 m higher than projected in sea level rise by 2100. For a 1.4 m rise by 2100 (0.7 m by 2050) berm heights may be expected to increase by close to an equal amount.

Adopting the rationale used for the beach erosion hazard, the average berm height at a creek/lagoon over years was used to represent the ‘almost certain’ entrance hazard and the maximum berm height to represent the ‘unlikely’ entrance hazard at the immediate timeframe. The extreme case (3.5 m AHD) was adopted as the ‘rare’ entrance hazard at the immediate timeframe.

For the 2050 and 2100 planning horizons, there is an ‘almost certain’ likelihood that berm heights will be at least as high as they are at present (i.e. regardless of sea level rise). There is an ‘unlikely’ probability that berm heights will reach a maximum level plus an additional 0.4 m and 0.9 m in elevation in response to projected sea level rise by 2050 and 2100, respectively. The future ‘rare’ scenario berm height relates to either a higher than projected sea level rise, or an extreme entrance condition plus predicted sea level rise. For the ‘rare’ scenario then, the greater of the following two outcomes was adopted:

- The extreme berm height plus an increase in elevation due to sea level rise of 0.4 m by 2050 and 0.9 m by 2100; or
- A maximum berm height plus an increase in height equivalent to a higher sea level rise of 0.7 m by 2050 and 1.4 m by 2100.

In all cases, the ‘rare’ probability berm height related to the extreme condition plus predicted sea level rise. The immediate, 2050 and 2100 coastal entrance hazard probability zones are summarised in Table 3-7 and values given for those entrances with data in Table 3-8.

For some typically open creeks or lakes, sea level rise may modify entrance dynamics such that they become more closed or more open in the future. For creeks such as Moonee Creek that have a strong geomorphic control, that is, bedrock underlying the main entrance channel, sea level rise may impact upon water velocities through this channel. An increase in the water level due to sea level rise may reduce flow velocity through the channel, resulting in sediment deposition and thus entrance constriction or even entrance closure.

For those entrances without bedrock beneath the main channel (even if bedrock is present at the sides of the channel) it is likely that the entrance area will move upward and landward in response to sea level rise, but remain similarly open as at present. Entrance areas at the southern ends of beaches will migrate further landward and change in shape and position, as the beach region is receded to a greater extent than at the northern beach end in response to sea level rise (refer Section 3.4.3). For entrances at the northern end, which will experience less landward recession, it is uncertain what impact the vertical accretion of the beach profile would have upon the frequency of entrance closure.

At present, the predicted impacts on rainfall due to climate change are inconclusive. As outlined in Table 2-2, an increase or a decrease in annual rainfall is possible. Likewise, rainfall intensity could increase or decrease. In this case, only a brief qualitative discussion of impacts on coastal entrances is possible. The complexity of the response to rainfall at each entrance makes it difficult to generalise about the response to potentially changed rainfall with climate change.

For the smaller, mostly closed lagoons such as Hayes Creek, the lagoon responds quickly to rainfall and may break out frequently, but may remain open for only a short time. An increase in rainfall intensity may increase the frequency of breakouts. Longer duration events allow for greater scouring, and so, entrances may remain open for longer.

For the larger mostly closed lagoons such as Woolgoolga Lake, the frequency of breakout is more dependent upon annual rainfall as the lake storage is greater and may need to be filled by events over time, before overtopping will occur. If annual rainfall were to decrease, prolonged entrance closure may ensue. However, if there is less water stored within the lake with reduced rainfall, there is unlikely to be an increase in the inundation hazard to surrounding properties. If annual rainfall were to increase in combination with higher berm heights (due to sea level rise), there may be an increase in the extent of inundation held behind the higher berm, until such time as a breakout occurs.

Some entrances, such as Woolgoolga Lake, are subject to artificial opening by Council when water levels start to threaten foreshore development. If the same opening trigger levels are to be adopted in the future, then the frequency of opening will increase significantly as sea level rises. Ultimately it may be impractical to try and keep opening the entrance if the trigger level is only marginally above elevated tidal levels.

For the typically open lakes and lagoons, the duration of rainfall events is important in maintaining a scoured and open entrance condition. An increase in rainfall intensity may allow for ongoing open conditions particularly where individual events are longer. A decrease in rainfall intensity may promote entrance constriction.

Table 3-7 Coastal Entrance Hazard Probability Zones

Probability	Immediate	2050	2100
Almost Certain	Average berm height[1]	As per immediate	As per immediate
Likely	NM[2]	NM	NM
Possible	NM	NM	NM
Unlikely	Maximum berm height	Maximum berm height + 0.4 m SLR	Maximum berm height + 0.9 m SLR
Rare	Extreme berm height[3]	**Worst Case of either:** Extreme berm height + 0.4 m SLR **OR** Maximum berm height + 0.7 m SLR	**Worst Case of either:** Extreme berm height + 0.9 m SLR **OR** Maximum berm height + 1.4 m SLR

[1] Measured over the past 3 - 5 decades
[2] NM = Not Mapped
[3] Taken to be 3.5 m AHD equivalent to incipient dunes, see text.

Table 3-8 Probable Entrance Hazard Berm Heights for Each Planning Period

			Immediate			**2050**			**2100**		
Creek / Lake / Lagoon	**Beach**	**Typical State**	*almost certain*	*unlikely*	*rare*	*almost certain*	*unlikely*	*rare*	*almost certain*	*unlikely*	*rare*
Bundageree	**Bongil**	closed									
Bonville	**Bongil**	open									
Boambee	**Boambee**	open									
Coffs	**Park Beach**	open									
Jordans	**Diggers**	open / closed future									
Unnamed	**Hills**	closed									
Pine Brush	**Hills**	closed									
South	**Campbells**	closed									
Hayes	**Pelican**	closed	2.4	3.2	3.5	2.4	3.6	3.9	2.4	4.1	4.6
Moonee	**Moonee**	open									
Fiddamans	**Emerald**	open / closed future	1.9	2.4	3.5	1.9	2.8	3.9	1.9	3.3	4.4
Hearnes	**Hearnes**	closed	2.0	2.6	3.5	2.0	3.0	3.9	2.0	3.5	4.4
Willis	**Woolgoolga Back**	closed									
Woolgoolga	**Woolgoolga**	closed	1.3	2.4	3.5	1.3	2.8	3.9	1.3	3.3	4.4
Darkum	**Safety Beach**	closed									
Arrawarra	**South Corindi**	open / closed future	1.5	2.4	3.5	1.5	2.8	3.9	1.5	3.3	4.4
Pipe Clay	**North Corindi**	closed									
Corindi River	**Station Creek**	open									
Unnamed	**Station Creek**	closed	1.6	2.7	3.5	1.6	3.1	3.9	1.6	3.6	4.4
Station Ck	**Station Creek**	open									

It is apparent that without more detailed future rainfall predictions, it is not possible to determine more specific conclusions for the coastal entrance hazard. However, the concept for changes to berm heights with sea level rise at 2050 and 2100, and the available levels for particular creeks (Table 3-8) should be incorporated into any assessment or re-assessment of catchment flooding.

Erosion at coastal entrances has been encompassed within the beach erosion hazard. The photogrammetry data was analysed and it was found that in all cases, coastal entrance berms may be eroded out completely. This is due to a combination of creek outflow and beach processes, not beach erosion alone. To account for the potential erosion of the entire berm region, the origin line from which beach erosion was measured was placed behind the berm region. Careful analysis of the historical data and dune heights ensured that areas of former breakout that are now vegetated and seemingly stable were included in the beach erosion extents.

However, in order to avoid overestimating the potential for beach erosion caused by wave action upon sections of the beach that are not within an entrance, the photogrammetric data within creek regions was excluded from the assessment of beach erosion, as noted in Section 3.3.

3.7 Stormwater Erosion

The location of stormwater outlets were noted during field investigations. There are also a number of small drainage lines (creeks) that may serve as stormwater discharge points along the beach. The location of stormwater outlets/drainage points noted during the field study included:

- Sawtell Beach (centre of beach, north of surf club, piped outlet);
- Park Beach (northern end, piped outlet);
- Charlesworth Bay (northern end, with rock protection at sides of pipe);
- Campbells Beach (southern end, piped outlet);
- Woolgoolga Beach (southern end, piped outlet with gating across front):
- Woolgoolga Beach (informal drainage point immediately north of Woolgoolga Lake entrance); and
- Ocean View Beach (informal drainage point at centre of beach).

During the analysis of photogrammetry the locations of other small informal drainage points (in addition to the larger creeks) were noted. The effects of erosion across the creeks was not directly analysed as part of the beach erosion assessment because erosion at drainage points is determined by stormwater outflow in addition to wave processes.

Dune heights at such points are typically below 4 m AHD. Thus, the 4 m contour line naturally indents further landward around the drainage points, for example along Jetty Beach (Figure 3-16). When the beach erosion hazard is applied at drainage points, greater erosion is observed, as consistent with the observation in such locations. That is, potential erosion at stormwater outlets is largely captured within the beach erosion hazard.

At the present time, climate change predictions are not adequate to determine likely changes to stormwater runoff volumes or flow rates, which may affect the extents of erosion at stormwater outlets in the future. Qualitatively, if runoff during individual storms were to increase, an increase in erosion around stormwater outlets may be expected. However, for the purposes of this study, it has been assumed that the extents of erosion at stormwater outlets at the 2050 and 2100 time horizons have been adequately captured within the beach erosion hazard.

The stormwater erosion hazard is discussed for each beach in Chapter 4.

3.8 Sand Drift

Windborne sediment transport is an important process in the building of sand dunes behind the active beach. Sand drift is a minor nuisance in most cases, but may present a notable hazard where significant volumes of sediment are being removed from the beach system and/or coastal developments are being overwhelmed by windborne sediment.

For the Coffs region, there does not appear to be a sand drift hazard at almost all those beaches where there is significant development (e.g. Park Beach, Sawtell Beach and the Korora to White Bluff stretch). In many of the remaining locations without development (Station Beach, Bongil Beach) windborne sediment transport is promoting the storage of sediments within incipient dunes and vegetated foredunes and is not considered to pose a hazard.

Sand drift may be of interest between Fiddamans Beach and Sandys Beach across Bare Bluff, where an active, unvegetated pathway (blowout) over Bare bluff appears to allow for the transport of sediment. Aeolian transport is likely to form part of the mechanism for sediment transport between these beaches, via the active blowout (which is currently used as beach access). In recent years dune care groups have attempted to stabilise the dune blowout across Bare Bluff. While stabilisation may be of use for reducing drift into nearby properties, it is unknown if stabilisation has had an effect upon sediment transport between the beaches, particularly into Sandys Beach.

Changes to wind regimes under a future climate may present a change in Aeolian transport characteristics, most importantly, wind direction, which may modify the direction of transport, and the duration of strong winds, which may modify transport volumes. However, the current predictions are not of sufficient detail to provide an accurate assessment. The predictions suggest that future wind patterns will be within the natural variability of wind patterns at present. Further, there is only one location for which sand drift is considered significant in the Coffs region (noted above), and Aeolian transport is not considered to pose a significant hazard.

Dune vegetation extents may assist to capture and stabilise wind blown sediments. Beaches within the national parks and nature reserves (e.g. Bongil, Station, Moonee) were typically found to have very good dune vegetation coverage. Beaches noted to have sparse dune vegetation coverage include Jetty Beach, South Park Beach, some parts of Charlesworth Bay, Korora and Hills Beaches, Campbells Beach, the southern end of Emerald Beach, Sandys Beach, the southern end of Woolgoolga Beach, the southern end of South Corindi Beach and locations along Middle Corindi (particularly at car park access). Rehabilitation of dune vegetation in some of these areas (following a more detailed vegetation assessment) may assist to capture and store sediment in dune systems at these beaches.

During the field inspection, some locations of weed infestation (particularly bitou bush) were also noted, typically intermingled with native dune vegetation species such as Spinifex, Acacia, and

Pandanus Palm. These areas may also require rehabilitation, with priority given to those areas where weeds are an obstacle to effective storage of sediment within dunes.

The sand drift hazard is discussed for individual beaches in Chapter 4.

Figure 3-16 Example of Drainage Points on Jetty Beach

5 REFERENCES

Baker, R.G.V., Haworth, R. J., Flood, P.G. (2001). Inter-tidal indicators of former Holocene sea levels in Australia: a summary of sites and a review of methods and models. *Quaternary International* **83-85** (2001), pp. 257-273.

BBW [Blain, Bremner and Williams], (1985). *Elevated Ocean Levels, Storms Affecting the NSW Coast 1880-1980*, prepared for the NSW Public Works Department Coastal Branch in conjunction with Weatherex Meteorological Services, PWD Report No. 85041.

BBW [Blain, Bremner and Williams], (1986). *Elevated Ocean Levels, Coffs Harbour*, prepared for the NSW Public Works Department Coastal Branch in conjunction with Weatherex Meteorological Services, PWD Report No. 86005.

Binnie & Partners Pty Ltd (1987), Northern Areas Wastewater Scheme Environmental Impact Statement prepared for Public Works Department NSW on behalf of Coffs Harbour Shire Council, June 1987.

Blackham, D. (2006). Late Holocene shoreline evolution and mean wave direction, mid North Coast, New South Wales. Unpublished B Sc. honours thesis, University of Newcastle, 102pp.

Blackmore, K. and Goodwin, I.D. (2009). *Hunter, Central and Lower North Coast regional climate change project. Report 3. Climatic change impacts on the Hunter, Central and lower North Coast region of NSW*. Environment Division, Hunter Councils, pp99.

BMT WBM (2008), *Emerald Avenue, Sapphire Beach Coastal Hazards and Retaining Wall Assessment*, prepared for Coffs Harbour City Council, December 2008.

BMT WBM (2009a), *Pipe Clay Lake Draft Estuary Management Plan*, prepared for Coffs Harbour City Council, June, 2009.

BMT WBM (2009b), *Hearnes Lake Estuary Management Study and Plan*, Final Draft, prepared for Coffs Harbour City Council, August 2009.

BMT WBM (2009c) *Coffs Harbour Coastal Processes Progress Report*, Draft Report, prepared for Coffs Harbour City Council, September 2009.

Browning, S. and Goodwin, I. 2008. A 700 year reconstruction of East Coast Cyclone Frequency. *Risk Frontiers Report* , Macquarie University.

Bruun, P., (1962). Sea-level rise as a cause of shore erosion, *Journal of Waterways and Harbors Division*, American Society of Civil Engineers, **88**, 117-130.

Carley, J.T., Wyllie, S.J., Lord, D.B. and R.J. Cox, (2006). *Coastal Processes in the Coffs Harbour Region*, Proceedings of the 15th NSW Coastal Conference.

CERC (1984). *Shore Protection Manual*. Coastal Engineering Research Center [CERC] U.S. Army Corps of Engineers, Washington, D.C.

Cowell, P.J., Roy, P.S., and R.A. Jones, (1992). Shoreface Translation Model: computer simulation of coastal-sand-body response to sea level rise, *Mathematics and Computers in Simulation*, **33**, 603-608.

Cowell, P.J., Roy, P.S., and R.A. Jones, (1995). Simulation of Large-scale Coastal Change Using a Morphological Behaviour Model, *Marine Geology*, **126**, 45-61.

Cowell, P.J., Stive, M.J.F., Niedoroda, A.W., de Vriend, H.J., Swift, D.J.P., Kaminsky, G.M. and M. Capobianco. (2003). The Coastal-Tract (Part 1): A conceptual approach to aggregated modelling of low-order coastal change. *Journal of Coastal Research*, **19**, 828-848.

Cowell, P.J., Thom, B.G., Jones, R.A., Everts, C.H., and Simanovic, D., (2006). Management of Uncertainty in Predicting Climate-Change Impacts on Beaches, *Journal of Coastal Research*, **22**, 232-245.

CSIRO (2007). *Climate Change in Australia Technical Report 2007*. CSIRO Marine and Atmospheric Research and Bureau of Meteorology, Melbourne, VIC, Australia.

DECC (2005), INTERNAL DOCUMENT *New South Wales Coastal Lands Risk Assessment,* prepared by Patterson Britton & Partners and Department of Environment and Climate Change.

DECCW (2009a), *NSW Sea Level Rise Policy Statement*, October 2009.

DECCW (2009b), *Derivation of the NSW Government's sea level rise planning benchmarks, Technical Note*, October 2009.

DECCW (2009c), *Draft Coastal Risk Management Guide: Incorporating sea level rise benchmarks in coastal risk assessments*, October 2009.

Danish Hydraulics Institute, (2008). Mike 21 Spectral Wave Model FM software. Danish Hydraulics Institute.

DNR (2006), *NSW Coastal Lands Risk Assessment*, prepared for the Comprehensive Coastal Assessment (Department of Planning) Project 06, June 2006.

DP (2009), *Mid North Coast Regional Strategy*, Final, NSW Department of Planning, March 2009.

DP (2009) *How the Mid North Coast Strategy Will Help the Coffs Coast Subregion* Fact Sheet, Department of Planning, March 2009.

ERA (1973), *Study of Shoreline Stability Macauleys Beach and Charlesworth Bay Coffs Harbour New South Wales* prepared by Environmental Resources of Australia, March 1973.

Floyd, A. G. (1991), *Vegetation Survey of Proposed Pipeline Look-At-Me-Now Headland,* prepared for Department of Public Works, October 1991.

Folland CK, Renwick JA, Salinger MJ, Mullan AB. 2002. Relative influences of the Interdecadal Pacific Oscillation and ENSO on the South Pacific Convergence Zone. *Geophysical Research Letters* **29**(13): 21-1 – 21-4.

Foster, D. N., Gordon, A. D., and N. V. Lawson, (1975). The Storms of May-June 1974, Sydney, N.S.W, *2nd 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 southeastern Australia and its relationship to the El Nino-Southern Oscillation since 1878 A.D., *International Journal of Climatology*, **25**, 1715-1729.

Goodwin, I.D., Stables, M. A. and Olley, J. (2006). Wave climate, sand budget and shoreline alignment evolution of the Iluka–Woody Bay sand barrier, northern New South Wales, Australia, since 3000 yr BP *Marine Geology* 226, 127-144.

Gordon, A.D., (1987). Beach Fluctuations and Shoreline Change - NSW, reprints of Papers, *8th Australasian Conference on Coastal and Ocean Engineering*, 30 November to 4 Dec, Institution of Engineers Australian National Conference Publication No 87/17 pp 103-167.

Haines, P., (2006), *Physical and Chemical Behaviour and Management of ICOLLs in NSW*, PhD Thesis, Griffith University.

Haines P. E., Tomlinson R.B., Thom B.G., (2006), Morphometric assessment of intermittently open/closed coastal lagoons in New South Wales, Australia *Journal of Estuarine, Coastal and Shelf Science* **67**:(1-2) 321-332.

Haines P. E. and B. G. Thom, (2007). Climate change impacts on entrance processes and behaviour of intermittently open/closed coastal lagoons in NSW, Australia, *Journal of Coastal Research* **SI 50,** (Proceedings of the 9th International Coastal Symposium), 242-246.

Hanslow, D. J., Davis, G. A., You, B. Z. and Zastawny, J. (2000), Berm heights at coastal lagoon entrances in NSW, *Proceedings of the 10th Annual NSW Coastal Conference*, Yamba.

Hanslow, D. J., (2007). Beach Erosion Trend Measurement: A Comparison of Trend Indicators, *Journal of Coastal Research* **SI 50** (Proceedings of the 9th International Coastal Symposium), 588 – 593. Gold Coast, Australia.

Hemer, M. A., McInnes, K., Church, J. A., O’Grady, J., and J.R. Hunter, (2008), *Variability and Trends in the Australian Wave Climate and Consequent Coastal Vulnerability*, Final Report prepared for Department of Climate Change Surface Ocean Wave Variability Project, September 2008.

Hopkins, L.C. and G.J. Holland (1997). Australian heavy-rain days and associated East Coast Cyclones: 1958-92, *Journal of Climate*, **10**, pp.621-635.

Hsu, J.R.C., Evans, C., 1989. Parabolic bay shapes and applications. Proc. Institution of Civil Engineers, London (Part 2), 87, 556 - 570.

Hsu, J.R.C et al.., 2008. Appreciation of Static Bay Beach Concept for Coastal Management and Protection. J. Coastal Research, 24 (1), 198-215.

IPCC (2007), *Climate Change 2007: Synthesis Report*, Intergovernmental Panel on Climate Change key findings and uncertainties contained in the Working Group contributions to the Fourth Assessment Report.

John Allen & Associates (1988), *Hills Beach Reserve, Korora Plan of Management*.

John Allen & Associates (1990), *Look-At-Me-Now Headland Draft Plan of Management* prepared for Department of Lands, January 1990.

Jones, C., (1981), *Coffs Harbour Coastal Planning Study - Working Paper 10: Coastal Geomorphology*, NSW Department of Environment and Planning, Report No 80/08, Grafton, July 1981.

Laurie, Montgomerie & Pettit Pty Ltd (1983), *Moonee Beach Sewage Outfall - Review of Feasible Methods for Headland Discharge at Green Bluff*, prepared in association with Lewis & Duvivier, for the Public Works Department of NSW, June 1983.

Lawson & Treloar, (1986). *Elevated Ocean Levels, Storms Affecting the NSW Coast 1980-1985*, prepared for the NSW Public Works Department Coastal Branch in conjunction with Weatherex Meteorological Services, PWD Report No. 86026.

Lord, D.B, and A. Van Kerkvoort, (1981). *A Coastal Process Investigation, Coffs Harbour*, NSW, Proceedings of the 5th Australian Conference on Coastal and Ocean Engineering, Perth, Institute of Engineers Australia.

Lord, D.B. (1984). *An Assessment of Harbour Infilling Resulting from Longshore Sediment Transport at Coffs Harbour*, Master of Engineering Science Thesis, University of New South Wales.

Macadam, I., McInnes, K. and J. O'Grady, (2007). *Climate Change Projections for the Wooli Wooli Estuary and Batemans Bay*, prepared by CSIRO for the Department of Environment and Climate Change [DECC].

Masselink, G and M. G. Hughes (2003). *Introduction to Coastal Processes & Geomorphology*, pp 347.

McInnes, K. L., Abbs, D.J., O'Farrell, S.P., Macadam, I., O'Grady, J. and R. Ranasinghe, (2007). *Projected Changes in Climatalogical Forcing for Coastal Erosion in NSW*, prepared by CSIRO for the Department of Environment and Climate Change [DECC].

McLean, R., and J. Shen, (2006). From Foreshore to Foredune: Foredune Development Over the Last 30 Years at Moruya Beach, New South Wales, Australia, *Journal of Coastal Research*, **22**, 28-36.

MHL (1983), *Moonee Ocean Outfall Investigation* prepared by Manly Hydraulics Laboratory PWD Public Works Department, Report No. 376, August 1983.

MHL (1986), *Coffs Harbour Northern Areas Outfall Investigation - Stage 1 Report* prepared by Manly Hydraulics Laboratory Report No. 462; PWD Public Works Department NSW Report No. 86039, August 1986.

MHL (1987), *Coffs Harbour Northern Areas Outfall Investigation - Design Stage Report* prepared by Manly Hydraulics Laboratory [MHL] Report No. 494; PWD Public Works Department NSW Report No. 87018, June 1987.

Nielsen, P (1988). Wave Setup: A Field Study, *Journal of Geophysical Reseach*, **93**, 15,643-15,652.

Nielson, A.F., Lord, D.B., and H.G. Poulos, (1992). *Dune Stability Considerations for Building Foundations* , Institution of Engineers, Civil Engineering Transactions Vol CE34, No.2, June 1992, pp. 167-173.

NSW Government (1990). *Coastline Management Manual*, prepared September 1990.

Patterson, D., (2009). Modelling the Shoreline Impacts of Richmond River Training Walls, *Proceedings of the 18th NSW Coastal Conference*, 3 – 6 November 2009, Ballina.

P. Baker and Associates (1984), *Environmental Land Capability Study Moonee Development Area* August 1984.

PBP (1995), Proposed Development of Lot 2 DP 840016 Pacific Highway Emerald Beach prepared by Patterson Britton and Partners [PBP], November 1995.

PBP, (2004). *45 Hearns Lake Road Woolgoolga Coastline Hazard Definition and Lake Entrance Processes*, prepared by Patterson Britton and Partners [PBP], October 2004.

Peter Parker (1988), *Red Rock Recreation Reserve Draft Plan of Management* prepared by Peter Parker Environmental Consultant for Department of Lands (Crown Lands Office), April 1988.

Phinn, S.R. and P.A. Hastings, (1992). Southern Oscillation Influences on the Wave Climate of South-Eastern Australia, *Journal of Coastal Research*, **8**, 579-592.

Pitt, M.W. (1991). *Tourism and Coastal Land Management - Survey of Visitors on the North Coast of NSW*.

Power, S., Casey, T., Folland, C., Colman, A., and V. Mehta, (1999). Inter-decadal modulation of the impact of ENSO on Australia, *Climate Dynamics*, **15**, 319-324.

PWD (1983), *Coffs Harbour Shire - Northern Areas Sewerage Moonee Sewage Treatment Works: A Review of Treatment Works Sites and Effluent Disposal Options* prepared by Public Works Department NSW [PWD] for Coffs Harbour Shire Council. Report No. CH002; PWD Report No 8302, October 1983.

PWD (1986), *Moonee Development Area Draft Local Environment Plan* prepared by Public Works Department NSW, 1986.

PWD (1987), *Coffs Harbour Northern Areas Wastewater Scheme Geological Feasibility Investigation for Proposed Outfall Sites at Woolgoolga Headland and Look At Me Now Headland* prepared by Public Works Department NSW Geotechnical Centre. Report No. G87006, April 1987.

PWD (1989), *Woolgoolga Beach Examination of Recession Trends*, Preliminary Copy prepared by Public Works Department NSW, March 1989.

PWD (1991a), *Red Rock Beach Surf Environmental Analysis* prepared by Public Works Department NSW [PWD] Coast and Rivers Branch, October 1991.

PWD (1991b), *Sandys Beach Surf Environmental Analysis* prepared by Public Works Department NSW [PWD] Coast and Rivers Branch, October 1991.

PWD (1992), *North Sapphire Beach Surf Environmental Analysis* prepared by Public Works Department NSW [PWD] Coast and Rivers Branch, September 1992.

PWD (1995), *Coffs Harbour City Coastal Assessment Report*, prepared by Public Works Department NSW [PWD] Coast and Flood Policy Branch, Report No. 94066, March 1995.

Ranasinghe, R., McLoughlin, R., Short, A. D., and G. Symonds, (2004). The Southern Oscillation Index, wave climate and beach rotation, *Marine Geology*, **204**, 273-287.

Ranasinghe, R., Watson, P., Lord, D., Hanslow, D. and P.Cowell, (2007). *Sea Level Rise, Coastal Recession and the Bruun Rule*, Proceedings of the Coasts and Ports Conference '07, Engineers Australia.

RDM (1998a), *Park Beach Coastline Hazard Definition and Management Study* prepared by Resource Design & Management [RDM] for Coffs Harbour City Council and Department of Land & Water Conservation, December 1998.

RDM (1998b), *Park Beach Coastline Hazard Management Plan* prepared by Resource Design & Management [RDM] for Coffs Harbour City Council and Department of Land & Water Conservation, December 1998.

Roy, P.S. and Stephens, A.W. (1980). Regional geological studies of the N.S.W. inner continental shelf. summary results. Geological Survey Report No GS 1980/028. Geological Survey of New South Wales, Department of Mines.

Roy, P. S. (1982). Regional geology of the central and northern Nsw South Wales coast. In Heavy mineral exploration of the East Australian Shelf ‘SONNE’ Cruise SO-15 1980. Geologisches Jahrbuch, Reihe D, Hefy 56, 25-35.

Short, A. D. and N. L. Trenaman, (1992). Wave Climate of the Sydney Region, an Energetic and Highly Variable Ocean Wave Regime, *Australian Journal of Marine and Freshwater Research*, **43**, 765-91.

Short. A.D. (1999). In Short A.D. (ed.), *Beach and Shoreface Morphodynamics*. John Wiley & Sons, Chichester.

Short, A.D., (2007). *Beaches of the New South Wales Coast A guide to their nature, characteristics, surf and safety*, 2nd Edition, February, 398p.

Short, A.D., Trembanis, A., and Turner, I., (2000). *Beach oscillation, rotation and the southern oscillation - Narrabeen Beach, Australia*, Proceedings of the 27th International Coastal Engineering Conference, ASCE: Sydney, pp. 2439-2452.

Short, A.D. and A.C. Trembanis, (2004). Decadal Scale Patterns in Beach Oscillation and Rotation Narrabeen Beach, Australia - Time Series, PCA and Wavelet Analysis, *Journal of Coastal Research*, **20**, 523-532.

Skene, D.L. and P.S Roy (1985), *The Quarternary Geology of the Coast and Inner Shelf At Wooli, Northern NSW*, prepared for the Geological Survey of New South Wales Department of Mineral Resources Geological Survey Report No. 1986/216, December 1985.

SMEC (2004), *Coastal Engineering Advice, 14 Hofmeier Close, Woolgoolga*, prepared for Lesiuk Architects, August 2004.

SMEC (2005), *Lot 216 DP 228582 15 Shell Cove Lane Korora, Coastal Engineering Advice*, February 2005.

Soil Conservation Service of NSW (Date Unknown), *Beach Dune Management Woolgoolga Beach Reserve* (date not stated on report).

Stephens,A.W. and Roy P.S. (1980) Quaternary geology of the coast and inner continental shelf at Coffs Harbour, northern New South Wales. Unpublished Geological Survey of New South Wales, Department of Mines, New South Wales.

Sustainable Futures Planning & Design (1990), *Report on Proposed Woolgoolga-Grafton Surf Life Saving Club*, May 1990.

Thom and Short (2006), Introduction: Australian Coastal Geomorphology, 1984 – 2004, *Journal of Coastal Research* **22**, 1, January 2006, p1-10.

Troedson, A., Hashimoto, T.R., Jaworska, J., Malloch, K., Cain, L. (2004), *New South Wales Coastal Quaternary Geology*, prepared for the Comprehensive Coastal Assessment (DoP) by the NSW Department of Primary Industries, Mineral Resources, Maitland.

Wainwright, D and Baldock, T.E. (2010), A Framework for Probabilistic Berm Height Determination – Application to ICOLL Flood Studies, *Proceedings 50th Annual Floodplain Management Authorities Conference*, 23-26 February 2010, Gosford.

WBM (2003). *Ballina Shire Coastline Hazard Definition Study Stage 1*, prepared by WBM Oceanics Australia for Ballina Shire Council, February 2003.

WP Geomarine (1998), *Campbells Beach Coastline Management Study Stage One Coastal Processes and Hazard Definition Study*, December 1998.

WP Geomarine (1999a), *Coastal Engineering Advice, Lot 4 DP 774491, Coachmans Close, Sapphire*, prepared for Newnham Karl and Partners, May 1999.

WP Geomarine (1999b), *Campbells Beach Draft Coastline Management Plan Stage Three* prepared for Coffs Harbour City Council, October 1999.

Wright, L.D. and A.D. Short (1984). Morphodynamic variability of surf zones and beaches: a synthesis. *Marine Geology*, **56**, pp 93-118.

You, Z. and D. Lord, (2008). Influence of the El-Nino-Southern Oscillation on NSW Coastal Storm Severity, *Journal of Coastal Research*, **24**, 2B, 203-207.

4 COFFS REGION BEACH ASSESSMENT

4.1 Introduction

This chapter provides an outline of coastal hazards at the individual beaches in the Coffs LGA. This includes a brief description of each beach and its geomorphology, followed by discussion of photogrammetry, derivation of the beach erosion hazard and shoreline recession hazard. The remaining coastal hazards (coastal inundation, coastal entrances, stormwater erosion, sand drift) are also outlined.

Climate change is included in the definition for each of the coastal hazards for the 50 and 100 year planning horizon. The impacts of a future sea level rise, as well as future storm surge conditions and wave climate are discussed as applicable to the hazard.

A summary of prior studies and information for the beach embayments and headlands is given in the Progress Report (Appendix A). Beaches are discussed from south to north along the LGA coastline.

4.2 North Beach and Bundagen Head

North Beach runs for 8.75 km from the northern entrance wall of the Bellinger River to Bundagen Head. The northern most 2 km of this beach, north of Tucker Rocks, lies within the Coffs LGA, and is shown in Figure 4-1. This beach section also lies within Bongil Bongil National Park (NP), which extends north to Bongil Beach.

The beach is a double barred system, facing east-south-east into the prevailing swell. The beach is composed of fine sand. The inner bar is generally a continuous attached bar (low tide terrace), occasionally crossed by rips. A deep, wide trough, which is generally swept by strong currents, separates the inner bar from an outer bar further offshore (Short, 2007).

Bundagen Head is a fairly low headland, separating North Beach and Bongil Beach. The small **Bundageree Creek** entrance lies amongst the rocks on the northern side of Bundagen Head. Both lie within the Bongil Bongil NP.

Long Term Recession

There is no photogrammetric data for this section of the Coffs Coastline.

North Beach is of similar geology to Bongil Beach, thus is also likely to have been accreting in response to the wave climate since the late 1970s to the present, which is noted to have enhanced accretion on the longer, south east facing embayments such as Bongil Beach. The accretion is related to wave climate variability, rather than an increase in sediment supply to this coastline. Shoreline modelling suggests this beach has not been affected by the construction of Coffs Harbour to the north. Thus North Beach is taken to be stable at the present time (i.e., not accreting or receding over the long term).

Without sea level rise, the shoreline modelling suggests North Beach would remain stable (i.e. neither accretion nor recession) over the next 50 and 100 years.

Future Long Term Recession

Given that the modelling has been verified against the photogrammetry for other beaches, it is appropriate to adopt the values derived from the modelling.

On North Beach, the shoreline modelling suggests recession due to sea level rise of 0.9 m by 2100 of 30 m at the centre of the beach (i.e. at the boundary of the Coffs LGA) to 15 m recession at the northern end of the beach adjacent to Bundagen Head.

For the ‘rare’ scenario of 1.4 m sea level rise by 2100, the shoreline modelling suggests recession of 45 m at the centre to 20 m at the northern end of the beach. As derived from calculating longshore transport rates for easterly and south east wave directions, it has been determined that for the ‘rare’ case of a more easterly wave climate, there is likely to be an increase in the extent of recession at the northern end of the beach. This is because of reduced rates of longshore transport to the northern end with more easterly waves.

The extents of beach erosion and shoreline recession at North Beach for the immediate, 2050 and 2100 planning horizons are contained in the Figures Compendium.

Beach Erosion

There is no photogrammetric data for this section of the Coffs Coastline. The geomorphology is very similar to that of Bongil Beach, being a long, south east facing sandy shoreline. Thus beach erosion values assessed for Bongil Beach have been adopted for North Beach.

Coastal Inundation

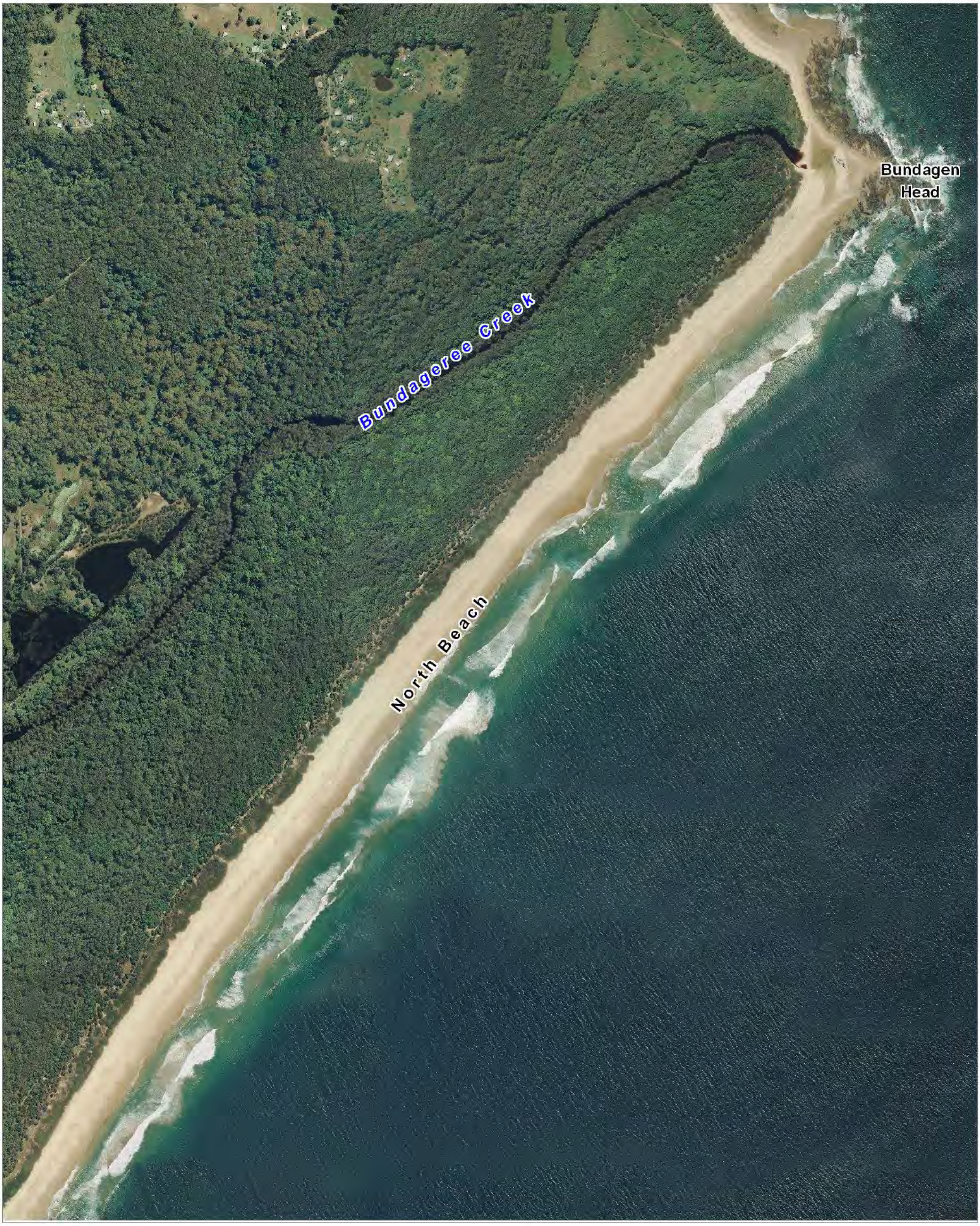
As the section of North Beach within the Coffs LGA does not have any significant entrances between the ocean and back beach areas, the inundation hazard is not considered significant behind North Beach. Coastal Inundation for the immediate, 2050 and 2100 horizons are mapped for the entire Coffs LGA in the Figures Compendium.

Coastal Entrances and Stormwater Erosion

There are no coastal entrances or drainage points (stormwater erosion hazard) found on the section of North Beach within Coffs LGA.

Sand Drift

Windborne sediment transport allows for the growth and stability of dunes throughout the Coffs LGA. On North Beach, windborne sediment transport is not considered to constitute a sand drift hazard in terms of either sediment losses or nuisance to back beach development.



Title:

North Beach

Figure:

4-1

Rev:

A

N

0 250 500m

Approx. Scale

BMT WBM

www.wbmpl.com.au

Filepath : K:\N1440 Coffs Coastal Process Hazard Definition Study\MapInfo\Workspaces\DRG_001_100510 North Beach.WOR

4.3 Bongil Beach and Bonville Headland

Bongil Beach extends from Bundagen Head to Bonville Head for a length of 5.8 km, as shown in Figure 4-3. The beach is composed of fine grained quartzose sand. It faces southeast and receives the full extent of the prevailing wave climate. As such, a well maintained double barred surf zone has developed. There are often many rips (up to 30) across the inner transverse bar. A deep trough separates the inner bar from the outer rhythmic bar, which has more widely spaced rips. At the far southern end at the rocks surrounding Bundagen Head, waves are reduced slightly, although rips still form in this vicinity.

The entrance to **Bonville Creek** is located at the northern end of the beach, flowing hard against Bonville Head. Flows from the creek develop deep channels and strong tidal currents. There is a tidal rock pool located on Bonville Head, along which lies a strong permanent rip (Short, 2007).

The beach is largely backed by Bongil Bongil National Park and remains relatively isolated and untouched. There is no regular vehicle access to the beach, and surfers occasionally access the beach by crossing Bonville Creek.

Bonville Head is ~ 15 m high, separating Bongil Beach and Bonville Creek from Sawtell Beach. Approximately 600 m offshore of the Headland are two rock reefs known as Sawtell Island. The lower back of the headland is likely to have experienced disturbance by clearing in the past, and largely consists of dune sands. A car park and lookout is located on top of the headland.

Photogrammetry Data Quality

The photogrammetric data from 1964 appears to be inaccurate relative to other dates, and has not been included in the analysis. The 1973 data also appears to be inaccurate particularly in blocks at the southern end of the beach. The 1973 data has been discussed, but volume data from this date has not been included in the beach erosion analysis, given the lack confidence in the data accuracy.

Long Term Recession

The photogrammetric data did not suggest long term recession to be occurring at Bongil Beach. Rather, there has been a trend of accretion since 1974 (as stated above, the 1964 and 1973 data was not included due to potential inaccuracy). Along the beach length, profiles have exhibited growth in incipient foredune height / volume and beach width from 1974 to 2007, as shown in Figure 4-2. From the block cumulative volume data, an average of 1.8 m/year accretion across the beach and a range of 0.3 m/yr towards the southern end to 3.5 m/yr at the northern end were calculated (between 1974 and 2007). Data within the creek mouth was included in this assessment as it may act as a sink for sediment.

The beach has experienced a long (decadal) period of accretion that is likely to be a response to the period of wave climate since the late 1970s, typically reported in the literature to be of lower storminess (lower wave height) and more persistently south-east in direction (refer Section 2.4.4). Such conditions produce a strengthened northerly longshore transport (due to the south east wave climate) and fewer erosion events, enabling accretion upon south-south-east facing beaches, particularly the longer beaches such as Bongil Beach. It is unlikely that there has been an increase in sediment supply into Bongil Beach, rather the current trend of accretion is a response to the gentler wave climate over the previous decades.

The shoreline modelling indicates that Bongil Beach has not been affected by the harbour construction and has remained stable. This is consistent with the observations in the historical data as discussed above. Without sea level rise, the modelling indicates that Bongil Beach would remain stable and unaffected by the harbour construction over the 50 and 100 year planning horizons (2050, 2100).

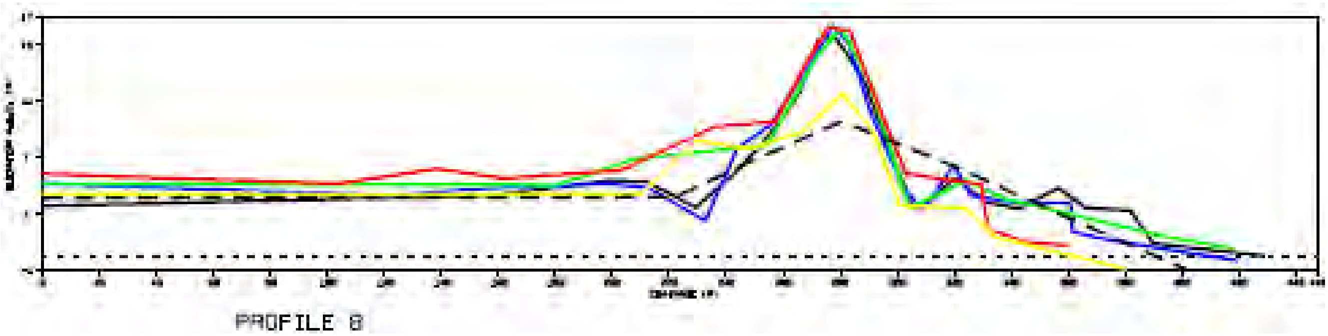


Figure 4-2 Profile 8 Block 5, Northern End of Bongil Beach*

**Legend: Black dashed line – 1964, Yellow line – 1973, Red line – 1974, Green line – 1981, Blue line 1996, Grey line – 2007.*

Future Long Term Recession

At Bongil Beach, shoreline modelling suggests that the southern end of the beach shall experience a far greater impact from sea level rise than observed at the northern end of the beach. By 2100 with 0.9 m sea level rise, up to 75 m recession at the southern end grading to 20 m at the northern end of the beach is expected. The impact is not uniform along the beach because of the predominant south-easterly wave climate, which generates northerly longshore sediment transport. The transport results in greater recession at the southern end of the beach while the northern end of the beach is supplied by this transport, mitigating recession to some degree. The existing south-easterly wave climate is at present predicted to continue into the future.

The photogrammetric data suggests that the northern end has experienced greater accretion than the southern end since 1974, which was noted above to be in response to the south easterly wave climate, particularly over recent decades. This provides evidence that the response given in the modelling to sea level rise and wave climate (i.e. greater erosion at the southern compared with northern end) is sensible.

For the 'rare' possibility of 1.4 m sea level rise by 2100, the shoreline modelling suggest Bongil Beach may experience up to 125 m recession at the southern end and up to 30 m recession at the northern end. Recession at the southern end of the beach is further enhanced as the beach becomes more separated from North Beach by Bundagen Head as sea level rises, and there is greater interruption of sediment transport between the beaches by the headland.

Based upon calculations of longshore transport with the CERC (1984) equation, under a more easterly average wave climate (120° TN wave direction), the rate of longshore transport is much reduced compared with transport rates during a south easterly average wave climate (135°). For the ‘rare’ case of a more easterly wave climate, an enhanced recession of up to 50 m at the northern end was estimated, with recession at the southern end of up to 45 m by 2100, based on a sea level rise of 0.9 m. This is because the more easterly wave climate does not produce a strong transport of sediment towards the northern end, resulting in greater recession, compared with the existing south easterly wave climate.

Beach Erosion

Bongil Beach is not affected by the harbour construction and so provides a useful data set for analysing beach erosion at Coffs Beaches. In general, Bongil Beach profile cross sections illustrate natural erosion and accretion cycles relating to storm periods, with a period of strong accretion evident since 1974.

The general trend in the 1973 data (from which volumes have not been analysed due to data inaccuracy) is a lower subaerial beach face without incipient foredunes towards the northern end of the beach, and higher subaerial beach face and incipient region compared with other dates at the southern end of the beach. 1973 was reported to have experienced tropical cyclones, which would have arrived from a more easterly direction at Bongil Beach. The more easterly storm waves generate southerly directed transport resulting in accretion at the southern end and erosion at the northern end of the beach. This is consistent with the general observations in the 1973 profile data.

At the majority of profiles the 1974 data exhibits the most eroded state, with cutting back into the foredune face and a lowered sub-aerial beach position. 1974 was a highly stormy year, with east coast low cyclones generating storms during May to June between Eden and Sydney, which would have arrived from a south easterly direction at Bongil Beach. The entire Bongil Beach length exhibits erosion in 1974.

Visual interrogation of the cross sections suggests seaward movement of 40 to 60 m between 1974 and 2007 (e.g. Figure 4-2). Analysis of the movement of the 4 m AHD contour position gave an average of 49 m and maximum of 117 m movement between the 2007 and most eroded beach profiles. In terms of profile volumes, an average of 237 m^3/m and maximum of 493 m^3/m difference in volume was calculated between the 2007 and most eroded beach profiles.

It is noted that the 1974 profile is not the product of a single ‘design’ storm, but rather a series of closely spaced, large magnitude storms occurring within a longer (decadal) period of higher storminess upon the NSW coast. That is, it is not expected that this extent of erosion could recur during one storm. However, it is likely that the wave climate conditions resulting in the 1974 profile may occur again sometime over the next 100 years.

It is prudent to adopt 50 m landward movement of the 4 m AHD contour for Bongil Beach as the ‘almost certain’ beach erosion extent. The maximum value of 120 m landward movement of the 4 m AHD contour is adopted as an ‘unlikely’ probability of occurrence. This is reasonable, as it allows for the possibility that rip currents may form at any location along the beach, producing scarping at the beach face. The maximum erosion value also allows for the possibility that a ‘design’ storm may occur when the beach is already in an eroded state. For the ‘rare’ scenario, the difference between the average and maximum values (70 m) is added to the maximum value (120 m), to give 190 m landward movement of the beach profile. The ‘rare’ scenario is considered highly unlikely, but accounts for extreme conditions that are not recorded within the limited measured data set.

The analysis of contour movement and volumes given above excluded photogrammetric data that crossed Bonville or the other two small drainage creeks on Bongil Beach, as the data is not indicative of beach processes alone, but includes outflow from the creeks as well.

In the vicinity of Bonville Creek the photogrammetric data illustrated that the entire entrance bar from Bonville Head to a distance of ~ 1.2 km south along the shore had been eroded in the past. The entrance bar could be eroded entirely during a storm / flood in the future (i.e. due to rainfall and coastal processes). This has been incorporated into the beach erosion hazard at Bongil Beach by adopting the beach erosion set backs from behind the entrance bar region (further explanation is given in Section 3.6). Likewise, erosion set backs at the other drainage creeks and Bundageree Creek are also taken from further landward of the drainage point, based upon the location of the 4 m contour.

The extent of beach erosion and shoreline recession upon Bongil Beach at the immediate, 2050 and 2100 planning horizons is illustrated in the Figures Compendium.

Coastal Inundation

Coastal inundation has an ‘almost certain’ potential to affect large areas of land westward of the northern half of Bongil Beach through the Bonville Creek entrance in an immediate timeframe. The area of land affected in an ‘unlikely’ or ‘rare’ scenario is not greatly increased by 2100. There may be impacts to the Pacific Highway, but there does not appear to be impacts to residential development. Bundageree Creek may allow for minor inundation within Bongil Bongil National Park at the southern end of the beach.

An explanation of the adopted inundation levels (‘almost certain’, ‘unlikely’, ‘rare’) at the immediate, 2050 and 2100 planning periods is given in Section 3.5. Coastal Inundation for the immediate, 2050 and 2100 horizons are mapped for the entire Coffs LGA in the Figures Compendium.

Coastal Entrances

Bonville Creek at the northern end of Bongil Beach is a typically open entrance. However, it is as yet uncertain if there may be an increase in entrance constriction in a response to shoreline recession and vertical accretion due to sea level rise.

There is currently no photogrammetric data available for Bundageree Creek with which to assess the average and maximum berm heights over time. The rise in sea level is likely to cause an increase in typical berm height of 0.4 m by 2050 and 0.9 m by 2100. Potential inundation extents during closed entrance conditions are expected to also rise by these amounts. Further discussion of future entrance characteristics is given in Section 3.6.

The climate change projections for future annual rainfall and rainfall intensity are at present inconclusive. Thus, it is not yet possible to determine potential changes to the entrance condition in response to climate change induced changes to rainfall.

Erosion of coastal entrance berms (and immediately adjacent regions) is included within the beach erosion / shoreline recession hazard for all planning periods. As noted in Section 3.3, the beach erosion extent is measured landward of all coastal entrance berms because the photogrammetric data across the Coffs region consistently demonstrates that erosion of the entire entrance bar has occurred in the past.

Stormwater Erosion

There are a number of small drainage points across the sand dunes and onto Bongil Beach, in addition to Bonville Creek and Bundageree Creek. As noted in Section 0, erosion at these locations is largely covered within the beach erosion hazard zones (as the hazard extent is adopted landward of the footprint of the drainage outlet).

Climate change predictions for future rainfall are at present largely within natural climate variability. The adopted approach to defining probability zones for beach erosion has likely captured the potential changes in erosion at drainage points in the future.

Sand Drift

Windborne sediment transport allows for the growth and stability of dunes throughout the Coffs LGA. For Bongil Beach, windborne sediment transport is not considered to constitute a sand drift hazard in terms of either sediment losses or nuisance to back beach development (particularly as the back beach region lies within Bongil Bongil NP).

Title:

Bongil Beach

Figure:

4-3

Rev:

A

BMT WBM
www.wbmpl.com.au

Filepath : K:\N1440 Coffs Coastal Process Hazard Definition Study\MapInfo\Workspaces\DRG_002_100510 Bongil Beach.WOR

4.4 Sawtell Beach and Boambee Head

Sawtell Beach lies between Bonville Head in the south and Boambee Head in the north and is illustrated in Figure 4-5. **Boambee Head** is 60 m in height (Short, 2007). Sawtell Beach is 2.1 km in length. The majority of the beach is exposed to the predominant wave climate, although the southern end of the beach is protected by Sawtell Island and Bonville headland, and a reflective beach has developed in the lee of this protection. A shallow sandy tombolo has formed between the reefs of the island and the shore under accretionary conditions. This southern part of the beach may be accessed from Bonville Headland, where there is also a boat ramp and some sheltered rock pools.

The remainder of the beach, under normal wave conditions, experiences a transverse bar rip morphology, with frequent rip channels (~ 8). In higher wave conditions a second outer bar may form, cut by more widely spaced rips. (Short, 2007)

The beach is backed by a well vegetated foredune, with the township of Sawtell (~15000 people) located behind the beach. The Sawtell Surf Life Saving Club (SLSC) is situated on top of the foredune immediately behind the middle to southern end of the beach.

Photogrammetric Data Quality

All data was considered suitable for use in the assessment, based upon the review of photogrammetry profile cross sections for all dates of photography.

Long Term Recession

Sawtell does not exhibit a long term recessionary trend, rather the beach appears to have been accreting over the period of photogrammetric data (1967 to 2007) at an average of 0.4 m/yr. The cross section of photogrammetric profiles confirms that there has been a sustained growth in incipient foredune height and volume over the period of data collection (e.g. as given in Figure 4-4.)

It is likely that accretion upon Sawtell has been enhanced by wave climate conditions particularly since the late 1970s, which are reported to have been less stormy (lower mean wave height) and persistently south easterly in wave direction, enhancing the northwards littoral transport. The rate of accretion upon Sawtell Beach over this wave climate period is slightly lower than observed on Bongil Beach, due to their different geomorphology. Sawtell Beach faces towards the east, so incoming waves generate lower longshore transport rates. The beach is also shorter in length and has headlands and bedrock outcrops that will interrupt transport to some degree also. If the wave climate were to shift into a period of greater storminess (higher wave height) with more easterly storm events (such as occurred during the 1970s), There may be a reduction in beach width due to erosion during short term storm events.

Sawtell Beach is concluded to be stable, with the accretionary pattern evident at the present time due to a trend in wave climate rather than an ongoing increase in sediment supply to the beach. The shoreline modelling indicated that Sawtell has remained stable to date in response to the harbour construction. This is consistent with the historical data.

In the future however, without sea level rise, the shoreline modelling indicates up to 5 m of accretion (~ 0.1 m/yr) by 2050, and up to 20 m of accretion by 2100 (~0.2 m/yr) on Sawtell beach in response to the harbour construction. The impact of constriction of longshore transport by the harbour migrates southwards as accretion on Boambee Beach restricts further northerly transport from Sawtell.

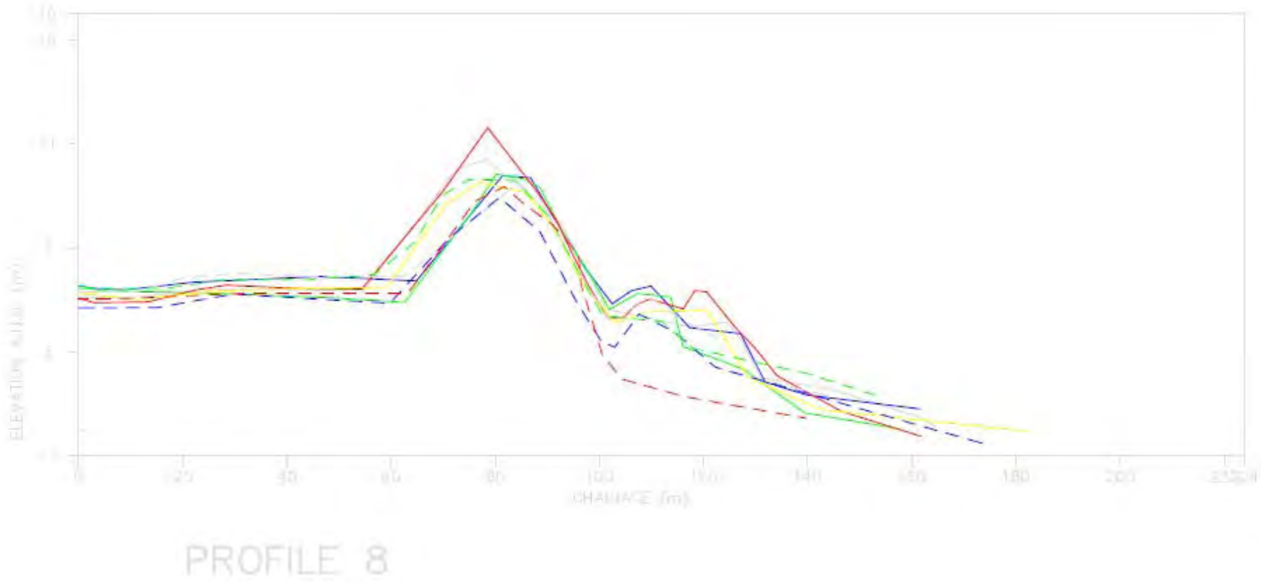


Figure 4-4 Profile 8 of Block 2 on Sawtell Beach*

**Legend: Red dashed line – 1967, Green dashed line – 1977, Blue dashed line – 1980, grey dashed line – 1983, Yellow – 1988, Red – 1993, Green – 2000, Blue – 2004, Grey – 2007.*

Future Long Term Recession

The shoreline modelling indicates that in response to sea level rise of 0.4 m and 0.9 m respectively, 25 m to 10 m of shoreline recession is expected from the south to north by 2050, and 50 to 15 m by 2100 along Sawtell Beach. The response is not quite uniform along the beach due to the south easterly wave climate that generates sediment transport towards the north, reducing the extent of recession.

In response to the 'rare' possibility of either a higher rise in sea level to 1.4 m by 2100 (0.7 m by 2050) and / or a persistent shift to a more easterly wave climate, additional recession values have been derived for Sawtell Beach. The impact of sea level rise to 1.4 m has been derived from the shoreline modelling, and outputs suggest 70 to 20 m recession from south to north by 2100. The impact of a more easterly wave climate has been derived based upon assessment of transport rates when compared with the existing south easterly wave climate. Sawtell Beach faces nearly east, and so there is likely to be only a small reduction in the rate of northerly transport along the beach with a more easterly wave climate. Thus, slightly greater recession of up to 20 m at the northern end and slightly reduced recession of up to 40 m at the southern end under this 'rare' scenario has been assumed. The use of the 'rare' scenarios to generate hazard zones is discussed in greater detail in Section 3.4.4.

Beach Erosion

At Sawtell, interrogation of the photogrammetric profiles cross sections and volumetric data indicated that for the majority of profiles, the 1967 data exhibited the most eroded beach state. Visual interrogation of profile cross sections determined that erosion of 30 m of beach width was not uncommon in the data. In this case, the entire incipient foredune would be removed to the base of the stable older foredune (and in some cases bedrock). Figure 4-4 provides an example of this, when comparing 2007 with 1967 data. This figure also illustrates the relatively stable foredune, with some cutting of the foredune face in 1980, then the growth of the incipient foredune up to ~ 5 m in height in front of the stable foredune by 2007.

Calculation of the movement of the 4 m AHD contour on Sawtell beach showed an average of 12 m and maximum of 45 m landward movement of the most eroded profile compared with the 2007 data. An average of 101 m^3/m and maximum of 225 m^3/m difference in beach volume between the most eroded and 2007 beach states was also calculated.

At each profile the most eroded state (i.e. minimum profile volume) was not significantly rare. That is, over the 1967 to 2007 period, there were a number of fairly similarly eroded profiles. Thus, landward movement of 15 m of the 4m AHD profile (representing the average in the data) is considered to have an ‘almost certain’ probability of occurrence. Landward movement of the 4 m AHD contour by 50 m is considered to have an ‘unlikely’ probability of occurrence. This accounts for the possibility that rip currents and associated scarps may occur anywhere along the shoreline, and that headland bypassing events that may result in extensive erosion. There is also a likelihood that a ‘design’ storm could occur when the beach is in an already eroded state. The ‘rare’ beach erosion extent of 85 m accounts for extreme climatic conditions and potential beach erosion that has not been measured to date.

The extent of beach erosion and shoreline recession upon Sawtell Beach at the immediate, 2050 and 2100 planning horizons is illustrated in the Figures Compendium.

Coastal Inundation

Sawtell Beach does not have any coastal entrances that would facilitate the inundation of back beach areas. Coastal Inundation for the immediate, 2050 and 2100 horizons are mapped for the entire Coffs LGA in the Figures Compendium.

Coastal Entrances

There are no coastal entrances on Sawtell Beach.

Stormwater Erosion

A stormwater outlet has been noted at the centre of Sawtell Beach, north of the Surf Club. There appear to be additional informal drainage points adjacent to bedrock outcrops at the centre of the beach and at the northern end of the beach. Erosion at stormwater outlets and drainage points is largely covered within the beach erosion hazard zones, with erosion extents measured from landward of the drainage point /outlet as discussed in Section 0.

Climate change predictions for future rainfall are at present largely within natural climate variability. The approach to defining probability zones for beach erosion has likely captured the potential changes in erosion at drainage points in the future.

Sand Drift

Windborne sediment transport allows for the growth and stability of dunes throughout the Coffs LGA. Windborne sediment transport is not considered to constitute a sand drift hazard in terms of either sediment losses or nuisance to back beach development on Sawtell Beach.

Title:

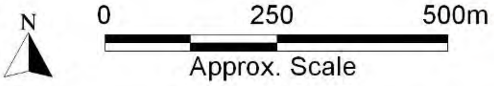
Sawtell Beach

Figure:

4-5

Rev:

A



BMT WBM
www.wbmpl.com.au

Filepath : K:\N1440 Coffs Coastal Process Hazard Definition Study\MapInfo\Workspaces\DRG_003_100510 Sawtell Beach.WOR

4.5 Boambee Beach and Corambirra Point

Boambee Beach is a 5.7 km stretch of sandy beach from Boambee Head and the mouth of Boambee Creek in the south to Corambirra Point in the north, as illustrated in Figure 4-8. The beach is composed of fine grained sand. It faces the south-east and receives the full extent of the predominant wave climate, resulting in a well-developed double sand bar system. The inner transverse bar has regular rips across its length. A broad deep trough has developed between this and the outer bar. The outer bar is generally continuous. Extensive foredunes back Boambee Beach (of ~ 10 – 20 m in height), with sand mining of the hind dune ridges during the 1960s and 1970s.

Boambee Creek flows behind the southern half of the beach and out to the ocean against Boambee Head. It typically remains open and produces strong tidal currents in the creek mouth and beach shoals (Short, 2007).

The very northern end of Boambee Beach between a small rock outcrop and Corambirra Point is often called **Gallows Beach**. This 150 m stretch is at times eroded back to form a cobble beach, exposing the underlying bedrock and rock wall land bridge with South Coffs Island / Corambirra Point. The surfzone of Gallows has a large permanent rip running out to Corambirra Point. Gallows Beach is backed by a gravel and bitumen car park servicing a boat ramp into Coffs Harbour (Short, 2007).

Coffs Harbour Airport, the Northern Railway line and Coffs Harbour Water Reclamation Plant are located behind the northern half of Boambee Beach. The deep sea release is located along Boambee Beach 1 km south of Corambirra Point. Access is only possible onto the beach from the northern end.

Corambirra Point extends for 800 m seaward, comprising the southern land bridge to South Coffs Island out to the point. The eastern breakwater of Coffs Harbour is attached to the end of Corambirra Point. In European times, Corambirra Point has been heavily quarried, with a large scarp evident on its northern edge.

Photogrammetric Data Quality

Sand mining did occur on Boambee Beach (refer Figure 2-2), however review of the photogrammetric profile cross sections revealed that the incipient foredune to foredune crest region of interest to this study showed little to no mining impacts. All of the photogrammetric data was included for analysis.

Long Term Recession

Boambee Beach has experienced a sustained trend of accretion in response to the construction of Coffs Harbour breakwaters. The harbour has constrained the transport of sediment from Boambee into the harbour and beaches beyond, resulting in accretion on Boambee Beach. Ongoing infilling of the harbour (and accretion of Jetty Beach) indicates there is bypassing of sediment from Boambee around the eastern breakwater into the harbour. Assessment of total block volumes indicated the average rate of accretion is 3.4 m/yr along the beach.

The data suggests minor recession of 0.1 m/yr at the very southern end the beach. This is likely related to the Boambee Creek entrance as variation in the creek outflow strength and position may cause erosion of the southern end of the beach adjacent to the creek.

In the middle of Boambee Beach (Block 1), it is clearly evident that significant accretion has occurred up to 2007. Moving towards the northern end of the beach, the growth and seaward advance of incipient dunes and increase in beach volumes from 1969 to 2007 becomes increasingly evident in the photogrammetric cross sections.

The northern end of the beach is accreting at 4 m/yr. Sand is periodically removed from the intertidal zone at the far northern end of Boambee Beach (under licence with Dept of Lands), with a reported 151,000 m^3 removed over a 10 year period (pers. comm., Robert Kasmarik, DECCW, February, 2009). The mined sand is removed permanently from the system (it is not used to nourish other beaches). If the intertidal sand mining data is included in the analysis, the northern end of the beach may be accreting by up to 5 m/yr.

In addition to the harbour impact, Boambee Beach will also have responded to the wave climate over recent decades in a similar manner to Bongil Beach, as both beaches are long, uninterrupted sandy beaches facing south-south east.

Modelling of the shoreline response to the harbour construction indicates sustained increase in the width of Boambee Beach consistent with the observations in the photogrammetry. The modelling suggests accretion of smaller magnitude at the southern end of the beach in response to the harbour construction. The model results are consistent with historical response described above, that being ongoing accretion upon Boambee Beach.

Without sea level rise, the shoreline modelling suggests continued accretion on Boambee Beach of a further 10 to 20 m, from north to south. The accretionary impact is enhanced towards the southern end of the beach as the sediment accumulation further north blocks northward migration to some degree.

Future Long Term Recession

The impact of sea level rise in causing the recession of sandy shorelines is typically well understood, as explained by the Bruun Rule (1962). However, the shoreline modelling is capable of demonstrating the response of the shoreline north and south of the harbour construction to sea level rise. The recession due to sea level rise subdues the accretion of sediment at the northern end of Boambee and so, bypassing around the harbour. This will enhance the impact of sea level rise on beaches to the north because the harbour impact is re-introduced. Accretion due to the harbour construction however, will slightly reduce the sea level rise impact upon Boambee Beach.

The shoreline response modelling suggests that with sea level rise of 0.9 m by 2100, up to 60 m recession at the southern end grading to 20 m at the northern end of Boambee Beach (with 25 m and 5 m at south and north by 2050 with 0.4 m sea level rise) is expected. The shoreline response modelling was shown to be sufficiently consistent with the historical data for Boambee Beach, and so model results for sea level rise scenarios may be adopted with confidence for the shoreline recession hazard.

The ‘rare’ possibility of a greater sea level rise of up to 1.4 m by 2100 was also modelled. The results suggest Boambee Beach may experience from 110 to 30 m recession from south to north along the beach under this scenario.

The potential impacts of the 'rare' case of a permanent shift to a more easterly wave climate (in combination with predicted sea level rise of 0.9 m by 2100) have been assumed based upon comparison of longshore transport rates from an easterly and existing south easterly wave climates. For beaches such as Boambee that face south-south-east and the calculations indicate there may be a complete reversal of the direction of sediment transport for easterly compared with south easterly average waves. The modelled sea level rise values have been reversed to reflect this 'rare' scenario, that is, up to 60 m recession at the northern end and 20 m at the southern end is expected with predicted sea level rise and a more easterly wave climate.

Beach Erosion

Due to the influence of the harbour construction upon sediment volumes at Boambee Beach it was not possible to reliably estimate the extent of probable erosion. Bongil Beach (to the south) has a similar geomorphology to Boambee, being a long, south-east oriented compartment with few headland or reef interruptions. Thus, the beach erosion hazard from Bongil Beach was adopted at Boambee, being an 'almost certain' probability of 50 m, 'unlikely' likelihood of 120 m and 'rare' likelihood of 190 m landward movement of the 4 m AHD contour position.

In comparison with the data, the maximum value at Bongil Beach (120 m) is appropriate at Boambee Beach. Observation of the profile cross sections indicates there has been typically 80 to 120 m of seaward increase in beach width (out to the 0 m contour) between 1974 and 2007 at Boambee, as shown in Figure 4-6. At the northern end, the 2007 beach is typically ~ 155 m wider than the 1974 beach however, this value also includes long term accretion. Historical and ongoing capture of northerly directed transport at Boambee would protect the northern end to some degree from a period of enhanced storminess.

At the southern end of Boambee, a difference in beach width of 120 m is greater than that observed in the data (typically 20 – 60 m shift in beach width) between the 2007 and most eroded profiles, as shown in Figure 4-7. However, 1986 displayed a wider beach than 2007, suggesting landward erosion of this magnitude (120 m) is possible. It is also prudent to adopt such values along the beach length because storms may arrive from any direction with the same intensity.

The extent of beach erosion and shoreline recession upon Boambee Beach at the immediate, 2050 and 2100 planning horizons is illustrated in the Figures Compendium.

Coastal Inundation

Coastal inundation has the potential to affect large areas of land behind Boambee Beach through the Boambee Creek entrance at the southern end of the beach. An explanation of the adopted inundation levels ('almost certain', 'unlikely', 'rare') at the immediate, 2050 and 2100 planning periods is given in Section 3.5. Coastal Inundation for the immediate, 2050 and 2100 horizons are mapped for the entire Coffs LGA in the Figures Compendium.

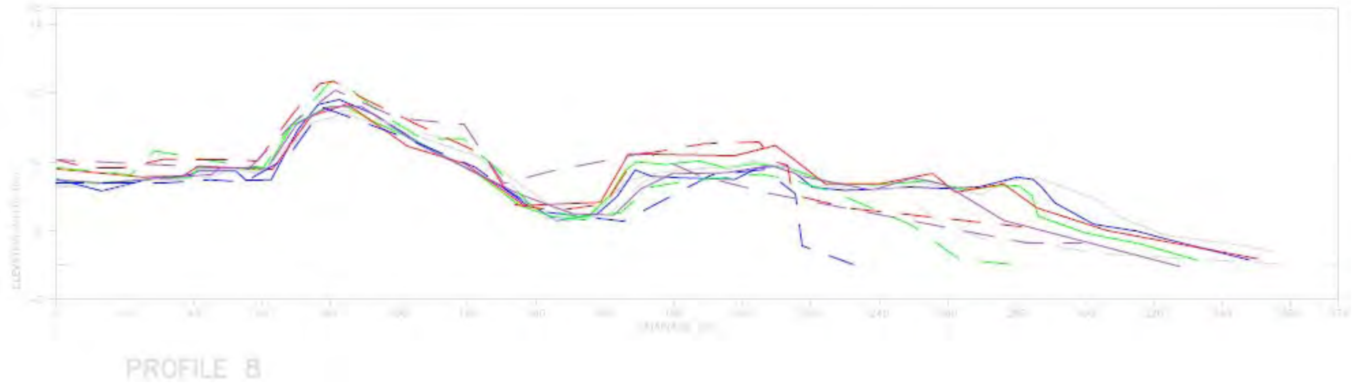


Figure 4-6 Profile 8 of Block 2, Northern End of Boambee Beach*

**Legend: Red dashed line – 1969, Green dashed line – 1973, Blue dashed line – 1974, grey dashed line – 1986, Purple – 1993, Red – 1996, Green – 2000, Blue – 2004, Grey – 2007.*

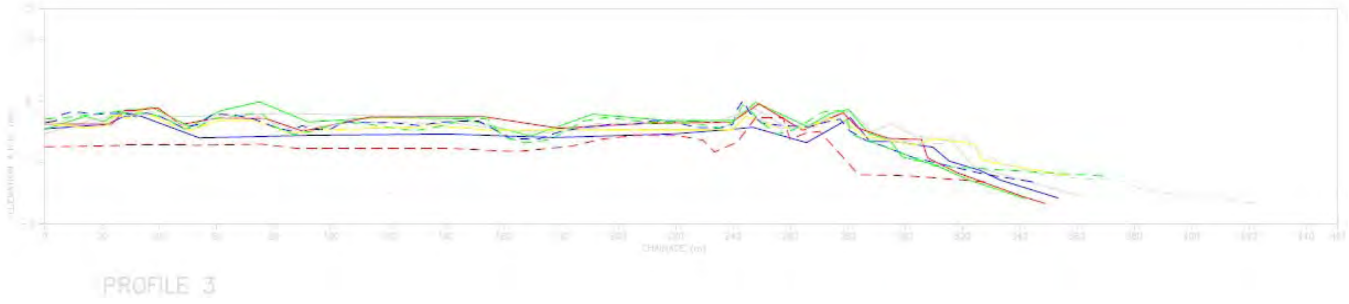


Figure 4-7 Profile 3 of Block 8, Southern End of Boambee Beach**

***Legend: Red dashed line – 1942, Green dashed line – 1969, Blue dashed line – 1977, grey dashed line – 1986, Yellow – 1993, Red – 1996, Green – 2000, Blue – 2004, Grey – 2007.*

Coastal Entrances

Boambee Creek at the southern end of Boambee Beach is a typically open entrance. The entrance area is likely to be significantly changed in response to ongoing recession at the southern end of the beach due to sea level rise. It is uncertain if this may result in entrance closure in the future, although this is considered unlikely. Further discussion of future entrance characteristics is given in Section 3.6.

The climate change projections for future annual rainfall and rainfall intensity are at present inconclusive. Thus, it is not yet possible to determine potential changes to the entrance condition in response to climate change induced changes to rainfall.

Erosion of coastal entrance berms (and immediately adjacent regions) is included within the beach erosion and shoreline recession hazard for all planning periods. As noted in Section 3.4.4, the beach erosion extent is measured landward of all coastal entrance berms. This is because the photogrammetric data at all entrances in the Coffs region demonstrates that erosion of the entire berm occurs consistently in the past.

Stormwater Erosion

There are a number of small drainage points onto Boambee Beach, in addition to Boambee Creek. As noted in Section 0, erosion at these locations is largely covered within the beach erosion hazard zones (as the erosion extents are adopted landward of the footprint of the drainage outlet).

Climate change predictions for future rainfall are currently too coarse to confidently estimate local changes in rainfall and runoff and subsequent erosion extents at outlets / drainage points. However, the approach to defining probability zones for beach erosion has likely captured the potential changes in erosion at drainage points in the future.

Sand Drift

Windborne sediment transport allows for the growth and stability of dunes throughout the Coffs LGA. On Boambee Beach, windborne sediment transport is not considered to constitute a sand drift hazard in terms of either sediment losses or nuisance to back beach development.

Title:

Boambee Beach

Figure:

4-8

Rev:

A

N

0 0.5 1km

Approx. Scale

BMT WBM

www.wbmpl.com.au

Filepath : K:\N1440 Coffs Coastal Process Hazard Definition Study\MapInfo\Workspaces\DRG_004_100510 Boambee Beach.WOR

4.6 Coffs Harbour, Jetty Beach and Muttonbird Island

Coffs Harbour is bounded by a land bridge between the mainland and South Coffs Island (Corambirra Point), the eastern breakwater extending 400 m off Corambirra Point, and a northern breakwater attaching Muttonbird Island with the mainland. The eastern breakwater is oriented roughly north east offering protection to the harbour from the predominant south east swell. Muttonbird Island offers protection to the harbour mouth from north to east swell. Waves frequently break upon the eastern breakwater, and damage to the breakwater has been sustained during large storms, (for example, in 1996). The harbour and Jetty Beach are illustrated in Figure 4-9.

A safe inner harbour for small craft with marina berths was built in the mid 1970s. It is outlined by a small southern breakwater attached to the western shore of Muttonbird Island (Short, 2007). A small basin forming a protected boat ramp was cut in the causeway between South Coffs Island and the mainland (RDM, 1998a).

Prior to causeway and breakwater construction, South Coffs Island and Muttonbird Island were separated from the mainland by a nearshore channel, through which the net northerly littoral drift could proceed uninterrupted from Boambee Beach to Park Beach and beyond (RDM, 1998a).

Jetty Beach is the 1.4 km stretch of beach inside the harbour, and so is heavily protected by harbour breakwaters and Muttonbird Island. Waves are rarely greater than 0.5 m in height. The beach has a wide, low attached bar with no rips, and displays a low tide terrace morphology (Short, 2007).

Behind Jetty Beach there is a limited width of dune vegetation, then car parking and a large park and picnic area. There is also a jetty upon the beach extending seaward to the mouth of the inner harbour. A small creek / drainage line exits onto the beach at the southern end.

Photogrammetric Data Quality

Jetty Beach shows no evidence of mining either in the mining map (Figure 2-2) or photogrammetric profiles. It is noted that there has been ongoing dredging of Coffs Harbour to maintain water depth, but it is uncertain if or what effect this may have had upon the beach, given the low energy wave conditions.

Long Term Recession

Jetty Beach shows evidence of long term accretion, most likely due to the construction of the harbour. Sediment bypassing the eastern breakwater is known to be infilling the harbour at rates of 25,000 to 50,000 m^3/yr (Carley *et al.*, 2006) as well as being deposited upon Jetty Beach. Average rates of accretion of 1.3 m/yr across the beach have been calculated from total volumes. The profile cross sections confirm there has been seaward growth of the beach profile from 1942 to 2007.

The shoreline response model results are consistent with the historical data, and suggest that without sea level rise, Jetty Beach may continue to prograde by up to 10 m by 2100.

Future Long Term Recession

The shoreline modelling for predicted sea level rise indicates that Jetty Beach may recede by up to 40 m by 2100 with 0.9 m rise (up to 20 m with 0.4 m rise by 2050). The beach is afforded some protection from recession by sediment bypassing of the eastern harbour breakwater (from Boambee Beach).

Shoreline modelling for the ‘rare’ scenario of 1.4 m sea level rise by 2100 suggests that recession of up to 50 m may occur on Jetty Beach (up to 30 m with 0.7 m rise by 2050). Jetty Beach is very protected from waves, being located within the harbour, and is oriented towards the east. There is unlikely to be any shift in sediment transport and recession rates along this beach in the ‘rare’ case that the average wave climate becomes more easterly.

Beach Erosion

There is significant protection afforded to Jetty Beach from storm wave attack due to the harbour construction. There is also lack of evidence of significant storm erosion in the photogrammetric data, which is obscured by long term accretion on this beach. 1973 is the most eroded profile in all cases however, this is likely in part due to ongoing accretion since this time, not just storm impacts.

At the southern end of the beach, the 2004 data exhibits the narrowest beach, while at the northern end of the beach the 2004 data shows the widest beach width since 1986. This suggests a rotation of the beach between these dates.

While Jetty Beach is considered at low risk of storm wave attack, stored sediment volumes in the beach and dune are low, with dunes typically below 3 m AHD. Thus, the beach erosion extents for Sawtell were adopted for Jetty Beach and have been applied to the 2 m AHD contour, to reflect the lower storage. Analysis of the photogrammetric data since 1986 (which is of higher accuracy) is consistent with the Sawtell values for beach erosion when taken from the 2 m AHD contour.

For the immediate timeframe, ‘almost certain’ , ‘unlikely’ and ‘rare’ erosion extents of 15 m, 50 m and 85 m respectively are adopted for the beach erosion hazard at Jetty Beach. The extent of beach erosion and shoreline recession upon Jetty Beach at the immediate, 2050 and 2100 planning horizons is illustrated in the Figures Compendium.

Coastal Inundation

The minor drainage points along Jetty Beach would enable minor inundation of back beach areas. An explanation of the adopted inundation levels (‘almost certain’, ‘unlikely’, ‘rare’) at the immediate, 2050 and 2100 planning periods is given in Section 3.5. Coastal Inundation for the immediate, 2050 and 2100 horizons are mapped for the entire Coffs LGA in the Figures Compendium.

Coastal Entrances

One minor creek/drainage line is assessed under the Stormwater Erosion Hazard (below).

Stormwater Erosion

As noted in Section 0, there are two minor creeks / drainage points along Jetty Beach. Erosion at these locations is largely covered within the beach erosion hazard zones (as the hazard extent is measured from landward of the drainage outlet).

Climate change predictions for future rainfall are currently too coarse to confidently estimate local changes in rainfall and runoff and subsequently, to what extent there may be further erosion at outlets / drainage points. However, our approach to defining probability zones for beach erosion has likely captured the potential changes in erosion at drainage points in the future.

Sand Drift

Windborne sediment transport allows for the growth and stability of dunes throughout the Coffs LGA. On Jetty Beach, windborne sediment transport is not considered to constitute a sand drift hazard in terms of either sediment losses or nuisance to back beach development. It is noted also that back beach areas are of relatively low elevation at Jetty Beach, with little dune development.

Title:

Coffs Harbour and Jetty Beach

Figure: **4-9**

Rev: **A**

N

0 125 250m

Approx. Scale

BMT WBM

www.wbmpl.com.au

Filepath : K:\N1440 Coffs Coastal Process Hazard Definition Study\MapInfo\Workspaces\DRG_005_100510 Jetty Beach.WOR

4.7 South Park and Park Beaches, Macauleys Head

South Park Beach extends 600 m between the northern breakwater adjoining Muttonbird Island and the mouth of Coffs Creek and the sandy cuspate foreland which has formed in the lee of Little Muttonbird Island. Waves are typically small (average < 1 m) at the beach, as it is protected by the northern breakwater and Muttonbird Island to the south and Little Muttonbird Island to the north. The beach exhibits a low tide terrace morphology, maintaining an attached sand bar which may be cut by rips during high wave conditions (Short, 2007).

The northern breakwater extends into a rock revetment wall immediately behind the southern end of South Park Beach. Between the wall and the water line is a narrow beach strip that is often inundated at high tide. Reflected waves and currents along the seawall and breakwater are common. There is a car park at the southern end, around the port and sailing club, from which a small ramp offers access to the beach.

Coffs Creek exits to the ocean at the southern end of Park Beach, with a northern training wall to enable the creek mouth to remain open for the majority of the time. Behind the beach lies a fenced foredune (largely vegetated), which is occasionally undercut by storm waves, leaving a high erosion escarpment.

Park Beach extends from the cuspate foreland in the lee of Little Muttonbird Island and the mouth of Coffs Creek for 1.5 km to Macauleys Head in the north. Both Little Muttonbird and Muttonbird Islands provide a small amount of protection from south east waves. The beach faces east and receives the majority of the prevailing swell particularly at the northern end. A transverse bar and rip morphology is typically evident, with up to 10 beach rips, and a permanent rip along Macauleys Headland. In summer, strong rips may form adjacent to the sandy foreland at the southern end under north east wind and wave conditions (Short, 2007).

Park Beach is the main beach for the township of Coffs Harbour. An access road runs behind the length of the beach. There is extensive parking, many pedestrian accessways, a picnic area between the southern car park and creek, a caravan park, hotel and the Coffs Surf Life Saving Club (SLSC), established in 1923 all located behind the beach (Short, 2007).

Macauleys Headland is a wide, high headland forming the northern constraint of Park Beach. A 30 m wide beach is wedged between the high cliffs on the southern side of Macauleys Headland. The beach consists of a mixture of sand, cobbles and boulders. It is fronted by rocks and reef, and is likely to be popular for rock fishing (although dangerous and unsuitable for swimming or surfing).

South Park Beach, Coffs Creek, Park Beach and the bounding headlands are shown in Figure 4-11.

Photogrammetry Data Quality

South Park Beach was not affected by mining, thus all photogrammetric data is used in analyses.

The mining map illustrates the northern photogrammetry Blocks (5S, 5N) on Park Beach to have been mined. Review of the data suggests possible mining particularly between 1942 and 1969 (with possible smaller impacts between 1969 and 1973). The 1942 data is not available for the northern Block (5N). Wherever possible, the data was analysed from seaward of the mining footprint, to reduce potential distortion of photogrammetric data. All available photogrammetric data for Park Beach was utilised, taking mining impacts into consideration.

Long Term Recession

The photogrammetry data for South Park Beach does not exhibit a recessionary trend, but rather, the data suggests South Park Beach is accreting at 0.6 m/yr. Excluding the profiles across the seawall at the southern end of the beach and the creek at the northern end of the beach, the data calculations show accretion of 0.4 m/yr.

South Park Beach is relatively protected from the predominant south easterly swell by the northern harbour breakwater and Muttonbird Island and from easterly to northerly swells by Little Muttonbird Island. In a similar fashion, beaches to the south that are not affected by harbour construction (Bongil, Sawtell) have experienced strong accretion since the 1970s, which may be attributed to wave climate conditions over this time. The data suggests that the response of South Park Beach to the harbour construction has stabilised. This may be in part due to sheltering of this beach from wave effects and recent generally lower wave climate that has promoted accretion at other locations. It may also indicate there has been some bypassing of sediment from the harbour into this beach, enabling the beach to remain stable.

At South Park Beach, the shoreline evolution modelling suggests an initial period of extreme erosion between 1930 and 1950, after which the beach begins to recover slowly. By 2000, the shoreline modelling suggests total recession of South Park Beach of up to 25 m. The modelling results are consistent with the findings from photogrammetric data described above that also suggest South Park Beach may have started to stabilise and recover from the harbour impacts. Without sea level rise, the modelling suggests further recovery (progradation) of up to 10 m in beach width on South Park Beach by 2100.

Ongoing recession is clearly evident in the Park Beach photogrammetry, with typically 20 – 30 m recession between the most accreted (~ 1969) and most eroded (~ 2000) states. The cross sections illustrate the removal of the entire incipient foredune then scarping into the hind dune face particularly towards the northern end of the beach (for example, Figure 4-10).

Small amounts of sand nourishment have been undertaken from time to time which will have assisted to reduce the rate of recession at Park Beach. Between 1988 and 1998, 116,000 m^3 of sand was placed upon Park Beach (in the location of the SLSC northwards for ~ 500 m), based on data from RDM (1998a). Since 1998, dredge spoil from the harbour has been periodically placed either at the SLSC or in the surf zone around 400 m north of Muttonbird Island opposite Park Beach (pers. comm., Robert Kasmarik, DECCW, 2009), although volumes are not known.

Recession of 0.9 m/yr was calculated for Park Beach, based upon total beach volumes over time. It is assumed that the effect of sand nourishment events upon the sub-aerial beach volume is included in this calculation. Based upon the nourishment data above for 1988 to 1998, if it is assumed that nourishment accounts for ~ 16,000 m^3/yr of the sub-aerial volume from 1988 to 2007, without this nourishment the rate of recession is 1 m/yr on average across Park Beach. The recession values equate to 30 – 40 m of recession since 1969.

The beach volume data and cross sections illustrate that the rate of recession has slowed since 1990, to an average of 0.7 m/yr. This may in part be due to wave climatic conditions, which have favoured beach accretion over this time. It may also suggest the beginning of recovery at Park Beach.

The shoreline modelling results indicate up to 100 m of recession between 1930 and 2000 on Park Beach. The modelling suggests the rate of recession slows to 2000, after which the beach begins to stabilise then accrete slowly, as bypassing of the harbour commences. The modelling results are fairly consistent with the photogrammetric cross sections and recession rates described above. Without sea level rise, the model results suggest that Park Beach would continue to recover, with up to 35 m progradation at the southern end and 10 m at the northern end of the beach by 2100.

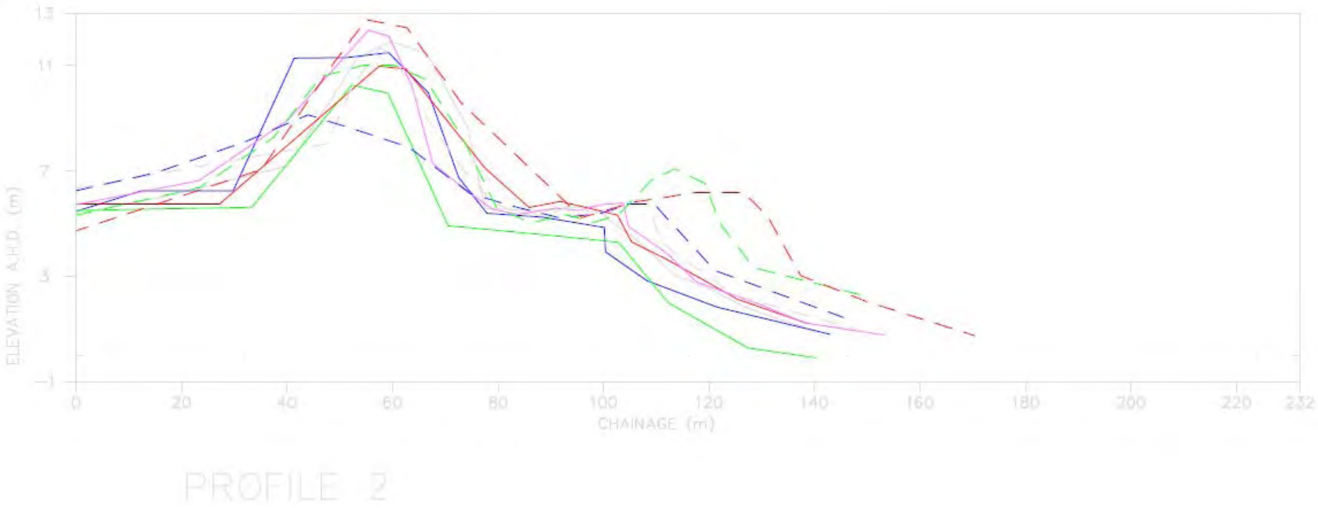


Figure 4-10 Profile 2 Block 5N, Northern end of Park Beach*

**Legend: Red dashed line – 1942, Green dashed line – 1969, Blue dashed line – 1975, Grey dashed line – 1977, Pink – 1986, Red – 1989, Green – 1994, Blue – 1996, Grey – 2000 (2007 line not available on diagram).*

Future Long Term Recession

The model results for predicted sea level rise demonstrate that, in addition to the expected recession, the sea level rise acts to re-initiate the harbour impact. The Coffs coastline to some degree will have started to reach an equilibrium to the harbour construction by 2000. Most notably, bypassing enables beaches closest to the harbour to stabilise and recover first, however, there is still a deficit in sediment demand, hence the harbour impact migrates north, resulting in recession at beaches further north such as Sapphire and Moonee.

When sea levels rise however, the beaches either side of the harbour become further embayed and this again limits the potential for sediment transport around the harbour. The sea level rise constricts accretion upon Boambee Beach as it responds to the sea level rise, thus bypassing into the harbour is reduced. In turn, this limits accretion in the harbour and the increasing water depths at the harbour mouth further limit the potential for sediment transport into South Park and Park Beaches (as greater wave heights are required to mobilise the sediment). The result is that recession on South Park and

Park Beaches due to the harbour re-commences, and this is in addition to the recessionary effects of sea level rise. Given the lack of sediment within the beach systems adjacent to the harbour, the migration of the harbour impact to Sapphire, Moonee and beyond will also continue and is added to the recession due to sea level rise.

With sea level rise of 0.9 m by 2100 (0.4 m rise by 2050), the shoreline modelling suggests up to 115 m recession at South Park Beach and the southern end of Park Beach, grading to 50 m recession at the northern end of Park Beach (55 m at the south and 20 m at the north by 2050). As described above, the enhanced recession compared with sea level rise alone is related to re-initiation of interruption of sediment transport by the harbour breakwaters. The effects of sea level rise are greater at the south than the north due to the south easterly wave climate which enables sediment transport from the southern end of the beach to the north, enhancing and reducing erosion at the south and north respectively.

The modelling also demonstrates the complicated effects of sea level rise upon the tombolo and shoreline behind Little Muttonbird Island. In short, the island is further separated from the shoreline, and increasing water depths behind the island enable greater wave attack to the shoreline. In addition, to maintain the tombolo at its current position relative to sea level, further sediment is required to enhance the height of the tombolo, which may be sourced from the shoreline behind.

The model results for the ‘rare’ possibility of 1.4 m sea level rise by 2100 illustrate further recession of up to 180 m on South Park Beach and the southern end of Park Beach grading to 115 m on north Park Beach. The higher sea level rise exacerbates the harbour impact, in addition to the natural recession response from south to north along the beach (under a south east wave climate).

Calculations of longshore transport rates suggest that at South Park and Park Beaches, which are oriented nearly east, there is likely to be only a small reduction in the rate of northerly sediment transport for an easterly (120°) compared with the existing south easterly (135°) wave climate. Thus, a slight reduction in recession at South Park Beach and the southern end of Park Beach (to a total of 105 m recession) has been assumed, along with slightly increased recession of up to 70 m at the northern end of Park Beach because there is slightly less sand transported to the north, for the ‘rare’ case of a permanent shift to an easterly wave climate in combination with the predicted sea level rise.

Beach Erosion

South Park Beach is relatively protected from south easterly waves by the northern breakwater and Muttonbird Island and easterly to northerly waves by Little Muttonbird Island. A seawall located behind the southern end of South Park Beach will have constrained beach erosion under current sea level conditions, and storm erosion will result in lowering of the beach level in front of the seawall.

Park Beach is oriented roughly east, with some protection from south easterly swells afforded by the harbour, Muttonbird Island and Little Muttonbird Island and from easterly swells by Macauleys Headland to the north.

Both South Park and Park Beaches have been affected by recession due to the interruption of littoral transport by the harbour. As such it is not possible to confidently determine a beach erosion hazard from the photogrammetric data. Sawtell Beach is of similar orientation with similar headland controls to South Park and Park Beaches, although it is less protected from storm wave attack. However, Park Beach in particular is in a highly eroded state, making it susceptible to erosion.

Sawtell Beach values have been adopted as the beach erosion hazard at South Park and Park Beach, that is, an ‘almost certain’ probability of 15 m, ‘unlikely’ probability of 50 m and ‘rare’ likelihood of 85 m landward movement of the 4 m AHD contour.

The extent of beach erosion and shoreline recession upon South Park and Park Beach at the immediate, 2050 and 2100 planning horizons is illustrated in the Figures Compendium.

Coastal Inundation

Coastal inundation has the potential to affect areas of land behind Park Beach through the Coffs Creek entrance located behind Little Muttonbird Island. An explanation of the adopted inundation levels (‘almost certain’, ‘unlikely’, ‘rare’) at the immediate, 2050 and 2100 planning periods is given in Section 3.5. Coastal Inundation for the immediate, 2050 and 2100 horizons are mapped for the entire Coffs LGA in the Figures Compendium.

Coastal Entrances

Coffs Creek located at the centre of Park Beach (behind Little Muttonbird Island) typically remains open particularly due to the training wall along one side of the channel. The entrance region is likely to experience significant recession in response to sea level rise (combined with the impact of the harbour construction). It is considered unlikely that this would increase the frequency of entrance closure in the future. Further discussion of the response of entrances to sea level rise is given in Section 3.6.

The climate change projections for future annual rainfall and rainfall intensity are at present inconclusive. Thus, it is not yet possible to determine potential changes to the entrance condition in response to climate change induced changes to rainfall.

In the region of Coffs Creek, the use of the 4 m AHD contour implies that the entire beach berm may be eroded during a [flooding] storm. This is consistent with the photogrammetric data, which illustrates the beach berm to have been significantly eroded in the past. Thus, as noted in Section 3.4.4 the beach erosion hazard includes erosion of the entrance berm as it is measured landward of the berm.

Stormwater Erosion

A stormwater outlet is located at the northern end of Park Beach. Erosion at stormwater outlets and drainage points is largely captured within the beach erosion hazard zones, as discussed in Section 0 (as the hazard extent is measured from landward of the drainage outlet).

Climate change predictions for future rainfall are currently too coarse to confidently estimate local changes in rainfall and runoff and subsequently, to what extent there may be further erosion at outlets / drainage points. However, the approach to defining probability zones for beach erosion has likely captured the potential changes in erosion at drainage points in the future.

Sand Drift

Windborne sediment transport allows for the growth and stability of dunes throughout the Coffs LGA. Windborne sediment transport is not considered to constitute a sand drift hazard in terms of either sediment losses or nuisance to back beach development on South Park or Park Beaches.

Title:

South Park and Park Beach

Figure: **4-11**

Rev: **A**

N

0 250 500m

Approx. Scale

BMT WBM

www.wbmpl.com.au

Filepath : K:\N1440 Coffs Coastal Process Hazard Definition Study\MapInfo\Workspaces\DRG_006_100510 Park Beach.WOR

4.8 Diggers Beach and Diggers Head

Diggers Beach is bounded by Macauleys Headland in the south and Diggers Head in the north, and is shown in Figure 4-13.

The southern part of Diggers Beach extends 800 m to Jordans Creek and faces east, with wave heights decreasing towards the south. The beach transitions from a lower energy low tide terrace morphology in the south to a transverse bar and rip morphology in the north. Permanent rips may be found against the southern headland and the rock outcrop defining the northern end of the southern portion of the beach, and there is typically a beach rip in the centre of the beach (Short, 2007).

The northern portion of the beach between a small rock outcrop and Diggers Head is 300 m in length, and faces east. The predominant south-easterly wave climate has resulted in typically higher waves at this northern end of the beach and the beach exhibits a transverse bar and rip morphology. Permanent rips occur along the northern headland and southern rock outcrop (Short, 2007). This section of beach is accessed by walking along the beach from the south.

Jordans Creek exits to the ocean across the beach immediately south of the small rocky outcrop around the centre of Diggers beach. Diggers Beach is sometimes considered as two beaches due to the minor separation by the small, rocky outcrop at Jordans Creek entrance.

Residential and tourist development including Aanuka Beach Resort is located behind Diggers Beach. The beach has two car parks at its southern end (Short, 2007). Access is also possible from Aanuka Beach Resort by a foot bridge across Jordans Creek and to the beach.

Diggers Head is a high, large outcrop of bedrock, protruding ~ 250 m from the shoreline of Diggers Beach (MHL, 1983). There are some rocks immediately offshore of the headland however, the surrounding sea bed is largely clear of bedrock. The water depth at Diggers Head is relatively shallow (2-3 m, MHL, 1983). Waves of smaller height are thus able mobilise sediment for bypassing at this location, and as shown by Lord and Van Kerkvoort (1981), significant volumes of sediment may be transported under higher (3+ m) wave conditions.

Photogrammetry Data Quality

Mining of Diggers Beach dunes for sand and gravel is well documented (e.g. ERA 1973). The mining lease map (Figure 2-2) indicates potential mining of all photogrammetric blocks except Block 7 (beach north of Jordans Creek). The photogrammetric cross sections demonstrate mining impacts between 1973 and 1977, including complete removal of dunes in some locations. Mining of hinddune regions is also evident between 1964 and 1969. The natural variability of Jordans Creek means it is not possible to discern if mining occurred in this region. The impacts of mining affect the foredune and sub-aerial beach, and so are not able to be avoided in photogrammetry volume calculations. Thus, the data from 1977 to 2007 only was used in the assessment.

Long Term Recession

Beach volume data has been analysed to determine that since 1977, Diggers Beach has been receding at a rate of 1.7 m/yr. Photogrammetric cross sections for 2000 and 2004 exhibit the lowest beach volumes, showing scarping of the foredune face and a lower sub aerial beach. Between 2004 and 2007 the cross sections indicate accretion upon the sub aerial beach face and in front of the foredunes. An example of this is given in Figure 4-12. The northern end of the beach (north of Jordans Creek), has been lowered over time, but landward beach movement is constrained by the bedrock slopes behind the beach.

Shoreline modelling results indicate a rate of recession ~ 8 times lower than the observed recession at Diggers Beach, with only ~ 20 m of shoreline loss since the harbour construction to 2000. Model results suggest that recession will stabilised around 2000 and recovery of Diggers Beach will begin by 2010. Without sea level rise, the modelling results suggest recovery of up to 10 m by 2100 on Diggers Beach.

The modelling appears to under-predict recession due to the harbour impact at Diggers Beach, when compared with the historical data. Even since 1994, the rate of recession along the beach is 1 m/yr. The main reason for this is that, while the model internally refracts incoming waves, the heavily embayed nature of Diggers Beach is not able to be fully replicated by the model. Diggers Beach geomorphology is unusual in the region, and as discussed below, sediment transport processes will be driven by storm bypassing, rather than average conditions at Diggers Beach.

We have noted that wave climate conditions since the late 1970s have favoured beach accretion, particularly at the northern end of longer, south east facing beaches where optimal longshore transport is generated, e.g. Bongil Beach. Diggers Beach is heavily embayed by headlands and is likely to require storm events to initiate sand bypassing around the headlands and supply into the beach (refer Section 2.8.2). The recent wave climate conditions, which are reported to have generally been less stormy than decades prior, may in fact have exacerbated the rate of recession we would have expected due to the harbour. This may account for some of the variance between modelled and historical results.

In utilising the model results to derive a recession due to sea level rise, the variance in modelled to historical results has been used to scale the modelling results at Diggers Beach accordingly. Thus, recession of up to 150 m grading to 110 m from south to north along Diggers Beach has been adopted for predicted sea level rise of 0.9 m by 2100 (with 75 m to 55 m from south to north with a 0.4 m rise by 2050).

The interpretation of modelling results for the ‘rare’ scenario of 1.4 m sea level rise by 2100 on Diggers Beach suggests 210 m to 170 m recession from south to north.

Based upon the comparison of longshore transport rates for easterly and south easterly average wave climates, we would expect a slight reduction at the southern end and slight increase at the northern end in recession on Diggers Beach under predicted sea level rise of 0.9 m by 2100. Diggers Beach faces towards the east, and so there is minor change in the strength of longshore transport towards the rate for easterly compared with south easterly average waves. In addition, longshore transport upon Diggers Beach is driven more by storm events, rather than average conditions.

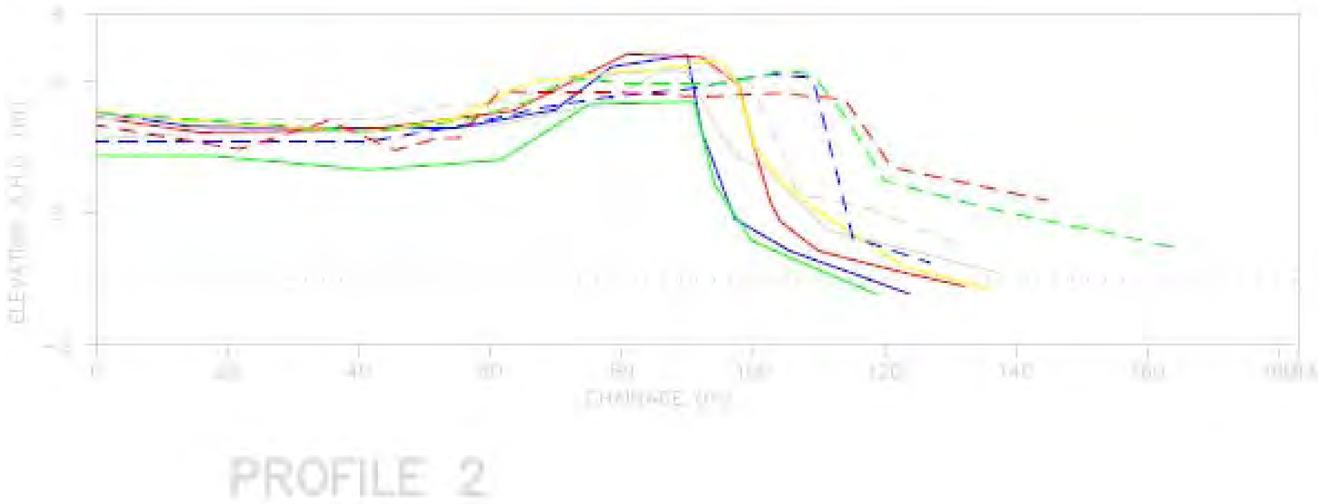


Figure 4-12 Block 4 Profile 2 on Diggers Beach*

**Legend: Red dashed line – 1964, Green dashed line – 1969, Blue dashed line – 1973, Grey dashed line – 1977, Yellow – 1986, Red – 1996, Green – 2000, Blue – 2004, Grey – 2007.*

Beach Erosion

Diggers Beach has been affected by the harbour construction, with ongoing recession of the beach as a result. Thus it is not possible to determine beach erosion values specific to this beach.

Diggers Beach is currently in a receded state (in relation to the harbour construction), with little beach volume to provide protection from a period of enhanced storminess. In fact, the embayment created by Macauleys and Diggers Headlands likely requires storm events to initiate bypassing to supply the beach with sand from the south.

The values for beach erosion from Sawtell Beach have been adopted at Diggers Beach that is, an ‘almost certain’ probability of 15 m, ‘unlikely’ probability of 50 m and ‘rare’ likelihood of 85 m landward movement of the 4 m AHD contour (and 2 m AHD contour at Jordans Creek as explained below). Sawtell is considered suitable as it is oriented toward the east also, although it is noted to be less embayed by headlands from incoming waves.

In the vicinity of Jordans Creek mouth, the photogrammetric data indicates that the entrance berm may be fully eroded during flooding of the creek and storms. Land behind the creek and berm is low lying, typically below 3 m AHD. To ensure the beach erosion hazard is reasonably represented in this location, values have been applied to the 2 m contour on the western bank of the creek. In this manner, the erosion hazard is assumed to erode the entire berm region before cutting into land behind.

The northern end of Diggers Beach (immediately north of Jordans Creek) is backed by steep bedrock cliffs, up to 20 m in height. The photogrammetric data indicates that, due to ongoing recession, the beach has been lowered over time, but has not moved landward due to the constraint of the bedrock. The beach erosion hazard has been applied to the beach but not bedrock region at this end of the beach.

The extent of beach erosion and shoreline recession upon Diggers Beach at the immediate, 2050 and 2100 planning horizons is illustrated in the Figures Compendium.

Coastal Inundation

Coastal inundation has the potential to affect land area behind Diggers Beach through the Jordans Creek entrance at the centre of the beach. An explanation of the adopted inundation levels (‘almost certain’, ‘unlikely’, ‘rare’) at the immediate, 2050 and 2100 planning periods is given in Section 3.5.

Coastal Inundation for the immediate, 2050 and 2100 horizons are mapped for the entire Coffs LGA in the Figures Compendium.

Coastal Entrances

Jordans Creek entrance is located at the northern end of the southern portion of Diggers Beach. . At the present time, the creek remains typically open, although entrance closure is possible in the future. Diggers Beach is likely to experience significant recession in response to sea level rise and the harbour impact in the future. As an additional response to sea level rise, on those occasions when the entrance closes, the height of the entrance berm may increase by an equal amount as the rise in sea level, i.e. 0.4 m by 2050 and 0.9 m by 2100.

Photogrammetric data coverage is insufficient across Jordans Creek, thus an assessment of probable berm heights for the immediate and future planning periods (i.e. with sea level rise) was not possible. Further discussion of the response of entrances to sea level rise is given in Section 3.6.

The climate change projections for future annual rainfall and rainfall intensity are at present inconclusive. Thus, it is not yet possible to determine potential changes to the entrance condition in response to climate change induced changes to rainfall. The photogrammetric data indicates entire removal of the creek entrance berm occurs from time to time due to natural processes (beach erosion, creek outflows). As explained for the beach erosion hazard above (and in Section 3.3), the beach erosion hazard is applied landward of the creek entrance, thus accounting for erosion of the entrance berm.

Stormwater Erosion

Jordans Creek is likely to form the main discharge for stormwater on Diggers Beach. The creek is discussed under the Coastal Entrance hazard.

Sand Drift

Windborne sediment transport allows for the growth and stability of dunes throughout the Coffs LGA. For Diggers Beaches, windborne sediment transport is not considered to constitute a sand drift hazard in terms of either sediment losses or nuisance to back beach development.

Title:

Diggers Beach and Charlesworth Bay

Figure:

4-13

Rev:

A

N

0 125 250m

Approx. Scale

BMT WBM

www.wbmpl.com.au

Filepath : K:\N1440 Coffs Coastal Process Hazard Definition Study\MapInfo\Workspaces\DRG_007_100510 Diggers Beach.WOR

4.9 Charlesworth Bay and Fowlers Head

Charlesworth Bay is a 500 m long, curved, north-east facing beach. It is bounded by Diggers Head at its southern end and **Fowlers Head** at its northern end, as illustrated in Figure 4-13.

Diggers Head extends nearly 1 km from the shoreline at Charlesworth, providing significant protection to this beach (and beaches further north) from the predominant south easterly waves. There are also known to be many reefs and bedrock outcrops on the sea bed around this location, particularly the reef extending from Korora Beach past Fowlers Head, which further dissipate incoming wave energy to this beach. Thus, waves are typically less than 0.5 m and Charlesworth Bay is considered the lowest energy beach in the Coffs region.

Charlesworth Bay exhibits a typical reflective beach morphology in response to the low wave energy and coarse beach sediment. It has a steep upper beach face of coarse sand and cobbles, and a wider bar evident at low tide. A rip may form against the northern headland under higher wave conditions (Short, 2007).

The valley behind the beach is mostly occupied by the Novotel Pacific Bay resort. A road runs to the southern end of the beach. An old boat shed exists at the southern end of the beach.

Photogrammetric Data Quality

The photogrammetric data cross sections do not show evidence of sand mining, although a lease is shown at Charlesworth Bay on the map of sand mining leases (refer Figure 2-2). Thus, all photogrammetric dates were included in the analysis. The photogrammetric cross sections indicate that the back beach area has been filled, likely in relation to landscaping completed as part of the Novotel Resort (located behind the beach). These areas were excluded from the data analysis.

Long Term Recession

In the active beach zone, analysis of beach volumes suggests Charlesworth Bay has been accreting at an average rate of 0.8 m/ yr between 1964 and 2007. The shoreline modelling suggests Charlesworth Bay would have receded by up to 35 m due to impact of the harbour. There are a number of reasons for this discrepancy.

Charlesworth Bay is predominantly composed of gravel sediment, which requires greater wave energy to be transported. The beach experiences low wave energy, protected by Diggers Head to the south and rock reefs in the surf zone to the north. In response to the harbour construction, the gravel sediments are retained upon the beach due to the typically lower wave energy, maintaining beach volume such as evident in photogrammetry), however, fine sediments will likely have been winnowed from the beach. Thus, Charlesworth Bay does not show evidence of ongoing recession.

The shoreline response modelling assumes this beach is composed of sand, however, it accounts for the rock reefs in the surf zone and Diggers Head that act to reduce wave energy at the shoreline. The modelling suggests that recession should have slowed by 2000 then begin to stabilise after this. Without sea level rise, the shoreline model results suggest that Charlesworth Bay would recover by 5 m at 2050 and 10 m at 2100, as harbour bypassing begins to supply beaches to its north.

Future Long Term Recession

As already noted, Charlesworth Bay is protected from incoming wave energy by extensive offshore rock reefs to the north. With sea level rise, the reefs will become more submerged and thus there is less dissipation of wave energy, such as by bottom friction, wave breaking and refraction, resulting in an increase in wave height at the shoreline in lee of the reefs.

The shoreline response modelling for sea level rise of 0.9 m by 2100 suggests up to 40 m recession upon Charlesworth Bay (20 m recession by 2050 with 0.4 m rise in sea level). This is consistent with the historical data described above and the response expected from a gravel, low energy beach.

In the ‘rare’ possibility of 1.4 m sea level rise by 2100, the modelling suggests recession may extend to 65 m on Charlesworth Bay.

This beach is composed of gravel sediments and is protected from waves from the north to south. Thus, no change is expected in the extents of recession in response to the ‘rare’ scenario of a shift to more easterly average waves combined with predicted sea level rise.

Beach Erosion

Charlesworth Bay is close to the most protected beach on the Coffs coast. Storm effects are expected to be far less common at this beach. The beach is also predominantly gravel sediment, requiring much greater wave energy to be transported.

While this beach lies north of the harbour, the coarse sediments and low energy environment have somewhat precluded harbour effects. There are no beaches of similar geomorphology in the region. Thus, the photogrammetric data from Charlesworth has been used to assess its beach erosion hazard.

Charlesworth Bay is backed by relatively high slopes at its southern and northern extents, but at the centre of the beach, the back beach area is typically below 3 m AHD. Analysis of the 4 m AHD contour was not possible, and the gravel sediment has likely precluded the development of dunes at this location. The 2 m AHD contour was found to best delineate the edge of the beach profile at this location, and has been used instead of the 4 m contour.

The movement of the 2 m AHD contour position for eroded photogrammetric profiles relative to the 2007 position suggests an average of 37 m and maximum of 69 m landward movement. Based upon this information, a beach erosion hazard of 40 m, 75 m and 110 m landward movement (of the 2 m AHD contour) has been adopted as the ‘almost certain’, ‘unlikely’ and ‘rare’ probability beach erosion hazard respectively. These values are appropriate to the high natural protection afforded to Charlesworth Bay at the present time.

The extent of beach erosion and shoreline recession on Charlesworth Bay at the immediate, 2050 and 2100 planning horizons is illustrated in the Figures Compendium.

Coastal Inundation

A small drainage line exiting onto Charlesworth Bay’s shoreline connects to lagoons behind the beach, however inundation of back beach areas appears to only occur under the ‘unlikely’ and ‘rare’ scenarios at 2050 and 2100. An explanation of the adopted inundation levels (‘almost certain’, ‘unlikely’, ‘rare’) at the immediate, 2050 and 2100 planning periods is given in Section 3.5.

Coastal Inundation for the immediate, 2050 and 2100 horizons are mapped for the entire Coffs LGA in the Figures Compendium.

Coastal Entrances

There is a stormwater outlet point but no significant coastal entrance upon Charlesworth Bay.

Stormwater Erosion

A stormwater outlet pipe with rock protection is located at the northern end of Charlesworth Bay and appears to be linked with the lagoon system in the [Novotel] development behind the beach.

As noted in Section 0, erosion at this location is largely included within the beach erosion hazard zones (as the hazard extent is measured from landward of the drainage outlet).

Climate change predictions for future rainfall are not currently detailed enough to confidently determine further erosion due to changes in rainfall runoff. However, it is likely that potential changes in erosion at drainage points has been captured within the probability zones for the beach erosion and shoreline recession hazards for future time horizons.

Sand Drift

Windborne sediment transport allows for the growth and stability of dunes throughout the Coffs LGA. However, Charlesworth Bay is largely composed of gravel and very coarse sand, little dune growth has occurred and we would not expect sand drift hazards arising from windborne transport.

4.10 Korora, Hills, Campbells, Pelican and Riecks Point Beaches to White Bluff

Korora Beach extends for 650 m between Fowlers Head to an unnamed reef and minor headland outcrop. **Hills Beach** extends from this outcrop to another small unnamed headland approximately 600 m further north, adjacent to Pine Brush Creek. **Campbells Beach** extends for 800 m from this headland to “Middle” Headland in the north. **Pelican Beach** runs for 750 m from this headland to a tombolo from behind Riecks Point Reef. North of this tombolo extending 450 m to White Bluff is **Riecks Point Beach** (BMT WBM, 2008). The beaches are illustrated in Figure 4-16.

All of these beaches are classified as reflective beaches (Short, 2007). The beaches are composed of medium to coarse grained sand, rounded gravels and cobbles, comprising both shell and rock fragments. The coarser gravels/cobbles are deposited more thickly on the high tide (upper) beach face by surging breakers and swash processes. All of the beaches exhibit a narrow beach face and beach berm.

Typical of reflective beach morphology, the beaches experience plunging waves breaking close to the shore at low tide and surging breakers onto the upper beach face at high tide. Such wave breaking conditions are dangerous to swimmers and are unsuitable for surfing, as the waves plunge in a heavy shore break. In typical low wave conditions, the beaches have one sand bar attached to shore.

During high wave conditions, the bar may migrate offshore (via cross-shore sediment transport), providing greater wave dissipation. The sand bar will migrate shoreward and attach to the shoreline via onshore sediment transport driven by the regular swell waves after the storm.

Rip currents, which provide the offshore component of surfzone circulation, will form adjacent to the headlands and rock reefs along this coastline under moderate to high wave conditions. Rip currents erode the shoreline behind the current to form a scarp, as observed at Campbells Beach.

Behind this compartment of beaches, the coastal ranges are noted to be close to the shore, making for narrow back barrier deposits behind these beaches. The beaches are composed of quaternary deposits, and there are thought to be no remnant Pleistocene deposits remaining in the small embayments.

The compartment from Korora to Riecks Point beaches is oriented towards the predominant south easterly swell. The protrusion of Diggers Head to the south affords a large measure of protection to the beaches between this head and White Bluff. A number of reefs in the nearshore zone also assist in dissipating and refracting incoming wave energy.

Riecks Point Reef is the largest reef in the compartment, and extends from ~ 650 m offshore towards the shore in a north east direction. A salient has formed between the reef and shore, separating Pelican and Riecks Point Beaches.

Another large reef formation extends from 700 m offshore of the southern end of Korora Beach toward the shore in a north east direction. A tombolo has formed between the reef and shore, separating Hills and Korora Beaches. Campbells Beach has a number of smaller rock reefs in the nearshore zone immediately offshore of the beach. All of these reefs modify incoming waves, through refraction and dissipation.

Pine Brush Lagoon is located at the northern end of Hills Beach, and is typically closed to the ocean. Another small unnamed creek is located at the southern end of Hills Beach. A small creek locally known as **South Creek** lies at the centre of Campbells Beach, and is usually closed to the ocean. **Hayes Creek** exits to the ocean around the centre of Pelican Beach and is also typically closed.

Photogrammetry Data Quality

The mining lease map suggests mining on the northern half of Hills Beach only in this compartment. At Hills Beach however, there is limited historical data with only one date (1964) prior to 1996. Review of the photogrammetry cross sections did not suggest mining at Hills Beach. Thus all available data at all beaches has been used in this assessment.

Long Term Recession

Korora Beach shows clear evidence of ongoing recession, with significant and ongoing scarping of the foredunes evident both during the site inspection and in photogrammetry cross sections, (e.g. Figure 4-14). Based upon the photogrammetric beach volume data, Korora has been receding at a rate of 0.4 m/yr since 1943.

The shoreline modelling predicts recession of 28 m by 2000 with ongoing recession to 2020 (ignoring sea level rise). The extent of recession given in the modelling is consistent with that given in the photogrammetric data (of ~ 25 m). Without sea level rise, the modelling suggests the beach would stabilise and accrete up to 5 m by 2100.

Recession or accretion is not easy to determine at Hills Beach due to a lack of sufficient photogrammetric data. When the 1964 data is included in the assessment, the data suggests Hills Beach is accreting at a rate of 0.8 m/yr. Excluding the data from 1964, the remaining data from 1996 to 2007 suggests Hills Beach is receding at 0.3 m/yr. In the photogrammetric cross sections it is evident that there has been oscillation of the beach width over 1996 to 2007, rather than a discrete trend of recession or accretion. During the site inspection, Hills Beach did not exhibit the extent of recession that was clearly evident on nearby beaches such as Korora. Hills Beach is likely to have been afforded some protection by rock reefs to the south (e.g. offshore of Korora Beach) that dissipate and refract incoming wave energy. It is concluded that in recent years at least, Hills Beach has remained stable.

The shoreline modelling indicates Hills Beach to have receded 15 m by 2000, which is equivalent to ~ 0.2 m/yr of recession. The recession rate obtained from the shoreline modelling is a good representation of measured rates of recession on Hills Beach over recent years. The modelling suggests that, without sea level rise, the beach will have stabilised by 2020, after which the beach may recover by up to 5 m by 2100.

Photogrammetric data is only available from 1973 onwards at Campbells to Riecks Point Beaches. Figures illustrating photogrammetry cross sections are available for 1942, but data from which to calculate beach volumes is not. We have discussed the trends from the 1942 figures, then the beach volumetric data from 1973 to 2007 below.

Examination of the cross section figures indicate Campbells, Pelican and Riecks Point Beaches experienced recession between 1942 and 1973, with cut back into the foredunes leaving a scarped foredune shape and 20 - 30 m recession. At the small headland protrusions which separate the three beaches there was also recession with the removal of small incipient dunes then lowering of the beach level over time in front of the headlands.

Since the 1970s, the profile cross sections indicate that the foredune scarp has oscillated around a similar position on Campbells Beach. There has been some recovery of the beach to 2007 since the lowest profile occurred, in 1993 at the southern end and 1996 at the northern end of the beach. An example profile cross section is given in Figure 4-15.

Based on calculations with beach volume data from 1973 to 2007, the average rate is ~0.1 m/yr accretion. Rates at Campbells, Pelican and Riecks are 0.4 m/yr accretion, 0.1 m/yr accretion and 0.1 m/yr recession, respectively. The photogrammetric data suggests the beaches have remained relatively stable, that is, no long term recession or accretion since the late 1970s to present.

Shoreline modelling results gave 22 m recession at the southern end of Campbells Beach to 33 m on Pelican Beach immediately south of Riecks Point Reef, and 10 to 16 m recession along Riecks Point Beach north of the reef. The shoreline modelling outputs for recession match the extents observed between the 1940s and 1970s on this shoreline (~ 20 – 30 m). However, the modelling suggests recession would have continued slowly to the present. It is possible that beach volumes appear to have remained stable, but that fine sand has been winnowed from the beach, leaving coarser sand and gravel that retains the volume observed.

Given the complexity of this length of shoreline due to extensive offshore reefs, it is not possible to reliably comment upon the likely response to wave climate conditions since the 1970s, which have favoured beach accretion at a number of Coffs Beaches of similar orientation. However, the stability of Hills to Riecks Beaches particularly over recent years (oscillating in beach width around a similar point) suggests it is possible that wave climate conditions has assisted the observed stability.

Without sea level rise, the modelling predicts recession would continue to 2050 (~a further 5 m), with the impact greatest at the central portion of this shoreline (around Pelican Beach) and less recession at the ends of this shoreline section. After 2050, the modelling suggests the beach may recover to a similar position at present by 2100, without sea level rise.

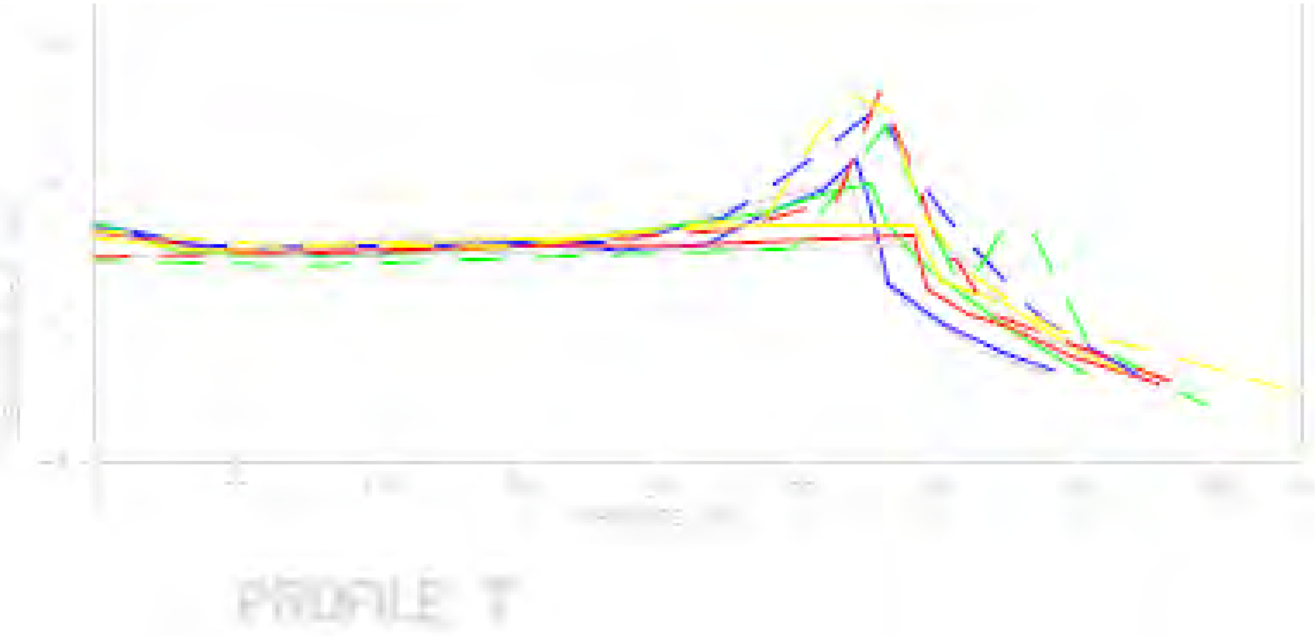


Figure 4-14 Profile 7 on Korora Beach*

**Legend: Yellow dashed line – 1943, Red dashed line – 1964, Green dashed line – 1973, Blue dashed line – 1981, Grey dashed line – 1986, Yellow – 1989, Red – 1996, Green – 2000, Blue – 2004, Grey – 2007.*

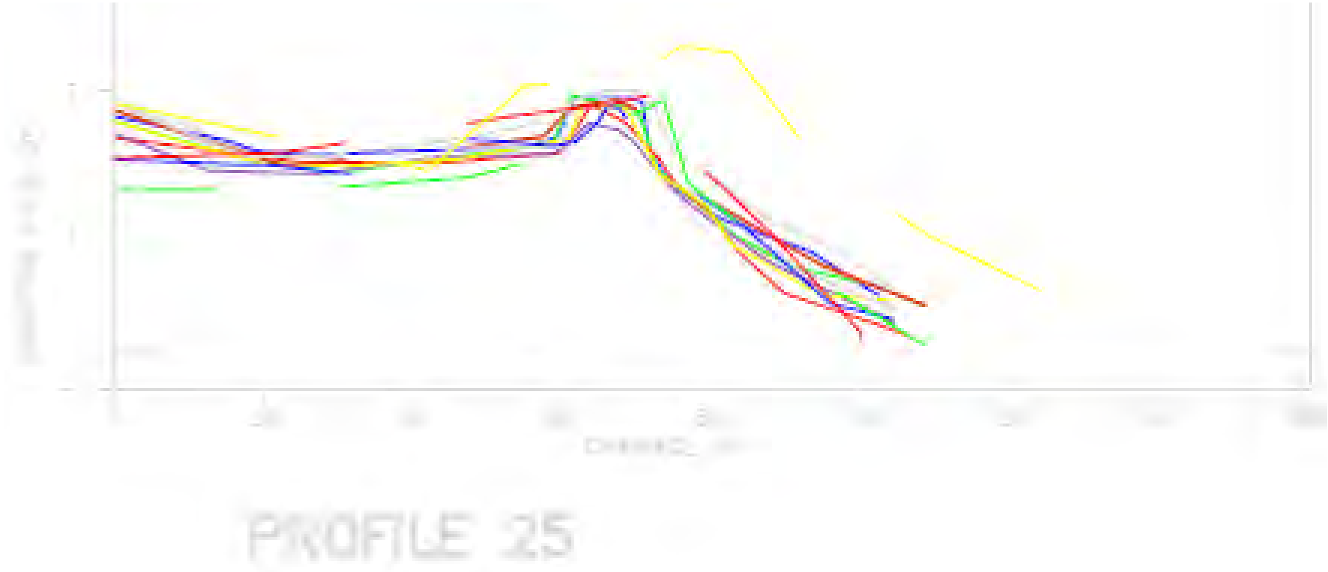


Figure 4-15 Block 1 Profile 25, Northern End of Campbells Beach**

**Legend: Yellow dashed line – 1942, Red dashed line – 1964, Green dashed line – 1973, Blue dashed line – 1978, Grey dashed line – 1980, Dark Red – 1986, Yellow – 1988, Purple - 1993, Bright Red – 1996, Green – 2000, Blue – 2004, Grey – 2007.*

Future Long Term Recession

The consistency of model outputs with historical data indicates shoreline modelling results for sea level rise may be reliably adopted at Korora to Riecks Point Beaches.

Shoreline model output predicts 35 m to 70 m recession from south to north on Korora Beach. The impact is modelled to be greater at the north than the south, which is opposite to that found in other beaches in the region. This is due to the complex reef systems offshore of the beach, which currently protect the northern end in particular from south easterly waves. Sea level rise will allow for increased wave energy at the shoreline as the refraction and dissipation of waves across the reef is reduced.

At Hills Beach, the shoreline modelling results have been used to derive recession of 65 m to 45 m from south to north in response to predicted sea level rise of 0.9 m by 2100.

For predicted sea level rise of 0.9 m by 2100 the model suggests 30 m to 75 m recession from south to north along Campbells Beach. At Pelican Beach the model suggests up to 95 m recession, but behind Riecks Point Reef the model predicts 120 m of recession by 2100. The northern end of Riecks Point Beach may erode up to 70 m with sea level rise to 2100. As observed at Korora, offshore reefs near Campbells are likely to have affected wave refraction and dissipation, sediment transport and therefore the extents of recession due to sea level rise. Particularly in the lee of Riecks Point Reef, the shoreline is currently accreted, forming a salient behind the reef. However, as the reef becomes submerged with sea level rise, wave dissipation is reduced, resulting in erosion of the salient and shoreline behind the reef.

The model results for the 'rare' probability of a 1.4 m sea level rise by 2100 suggest from 50 to 105 m recession from south to north on Korora Beach. On Hills Beach, for the 'rare' scenario of 1.4 m rise by 2100, recession of 80 to 85 m is predicted by the model results. For Campbells, the rare scenario is predicted to result in recession of 95 to 105 m from south to north. At Pelican and Riecks Point Beaches in lee of the reef, recession of 205 m to 155 m adjacent to White Bluff is predicted by the model.

The higher rise in sea level further submerges offshore reefs, resulting in greater wave heights and enhanced recession at the shoreline in lee of the reefs (i.e. the northern ends of Korora, Campbells and behind Riecks Point Reef).

For a ‘rare’ possibility of a permanent shift to a more easterly wave climate, the orientation of the Korora to White Bluff shoreline relative to the incoming wave direction suggests there would be weaker northerly longshore transport compared with the existing south easterly wave climate. Easterly waves may arrive more perpendicular to the shoreline and so recession extents are likely to be more uniform along the shoreline, compared with the existing south easterly wave climate. It is acknowledged that the use of the CERC equation at this location does not account for the complex nature of wave transformation across the numerous offshore reefs in this region. The longshore transport calculations are used as a guide to potential changes in transport rates.

On Korora and Hills Beach, the ‘rare’ probability of a more easterly wave climate combined with predicted sea level rise is assumed to result in a more uniform recession along the beach, of 50 to 55 m and 55 to 60 m from south to north along the beaches, respectively.

Around features such as Riecks Point Reef under a more easterly wave climate it can be assumed that recession would be enhanced on the southern boundary of the reef (Pelican Beach) and reduced at the northern side (Riecks Point Beach), producing a more even result along the shoreline behind. This outcome is reflected in adopted recession rates of 90 to 100 m along the Pelican to Riecks shoreline, and slightly enhanced recession at the northern end of Campbells Beach, for the ‘rare’ scenario of a more easterly wave climate and sea level rise.

Beach Erosion

All of the beaches from Korora to Riecks Point Reef have experienced recession in response to the harbour construction. Therefore, it is not possible to assess the photogrammetric data to determine beach erosion extents.

Campbells to Riecks Point Beaches were the subject of a comparison of beach volumes with storm severity data (BMT WBM, 2008). The comparison suggested an increase in beach volume during years of greater storminess. Such results are counter-intuitive and highlight the complexity of this section of coastline.

The beach erosion rates from Sawtell Beach have been adopted for the beaches. Although this section of shoreline is complicated by reefs and experiences lower wave energy than at Sawtell, the beaches are already in an eroded state and are susceptible to damaging erosion should a period of enhanced storminess recur. With sea level rise the protection afforded by the rock reefs is likely to be reduced and the beaches may experience greater wave energy in the future, increasing the likelihood for erosion.

For Korora to Riecks Point Beaches, an ‘almost certain’ probability of 15 m, ‘unlikely’ probability of 50 m and ‘rare’ probability of 85 m landward movement of the profile has been adopted for the beach erosion hazard in the immediate timeframe. For the 2050 and 2100 timeframes, the ‘almost certain’, ‘unlikely’ and ‘rare’ erosion extents are added to the long term recession values at these timeframes, in the manner described in Section 3.4.4.

The extent of beach erosion and shoreline recession on Korora, Hills, Campbells, Pelican and Riecks Point Beaches at the immediate, 2050 and 2100 planning horizons is illustrated in the Figures Compendium.

Coastal Inundation

There are a number of creeks and lagoons along this section of coastline however, inundation of back beach areas is quite limited, likely due to the steeply backing slopes behind this section of shoreline. The largest inundation extent is within Pine Brush Lagoon, but does not affect property. Coastal inundation remains relatively minor by 2100.

An explanation of the adopted inundation levels (‘almost certain’, ‘unlikely’, ‘rare’) at the immediate, 2050 and 2100 planning periods is given in Section 3.5. Coastal Inundation for the immediate, 2050 and 2100 horizons are mapped for the entire Coffs LGA in the Figures Compendium.

Coastal Entrances

There are two coastal entrances on Hills Beach, an unnamed creek at the southern end and Pine Brush Lagoon at the northern end. Campbells Beach has a coastal entrance, locally named South Creek, located at the centre of the beach. Hayes Creek exits across the centre of Pelican Beach. All of these entrances are typically closed.

The regions around these entrances are likely to experience significant recession in response to sea level rise, combined with the impact of the harbour construction. In addition, the heights of the entrance berms are likely to increase by an equal amount as the rise in sea level, i.e. 0.4 m by 2050 and 0.9 m by 2100.

Sufficient photogrammetric data was only available for Hayes Creek. The assessment determined the present berm height to reach 2.4 m AHD on average, and a maximum of 3.2 m AHD. The extreme scenario adopted for all coastal lagoons is 3.5 m AHD, and relates to the potential height of incipient dunes should an entrance remain closed over a longer period (decades). The ‘almost certain’, ‘unlikely’ and ‘rare’ probability berm heights for Pine Brush Creek for the immediate, 2050 and 2100 timeframe are given in Table 3-8.

For the remaining lagoons, assessment of probable berm heights for the immediate and future planning periods (i.e. with sea level rise) was not possible. Further discussion of the response of entrances to sea level rise and derivation of the probable berm heights is given in Section 3.6.

The climate change projections for future annual rainfall and rainfall intensity are at present inconclusive. Thus, it is not yet possible to determine potential changes to the entrance condition in response to climate change induced changes to rainfall.

Erosion of coastal entrance berms (and immediately adjacent regions) is included within the beach erosion and shoreline recession hazard for all planning periods. As noted in Section 3.3, the beach erosion extent is measured landward of all coastal entrance berms. This is because the photogrammetric data at all entrances in the Coffs region demonstrates that erosion of the entire berm occurs consistently in the past.

Stormwater Erosion

On Korora Beach, a drainage creek is located at the northern end of the beach, while on Campbells beach a stormwater pipe is located at the southern end of the beach (in addition to the creek system at the centre of the beach). There also appears to be a small drainage line behind Riecks Point Reef at Riecks Point Beach.

Stormwater outflow at Hills Beach will be captured within one of the two creeks located at each end of the beach (including Pine Brush Creek) and on Pelican Beach, Hayes Creek likely carries stormwater outflow. These creeks and lagoons are discussed in the Coastal Entrance Hazard.

Erosion at the small drainage points and stormwater outlets is largely captured within the beach erosion hazard, as outlined in Section 0 (as the hazard extent is measured from landward of the drainage outlet).

Climate change predictions for future rainfall are currently too coarse to confidently estimate local changes in rainfall and runoff and subsequently, to what extent there may be further erosion at outlets / drainage points. However, the approach to defining probability zones for beach erosion has likely captured the potential changes in erosion at drainage points in the future.

Sand Drift

Windborne sediment transport allows for the growth and stability of dunes throughout the Coffs LGA. Korora, Hills, Campbells, Pelican and Riecks Point Beaches are not considered to experience sand drift hazards, particularly because sediments upon these beaches are coarser and less mobile under windborne sediment transport.

Title:

Korora, Hills, Campbells, Pelican and Riecks Point Beaches

Figure:

4-16

Rev:

A

N

0 375 750m

Approx. Scale

BMT WBM

www.wbmpl.com.au

Filepath : K:\N1440 Coffs Coastal Process Hazard Definition Study\MapInfo\Workspaces\DRG_008_100510 Fowlers Head to White Bluff.WOR

4.11 White Bluff and Sapphire Beach

White Bluff forms the southern headland of Sapphire Beach. The bluff is ~ 30 m above sea level, with sheer cliffs falling to the beach (MHL, 1983). The headland consists of bedrock outcrops which form a short projection into the surf zone, with shallow water depths adjacent. There is extensive bedrock immediately offshore of the Bluff including Lobster Rocks, an outcrop of bedrock ~ 130 m offshore (MHL, 1983).

Sapphire Beach is 2.3 km in length extending from White Bluff to Green Bluff, as shown in Figure 4-17. The beach faces south east. Split Solitary Island is located 2.5 km offshore of White Bluff, and is said to provide some protection from swells to Sapphire Beach. The beach has a double barred system, of transverse bar rip morphology for the inner bar and rhythmic bar and beach for the outer bar. Up to 10 rips may cross the inner bar, which increase in strength when the outer bar attaches to the inner bar (Short, 2007).

Photogrammetry Data Quality

In the photogrammetric cross sections, the data from 1943 appears to be incorrect for the majority of profiles in Blocks 1 and 2. The data appears more sensible for Block 3, but for consistency the 1943 data has not been used in the assessment of beach volumes / widths.

Sapphire Beach was mined, as shown by the sand mining lease map in Figure 2-2. The profile cross sections indicate mining occurred mainly in the hind dune region, and so the impacts of mining have been excluded from the beach volume calculations. There is some evidence of mining of dunes between 1969 and 1973 at a few of the profiles. At other profiles, the 1969 and 1973 data is consistent with natural changes, such as evident at other dates. These dates have been included in the assessment.

Long Term Recession

The 1943 data is not included in the calculation of beach volumes / widths, however the 1943 profile cross sections suggest the loss of foredunes between 1943 and 1964. This may be due to mining or the harbour impact however, it is not possible to discern from the available data. The profiles suggest the beach has oscillated around a similar position since 1964. Calculations from beach volumes and from the position of the 4 m AHD contour both suggest the beach has been accreting at 0.2 m/yr since 1964.

The profile cross sections illustrate the growth of incipient dunes (in front of the foredune) from 1996 to 2007 to a height of 2 – 3 m. Recent growth of incipient dunes is likely to be a response to wave climate conditions since the late 1970s, which has been noted on other beaches south of the harbour to have allowed for a period of general beach accretion.

The shoreline modelling suggests recession of the shoreline of 20 to 120 m from south to north along Sapphire Beach by 2000, with ongoing recession (at a slow rate) after this (i.e. without sea level rise). Recession would have been initiated later than observed at beaches to the south, as the sediment supplies are eroded from beaches closer to the harbour first then the impact migrating northwards over time.

The modelled pattern and extents of recession are slightly in contrast with the photogrammetry, which suggests the beach has remained relatively stable since the 1960s. The discrepancy is likely to be related in part to wave refraction across this section of coastline, which is very complex due to numerous rock reefs, particularly offshore of White Bluff and out to Split Solitary Island. Reefs are represented in the model however, due to a lack of adequate hydrosurvey data, may not be replicated exactly. The discrepancy is also likely in part to relate to the recent decades of wave climate that have favoured beach accretion, particularly on beaches such as Sapphire Beach that are longer, oriented more south east and composed of fine grained sands.

Future Long Term Recession

Accounting for the slight discrepancy between modelled results and historical data, it is appropriate to adopt the model results for sea level rise scenarios at Sapphire Beach. Modelling of 0.9 m sea level rise by 2100 indicates recession of 110 m grading to 70 m from south to north along the beach.

For the ‘rare’ case of 1.4 m sea level rise by 2100, the model results indicate from 105 m to 160 m from south to north along the beach. The recession at the southern end is likely to be reduced by supply from the shoreline at Riecks Point Reef, while recession at the northern end may be enhanced in relation to offshore reefs in the surfzone. Harbour impacts also manifest within the observed recession extents at Sapphire Beach.

Longshore transport rates for easterly compared with south easterly waves have been calculated, to provide insight into likely changes on a south east facing beach such as Sapphire. There is a notable reduction in northerly transport under a more easterly wave climate. With reduced northerly transport, recession is expected to be enhanced at the northern end and reduced at the southern end. At Sapphire Beach the increase and decrease at north and south would result in a roughly uniform recession of 80 to 90 m along the beach, for the ‘rare’ case of a permanent shift to a more easterly wave climate and sea level rise of 0.9 m by 2100.

Beach Erosion

At the southern end of the beach, the most eroded profile occurs in 1996, with evidence of an erosion scarp into the foredune face. At the northern end, the 1996 profile is one of the most accreted beach positions. This is good evidence of a ‘rotation’ of the beach, whereby one end of the beach is impacted to a greater extent from the storm waves and the sediment eroded is transported towards the opposing end of the beach via longshore transport. The 1964 profile is evident as the most eroded beach profile towards the northern end of the beach.

Based upon the shoreline modelling results, there is possibly a minor impact from the harbour construction on Sapphire Beach. The beach erosion values from Sawtell have thus been conservatively applied at Sapphire Beach. The beaches are similarly oriented and of similar length, both with reef platforms at their southern ends. As a comparison with Sawtell, analysis of the movement of the 4 m contour for the most eroded profile compared with 2007 beach profile position was conducted. The results were an average of 15 m movement and maximum of 33 m landward movement of the 4 m AHD contour. The Sapphire erosion values are reasonably consistent with that of Sawtell.

Hence, for beach erosion, an ‘almost certain’ 15 m, ‘unlikely’ 50 m and ‘rare’ 85 m probable movement of the 4 m AHD contour has been adopted at Sapphire Beach for the Immediate planning horizon. For the 2050 and 2100 timeframes, the ‘almost certain’, ‘unlikely’ and ‘rare’ erosion extents are added to the long term recession values at these timeframes, in the manner described in Section 3.4.4. The extent of beach erosion and shoreline recession on Sapphire Beach at the immediate, 2050 and 2100 planning horizons is illustrated in the Figures Compendium.

Coastal Inundation

There are no creek outlets on Sapphire Beach. The coastal inundation maps illustrate inundation of back beach area at the northern to central region of Sapphire Beach, as they are connected with (drained by) Moonee Creek, to the north. By 2100, ‘unlikely’ and ‘rare’ impacts may extend to the southern back beach areas of Sapphire.

An explanation of the adopted inundation levels (‘almost certain’, ‘unlikely’, ‘rare’) at the immediate, 2050 and 2100 planning periods is given in Section 3.5. Coastal Inundation for the immediate, 2050 and 2100 horizons are mapped for the entire Coffs LGA in the Figures Compendium.

Coastal Entrances

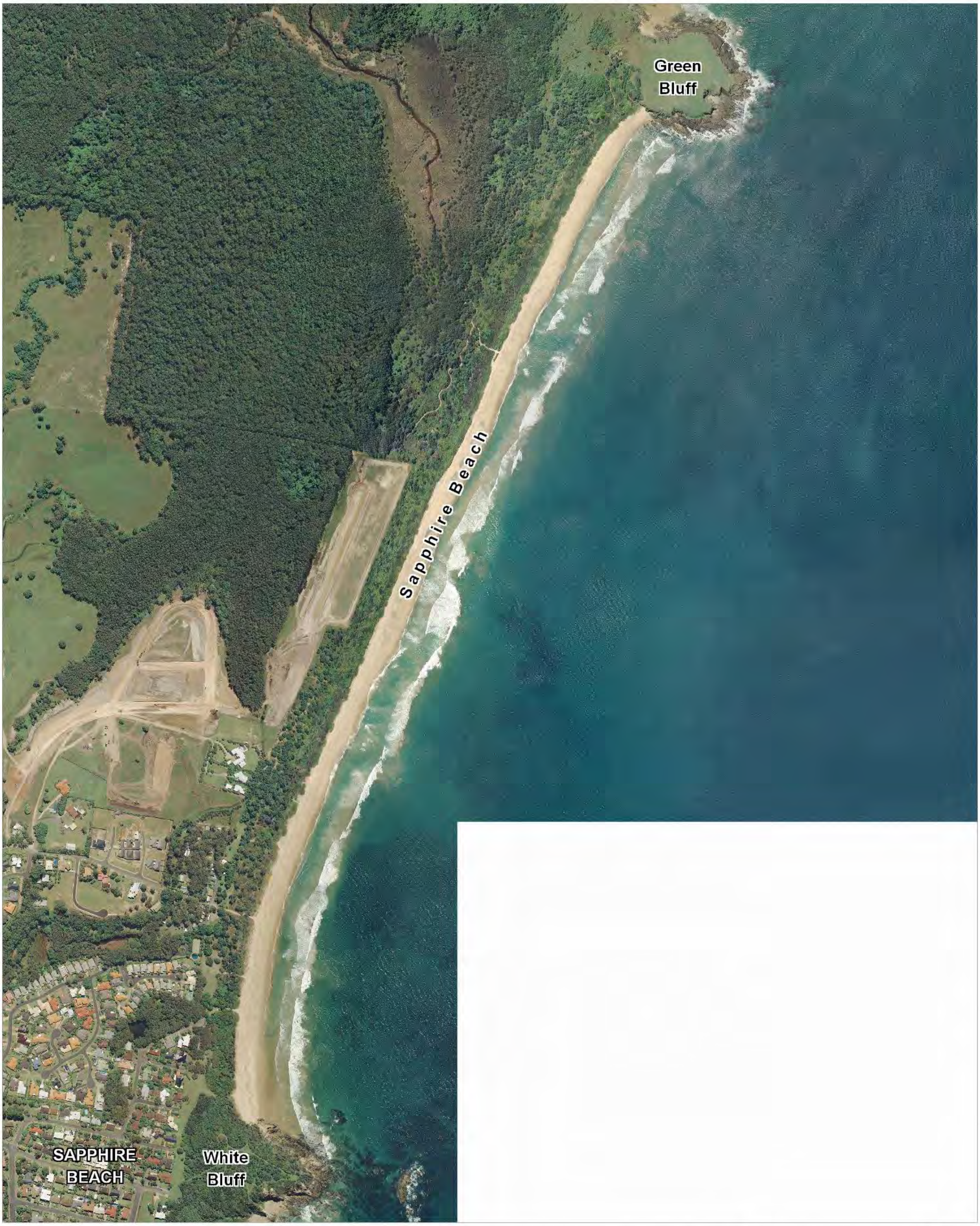
There are no coastal entrances on Sapphire Beach.

Stormwater Erosion

There does not appear to be any significant drainage points onto Sapphire Beach. This is likely due to the high dunes backing the beach (up to ~ 12 m in height).

Sand Drift

Windborne sediment transport allows for the growth and stability of dunes throughout the Coffs LGA. Sapphire Beach is considered to have a low risk of sand drift hazards from windborne sediment transport, in terms of either sediment losses or nuisance to back beach development, as the beach has high typically well vegetated dunes that would capture windblown transport.



Title:

Sapphire Beach

Figure:

4-17

Rev:

A

BMT WBM

www.wbmpl.com.au

Filepath : K:\N1440 Coffs Coastal Process Hazard Definition Study\MapInfo\Workspaces\DRG_009_100510 Sapphire Beach.WOR

4.12 Green Bluff and Moonee Beach

Green Bluff is a 200 m wide headland which projects 150 m seaward of the line of adjacent beaches (Moonee, Sapphire). Its highest point is ~ 20 m above sea level. The lower edge of Green Bluff headland consists of steep rocky slopes and gullies (Laurie, Montgomerie & Pettit,1983).

Water depths are shallow immediately offshore of Green Bluff, meaning that ocean waves and swell are an important influence on currents (and hence, sediment transport) (MHL,1983). Waves of Hs > 1 m will break in shallow water offshore of the headland.

Moonee Beach is one of the longer stretches of beach in the Coffs area, running 4.6 km between Green Bluff and Look At Me Now Headland, illustrated in Figure 4-20. The beach is backed by Moonee Beach Nature Reserve, which has state significant habitat value. The beach experiences the full prevailing wave climate, facing south east. The beach displays a well developed double barred system for its full length. The inner bar typically has numerous rips (up to 16), with rips more widely spaced across the outer bar due to the higher wave energy. The inner bar is noted as a transverse bar and rip, and the outer bar a rhythmic bar and beach morphology (Short, 2007).

Moonee Creek exits to the ocean at the southern end (along the northern side of Green Bluff). The Creek is open to the ocean, assisted by a shallow rock shelf under the entrance channel, which keeps tidal velocities high enough to prevent sand accumulation (Laurie, Montgomerie & Pettit, 1983; Binnie & Partners, 1987). At high tide, access to Moonee Beach is typically cut off by the Moonee Creek entrance. There is also a minor, steeply sided drainage channel at the northern end of the beach (from Look at Me Now Headland), east of Lighthouse Crescent (John Allen & Associates, 1990).

Moonee Creek is one of the larger creek systems in the Coffs region, with its entrance located at the southern end of Moonee Beach adjacent to Green Bluff.

Photogrammetry Data Quality

The mining lease map indicates that sand mining occurred at Moonee Beach in the past (refer Figure 2-2). This is confirmed in the photogrammetry, with profile cross sections showing clear evidence of removal of entire dunes and hind dunes between 1964 and 1973 that can be attributed to sand mining. The southern profiles do not show evidence of mining (and this is consistent with the mining map). However, the older dates of photogrammetry appear to be less precise than more recent dates. For this reason, the 1956 and 1964 data has been excluded from the assessment of beach volumes / width.

Long Term Recession

The average rate of recession calculated from the movement of the 4 m AHD contour and from the beach volume data indicate Moonee Beach has been accreting at 0.3 to 0.4 m/yr since 1973. The southern end of the beach is in fact receding at 0.2 m/yr, grading to accretion of 1.2 – 1.7 m/yr at the northern end of the beach.

Examination of the photogrammetric profiles indicates that the foredune scarp (formed by a beach erosion event) has remained in a similar position since around 1974. There has been growth of incipient dunes in front of the 1974 foredune scarp particularly since the 1990s along the northern end of the beach, such as evident in Figure 4-19. At the southern end of the beach, the 2000 foredune scarp is landward of the 1974 scarp (with the beach remaining unaffected at the northern end in 2000).

Wave climate from the late 1970s to the present has been noted as conducive to beach accretion particularly at the northern ends of beaches with the geomorphology of Moonee (i.e. long, south east facing, higher wave energy sandy beaches). Recession at the southern end of the beach is consistent with the wave climate, where enhanced longshore transport and reduced storm bypassing of headlands promotes transport from south to north, and which may cause erosion at the southern end. Further, there may be some impacts from Moonee Creek mouth at the southern end of the beach.

The shoreline modelling suggests Moonee Beach will have started to be impacted by the harbour construction by around 1960, and by 2000 would have receded by 20 m at the southern end grading to virtually no recession at the northern end of the beach.

While overall the beach has been accreting in recent years, it is very likely that Moonee Beach is experiencing impacts from the harbour construction, albeit at a slower rate than given in the modelling. In response to the recent wave climate, Moonee Beach has not accreted at the rate evident on beaches with similar morphology south of the harbour (e.g. Bongil Beach). At the southern to central region of the beach, recent events (2000) have produced the greatest erosion extents evident in the data. The aerial photography also shows evidence of erosion of the contemporary dune field and truncation of the historical dune ridge line at the southern end of the beach.

Moonee Beach is therefore assumed to have been impacted by the harbour construction, with the impact evident as a reduction in the expected natural accretion rate and impeded recovery from past storm events at the southern end of the beach. The use of model results to determine recession in the future due to sea level rise and the harbour construction is also considered appropriate.

Future Long Term Recession

Model results for a predicted 0.9 m rise in sea level by 2100 indicate 135 m grading to 20 m recession from south to north along Moonee Beach (and 60 m to 10 m from south to north with 0.4 m rise by 2050). As noted for other beaches in the region, impacts are enhanced at the southern end and subdued at the northern end of the beach due to the northerly directed sediment transport that is generated by the predominant south east wave climate. As the sea level rises, bypassing of headlands to beaches further north is reduced, starving the southern ends of beaches and allowing accumulation at the northern ends.

The extent of recession along Moonee Beach due to sea level rise is enhanced by the harbour construction. Without sea level rise, the shoreline modelling indicates Moonee Beach would recede by 60 m grading to 10 m from south to north by 2100, in response to the harbour construction alone.

For the ‘rare’ probability of 1.4 m sea level rise by 2100, the modelling exhibits even greater extents of recession, of 175 m to 20 m from south to north.

Moonee beach faces south to south east. For a beach of this orientation, a shift to a more easterly wave climate results in a significant decrease in longshore transport to the north, based upon calculations with the CERC (1984) equation. Using such calculations as a guide, for the ‘rare’ probability of a more easterly wave climate and sea level rise we would expect the extent of recession to reverse along the beach, resulting in 20 m recession at the south grading to 135 m at the northern end. This assumes that Look At Me Now Headland acts to constrict sediment transport from beaches to the north under this ‘rare’ scenario also.

Beach Erosion

The photogrammetric cross sections illustrate that the 1974 beach position is typically the most eroded, with a prominent foredune scarp, no incipient dunes and a lower beach face. At the southern to central region of the beach, the 2000 beach profile is eroded to the greatest extent, beyond the 1974 scarp, as shown in Figure 4-18. There has been some recovery in the form of incipient dunes in front of the foredune scarp at the southern to central region of the beach by 2007. At the northern end of the beach, incipient dunes are present in the 2000 profile, indicating it was not impacted by the storm(s) events in 2000, Figure 4-19.

While we have not included the 1964 profile in the assessment of beach volumes, the profile shows evidence of an erosion scarp into the foredune face relative to the 1956 profile, with up to 20 m landward movement of the profile between these dates. 1964 was shown to be eroded at other beaches, such as Sapphire.

Assessment of the movement of the 4 m AHD dune contour suggests an average of 33 m and maximum of 100 m landward erosion of the dune contour position. However, at the southern end of the beach, the events of 2000 have not recovered much, and the 4 m AHD contour remains in a similar position by 2007. The southern end of the beach is in a relatively eroded state at the present time and is susceptible to further erosion beyond that reported in the existing data.

Further, as discussed above, it is likely that Moonee Beach is being impacted by the harbour construction particularly at the southern end of the beach. Given the similar morphology and similar erosion values determined from the dune position analysis at the northern end of Moonee Beach, the beach erosion values from Bongil Beach have been adopted for Moonee Beach. The values are also appropriate at the southern end of the beach because it is already in a receded position and less able to withstand storm attack.

Thus for an immediate planning period, 50, 120 and 190 m landward movement has been adopted as the ‘almost certain’, ‘unlikely’ and ‘rare’ probability beach erosion hazard respectively for Moonee Beach. For the 2050 and 2100 timeframes, the ‘almost certain’, ‘unlikely’ and ‘rare’ erosion extents are added to the long term recession values at these timeframes, in the manner described in Section 3.4.4.

The extent of beach erosion and shoreline recession on Moonee Beach at the immediate, 2050 and 2100 planning horizons is illustrated in the Figures Compendium.

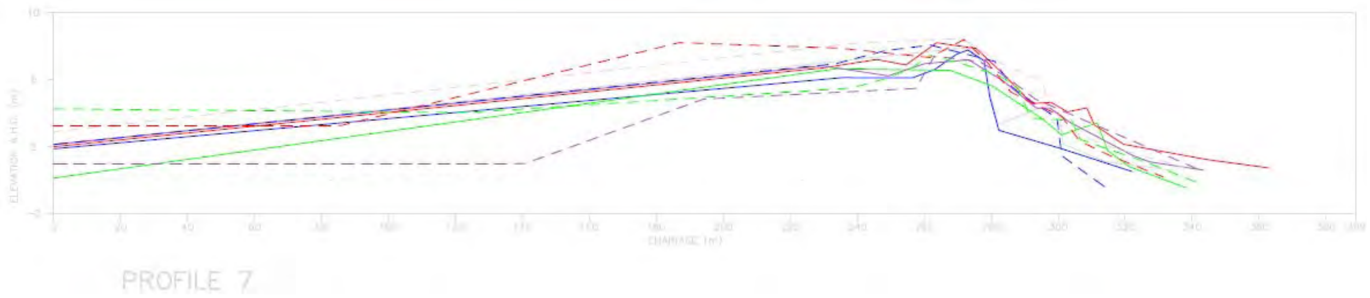


Figure 4-18 Block 1 Profile 7, Southern End of Moonee Beach*

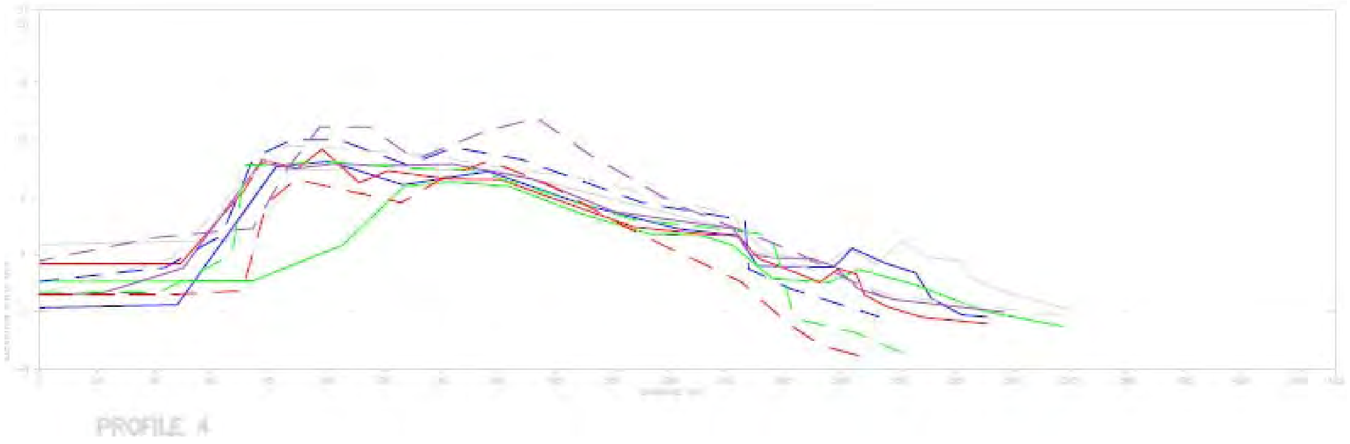


Figure 4-19 Block 5 Profile 4, Northern End of Moonee Beach*

**Legend: Purple dashed line – 1956, Red dashed line – 1964, Green dashed line – 1973, Blue dashed line – 1974, Grey dashed line – 1976, Purple - 1981, Red – 1986, Green – 1994, Blue – 2000, Grey – 2007.*

Coastal Inundation

The wide entrance of Moonee Creek suggests there will be inundation into back beach areas for much of the length of the beach to the north, as well as behind Sapphire Beach to the south. At 2100, the inundation behind Moonee Creek for the ‘unlikely’ and ‘rare’ scenarios is extensive.

An explanation of the adopted inundation levels (‘almost certain’, ‘unlikely’, ‘rare’) at the immediate, 2050 and 2100 planning periods is given in Section 3.5. Coastal Inundation for the immediate, 2050 and 2100 horizons are mapped for the entire Coffs LGA in the Figures Compendium.

Coastal Entrances

Moonee Creek at the southern end of the beach is a typically open entrance. The entrance area is likely to be significantly changed as a response to ongoing recession at the southern end of the beach due to sea level rise combined with the harbour impact. It is uncertain if this may result in entrance closure in the future.

Maintenance of the entrance channel is assisted by shallow bedrock at the base of the channel. With sea level rise, flow velocities will be reduced across the bedrock (due to greater water depth), and entrance constriction (and possible closure) may increase. Further discussion of future entrance characteristics is given in Section 3.6.

The climate change projections for future annual rainfall and rainfall intensity are at present inconclusive. Thus, it is not yet possible to determine potential changes to the entrance condition in response to climate change induced changes to rainfall.

Erosion of coastal entrance berms (and immediately adjacent regions) is included within the beach erosion and shoreline recession hazard for all planning periods. As noted in Section 3.3, the beach erosion extent is measured landward of all coastal entrance berms. This is because the photogrammetric data at all entrances in the Coffs region demonstrates that erosion of the entire berm occurs consistently in the past.

Stormwater Erosion

Moonee Creek appears to form the only outflow point on Moonee Beach, and is discussed within the Coastal Entrance Hazard. High dune heights on Moonee Beach (up to ~ 15 m) are likely to have directed flows into Moonee Creek which flows behind the high dunes.

Sand Drift

Windborne sediment transport allows for the growth and stability of dunes throughout the Coffs LGA. Moonee Beach is considered to have a low risk of sand drift hazards from windborne sediment transport, in terms of either sediment losses or nuisance to back beach development, as the beach has high typically well vegetated dunes that would capture windblown transport.

Title:

Moonee Beach

Figure:

4-20

Rev:

A

N

0 0.5 1km

Approx. Scale

BMT WBM

www.wbmpl.com.au

Filepath : K:\N1440 Coffs Coastal Process Hazard Definition Study\MapInfo\Workspaces\DRG_010_100510 Moonee Beach.WOR

4.13 Look At Me Now Headland, Shelly Beach, and Dammerels Head

Look At Me Now Headland is a large headland feature which forms the northern boundary of Moonee Beach. The headland is steeply cliffed up to ~10 m above sea level, then rises gently to form a dome shaped crest on the southern portion of the headland, at 20 – 30 m above sea level. Rock outcrops form small islands off the north eastern edge of the headland (Binnie and Partners, 1987). A low rock platform exists below the steeply cliffed drop (MHL, 1983).

Shelly Beach is a 300 m east facing beach between Look At Me Now Headland and Dammerels Head. It is moderately protected by the headland, with waves generally < 1 m. It has a low continuous sand bar and a cobble/boulder beach face at high tide at its southern end, forming a low tide terrace beach. Bedrock outcrops along the northern half of Shelly Beach. A permanent rip exists along Dammerels Head (Short, 2007). This is a small pocket beach with a thin veneer of sand that is likely to be completely removed under certain storm conditions.

Dammerels Head forms the southern end of Emerald Beach with a shallow rock zone immediately offshore. A small drainage channel occurs on the northern side of Dammerels Head near Fiddamans Road (John Allen & Associates, 1990).

The headlands and Shelly Beach are illustrated in Figure 4-21.

Beach Erosion and Shoreline Recession at Shelly Beach

The small pocket beach of Shelly Beach had not been assessed, as there is no photogrammetric data. Beach erosion from Emerald Beach has therefore been adopted for Shelly Beach, that is, ‘almost certain’ erosion of 20 m, ‘unlikely’ erosion of 55 m and ‘rare’ erosion of 95 m. Given the beach is backed by bedrock cliffs, it is assumed the entire sand body may be eroded during extreme storm conditions. In the future due to sea level rise, recession and inundation of the pocket beach is almost certain. The shoreline response modelling indicates recession due to sea level rise of 95 m, or, to the base of bedrock cliffs, whichever is more seaward, by 2100.

The extent of beach erosion and shoreline recession on Shelly Beach at the immediate, 2050 and 2100 planning horizons is illustrated in the Figures Compendium.

Title:

Emerald Beach and Fiddamans Beach

Figure:

4-21

Rev:

A

N

0 250 500m

Approx. Scale

www.wbmpl.com.au

Filepath : K:\N1440 Coffs Coastal Process Hazard Definition Study\MapInfo\Workspaces\DRG_011_100510 Emerald Beach.WOR

4.14 Emerald Beach, Diggers Point and Fiddamans Beach

Emerald Beach is 800 m long stretch of beach between Dammerels Head and Diggers Point. There is also a reef towards the southern end. There are four permanent rips on the beach adjacent to the reefs and headlands, in addition to shifting beach rips. It is noted to be a double barred system, facing into the dominant swell direction (south east), with a transverse inner bar and rhythmic outer bar (Short, 2007).

Fiddamans Creek exits to the ocean towards the southern end of the beach. The creek is typically open to the ocean as its entrance is controlled by a bedrock outcrop on the beach and reef in the water at its entrance. PBP (1995) described the position of the entrance on the beach to have remained stable over at least a 50 year period, likely due to the bedrock outcrop that forms a hard edge for at least the lower 100 m of the creek channel. Residential development adjoins the southern bank of Fiddamans Creek with a caravan park on the northern side.

Little is known about **Diggers Point**, which separates Fiddamans and Emerald Beaches. A site inspection revealed it to be a low headland which protrudes only a short way between the two beaches.

Fiddamans Beach is located between Diggers Point and Bare Bluff. It is 1 km in length, and faces south east, into the dominant south easterly swell. This has resulted in a high energy double barred rip dominated beach. The outer bar displays a rhythmic bar and beach shape, the inner bar a transverse bar and rip beach state. The inner bar usually has more frequent rips (~ 5), with more widely spaced rip cells across the outer bar. Permanent rips exist along both bounding headlands.

A track across Diggers Point provides access to Fiddamans Beach. Otherwise, access across Bare Bluff is the only other access point to the relatively quiet Fiddamans Beach. The backing foredune and hinddune regions are part of the Moonee Beach Nature Reserve and consist of a large area of undisturbed coastal wetland and dune species, which are likely to be of high ecological value.

Bare Bluff is a headland standing approximately 30 m high and protruding 800 m to the east (Short, 2007). A large, unvegetated sand blowout traverses from Fiddamans Beach over the back of Bare Bluff onto Sandys Beach in the north. Behind the northern end of Fiddamans Beach for a few hundred metres inland there are high, vegetated sand dunes, with occasional large blowout features. The high dunes and blowouts will have formed over time in response to the Aeolian sediment transport from Fiddamans Beach across Bare Bluff.

The beaches of Emerald and Fiddamans are illustrated in Figure 4-21.

Photogrammetry Data Quality

Both Emerald and Fiddamans Beach were evidently mined for sand in the past, based upon mapping of sand mining leases (Figure 2-1). The first four blocks on Emerald Beach do not show evidence of mining. The northern half of profiles (5 to 11) in Block 5 show evidence of the removal of the entire dune between 1964 and 1969. Dune shape has been repaired by 1973 for these profiles.

At Fiddamans beach, the 1943 data appears to be inaccurate. There is clear evidence of mining of the foredunes in profiles 7 to 10 of Block 1 and all profiles in Block 2 after 1973. Thus data from 1943 to 1973 has not been included in the assessment of beach volumes. However, as the effects of mining are not evident in the incipient region of the 1973 profiles, the 1973 data has been utilised in the assessment of the 4 m AHD contour position.

Long Term Recession

Assessment of historical beach volumes over time indicates very little change on Emerald Beach between 1943 and the present. Shifts in beach width due to wave climate variability are evident, but over time, the beach has remained in a similar position.

The beach volume data at Fiddamans Beach indicates that it has been accreting since 1988 (i.e. after the period of mining) at average rate of 0.8 m/yr. The photogrammetric cross sections show evidence of the growth of incipient dunes and beach volume over this time, with the most accreted beach position occurring in 2007. As has been noted for other beaches, Fiddamans (at the northern end of the compartment) is likely to have experienced accretion in response to the favourable wave climate since the late 1970s. Emerald Beach, at the southern end of the compartment, is not expected to have accreted under these wave climate conditions. Both beaches are thus considered stable, with recent accretion as a response to wave climate and not indicative of a long term, ongoing trend.

The shoreline modelling indicates that Emerald Beach and Fiddamans Beach, located north of Look At Me Now Headland, are not affected by the harbour construction by 2010. This is consistent with the historical data.

The shoreline modelling presents Look At Me Now Headland as a major control on sediment transport in the Coffs Region. In relation to the harbour position, Look At Me Now Headland protrudes further seaward, presenting a natural control on longshore sediment transport in the region.

The shoreline modelling indicates minor impacts (1 to 5 m recession) will occur from the present to 2050, with 10 -15 m recession by 2100, without sea level rise. In spite of the control on sediment transport by Look At Me Now Headland, the modelling demonstrates that impacts from the harbour eventually affect beaches in the northern half of the LGA, as the impact of cessation of littoral transport migrates slowly northwards over time.

Future Long Term Recession

The consistency of the historical data with the results from the shoreline modelling indicate model results to be suitable for predicting future recession due to sea level rise.

With the predicted 0.9 m sea level rise by 2100, the shoreline modelling indicates that Emerald Beach may experience up to 95 m recession, and enhanced recession upon Fiddamans Beach of up to 105 m. The modelling demonstrates that the rise in sea level causes greater separation of the beaches by Diggers Point, which acts like a groyne to impede sediment transport from Emerald into Fiddamans Beach. The result is enhanced recession of Fiddamans Beach relative to Emerald Beach.

In the ‘rare’ case of a 1.4 m sea level rise by 2100, the impact of Diggers Point acting as a groyne is enhanced causing greater recession upon Fiddamans Beach of up to 150 m recession by 2100 in the shoreline modelling. The modelling illustrates that at Emerald Beach recession of 125 m by 2100 may occur due to a 1.4 m sea level rise.

Emerald Beach and Fiddamans Beach are oriented the same direction as Moonee Beach, facing south east. Investigation of longshore transport rates for easterly compared with south easterly wave direction indicated beaches of this orientation will experience a reversal of longshore transport direction (i.e. the transport is directed to the south rather than the north under an easterly wave climate). Emerald and Fiddamans beaches are not as long as Moonee Beach and longshore sediment transport is constrained by the bounding headlands and Diggers Point to some degree. The historical data describes accretion on Fiddamans, but not at the rate observed on the longer uninterrupted south east facing beaches such as Moonee.

For the ‘rare’ scenario of easterly wave climate and 0.9 m sea level rise, nearly a reversal of the extent of recession has been assessed, such that there is up to 100 m recession upon Emerald Beach and up to 95 m upon Fiddamans by 2100. The impact of Diggers Point in constraining sediment transport would fall upon Emerald Beach under an easterly wave climate, with relatively less recession on Fiddamans Beach.

Beach Erosion

For the purpose of deriving a beach erosion hazard, the two beaches have been assessed as one compartment. Emerald and Fiddamans are separated by a small headland (Diggers Point) which does not protrude significantly, and sand bars are evident extending from one beach to the other behind the headland.

At the far southern end of the Emerald Beach, the 1973 profile appears to be the most eroded. 1964 and 1969 is also relatively eroded at the southern end of the beach. In contrast, the 1981 profile appears very accreted, with sand volume accumulated on the foredune face / incipient region at this time.

Moving from the centre to the northern end of Emerald Beach, the 2004 profiles show clear evidence of scarping into the foredune face, for example, in Figure 4-22. The 2004 profiles are relatively accreted at the southern end of the beach in contrast, describing a “rotation” of the beach during this year. This highlights the susceptibility of all areas of the beach to erosion.

The movement of the 4 m AHD contour and the beach position derived from beach volumes have been analysed to determine the average and maximum landward position of the foredune in the past. At Emerald Beach, there has been on average 9 m and a maximum of 24 m landward movement of the 4 m AHD contour for the most eroded compared with the 2007 position. The beach position determined from beach volumes was on average 21 m and a maximum of 51 m landward at the most eroded compared with 2007 position.

At Fiddamans Beach, the sub aerial region of the beach (unaffected by mining) in 1973 indicates erosion of the beach face and cut back into foredunes (e.g. Figure 4-23). The 1973 profiles are eroded relative to the 1988 and later beach positions. Assessment of the 4 m contour gave an average landward movement of 22 m and maximum of 37 m landward movement for the most eroded compared with 2007 position. When beach volumes were assessed (excluding data from

1973 due to mining impacts), this indicated 19 m and 35 m average and maximum landward movement of the beach position.

Combining the results from both beaches, an ‘almost certain’ landward movement of 20 m, ‘unlikely’ movement of 55 m and ‘rare’ movement of 90 m landward of the current position have been adopted, in response to wave climate variability that may produce beach erosion within an immediate timeframe.

For the 2050 and 2100 timeframes, the ‘almost certain’, ‘unlikely’ and ‘rare’ erosion extents are added to the long term recession values at these timeframes, in the manner described in Section 3.4.4. The extent of beach erosion and shoreline recession on Emerald and Fiddamans Beaches at the immediate, 2050 and 2100 planning horizons is illustrated in the Figures Compendium.

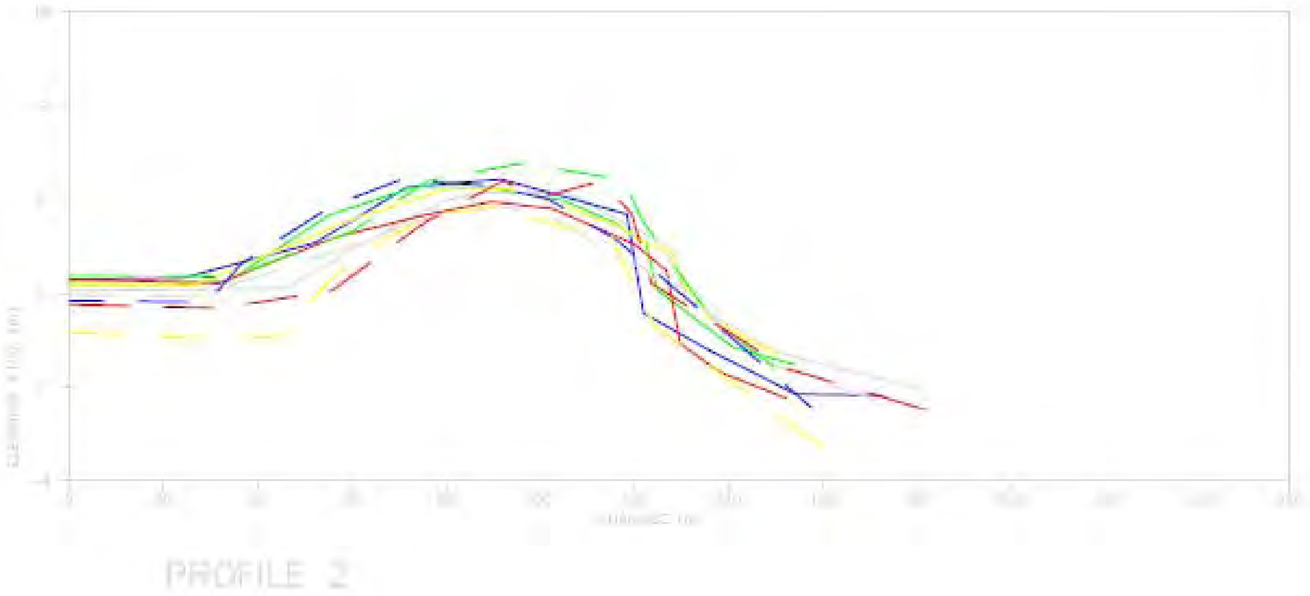


Figure 4-22 Block 5 Profile 2, Emerald Beach*

**Legend: Yellow dashed line – 1943, Red dashed line – 1956, Green dashed line – 1964, Blue dashed line – 1969, Grey dashed line – 1973, Yellow – 1983, Red – 1988, Green – 1993, Blue – 2004, Grey – 2007.*

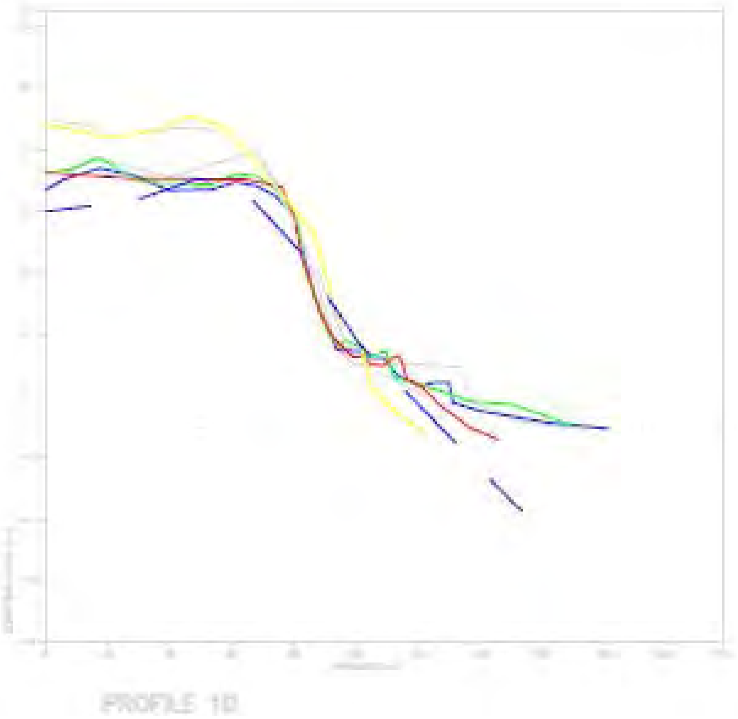


Figure 4-23 Block 2 Profile 10, Fiddamans Beach**

***Legend: Blue dashed line – 1943, Grey dashed line – 1964, Yellow line – 1973, Red – 1988, Green – 1993, Blue – 1996, Grey – 2007.*

Coastal Inundation

Coastal inundation courtesy of Fiddamans Creek may extend some way inland and along the length behind Emerald and Fiddamans Creek, during an elevated water level event at the present time. By 2100, particularly the low lying wetland area behind Fiddamans Beach may be inundated during an ‘unlikely’ water level event.

An explanation of the adopted inundation levels (‘almost certain’, ‘unlikely’, ‘rare’) at the immediate, 2050 and 2100 planning periods is given in Section 3.5. Coastal Inundation for the immediate, 2050 and 2100 horizons are mapped for the entire Coffs LGA in the Figures Compendium.

Coastal Entrances

Fiddamans Creek entrance is located at the central to southern portion of Emerald Beach. It typically remains open, flowing along an outcrop of bedrock on the beach. However, given the small size of the lagoon, it has been assessed as a typically closed entrance.

In combination with recession of the shoreline due to sea level rise, an upward and landward shift in berm position, in line with the shoreline shift, is expected. The height of the entrance berm across the creek may increase by an equal amount as the rise in sea level, i.e. 0.4 m by 2050 and 0.9 m by 2100.

Sufficient photogrammetric data to assess entrance berm height over time was available for Fiddamans. The assessment determined the berm height to reach 1.9 m AHD on average, and a maximum of 2.4 m AHD. The extreme scenario adopted for all coastal lagoons is 3.5 m AHD and relates to the potential height of incipient dunes should an entrance remain closed over a longer period (decades). The 'almost certain', 'unlikely' and 'rare' probability berm heights for Fiddamans Creek at the immediate, 2050 and 2100 timeframe are given in Table 3-8. Further discussion of the response of entrances to sea level rise and derivation of the probable berm heights is given in Section 3.6.

The climate change projections for future annual rainfall and rainfall intensity are at present inconclusive. Thus, it is not yet possible to determine potential changes to the entrance condition in response to climate change induced changes to rainfall.

Erosion of coastal entrance berms (and immediately adjacent regions) is included within the beach erosion and shoreline recession hazard for all planning periods. As noted in Section 3.3, the beach erosion extent is measured landward of all coastal entrance berms. This is because the photogrammetric data at all entrances in the Coffs region demonstrates that erosion of the entire berm occurs consistently in the past.

Stormwater Erosion

Fiddamans Creek appears to form the main outflow onto Emerald Beach, and there are no other points observed on Fiddamans Beach. Refer to the Coastal Entrance hazard for discussion of Fiddamans Creek.

Sand Drift

The most notable location of windblown transport in the Coffs region is between Fiddamans Beach and Sandys Beach across Bare Bluff. At this location, Aeolian transport is likely to form part of the mechanism for sediment transport between these beaches. In recent years dune care groups have undertaken measures to attempt to stabilise the dune blowout across Bare Bluff. While stabilisation may be of use for reducing drift into nearby properties, it is unknown what effect stabilisation has had upon sediment transport into Sandys Beach.

4.15 Sandys Beach, Hearnes Lake Beach and Woolgoolga Back Beach

The entire stretch of beaches from Bare Bluff to Woolgoolga Headland is ~ 5 km in length, with beaches separated by sandy, reef-bound cuspate forelands, including the spit between Flat Top Point and the shoreline.

Sandys Beach extends 1.2 km in length from Bare Bluff to the unnamed rocks and reef-tied foreland in the north. The beach faces roughly east. Bare Bluff headland and Groper Island located 3 km offshore provide moderate protection for the southern end of the beach, resulting in typical waves of < 1 m and a continuous sand bar (without rips), forming a low tide terrace morphology. The beach is transverse bar and rip type at its northern end, with typically 4 – 5 rips across the sand bar, and a permanent rip along the northern rocks and reef. The sand bar is continuous behind the reef into Hearnes Lake Beach. There are noted to be a few rock outcrops in the surf zone (Short, 2007).

Hearnes Lake Beach lies between the unnamed reef and reef-tied foreland to Flat Top Point in the north. The beach is ~ 2 km in length and faces east, thus is exposed to waves from north to south along its length. A rip-dominated double bar system has evolved, with numerous (~8) rips across the inner bar and a rhythmic outer bar with fewer, more widely spaced rips. In high seas, the outer bar is evident as waves break across it. The modal beach state is said to be a transverse bar and rip inner bar and rhythmic bar and beach outer bar. Waves are reduced slightly in the lee of the southern rocks and reef-tied foreland. A permanent rip is located against the southern rocks (Short, 2007)

Flat Top Point is usually linked to the mainland via an intertidal tombolo. Flat Top Point and its surrounding waters and rock reefs contain the highest diversity of marine life within the whole SIMP and the area is protected as a ‘sanctuary zone’. Flat Top Island is also part of the Coffs Coast Regional Park (BMT WBM, 2009b).

Hearnes Lake and its associated wetlands are situated behind much of the length of Hearnes Lake Beach. The entrance to the lake is at the northern end of the beach, behind Flat Top Point. Hearnes Lake is an Intermittently Closed and Open Lake or Lagoon (ICOLL) with a typical surface area of 10 ha and a catchment of 6.8 km^2. Its main tributary is Double Crossing Creek. To the immediate north of the Lake lies SEPP 26 Littoral Rainforest, while areas to the south contain the Endangered Ecological Community Coastal Saltmarsh as well as tracts of mangroves and fringing sedgelands, all of high environmental value (BMT WBM, 2009b).

Woolgoolga Back Beach is located between the sandy foreland in the lee of Flat Top Point to Woolgoolga Headland in the north, stretching for 1.8 km. The beach has double sand bars in the north which join together into a single bar at the southern end of the beach. Depending on the wave conditions, the inner bar is either attached or detached from the beach face, with many (~ 10) rips crossing it. Permanent rips are found adjacent to the headland in the north and along the reef at Flat Top Point, which extends 500 m offshore. The beach faces roughly east south east (Short, 2007).

Willis Creek entrance crosses Woolgoolga Back Beach at its southern end, adjacent to Flat Top Point.

The length of Woolgoolga Back Beach is backed by vegetated dunes, with a low swampy area behind the dunes in the centre of the beach (Short, 2007). Access is possible via Woolgoolga headland in the north, and an access point at the centre of the beach. Four wheel drive access is also located at the southern end of the beach, with driving permitted along the beach.

For the purpose of the assessment of coastal hazards, Sandys Beach, Hearnes Lake Beach and Woolgoolga Back Beach are treated as one compartment, as shown in Figure 4-25.

Photogrammetric Data Quality

The mining map (Figure 2-1) illustrates mining of Sandys, Hearnes and Woolgoolga Back Beaches.

For Sandys Beach the cross sections at Block 2 do not show evidence of mining and in fact have been very stable over the period of data. In Block 3, mining is evident in the most northern two profiles (profiles 7, 8) between 1973 and 1988. The two profiles have been excluded from the data analysis.

On Hearnes Lake Beach there is minor evidence of mining in the hind dune region between 1964 and 1973 however, this area is excluded from beach volume calculations. The variability in the data for Block 2 and 3 does not appear to suggest mining. Mining of Block 4 (profiles 5 – 8) and Block 5 (profiles 1 to 3) is evident between 1943 and 1964. The remaining Block 5 profiles are across Hearnes Lake entrance berm, thus it not possible to comment on mining impacts due to the natural variability of the entrance. However, there is an anecdotal report of mining (between the 1964 and 1973 dates) in the foredunes and incipient region of Block 5. Block 6 shows clear evidence of mining between 1943 and 1964 of the foredune and incipient region. Data affected by mining is not included in the beach volume calculations, with discussion of profile cross sections only for these dates.

At Woolgoolga Back Beach the 1943, 1964 and 1973 profiles are variable in datum position (i.e. not due to mining) in Block 1 and 2, which suggests the data should be used with caution. The data has been analysed with and without the 1943 to 1973 profiles, to ensure conclusions are appropriate.

Long Term Recession

Profiles on Sandys Beach exhibit strong stability, with very little movement of the foredune and beach position over time. The analysis of beach volumes confirms this, with an average of 0.1 m accretion over the period of data. The beach does not exhibit growth of incipient dunes such as has been observed at other Coffs Beaches up to 2007. For many profiles in the southern to centre of the beach, the 2007 position is the most landward (receded) in the historical data. Facing east and located at the southern end of the compartment (between Bare Bluff and Woolgoolga Head), Sandys Beach is not expected to have experienced accretion during the recent decades of wave climate.

Hearnes Lake Beach appears to have remained stable over time, (i.e. an average of 0 m/yr movement along the beach). The Block volume data suggests the ends of the beach have been receding slightly and the middle section accreting slightly over time. The profile cross sections also illustrate stability, with minor movements both landward and seaward, likely in response to storm(s) events.

On Woolgoolga Back Beach, when the 1943, 1964 and 1973 data is included, there is an average of 0 m/yr change in beach position. From 1986 to the present, the beach exhibits recession (0.3 m/yr) at the southern end and accretion (0.4 m/yr) at the northern end, giving an average of 0.1 m accretion.

Given that this section of shoreline faces towards the east and is complicated by reef-tied tombolos / forelands, islands, creek mouths and offshore reefs, the wave climate since the late 1970s has not facilitated accretion along this shoreline (the wave climate since the late 1970s has been observed to promote consistent and strong accretion on those beaches with long interrupted sandy stretches and facing south-south-east, particularly where there are little to no offshore reefs that may complicate wave dissipation).

The shoreline modelling illustrates that the Sandys to Woolgoolga Back coastline has not been affected by the harbour construction. This is consistent with the historical data described above, which also illustrates the beaches have remained stable over time.

The shoreline modelling indicates that, without sea level rise, the beaches may experience 1 – 2 m recession by 2050, increasing to 3 – 7 m recession by 2100.

Future Long Term Recession

The consistency of the shoreline modelling with the historical data suggests the modelling results for sea level rise are suitable for use in predicting future recession. The modelling results demonstrate the complicated response of this section of shoreline to sea level rise due to offshore reefs, reef tied forelands and islands with tombolos. With sea level rise, there is slight reduction in the dissipation of wave energy by reefs as they become more submerged, and the tombolos behind may experience recession. As such, with 0.9 m sea level rise by 2100 the modelling suggests up to 105 m recession at Sandys, 100 m at Hearnes and 105 m recession at Woolgoolga Back. In general, areas adjacent to the reefs experience the greatest impacts.

Modelled results for the ‘rare’ scenario of 1.4 m sea level rise suggest recession will be enhanced, particularly adjacent to the reef areas. With a 1.4 m sea level rise by 2100, the modelling shows up to 160 m recession at Sandys, 175 m at Hearnes and 130 m at Woolgoolga Back Beach.

For the ‘rare’ possibility of a more easterly wave climate, it is noted that Sandys to Woolgoolga Back Beach are oriented toward the east. Calculation of longshore transport rates suggest there is little change in longshore transport along the beach for a south easterly (135°) compared with easterly (120°) wave climate. Thus slightly enhanced recession at northern ends and slightly reduced recession at southern ends of the beaches is expected. The modelling of recession due to 0.9 m sea level rise has been adjusted slightly along this section of shoreline to reflect the likely response to a more easterly wave climate.

Beach Erosion

In a number of profiles on Sandys Beach, the 1964 position appears cut back and further landward than later dates (e.g Figure 4-24). 1964 is known to have experienced severe storms that would have affected beaches in Coffs Harbour.

An analysis of the 3 m AHD dune contour position (dunes on Sandys Beach are typically < 4 5 m AHD in height) suggests the dunes have remained very stable, with an average of 5 m and maximum of 20 m movement between 2007 and the most eroded position. Likewise, the 4 m AHD contour at Hearnes Lake Beach (excluding the lake entrance region) also exhibit an average of 5 m and maximum of 21 m movement between the 2007 and most eroded position.

When beach volumes are analysed, this gives an average of 9 and 12 m and maximum of 36 and 46 m movement of the beach position at Sandys and Hearnes Lake, respectively (i.e. between the existing and most eroded profiles).

At both Hearnes Lake and Sandys Beach, many of the most eroded profiles occur very recently (2000, 2007). At Woolgoolga Back Beach, when the 1964 data is excluded, the southern end of the beach is also at its most eroded in more recent times (2004, 2006). However, as noted above, the difference is typically minor as the beaches have remained quite stable over time.

At Woolgoolga Back Beach, the 1964 beach position is the typically most eroded in the data. However, the use of this data requires caution, as the cross sections suggest this data may be inaccurate and further, the effects of mining at this time are uncertain. Based upon analysis of beach volumes including the 1964 data, there is on average 16 m and a maximum of 50 m landward movement between the most recent and most eroded beach position. Excluding the earlier data (1943, 1964, 1973) there is an average of 5 m and maximum of 13 m movement of the beach position between most recent (~2007) and most eroded profile. This is consistent with the findings at Hearnes Lake and Sandys Beach.

The photogrammetric data suggests that the recent wave climate is not accretionary on coastlines such as Hearnes Lake, Sandys and Woolgoolga Back Beach. This coastline section faces towards the east and its geomorphology is complicated by reefs, tombolos, coastal entrances and short headlands, which when combined, result in a complicated and unpredictable effect upon incoming waves (i.e. in terms of refraction and dissipation) and subsequently accretion or erosion of the shoreline.

It is prudent to assume that wave climate periods of greater impact to this coastline are likely to occur in the future, and an appropriate buffer for beach erosion derived. The beach erosion values assessed for Sawtell Beach have been adopted at Sandys, Hearnes and Woolgoolga Back Beach. The Sawtell beach erosion values are consistent with that of Woolgoolga Back Beach when the 1964 data is included in the assessment, and are fairly consistent with the beach volume erosion values for Sandys and Hearnes Lake noted above. The beaches are also of similar orientation.

For the immediate timeframe, an ‘almost certain’ probability of 15 m, ‘unlikely’ probability of 50 m and ‘rare’ probability of 85 m landward movement of the beach position due to beach erosion has been adopted. For the 2050 and 2100 timeframes, the ‘almost certain’, ‘unlikely’ and ‘rare’ erosion extents are added to the long term recession values at these timeframes, in the manner described in Section 3.4.4.

The extent of beach erosion and shoreline recession on Sandys, Hearnes Lake and Woolgoolga Back Beaches at the immediate, 2050 and 2100 planning horizons is illustrated in the Figures Compendium.

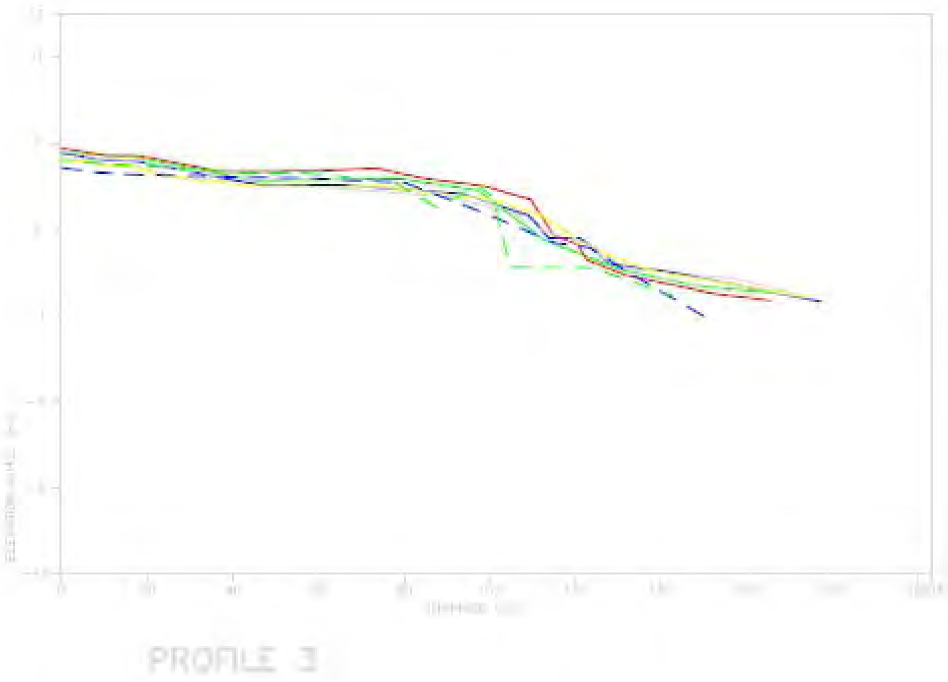


Figure 4-24 Block 3 Profile 3, Sandys Beach*

**Legend: Green dashed line – 1964, Blue dashed line – 1973, Grey dashed line – 1988, Yellow 1993, Red – 1996, Green – 2000, Blue – 2004, Grey – 2007*.

Coastal Inundation

At the immediate timeframe, inundation of back beach areas is facilitated through Hearnes Lake and Willis Creek, with the ‘almost certain’ to ‘rare’ probability water levels covering a similar extent, generally over the footprint of the lake and creek behind Hearnes Lake and Woolgoolga Back Beaches. By 2100 with sea level rise, the ‘unlikely’ and ‘rare’ inundation has expanded in area around the creek and lake footprints, but does not appear to threaten development.

An explanation of the adopted inundation water levels (‘almost certain’, ‘unlikely’, ‘rare’) at the immediate, 2050 and 2100 planning periods is given in Section 3.5.

The extent of coastal inundation in back beach and low lying areas behind Sandys, Hearnes Lake and Woolgoolga Back Beaches at the immediate, 2050 and 2100 planning horizons is illustrated in the Figures Compendium.

Coastal Entrances

Hearnes Lake entrance is located behind Flat Top Point at the boundary between Hearnes Lake and Woolgoolga Back Beach, and is often closed to the ocean. Willis Creek also exits at Flat Top Point at the southern end of Woolgoolga Back Beach and is typically closed. In combination with recession of the shoreline due to sea level rise, an upward and landward shift in berm position, in line with the shoreline shift, is expected. The height of the entrance berm across the lake and creek is likely to increase by an equal amount as the rise in sea level, i.e. 0.4 m by 2050 and 0.9 m by 2100.

Sufficient photogrammetric data to assess entrance berm height over time was available for Hearnes Lake, but not for Willis Creek. The assessment determined the berm height to reach 2.0 m AHD on average, and a maximum of 2.6 m AHD. The extreme scenario adopted for all coastal lagoons is 3.5 m AHD, and relates to the potential height of incipient dunes should an entrance remain closed over a longer period (decades). The ‘almost certain’, ‘unlikely’ and ‘rare’ probability berm heights for Hearnes Lake at the immediate, 2050 and 2100 timeframe are given in Table 3-8. Further discussion of the response of entrances to sea level rise and derivation of the probable berm heights is given in Section 3.6.

The climate change projections for future annual rainfall and rainfall intensity are at present inconclusive. Thus, it is not yet possible to determine potential changes to the entrance condition in response to climate change induced changes to rainfall.

Erosion of coastal entrance berms (and immediately adjacent regions) is included within the beach erosion and shoreline recession hazard for all planning periods. As noted in Section 3.3, the beach erosion extent is measured landward of all coastal entrance berms. This is because the photogrammetric data at all entrances in the Coffs region, including Hearnes Lake and Willis Creek, demonstrates that erosion of the entire berm occurs consistently in the past.

Stormwater Erosion

There appears to be a drainage point at the centre of Sandys Beach, in the vicinity of the lower lying dune elevation. As noted in Section 0, erosion at the drainage location on Sandys Beach is largely included within the beach erosion hazard zones (as the hazard extent is measured from landward of the drainage outlet).

Climate change predictions for future rainfall are currently too coarse to confidently estimate local changes in rainfall and runoff and subsequently, to what extent there may be further erosion at outlets / drainage points. However, our approach to defining probability zones for beach erosion has likely captured the potential changes in erosion at drainage points in the future.

Hearnes Lake and Willis Creek on Hearnes Lake Beach and Woolgoolga Back Beach are the dominant drainage paths, and are discussed as part of the Coastal Entrance hazard.

Sand Drift

Sand drift occurs between Fiddamans Beach and Sandys Beach, across Bare Bluff. At this location, Aeolian transport is likely to form part of the mechanism for sediment transport between these beaches. In recent years dune care groups have undertaken measures to attempt to stabilise the dune blowout across Bare Bluff. While stabilisation may be important for reducing sand drift into nearby properties, it is unknown what effect stabilisation has had upon sediment transport into Sandys Beach.

The remaining beaches (Hearnes Lake and Woolgoolga Back Beach) are considered to have a low risk of sand drift hazard in terms of either sediment losses or nuisance to back beach development. Windborne sediment transport is considered an important component of the growth and stability of dunes throughout the Coffs LGA.

Title:

Sandys, Hearnes Lake and Woolgoolga Back Beaches

Figure:

4-25

Rev:

A

N

0 0.5 1km

Approx. Scale

www.wbmpl.com.au

Filepath : K:\N1440 Coffs Coastal Process Hazard Definition Study\MapInfo\Workspaces\DRG_012_100510 Bare Bluff to Woolgoolga Headland.WOR

4.16 Woolgoolga Headland, Woolgoolga Beach and Safety Beach

Woolgoolga Headland is 50 m in height, and extends approximately 1 km into the sea (Short, 2007).

Woolgoolga Beach extends 1.7 km from Woolgoolga Headland to the sandy foreland at Woolgoolga Reef. The beach generally faces east, becoming curved to face towards the north at its southern end. The beach is sheltered by the large Woolgoolga Headland and attached reef at its southern end. This has shaped the morphology, which is typically a shallow gradient beach face and attached sand bar at the southern end (low tide terrace), grading to a transverse bar and up to five rips towards its northern end where it is more exposed to the prevailing wave climate. A permanent rip runs against Woolgoolga Headland, which is strengthened during summer north easterly winds (Short, 2007).

Woolgoolga Lake is located behind the beach, and is typically closed to the ocean. Woolgoolga Lake is a popular location for swimming and other recreational activities, and also supports a range of wetland species.

Safety Beach is a long sandy stretch of 1.2 km extending from the sandy foreland formed in lee of Woolgoolga Reef to an unnamed bluff in the north off Darkum Road. The beach grades from low tide terrace beach state at the southern end due to protection from the south east by Woolgoolga Reef, grading into transverse bar and rip morphology in the north. Typically, there is a single sand bar with a few rips crossing it, which may attach to the shoreline at the southern end. During high wave conditions, rips may form at the southern end, particularly near the reef. A permanent rip is located at the northern end of the beach against the bluff (Short, 2007).

Both beaches are shown in Figure 4-27.

Darkum Creek runs south behind Safety Beach for 1 km before crossing the beach to the ocean at the southern end (Short, 2007).

An unnamed highly embayed sand and pebble beach of only 50 m in length is situated on the southern side of the unnamed low bluff (that forms the southern headland of South Mulloway). The beach is a reflective beach, with a steep beach face and coarse grained sand, surrounded by cliff and rocks. It is accessed via a steep walking track from the unnamed bluff car park (Short, 2007). The beach has not been assessed directly, and is likely to be inundated completely with sea level rise.

Photogrammetry Data Quality

The mining map indicates that Woolgoolga Beach was not mined (refer Figure 2-1). Safety Beach to the north was mined, but this area is not covered by the photogrammetry. Older dates of photogrammetry (1943, 1956) appear to have reasonable to good consistency with the recent, more accurate photogrammetry. All data has been used in the assessment of beach volumes and position.

Long Term Recession

At the far southern end of Woolgoolga Beach, the profiles appear accreted relative to the 1964 and 1973 positions. However, moving northwards towards Woolgoolga Lake entrance, the profile cross sections show evidence of ongoing cut back into the foredune face, leaving a scarped appearance by

2007 (as shown in Figure 4-26). Across the beach as a whole the average rate of recession is 0.4 m/yr. Along the beach the rate of recession increases from south to north, with up to 0.5 m/yr recession around the lake's entrance.

Storm events are required to initiate bypassing of Woolgoolga Head to supply sediment into the compartment. Waves from the south east refracting around Woolgoolga Headland may meet with the shoreline just south of the lake entrance. The predominant south easterly swell generates longshore transport along the beach. Without headland bypassing to supply sediment into the compartment, the longshore transport will result in recession of the beach, particularly south of the Lake entrance where refracted south easterly swell meets the shoreline.

It is suggested that the wave climate since the late 1970s, which is generally noted to have been less stormy, is likely to have promoted recession at Woolgoolga Beach due to the reduction in events that generate sediment bypassing around the prominent Woolgoolga Headland. However, this situation is not considered permanent, but rather a response to the recent period of wave climate. Overall the beach is concluded to be stable.

The shoreline modelling of the harbour impact indicates that Woolgoolga Beach has remained stable to 2000. The recession evident on Woolgoolga Beach over recent decades (which is not consistent along the beach) is apparently a response to the recent wave climate conditions. Thus, the shoreline model results are considered suitable for use in assessing sea level rise on Woolgoolga and Safety Beaches.

Without sea level rise, the Coffs shoreline would continue to adapt to the harbour construction, with a migration of the harbour impact northwards over time to affect Woolgoolga and Safety Beaches. The shoreline modelling indicates that Woolgoolga Beach may experience up to 1 m recession by 2050 and from 3 to 6 m recession from south to north by 2100 due to the impact of the harbour construction, without sea level rise. On Safety Beach excluding sea level rise, the harbour impact is shown in the modelling to result in up to 1 m recession by 2050 and up to 5 m recession by 2100.

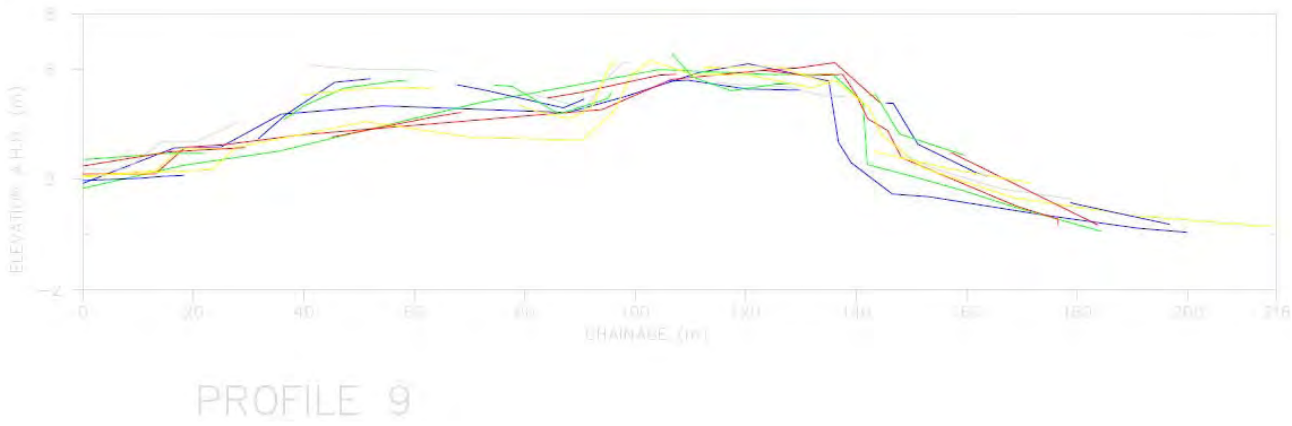


Figure 4-26 Block 2 Profile 9, Woolgoolga Beach*

**Legend: Yellow dashed line – 1943, Red dashed line – 1956, Green dashed line – 1966, Blue dashed line – 1973, Grey dashed line – 1981, Yellow – 1986, Red - 1993, Green – 1996, Blue – 2004, Grey – 2007.*

Future Long Term Recession

The modelling for sea level rise includes the impact of the harbour, as it is likely to exacerbate recession impacts on beaches to the north. With a 0.9 m sea level rise by 2100, the shoreline modelling indicates Woolgoolga Beach may experience significant recession of up to 105 m (and up to 45 m by 2050 with 0.4 m sea level rise). On Safety Beach the response to sea level rise is complicated by Woolgoolga Reef, located offshore of the Lake entrance. At present sea levels a lobe (salient) of sand has formed in the lee of the reef. Sea level rise is likely to reduce the amount of wave dissipation by the reef, enhancing the impact of waves on the shoreline in lee of the reef. On Safety Beach, the model results indicate up to 60 m recession in lee of the reef, with generally 20 m recession elsewhere by 2050. By 2100 we may expect recession of 120 m in the south to 45 m in the north with a 0.9 m rise in sea level is expected.

For the ‘rare’ case of a 1.4 m sea level rise by 2100 the extents of recession are shown by the shoreline modelling to increase, to up to 170 m at Woolgoolga and 160 m at Safety Beach.

The Woolgoolga to Safety Beach shoreline is roughly oriented towards the east. The very southern end of the beach faces almost north east. Calculation of indicative longshore transport rates for an easterly and south easterly average wave climate on east oriented beaches suggest there is minimal difference in longshore transport rates. For a north east facing beach, however, south easterly waves generate very little transport, while easterly waves generate northerly transport. This is consistent with the observations from the photogrammetry on Woolgoolga Beach that illustrated the extreme southern end was unaffected by the south east wave climate, while the more easterly facing beach area was affected.

Thus under the ‘rare’ scenario of a more easterly wave climate, it is assumed that the far southern end of Woolgoolga Beach (that faces north east) may experience enhanced erosion, while the remainder of the beach is unaffected or recession slightly reduced, due to longshore supply from the southern end of the beach. Recession values (based upon shoreline modelling for 0.9 m sea level rise) have been modified to reflect such changes in sediment transport for the ‘rare’ scenario of a more easterly wave climate.

Beach Erosion

At the extreme southern end of the beach, the 1964 and 1973 profile cross sections show evidence of erosion, with scarping of the foredune face. There is evidence of the growth of incipient dunes by 2007 at the extreme southern end of the beach.

Moving north towards the lake entrance, however, the 2004 and 2007 profiles appear as the most eroded beach position in a majority of profiles. The 2004 profile cross sections in particular show scarping of the foredune face and a lower sub aerial beach. The 2004 position is up to 20-30 m landward of the 1956 (most accreted) position.

As noted previously, the beach position is a response to wave climate over the last few decades. It is difficult to determine the potential extent of beach erosion at Woolgoolga because it appears that the recent beach state is the most eroded along a large extent of the beach. It is prudent to assume that a more eroded beach position may occur in the future, for example, if the current wave climate were to persist into the future.

Data from the southern end of the beach which is presently in an accreted state has been used to determine average and maximum extents of beach erosion on Woolgoolga Beach. The results indicate on average a 19 m landward movement of the beach position and up to 41 m maximum landward movement. These values are consistent with the approximate 20 – 30 m movement between 1956 and 2007 on some of the cross sections towards the northern end of the beach. Thus, an ‘almost certain’ probability of 20 m, an ‘unlikely’ probability of 55 m and a ‘rare’ probability of 90m landward movement of the beach position at Woolgoolga have been adopted to account for erosion on the full length of the beach, under various and variable wave climates (height and direction) over an immediate timeframe. In lieu of photogrammetric data for Safety Beach, the values from Woolgoolga have been applied at the adjacent Safety Beach.

For the 2050 and 2100 timeframes, the ‘almost certain’, ‘unlikely’ and ‘rare’ erosion extents are added to the long term recession values at these timeframes, in the manner described in Section 3.4.4.

The extent of beach erosion and shoreline recession on Woolgoolga and Safety Beaches at the immediate, 2050 and 2100 planning horizons is illustrated in the Figures Compendium.

Coastal Inundation

Inundation of low lying areas behind Woolgoolga Beach is seen to extend around the footprint of Woolgoolga Lake, and into developed areas behind the southern part of the beach, south of the lake for the ‘almost certain’ probability in an immediate timeframe. By 2100, the ‘unlikely’ and ‘rare’ scenarios suggest expanded inundation across developed areas in Woolgoolga on the southern slopes to the lake.

The inundation extents around Darkum Creek tend to be limited to vegetated and undeveloped areas, even with a ‘rare’ probability by 2100.

An explanation of the adopted inundation levels (‘almost certain’, ‘unlikely’, ‘rare’) at the immediate, 2050 and 2100 planning periods is given in Section 3.5. Coastal Inundation for the immediate, 2050 and 2100 horizons are mapped for the entire Coffs LGA in the Figures Compendium.

Coastal Entrances

Woolgoolga Lake exits to the ocean at the northern end of Woolgoolga Beach, at the bedrock highpoint at the centre of the beach. The lake entrance is frequently closed. Darkum Creek entrance also crosses to the ocean on the northern side of the bedrock highpoint, at the southern end of Safety Beach, and is also typically closed.

There is expected to be an upward and landward movement of the entrance berm position with sea level rise, in line with the recession of the shoreline. The height of the entrance berm across the lake and creek is likely to increase by an equal amount as the rise in sea level, i.e. 0.4 m by 2050 and 0.9 m by 2100.

Sufficient photogrammetric data to assess entrance berm height over time was available for Woolgoolga Lake, but not for Willis Creek. The assessment determined the berm height to reach 1.3 m AHD on average, and a maximum of 2.4 m AHD. The extreme scenario adopted for all coastal lagoons is 3.5 m AHD, and relates to the potential height of incipient dunes should an entrance remain closed over a longer period (decades). The ‘almost certain’, ‘unlikely’ and ‘rare’ probability berm heights for Woolgoolga Lake at the immediate, 2050 and 2100 timeframe are given in Table 3-8. Further discussion of the response of entrances to sea level rise and derivation of the probable berm heights is given in Section 3.6.

The climate change projections for future annual rainfall and rainfall intensity are at present inconclusive. Thus, it is not yet possible to determine potential changes to the entrance condition in response to climate change induced changes to rainfall.

Erosion of coastal entrance berms (and immediately adjacent regions) is included within the beach erosion and shoreline recession hazard for all planning periods. As noted in Section 3.3, the beach erosion extent is measured landward of all coastal entrance berms. This is because the photogrammetric data at all entrances in the Coffs region demonstrates that erosion of the entire berm occurs consistently in the past.

Stormwater Erosion

There is a formal stormwater outlet at the southern end of Woolgoolga Beach and an informal drainage point north of Woolgoolga Lake. Erosion at the two drainage points on Woolgoolga Beach is largely encompassed within the beach erosion hazard zones, as discussed in Section 0 (as the hazard extent is measured from landward of the drainage outlet).

Outflows from Woolgoolga Lake and Darkum Creek (on Safety Beach) are discussed within the Coastal Entrance hazard.

Climate change predictions for future rainfall are currently too coarse to confidently estimate local changes in rainfall and runoff and subsequently, to what extent there may be further erosion at outlets / drainage points. However, the approach to defining probability zones for beach erosion has likely captured the potential changes in erosion at drainage points in the future.

Sand Drift

Woolgoolga and Safety Beaches are considered to have a low risk of sand drift hazard in terms of either significant sediment losses or nuisance to back beach development. Windborne sediment transport is an important component of the growth and stability of dunes throughout the Coffs LGA.

Title:

Woolgoolga and Safety Beaches

Figure:

4-27

Rev:

A

N

0 375 750m

Approx. Scale

BMT WBM

www.wbmpl.com.au

Filepath : K:\N1440 Coffs Coastal Process Hazard Definition Study\MapInfo\Workspaces\DRG_013_100510 Safety Beach.WOR

4.17 Cabins (South Mullaway) Beach, Mullaway Headland and Mullaway Beach

South of Mullaway Headland lies **Cabins (South Mullaway) Beach**. This beach is 600 m in length, and extends from a small unnamed rocky bluff around 10 m high to Mulloway Headland. The beach has one sand bar with usually two beach rips across it, forming a typical transverse bar and rip morphology. There are permanent rips adjacent to both headlands (Short, 2007).

Mullaway Headland is a metasedimentary rock outcrop around 15 m in height (Short, 2007).

Mullaway Beach is a 700 m long stretch between Mullaway Headland in the south and Ocean View Headland in the north. The beach has a single bar with usually 2 to 3 rip across it, and is described as a transverse bar and rip morphology. Permanent rips exist against both headlands. Waves break along the southern rocks, in a point break (Short, 2007). Both beaches are illustrated in Figure 4-28.

A vegetated dune lies behind the beach. A small creek exits to the ocean at the southern end of Mullaway Beach (Short, 2007).

Photogrammetry Data Quality

The mining map illustrates that the entire length of Cabins Beach was under mining lease (refer Figure 2-1). Review of the photogrammetry profiles indicates that the southern half of the beach was not mined, but that mining took place between 1943 and 1956 for part of the northern half of the beach (profiles 5 to 8 of Block 2), with the entire foredune removed and not replaced. The 1943 data is excluded from analysis anyway as diagrams only are available for this date.

Mulloway Beach is not shown on the mining lease map (refer Figure 2-1) and review of photogrammetry cross sections confirm that mining did not take place at this beach. The 1943 data is excluded from beach volume calculations because only diagrams are available for this date.

Long Term Recession

On Cabins Beach, analysis of beach volumes and dune contour position (4 m AHD) indicate the beach overall has been accreting slightly, at an average rate of 0.1 m/yr. The southern end is shown to have receded by 0.1 m/yr while the northern end has accreted at 0.3 m/yr. The profile cross sections also illustrate the growth of incipient dunes by 2007 towards the northern end of the beach.

The photogrammetric data suggests Mulloway Beach has been accreting at a rate of 0.3 m/yr. There has been notable growth of incipient dunes between 1974 and 2007, particularly towards the northern end of the beach.

The observations on Cabins and Mulloway Beaches are consistent with that at other beaches of similar orientation and geomorphology in the Coffs region (e.g. Sawtell), where the recent wave climate has generated slight recession/slower accretion of southern ends and accretion at northern ends of the beaches. Thus, overall, it is concluded that the beaches are stable.

The shoreline modelling indicates that the harbour has not impacted Cabins or Mulloway Beaches. This is consistent with the historical data.

Future Long Term Recession

Without sea level rise, the modelling suggests there are unlikely to be recessionary impacts by 2050, with negligible recession of 2 to 5 m by 2100 on the beaches as a result of the harbour construction.

With predicted sea level rise (0.4 m by 2050 and 0.9 m by 2100), the modelling results suggests Cabins Beach will experience greater erosion than Mulloway Beach. This is considered to be a result of internal refraction of waves within the model, and which may not accurately reflect refraction into Mulloway Beach as it is quite embayed by bounding headlands. Given the similarity of the response of the two beaches in the historical data, it is prudent to expect similar recession rates. Thus, the recession values for Cabins in the modelling are adopted for Mulloway also, of up to 60 m recession by 2100.

For the ‘rare’ scenario of 1.4 m sea level rise by 2100, the modelling results suggest recession of up to 90 m at Cabins Beach, which is also adopted for Mulloway Beach. The results indicate recession is likely to be accelerated because the offshore reef systems become further submerged and are less effective in dissipating wave energy as the sea level rises.

Longshore transport calculations for the easterly compared with south-easterly wave climate on east-oriented beaches such as Cabins and Mulloway indicate little change in transport rates. Thus, for the ‘rare’ scenario of a shift to a more easterly wave climate, it has been assumed that there is likely to be little change in recession extents at the northern compared with southern end of the two beaches.

Beach Erosion

Given the similarity of the geomorphology of Cabins and Mulloway Beaches, the data for the beaches in combination have been used to derive suitable set backs for the beach erosion hazard.

On Cabins Beach at the southern end the 2007 profiles appear as the most eroded beach profiles, with the beach in 1964 also quite eroded. Moving northwards along Cabins Beach, the 1964 and 1974 profiles are commonly the most eroded profiles. The 1974 and 1964 profiles are also typically eroded at both ends of Mulloway Beach, with scarping of the foredune face and lowering of sub aerial beach on many profiles in these years.

The dune contour position (4m AHD) and beach volumes upon Mulloway and Cabins Beach were assessed. It is evident that in some case the 2007 position is currently eroded. The most eroded compared with the 2007 contour position are on average 12 m and a maximum of 47 m landward. The beach volumes suggested an average of 24 m and a maximum of 50 m landward movement between the current beach and most eroded positions.

Based upon the analysis of the historical data and current beach position, landward movement of the beach position of 20 m as ‘almost certain’, 55 m as ‘unlikely’ and 90 m as ‘rare’ has been adopted over the immediate timeframe. The historical data for Mulloway and Cabins Beach is quite consistent with outcomes for other similar beaches in the Coffs region (e.g. Emerald, Sawtell, Ocean View) providing further certainty to the adopted set backs. For the 2050 and 2100 timeframes, the ‘almost certain’, ‘unlikely’ and ‘rare’ erosion extents are added to the long term recession values at these timeframes, in the manner described in Section 3.4.4.

The extent of beach erosion and shoreline recession on South Mulloway and Mulloway Beaches at the immediate, 2050 and 2100 planning horizons is illustrated in the Figures Compendium.

Coastal Inundation

Cabins and Mulloway Beaches have only a minor drainage line each, thus coastal inundation of back beach areas is limited in the immediate timeframe. By 2100, the extent of inundation with a ‘rare’ probability remains limited on Cabins Beach, with some minor expansion of inundation with a ‘rare’ probability upon Mulloway Beach. In both cases, the inundation does not affect development.

An explanation of the adopted inundation water levels (‘almost certain’, ‘unlikely’, ‘rare’) at the immediate, 2050 and 2100 planning periods is given in Section 3.5.

The extent of coastal inundation in back beach and low lying areas behind Cabins and Mulloway Beaches at the immediate, 2050 and 2100 planning horizons is illustrated in the Figures Compendium.

Coastal Entrances

There are no significant coastal entrances upon Cabins or Mulloway Beaches (the minor drainage outlets are discussed within the Stormwater Erosion Hazard).

Stormwater Erosion

There is a small creek/drainage point at the centre of Cabins Beach and another towards the southern end of Mulloway Beach. As noted in Section 0, erosion at these locations is largely captured within the beach erosion hazard zones, as the hazard extent is measured from landward of the drainage outlet.

Climate change predictions for future rainfall are currently too coarse to confidently estimate local changes in rainfall and runoff and subsequently, to what extent there may be further erosion at outlets / drainage points. However, our approach to defining probability zones for beach erosion has likely captured the potential changes in erosion at drainage points in the future.

Sand Drift

Cabins and Mulloway Beaches are considered to have a low risk of sand drift hazard in terms of either significant sediment losses or nuisance to back beach development. Windborne sediment transport is an important component of the growth and stability of dunes throughout the Coffs LGA.

Title:

Cabins and Mullaway Beaches

Figure: **4-28**

Rev: **A**

BMT WBM
www.wbmpl.com.au

Filepath : K:\N1440 Coffs Coastal Process Hazard Definition Study\MapInfo\Workspaces\DRG_014_100510 Mullaway Beach.WOR

4.18 Ocean View Headland and Ocean View Beach

Ocean View Headland is an outcrop of fine grained metasedimentary rock (Short, 2007).

Ocean View Beach is a slightly curving, 900 m long beach between Arrawarra and Ocean View Headlands, as in Figure 4-29. The beach faces east and receives some protection from the dominant south easterly swell from Ocean View Headland. The beach is composed of medium sand, with rocks in the surf for the northern 300 m of beach. The beach is a transverse bar and rip type. It has a single sand bar, which is typically cut by 3 or 4 rips, a strong permanent rip along Arrawarra Headland in the north, and a lesser permanent rip along Ocean View Headland in the south. (Short, 2007).

Photogrammetry Data Quality

The mining lease map indicates Ocean View may have experienced sand mining in the past. The cross sections for photogrammetry clearly indicate mining occurred between 1964 and 1973 (and possibly between 1956 and 1964 in some profiles towards the north), with the removal of the entire foredune system from ~ Profile 8 in Block 1 to Profile 11 in Block 2 (i.e. the central portion of the beach). Data prior to 1973 has been excluded from analysis of beach volumes / widths, so that mining impacts do not distort the conclusions derived from the data.

Long Term Recession

The photogrammetric data for Ocean View Beach indicates the beach has remained stable since 1973 (after the era of mining). Beach volumes suggest a 0 m/yr change, while the dune contour (4 m) position suggests slight accretion (~0.1 m/yr) along the beach.

Review of the photogrammetric cross sections revealed that, following the removal of dunes by mining prior to 1973, the beach has remained in a similar position over time, with relatively little movement. In particular, there has not been growth of incipient dunes (as has been observed on other beaches in the region in response to recent wave climate) and in some profiles the most recent data is relatively receded.

On other east oriented beaches (such as Hearnes, Sandys) the recent decades of wave climate are not necessarily conducive to accretion (or recession) and this is also the observation at Ocean View Beach. Overall, Ocean View beach has remained stable.

The shoreline modelling indicates that Ocean View Beach has not experienced impacts in relation to the harbour construction. This is consistent with the historical data which indicates the beach has remained stable. The modelling results are considered appropriate for use in estimating future long term recession due to harbour impacts and sea level rise.

Future Long Term Recession

Without sea level rise, the shoreline modelling suggests a negligible recession of up to 3 m by 2100 on Ocean View Beach, as a response to the harbour construction alone.

For sea level rise of 0.4 m by 2050 and 0.9m by 2100, the shoreline modelling results suggest recession of up to 40 m and 100 m, respectively. The modelling indicates a slightly enhanced impact to the southern end of the beach however, the assessment of historical data suggests the greatest impact from sea level rise will likely occur at the centre of Ocean View Beach. The model results have been shifted slightly to better reflect the historical shoreline response.

In the ‘rare’ case of sea level rise of 1.4 m by 2100 (0.7 m by 2050) the shoreline modelling results indicate recession will be enhanced upon Ocean View Beach, with up to 160 m recession (70 m by 2050). Such high rates of recession are reflective of the “drowning” of offshore reefs that results in a reduction of wave dissipation (through friction and refraction) by the reef, and so enhanced wave energy at the shoreline in lee of the reef.

As Ocean View Beach faces east, we would expect little change in longshore transport rates along the beach under an easterly wave climate compared with the existing south easterly wave climate. This is derived through investigation of longshore transport rates with the CERC equation for easterly and south easterly average waves received at a shoreline of the orientation of Ocean View (i.e. roughly east). In the ‘rare’ case of a permanent shift to a more easterly wave climate then, minor changes to recession at the southern and northern ends have been assumed with the majority of impact remaining at the centre of the beach, as occurs under the existing wave climate.

Beach Erosion

As noted above, there has been little change in the beach position since the mining of prior to 1973. Mining of Ocean View Beach foredunes resulted in the most eroded beach position occurring in 1973. This is clearly not representative of the impact of stormy periods on this shoreline. The data from 1981 onwards is insufficient to accurately describe the impact of storms, with the 2007 often the most eroded beach position.

In this case, it is appropriate to adopt the beach erosion values from nearby beaches of similar geomorphology, such as Sandys, Hearnes and Sawtell Beaches. For Ocean View Beach an ‘almost certain’ landward movement of beach position of 15 m, ‘unlikely’ movement of 50 m and ‘rare’ movement of 85 m has been adopted for the beach erosion hazard. For the 2050 and 2100 timeframes, the ‘almost certain’, ‘unlikely’ and ‘rare’ erosion extents are added to the long term recession values at these timeframes, in the manner described in Section 3.4.4.

The extent of beach erosion and shoreline recession on Ocean View Beach at the immediate, 2050 and 2100 planning horizons is illustrated in the Figures Compendium.

Coastal Inundation

There is negligible inundation of back beach areas at Ocean View as there are only minor drainage lines onto the beach sourced from relatively high slopes behind the beach, for the immediate to 2100 planning timeframes.

An explanation of the adopted inundation water levels (‘almost certain’, ‘unlikely’, ‘rare’) at the immediate, 2050 and 2100 planning periods is given in Section 3.5.

The extent of coastal inundation in back beach and low lying areas behind Ocean View Beach at the immediate, 2050 and 2100 planning horizons is illustrated in the Figures Compendium.

Coastal Entrances

There are no significant creek entrances on Ocean View Beach (minor drainage outlets are discussed for the Stormwater Erosion Hazard).

Stormwater Erosion

An informal drainage point is located at the centre of Ocean View Beach and potential erosion at this point is largely encompassed within the beach erosion hazard zones. As discussed in Section 0 the beach erosion hazard extent is measured from landward of the drainage outlet.

Climate change predictions for future rainfall are currently too coarse to confidently estimate local changes in rainfall and runoff and subsequently, to what extent there may be further erosion at outlets / drainage points. However, the approach to defining probability zones for beach erosion has likely captured the potential changes in erosion at drainage points in the future.

Sand Drift

Ocean View Beach is considered to have a low risk of sand drift hazard in terms of either significant sediment losses or nuisance to back beach development. Windborne sediment transport is an important component of the growth and stability of dunes throughout the Coffs LGA.

Title:
Ocean View Beach

Figure:
4-29

Rev:
A

N

0 125 250m

Approx. Scale

BMT WBM
www.wbmpl.com.au

Filepath : K:\N1440 Coffs Coastal Process Hazard Definition Study\MapInfo\Workspaces\DRG_015_100510 Ocean View Beach.WOR

4.19 Arrawarra Headland to Red Rock Headland

Arrawarra Headland is a low, grassy headland comprising 250 million year old shales and slates Short, 2007).

South Corindi Beach as defined by the photogrammetry extends from Arrawarra Headland in the south to 1.3 km past the outlet of Arrawarra Creek in the north. The southern end of the beach, south of the creek mouth, is of shallow gradient, curving to face north east in the lee of the headland. The headland provides increasing protection toward the south, and this is evident in the beach morphology, with a wide, low gradient attached bar cut with occasional rips, typical of a low tide terrace beach type. From the creek outlet towards the north, the beach comprises a double bar system separated by a deep trough. The outer bar has a rhythmic bar and beach morphology and the inner bar is transverse bar and rip morphology. Both sand bars have rips crossing them (Short, 2007).

The far southern end of the beach is comprised of very fine sand sediment, and possible silty sediment from the nearby Arrawarra Creek mouth that, due to the low wave energy in the far southern corner of the beach, has remained deposited on the beach.

Arrawarra Creek entrance lies in the centre to southern end of South Corindi Beach.

Middle Corindi Beach extends from South Corindi Beach northwards to the second of two agglomerations of rocks on the beach face, based upon the photogrammetry cross section layout. Except for the section of shoreline between the two outcrops of beach rocks, the beach morphology is a continuation of South Corindi Beach, comprising a double bar system, with numerous beach rips crossing the inner transverse bar. The energy received along the shoreline increases towards the north, as the shoreline comes out from the lee of Arrawarra Headland.

Extending 350 m between two agglomerations of rocks lies a small section of low energy, coarse grained beach. The low energy morphology is due to two shallow reefs offshore which are linked by irregular shore platforms and rocks in the centre of the surfzone. Wave breaking on this offshore rocky reef reduces the waves to typically < 0.5 m at the shoreline (Short, 2007). Rips often form against the rocks. The sediment is typically medium to coarse sand with some gravel and cobbles. The coarser sediments in combination with the low waves have resulted in a steep beach face with well developed beach cusps, typical of a reflective beach profile.

North of the second collection of bounding rocks lies the entrance to **Pipe Clay Lake**.

North Corindi Beach (sometimes called Red Rock Beach, or Main Beach) extends from the northern boundary of Middle Corindi Beach (a collection of rocks and reef) for 5.2 km to Red Rock Headland. The beach faces southeast, experiencing the full impact of the predominant south easterly wave climate and so, average waves of ~ 1.5 m. A double barred surf zone has developed in response to the higher wave energy environment. The outer bar is rhythmic in shape with widely spaced rips, of transverse bar rip / rhythmic bar and beach morphology. The beach sand is medium to coarse, and as such, the inner bar is often attached to the shore forming a steep beach face. The inner bar typically has a reflective to low tide terrace profile. Permanent rips form along Red Rock

Headland in the north and against a bedrock outcrop located in the surf around 200 m south of Red Rock headland (Short, 2007).

Red Rock headland is a 20 m high red and white coloured outcropping of well bedded jaspers and chert, interbedded with altered basaltic lava (Short, 2007).

The beaches and headlands from Arrawarra to Red Rock are shown in Figure 4-31.

Photogrammetry Data Quality

The 1943 data appears out of alignment with other dates in the southern most block on South Corindi Beach. This data has been excluded from analysis.

The mining lease map indicates that mining may have occurred from the entrance of Arrawarra Creek northwards along Middle Corindi Beach to half way along North Corindi Beach (as shown in Figure 2-1).

Review of photogrammetric cross sections confirms that the far southern end of South Corindi Beach was not mined. It is not certain from the photogrammetric cross sections if mining occurred across Arrawarra Creek entrance as this region is naturally highly variable due to creek outflow processes. Block 3 and the first four profiles of Block 4 lie across the creek mouth. In Block 4, all profiles demonstrate high natural variability. The growth of dunes during the known era of mining (i.e. prior to 1990s) suggests mining did not occur in Block 4, even though it is shown on the mining lease map. Cross sections in Block 5 show evidence of mining between 1943 and 1974, involving the removal of the dune crest. The mined areas have not been included in the analysis of beach volumes.

On Middle Corindi Beach, the impacts of mining are evident in the hinddune region of Block 1 between 1964 and 1974. However, the incipient dune and upper beach face appear unaffected, and have been used in the data analysis (the hind dune region impacted by mining has been excluded). Profile 2 in Block 2 has been mined and it was not possible to avoid the effects in analysing this one profile. In all other profiles mining impacts are less evident (if at all). In Block 3, some profiles appear mined (1,2,3 between 1974 & 1981, 7,10,11 between 1964 & 1973), others appear unaffected. Block 4 does not appear to have been mined.

For Middle Corindi Beach, the impacts of mining were typically on the foredune crest and hinddune region. Areas of mining have been excluded where possible in the data processing, such that all dates and blocks could be included in the analysis.

Blocks 1 to 3 on North Corindi Beach are shown on the mining lease map. However, profile cross sections in all blocks show good consistency in the foredune shape and position between years of known mining and more recent dates. This suggests that if mining did occur, it occurred prior to the first date of photography in 1964. All photogrammetry data from this beach has been analysed.

Long Term Recession

The assessment of the historical beach data indicated that while there have been periods of erosion and recovery along the Arrawarra to Red Rock shoreline, overall the beach is stable. The historical data indicates that this section of shoreline has not been impacted by the construction of Coffs Harbour, some 28 km to the south.

On average, the South Corindi Beach section has been receding slightly by 0.2 m/yr, the Middle Corindi Beach section is stable and the North Corindi Beach section has been accreting slightly by 0.1 m/yr.

The extreme southern end of South Corindi Beach shows little variation in position over time. In part, the beach stability will be underpinned by the existence of “coffee rock” (indurated Pleistocene sands) beneath the dunes at this end of the beach (however, such substrate is not as strong as bedrock and is expected to recede). The extreme southern end faces north east and is in the shadow of Arrawarra Headland, thus receiving very little of the wave energy from the predominant south east direction.

Arrawarra Creek entrance region is highly variable due to wave and also creek outflow processes. The profile cross sections illustrate the changing position and growth and breakout of the entrance berm over time. Immediately north of the creek entrance, the dunes are also affected by creek outflow processes, and possibly an arm of Arrawarra Creek located behind the dunes.

North of the dune region affected by Arrawarra Creek channel, the profile cross sections exhibit slow growth of incipient dunes from 1943 to 1993 (which is the most accreted position). There is severe cut back removing the incipient dunes and scarping the foredune face by 1996 and 2000, with minor recovery by 2007 in some profiles (others have not recovered). An example of this is given by Figure 4-30. This process demonstrates the natural variability of the shoreline over time, as is applicable to the beach erosion hazard. However, the variability also demonstrates that overall the beach position has remained stable, with neither a trend of ongoing recession nor accretion.

Blocks across the Middle Corindi Beach section (not including the effects of mining) also illustrate both accretion and recession relating to storm events. In some cases, more recent profiles are the most eroded in the data however, this is in part due to the impacts of mining where older dune systems have been removed. Overall, the beach is assumed to be stable.

The North Corindi Beach section also exhibits variability in the profiles over time. For example towards the south of this section, the profiles are relatively eroded in 2007, while towards the north, the profiles are accreted in 2007 with the growth of incipient dunes. Overall, this section of beach is also assumed to be stable.

The coastline from Arrawarra Headland to the northern end of Station Beach (north of Red rock) is essentially one sandy compartment. This stretch is relatively uninterrupted by Red Rock headland. Sandbars are observed continuing from North Corindi around Red Rock headland into and along Station Beach to the north. This demonstrates that sediment transport is continuous along this stretch of coastline. Within this expanded compartment, North Corindi Beach is therefore approximately the central beach, or shoreline section.

During the recent period of wave climate, which has tended to promote accretion upon long sandy beaches, there has been only moderate growth of incipient dunes upon North Corindi Beach. North Corindi is the central beach in the compartment, with sediment transferring northwards to Station Beach under average conditions, thus there are lower rates of accretion. Station Beach has experienced significant growth of dune fields since ~ 1976, with sediment sourced from the Arrawarra to Red Rock coastline.

The shoreline response modelling indicates that the Arrawarra to Red Rock section will have remained unaffected by the harbour construction to the present time. This is consistent with the historical data, which demonstrates the beach to have remained stable over time. It is thus considered appropriate to utilise the shoreline modelling results for future long term recession estimates.

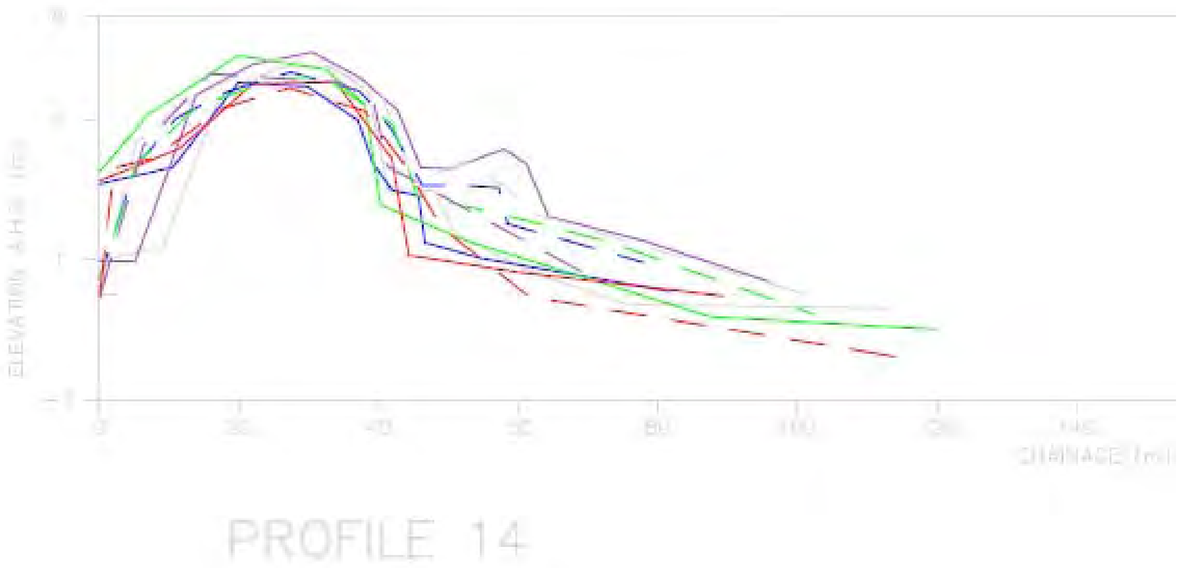


Figure 4-30 Block 4 Profile 14, South Corindi Beach*

**Legend: Purple dashed line – 1943, Red dashed line – 1974, Green dashed line – 1981, Blue dashed line – 1983, Grey dashed line – 1988, Purple – 1993, Red - 1996, Green – 2000, Blue – 2004, Grey – 2007.*

Future Long Term Recession

Without sea level rise, modelling results suggest this shoreline section will remain unaffected by the harbour to 2050. However, there may be very minor impacts (up to 5 m recession) by 2100 in response to the harbour construction by 2100 (without sea level rise).

Shoreline response modelling of the effect of predicted sea level rise of 0.9 m by 2100 suggests shoreline retreat of up to 100 m at South Corindi grading to 40 m at North Corindi Beach. The modelling also indicates that the Middle Corindi Beach section where offshore bedrock reefs are prevalent may experience exacerbated recession of up to 125 m by 2100. This is because with sea level rise there is less dissipation of incoming waves by the reefs, resulting in less protection from waves upon the shoreline behind.

For the ‘rare’ scenario of 1.4 m sea level rise by 2100 respectively, the shoreline response modelling suggests enhanced shoreline recession, with up to 155 m, 190 m and 60 m recession upon South Corindi, Middle Corindi to North Corindi Beaches respectively. The results again demonstrate the impact upon the shoreline of reduced dissipation across the surfzone reefs at Middle Corindi.

The ‘rare’ scenario of a more easterly wave climate was investigated by calculating longshore sediment transport rates for a south easterly (135°) compared with a more easterly (120°) average wave climate. The extreme southern end of Arrawarra Beach faces north east, so there is little transport under a south east wave climate, and enhanced transport under an easterly wave climate. The remainder of the shoreline section (Corindi to Red Rock) is roughly oriented towards the south east. However, there is a connection of sediment transport between Red Rock and Station Beach, meaning this section of the shoreline behaves like a central portion of a long uninterrupted beach. In this case little change in recession extents at Red Rock, and reduced recession at Arrawarra would be expected. Station Beach, at the northern end of the compartment, would be expected to experience enhanced recession under an easterly wave climate.

Beach Erosion

There is some erosion evident in the 1956, 1974 and 1983 profile data however, in general, the profiles at the extreme southern end of South Corindi Beach are very stable over time. The Arrawarra creek entrance was not assessed for dune contour movement, as this region is dominated by creek outflow.

North of Arrawarra Creek, the profile cross sections illustrate removal of incipient dunes and foredune cut back between 1993 and 1996, suggesting a storm period between these years. The 1996 scarp was further eroded by 2000, and this date is the most eroded position on a number of profiles in Block 4. Early dates such as 1956 and 1964 are also relatively eroded for some profiles.

On Middle Corindi, profiles illustrate scarping of the foredune face in 1996 also. Moving northwards along Middle Corindi, the 1974 profile becomes the lowest beach position in the recorded data.

At North Corindi Beach, there are fewer dates of photogrammetry. At different sections of this beach, different dates appear as the most eroded beach position. For example, 1985 and 1996 appear as most eroded in Block 1, in Block 2 and 3 the 2007 position is most eroded and by Block 4 and 5 in the north, 1973 and 1964 appear highly eroded. This illustrates that different storm events affect different regions of the beach at any one time, because of the different wave height and directions and different antecedent beach conditions.

For some profiles in all beach sections, the 2007 beach position is currently the most landward in the recorded data. It is prudent to assume that further erosion may occur in the future, depending upon the wave height and direction.

It is likely that the numerous rock reefs in the surf zone offshore of this shoreline are in part the reason for such variation in the impacts of the different storm periods along the shoreline. The reefs will refract and dissipate incoming wave energy, and the area of shoreline behind the reef that is protected or impacted will vary depending upon wave height, wave direction and water levels during the storms. Across the entire length of beach, however, there appears to have been a highly erosive period in 1996, as scarping of the foredunes is seen in this year at many locations along the beach.

Beach erosion hazard extents were analysed for each of the three beaches, as consistent with the observed impact in the historical data. The analysis considered the movement of the 4 m AHD contour position between the 2007 and most eroded data and the movement of the beach position derived from profile volume data for each beach, as given in Table 4-1.

Based upon the assessment of historical data and an understanding of coastal processes along this shoreline, the following probability zones for beach erosion hazard in an immediate timeframe have adopted:

- An ‘almost certain’ probability of 15 m, ‘unlikely’ probability of 50 m and ‘rare’ probability of 85 m landward movement of South Corindi Beach;
- An ‘almost certain’ probability of 20 m, ‘unlikely’ probability of 55 m and ‘rare’ probability of 90 m landward movement of Middle Corindi Beach; and
- An ‘almost certain’ probability of 25 m, ‘unlikely’ probability of 60 m and ‘rare’ probability of 95 m landward movement of North Corindi Beach.

Table 4-1 Difference between Most Eroded and 2007 Beach Position

	4m AHD contour		Beach volume converted	
	Average (m)	**Maximum (m)**	**Average (m)**	**Maximum (m)**
South Corindi Beach	8	48	12	34
Middle Corindi Beach	6	15	14	34
North Corindi Beach	15	35	20	47

For the 2050 and 2100 timeframes, the ‘almost certain’, ‘unlikely’ and ‘rare’ erosion extents are added to the long term recession values at these timeframes, in the manner described in Section 3.4.4.

The extent of beach erosion and shoreline recession on the Arrawarra – Corindi – Red Rock coastline at the immediate, 2050 and 2100 planning horizons is illustrated in the Figures Compendium.

Coastal Inundation

The coastal inundation extents are extensive behind the Arrawarra to Red Rock coastline. Connection with the ocean via Arrawarra Creek may allow for inundation of the caravan park and other development along the northern arm of the creek as ‘almost certain’ within the immediate timeframe. By 2100 further land area and developed area adjacent to the caravan park has a ‘rare’ likelihood of occurrence.

Pipe Clay Lagoon at the southern end of North Corindi Beach is also a connection allowing ‘almost certain’ inundation of a small area of back beach, with an increase in the area affected by a ‘rare’ probability of inundation by 2100. The inundation extents do not affect any developed areas.

An expanse of low lying land 0.5 to 1 km behind North Corindi Beach has an ‘almost certain’ likelihood of inundation within the immediate timeframe via Corindi River, which connects with the ocean north of Red Rock Headland. By 2100, there is a ‘rare’ possibility of the extent of inundation expanding, such that the northern arm of Pipe Clay Lagoon connects with the southern end of impacts from Corindi River. A small drainage line on North Corindi Beach also may allow for minor inundation of low lying back beach area by 2100.

An explanation of the adopted inundation water levels (‘almost certain’, ‘unlikely’, ‘rare’) at the immediate, 2050 and 2100 planning periods is given in Section 3.5.

Coastal Inundation for the immediate, 2050 and 2100 horizons are mapped for the entire Coffs LGA in the Figures Compendium.

Coastal Entrances

Arrawarra Creek is located at the southern end of South Corindi Beach, and while it is often found to be open, it does close on occasion. Thus, an assessment for closed conditions has been undertaken. Pipe Clay Lagoon entrance is located towards the centre of the compartment, in the lee of rocks separating Middle and North Corindi Beaches. It is typically closed.

In response to a rise in sea level, in similar manner as the recession of the shoreline, it is anticipated that entrance berms will also move upward and landward. The extent of height increase will be equivalent to the rise in sea level rise, i.e. 0.4 m by 2050 and 0.9 m by 2100.

There was only suitable photogrammetric data to assess entrance berm heights over time at Arrawarra Creek. The assessment determined the berm height to reach 1.5 m AHD on average, and a maximum of 2.4 m AHD. The extreme scenario adopted for all coastal lagoons is 3.5 m AHD, and relates to the potential height of incipient dunes should an entrance remain closed over a longer period (decades). The ‘almost certain’, ‘unlikely’ and ‘rare’ probability berm heights for Arrawarra Creek at the immediate, 2050 and 2100 timeframe are given in Table 3-8. Further discussion of the response of entrances to sea level rise and derivation of the probable berm heights is given in Section 3.6.

The climate change projections for future annual rainfall and rainfall intensity are at present inconclusive. Thus, it is not yet possible to determine potential changes to the entrance condition in response to climate change induced changes to rainfall.

Erosion of coastal entrance berms (and immediately adjacent regions) is included within the beach erosion and shoreline recession hazard for all planning periods. As noted in Section 3.3, the beach erosion extent is measured landward of all coastal entrance berms. This is because the photogrammetric data at all entrances in the Coffs region demonstrates that erosion of the entire berm occurs consistently in the past.

Stormwater Erosion

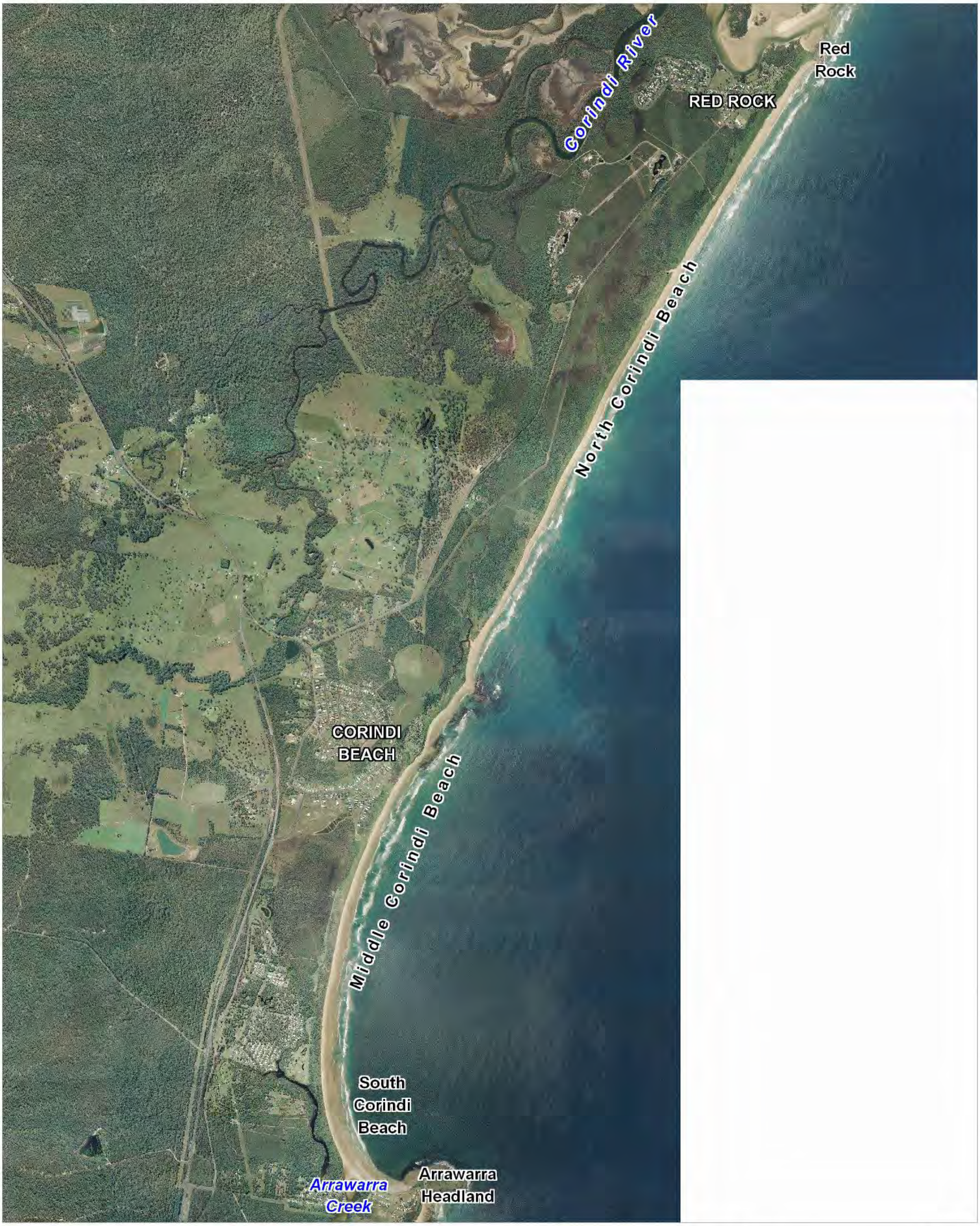
Arrawarra Creek at South Corindi and Pipe Clay Lagoon and Middle Corindi are discussed within the Coastal Entrance Hazard.

There is additionally a small drainage creek at the centre of North Corindi Beach. As noted in Section 0, erosion at this location is largely included within the beach erosion hazard zones, as the hazard extent is measured from landward of the drainage outlet.

Climate change predictions for future rainfall are currently too coarse to confidently estimate local changes in rainfall and runoff and subsequently, to what extent there may be further erosion at outlets / drainage points. However, the approach to defining probability zones for beach erosion has likely captured the potential changes in erosion at drainage points in the future.

Sand Drift

Arrawarra, Middle Corindi, North Corindi to Red Rock Beaches are considered to have a low risk of sand drift hazard in terms of either significant sediment losses or nuisance to back beach development. Windborne sediment transport is an important component of the growth and stability of dunes throughout the Coffs LGA.



Title:

Corindi Beach (South, Mid, North) from Arrawarra to Red Rock

Figure: 4-31

Rev: A

N

0 1 2km

Approx. Scale

BMT WBM

www.wbmpl.com.au

Filepath : K:\N1440 Coffs Coastal Process Hazard Definition Study\MapInfo\Workspaces\DRG_016_100510 Corindi Beach.WOR

4.20 Station Beach and Pebbly Beach

Corindi River exits to the ocean along the northern side of Red Rock Headland.

Red Rock North Beach, or Little Beach, is a 200 m section of beach between Red Rock and the Corindi River mouth. The beach is protected from south-east swell by Red Rock Headland, however, strong tidal flows from the Corindi River mouth form deep channels through the surf zone, particularly when the tide is ebbing out. The beach usually has a wide low bar and tidal shoals, as well as outflow channels (Short, 2007).

Station Beach extends 4 km from the mouth of the Corindi River to a series of rocks and the entrance to Station Creek. The beach is oriented south-east, before trending to face more south at its northern end. The beach is highly exposed to the predominant high energy south east wave climate and has developed a double sand bar configuration, with rips across the inner bar, and more widely spaced rips cutting the outer bar (Short, 2007). The outer bar is continuous from North Corindi Beach past Red Rock Headland and along the length of Station Beach.

Station Creek entrance is located at the northern end of Station Beach, in the lee of outcropping reef and rocks.

Pebbly Beach is an east facing arc of 900 m length extending northwards from the reef and rocks at Station Creek. The beach is composed of coarse sand and gravel. The northern half of Pebbly Beach has a continuous sand bar which is occasionally cut by rips. The bar narrows to the south, while the beach face steepens, as wave energy decreases towards the south in the lee of the southern rocks. Pebbly Beach lies within the Yuraygir National Park (NP) (Short, 2007).

Station Beach and Pebbly Beach are illustrated in Figure 4-33.

Photogrammetry Data Quality

The mining paths map indicates that the entire beach region of Station Beach was mined (refer Figure 2-1). Review of the photogrammetry cross sections indicate mining in the hind dune region, which has been excluded from data analysis. It is also possible that mining occurred prior to the first date of available photogrammetry (1966).

Long Term Recession

Station Beach forms the northern-most beach within a sandy compartment extending from Arrawarra Headland past Red Rock headland to the northern end of Station Beach. The connection of sediment transport along this stretch of coastline has allowed for extensive accretion on Station Beach, particularly towards the northern end, in part from sediment sourced from the southern beaches. The rate of change is on average 0.9 m/yr accretion across the entire beach.

The southern end of the beach is affected by the Corindi River entrance with profile cross sections illustrating an accreted entrance berm and adjacent dunes in 1978, which has been progressively cut back by 2000. This region of the beach is affected by creek outflow and movements of the river channel, in addition to coastal processes.

Immediately north of the creek influence the dune position appears more stable, with movement both landward and seaward between years. Moving northwards along the beach, accretion in the form of the seaward growth of incipient dunes becomes increasingly evident and extensive. By the northern end of the beach there has been of the order of 100 m increase in beach width between 1978 and 2007. Rates of accretion of up to 2.8 m/yr were measured at the northern end of the beach.

Wave climate conditions over the past 30 years have been observed to promote accretion upon other sandy beaches in the Coffs region, for example, Bongil and Moonee Beaches. Station Beach demonstrates the most extensive dune and beach growth in the Coffs region (excluding Boambee Beach which is affected by the harbour). The northerly directed sediment transport along the Arrawarra to Red Rock beaches in the south will have assisted to supply sediment into Station Beach. There are likely to be nearshore sediment sources which have additionally supplied Station Beach via cross shore sediment transport from swell wave action.

The current trend of accretion on Station Beach is assumed to be a response to recent decades of wave climate, rather than an ongoing trend relating to an increase in sediment sources/supply. Were wave climate conditions to change, we may observe a reversal of these trends. Overall, Station Beach is assumed to be stable.

The shoreline response modelling indicates there to be no change in shoreline position at Station Beach in response to the harbour construction, and this is consistent with the findings in the historical data. The use of model results for sea level rise is considered appropriate to predict future long term recession.

There is no photogrammetric data for Pebbly Beach. The shoreline response model results have been used to determine recession hazards for Pebbly Beach, given that model results have been consistent with the photogrammetric data at other locations in Coffs. The shoreline modelling results for Pebbly Beach suggest it has not been affected by the harbour construction, and has remained stable over time.

Future Long Term Recession

Without sea level rise, the modelling results suggest the harbour construction will not have an impact upon Station Beach by 2100, and the beach will remain stable.

Modelling of the effects of predicted sea level rise suggest 70 to 25 m of recession from south to north along Station Beach with a 0.9 m rise by 2100.

For the ‘rare’ case of 1.4 m sea level rise by 2100, the extents of recession may be expected to increase upon Station Beach, to up to 125 m at the southern end and 40 m at the north. The modelling demonstrates that as sea level rises, Red Rock headland increasingly acts to separate Red Rock and Station beaches, interrupting the transport of sediment between the beaches and exacerbating recession upon Station Beach, starting at the southern end.

Comparison of longshore transport rates for a south easterly and easterly wave climate indicates there may be a complete reversal of transport direction upon south-south east facing beaches. Station Beach lies at the northern end of a long stretch of coastline oriented towards the south east. We may expect a reversal of recession rates at Station Beach, to become similar to that found near to Arrawarra creek at the southern end of the compartment. That is, we may expect recession of up to 70 m at the northern end of Station Beach under the 'rare' case of a more easterly wave climate.

On Pebbly Beach, without sea level rise the modelling suggests the beach would remain the same, that is unaffected by the harbour, by 2100. Based upon the shoreline modelling results, with predicted sea level rise of 0.9 m by 2100, 65 to 55 m recession from south to north along the beach is expected. In the 'rare' case of a 1.4 m sea level rise by 2100, the modelling suggests up to 100 m recession on Pebbly Beach. Pebbly Beach is oriented towards the east, thus in the 'rare' scenario of a more easterly wave climate, we would expect minimal change in recession extents along the beach would be expected.

Beach Erosion

Photogrammetric profiles that are affected by creek entrances are excluded from the assessment of beach erosion, as the creek entrance process will obscure the effects of wave induced erosion. This includes Block 1 in the south (Corindi River), a central creek profile, and Block 6 in the north (Station Creek). Discussion of profile cross sections for these regions is given, however.

Block 1 next to Corindi River is relatively accreted in 1978 then progressively eroded to 2000 (and 2007). The southern end of Block 2 also exhibits erosion between the accreted 1978 position and 2000, with some recovery by 2007. However, moving northwards, the 1978 position becomes the most eroded position on the beach, followed by progressive accretion to 2007. Blocks 3, 4 and 5 also show this trend, with a highly eroded foredune scarp in 1978 then progressive accretion in front of the foredunes by 2007, e.g. (Figure 4-32). The growth of incipient dunes is extensive with ~ 100 m accretion between 1978 and 2007, particularly in Block 5. Block 6 across Station Creek also exhibits a large increase in berm width and height between 1978 and 2007.

Analysis of the movement of the 4 m AHD contour position over time demonstrates that there is on average 53 m and a maximum of 140 m landward movement between the 2007 and most eroded profiles. Analysis of beach width based upon beach volumes gives similar results. This analysis does not include the creek regions because erosion of entrance berms is affected by creek outflow, not just beach erosion. For example, within the creeks up to 500 m movement of beach position has been measured.

For beach erosion on Station Beach, the adopted values are 70 m as 'almost certain', 150 m as 'unlikely' and 230 m as 'rare' landward movement of the 4 m AHD contour position within the immediate timeframe.

There is no photogrammetry data on Pebbly Beach. Given its similar orientation and headland control, beach erosion extents from Sawtell have been adopted for Pebbly Beach (i.e. 'almost certain' likelihood of 15 m, 'unlikely' likelihood of 50 m, and 'rare' likelihood of 85 m landward movement of the beach position in an immediate timeframe).

For the 2050 and 2100 timeframes, the 'almost certain', 'unlikely' and 'rare' erosion extents are added to the long term recession values at these timeframes, in the manner described in Section 3.4.4.

The extent of beach erosion and shoreline recession on Station and Pebbly Beaches at the immediate, 2050 and 2100 planning horizons is illustrated in the Figures Compendium.

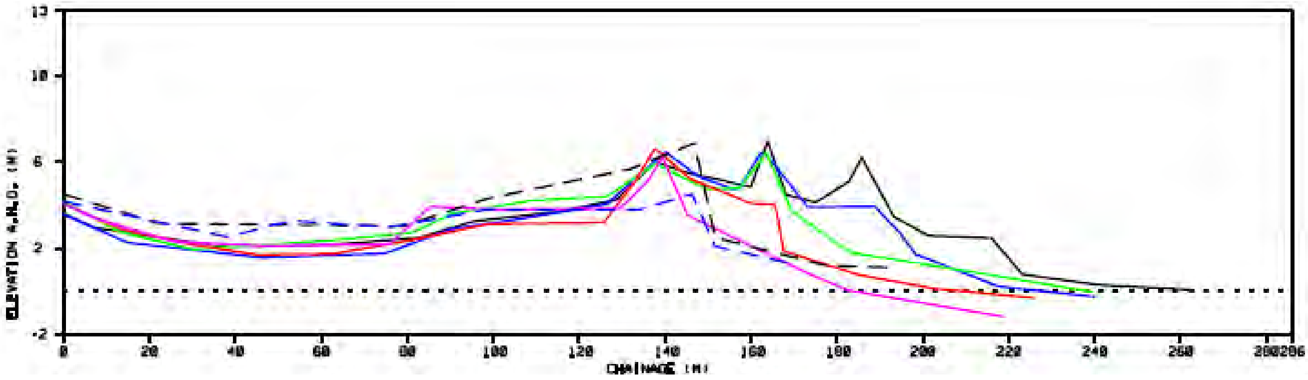


Figure 4-32 Block 4 Profile 6, Station Beach*

**Legend: Blue dashed line – 1966, Black dashed line – 1973, Pink – 1978, Red – 1985, Green – 1993, Blue – 2000, Grey – 2007.*

Coastal Inundation

There is a very large expanse of area affected by 'almost certain' coastal inundation via the Corindi River entrance to the ocean, extending largely westward and southward of the entrance, over the immediate timeframe. The area of land affected by inundation under an 'unlikely' and 'rare' scenario is expanded moderately by 2100, and may connect with Pipe Clay Lagoon in the south in a 'rare' scenario. At the immediate to 2100 timeframes, there is little development affected by inundation.

Inundation of a moderate expanse of low lying areas of the Yuraygir National Park behind Station Beach via Station Creek and a small drainage point at the centre of the beach is also 'almost certain' in an immediate timeframe. By 2100, there is minimal expansion of the area that is 'unlikely' or of 'rare' likelihood to be affected.

An explanation of the adopted inundation water levels ('almost certain', 'unlikely', 'rare') at the immediate, 2050 and 2100 planning periods is given in Section 3.5.

The extent of coastal inundation in back beach and low lying areas behind Station and Pebbly Beaches at the immediate, 2050 and 2100 planning horizons is illustrated in the Figures Compendium.

Coastal Entrances

Three creek systems traverse Station Beach, namely Corindi River, Station Creek and an unnamed creek in the centre of the beach. Both Corindi River and Station Beach remain typically open, with the unnamed creek typically closed.

The recession of the shoreline in response to sea level rise at the southern end of Station Beach will certainly be greater than at the northern end of the beach. It is not certain if there may be increased constriction of Station Creek at the northern end, due to the vertical movement of the beach position with sea level rise. At Corindi River, there are likely to be changes in the entrance position with sea level rise. There is some bedrock outcropping along the entrance channel, although it is not certain how far bedrock may underlie the channel region. If bedrock is extensive, an increase in sea levels would reduce flow velocities through the entrance during open conditions, and enable some sediment deposition and entrance constriction. However, it is not certain if this would be of sufficient volume to close the entrance.

The berm position on the unnamed creek is anticipated to move upward and landward in response to sea level rise, by an equivalent amount, i.e. 0.4 m by 2050 and 0.9 m by 2100.

There was one suitable photogrammetric profile to assess entrance berm heights over time at the unnamed creek. The assessment determined an average berm height of 1.6 m AHD and a maximum of 2.7 m AHD. The extreme scenario adopted for all coastal lagoons is 3.5 m AHD, and relates to the potential height of incipient dunes should an entrance remain closed over a longer period (decades). The ‘almost certain’, ‘unlikely’ and ‘rare’ probability berm heights for the unnamed creek at the immediate, 2050 and 2100 timeframe are given in Table 3-8. Further discussion of the response of entrances to sea level rise and derivation of the probable berm heights is given in Section 3.6.

The climate change projections for future annual rainfall and rainfall intensity are at present inconclusive. Thus, it is not yet possible to determine potential changes to the entrance condition in response to climate change induced changes to rainfall.

Erosion of coastal entrance berms (and immediately adjacent regions) is included within the beach erosion and shoreline recession hazard for all planning periods. As noted in Section 3.3, the beach erosion extent is measured landward of all coastal entrance berms. This is because the photogrammetric data at all entrances in the Coffs region demonstrates that erosion of the entire berm occurs consistently in the past.

Stormwater Erosion

Three creek systems traverse Station Beach, namely Corindi River, Station Creek and an unnamed creek in the centre of the beach. These systems deliver rainfall runoff across the beach and are discussed as part of the Coastal Entrance hazard. There are no stormwater drainage points on Station Creek.

Sand Drift

Station Beach, being a large and unconfined beach is likely to experience significant wind blown transport, as evidenced by the extensive growth of incipient dunes over recent decades. Aeolian sediment transport has allowed for storage of beach volumes within the incipient region. Station Beach is not considered at risk of sand drift hazard in terms of either significant sediment losses (with typically vegetated back beach areas that capture and store sediment) or nuisance to back beach development (as the beach lies within Yuraygir NP).

Title:

Station Beach and Pebbly Beach

Figure:

4-33

Rev:

A

BMT WBM
www.wbmpl.com.au

Filepath : K:\N1440 Coffs Coastal Process Hazard Definition Study\MapInfo\Workspaces\DRG_017_100510 Station Beach.WOR

A part of BMT in Energy and Environment

Coffs Harbour Coastal Processes Progress Report

R.N1440.001.00.CoastalProcesses_submitted2.doc
Draft Progress Report
September 2009

Coffs Harbour Coastal Processes Progress Report

Offices

Brisbane
Denver
Karratha
Melbourne
Morwell
Newcastle
Perth
Sydney
Vancouver

Prepared For:	Coffs Harbour City Council
Prepared By:	BMT WBM Pty Ltd (Member of the BMT group of companies), with assistance by Climate Risk CORE, Macquarie University

DOCUMENT CONTROL SHEET

BMT WBM Pty Ltd BMT WBM Pty Ltd 126 Belford Street BROADMEADOW NSW 2292 Australia PO Box 266 Broadmeadow NSW 2292 Tel: +61 2 4940 8882 Fax: +61 2 4940 8887 ABN 54 010 830 421 003 www.wbmpl.com.au	***Document :*** R.N1440.001.00.CoastalProcesses_submitted2.doc ***Project Manager :*** Philip Haines ***Client :*** Coffs Harbour City Council ***Client Contact:*** Martin Rose ***Client Reference***

Title :	Coffs Coast Coastal Process Progress Report
Author :	Verity Rollason, Ian Goodwin (Macquarie University)
Synopsis :	This document provides a description of the coastal processes along the Coffs Coast. It also describes local projections for climate change particularly in relation to waves and water levels. A beach by beach description of historical data is also provided.

REVISION/CHECKING HISTORY

REVISION NUMBER	DATE OF ISSUE	CHECKED BY		ISSUED BY	
0	Sept 09	PEH / DCP		PEH	

DISTRIBUTION

DESTINATION	REVISION			
	0	1	2	3
CHCC	1 +elec			
BMT WBM File	1			
BMT WBM Library	1			

ACKNOWLEDGEMENT

Macquarie University, Climate Risk CORE, provided assistance to sections of this document, notably parts of Sections 3.2.4, 3.2.5, Chapter 4 and Section 5.5.

MACQUARIE UNIVERSITY

CONTENTS

LIST OF FIGURES

LIST OF TABLES

1 INTRODUCTION

The Coffs Harbour Coastal Processes and Hazards Definition Study project shall outline the coastal processes operating on the Coffs Harbour coastline, which shape the morphology of the shoreline and determine the extent of the coastal hazards. This progress report provides preliminary findings on coastal processes and geomorphology, specifically regarding:

- the regional geology of the Coffs coastline;
- the coastal processes operating along this coastline;
- the interaction of coastal processes and geology to shape the shorelines we observe today; and
- climate change and predicted impacts on coastal processes.

Particular discussion is given to variability in the wave climate (wave height and direction), sea level and elevated ocean levels, driven by climatic anomalies such as the El Nino Southern Oscillation (ENSO) and the Interdecadal Pacific Oscillation (IPO). Variability in the wave climate in turn drives changes in the shoreline alignment and width. Natural variability in the shoreline morphology will only add to the possible/probable extent of coastal hazards, and must be incorporated into our assessment of hazard impacts, and to mitigate such impacts through coastal planning.

This report also outlines recent predictions of climate change which shall modify the future wave climate (wave height and direction), sea levels, storm surge water levels, wind climate and rainfall. Preliminary findings on predicted changes to coastal processes in response to climate change are also detailed in this report.

The mid north coast is expected to experience a population growth rate of ~ 1.1% per year over the next 25 years, a total growth of 28%. This growth rate is amongst the highest in regional NSW, with Coffs Harbour expected to experience one of the highest proportions of this population pressure (DP, 2009). Residential growth to accommodate the increasing population in the Coffs region is to occur within mapped urban areas, with Coffs Harbour as a regional centre and Woolgoolga as a major town in the Mid North Coast region (DP, 2009). Existing and future development (residential and recreational) within the coastal zone will require protection from existing coastal hazards, and appropriate planning to accommodate the future extent of coastal hazards, including climate change impacts.

The subsequent Coffs Harbour Coastal Processes and Hazards Definition Study report will detail final conclusions regarding our understanding of coastal processes, as well as provide a probabilistic estimate for coastal hazard extents in the present, and in the future under a future climate. In addition to a traditional assessment of recession due to sea level rise, the study will utilise recent predictions on the impact of climate change upon wave climate (wave height, wave direction), sea level and storm surge (elevated water levels) to provide a probably of the extent of each of the coastal hazards in the future. The extent of coastal hazards will be defined by probabilities in the immediate, 50 and 100 year planning periods, to enable Coffs Harbour City Council to manage coastal hazards within a probabilistic risk based framework.

This Coffs Harbour Coastal Processes Progress report is set out as follows:

Chapter 2 provides an outline of the regional geology and coastal evolution of the Coffs Harbour coastline

Chapter 3 describes the active coastal processes along the Coffs Coastline

Chapter 4 outlines the interaction of coastal processes and geology which has shaped the Coffs coastline to the present

Chapter 5 discusses the most recent climate change predictions for a range of parameters, and which will vary coastal processes in the future.

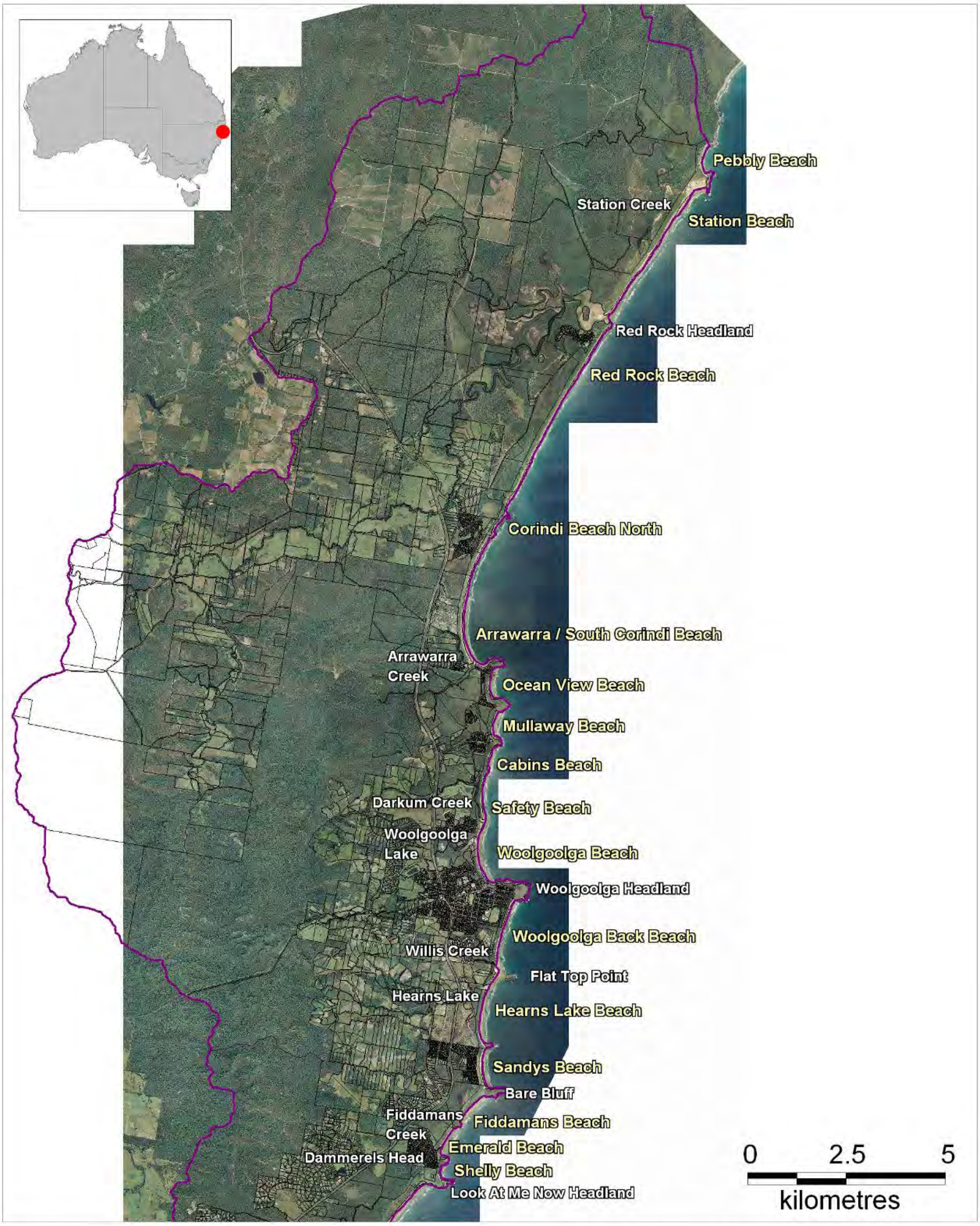
Chapter 6 provides a background data overview for each of the individual beaches of the Coffs coastline

1.1 Study Area

The Coffs Harbour Local Government Area (LGA) is situated on the NSW coast approximately half way between Sydney and Brisbane. Coffs Harbour township is approximately 540 km north of Sydney and 400 km south of Brisbane. The Coffs Harbour LGA coastline and its beaches are illustrated in Figure 1-1 and Figure 1-2.

The Coffs LGA coastline is 79 km in length, which includes 38 beach embayments (Short, 2007). Of these, 31 beach embayments lie within the Solitary Islands Marine Park (SIMP), which extends from Muttonbird Island at Coffs Harbour to north of the Coffs LGA.

Many of the Coffs Harbour beaches also lie within land based reserves, namely: Yuraygir National Park which includes Pebbly Beach and Station Beach; Bongil Bongil National Park which covers Bongil Beach and North Beach; Coffs Coast Regional Park, which incorporates beaches from Woolgoolga Back Beach to Charlesworth Bay; Moonee Beach Nature Reserve, which includes Moonee Beach and Fiddamans Beach; and Muttonbird Island Nature Reserve, which includes Muttonbird Island (but no beaches).



Title:

Coffs Harbour LGA Study Area
Northern Half

Figure:

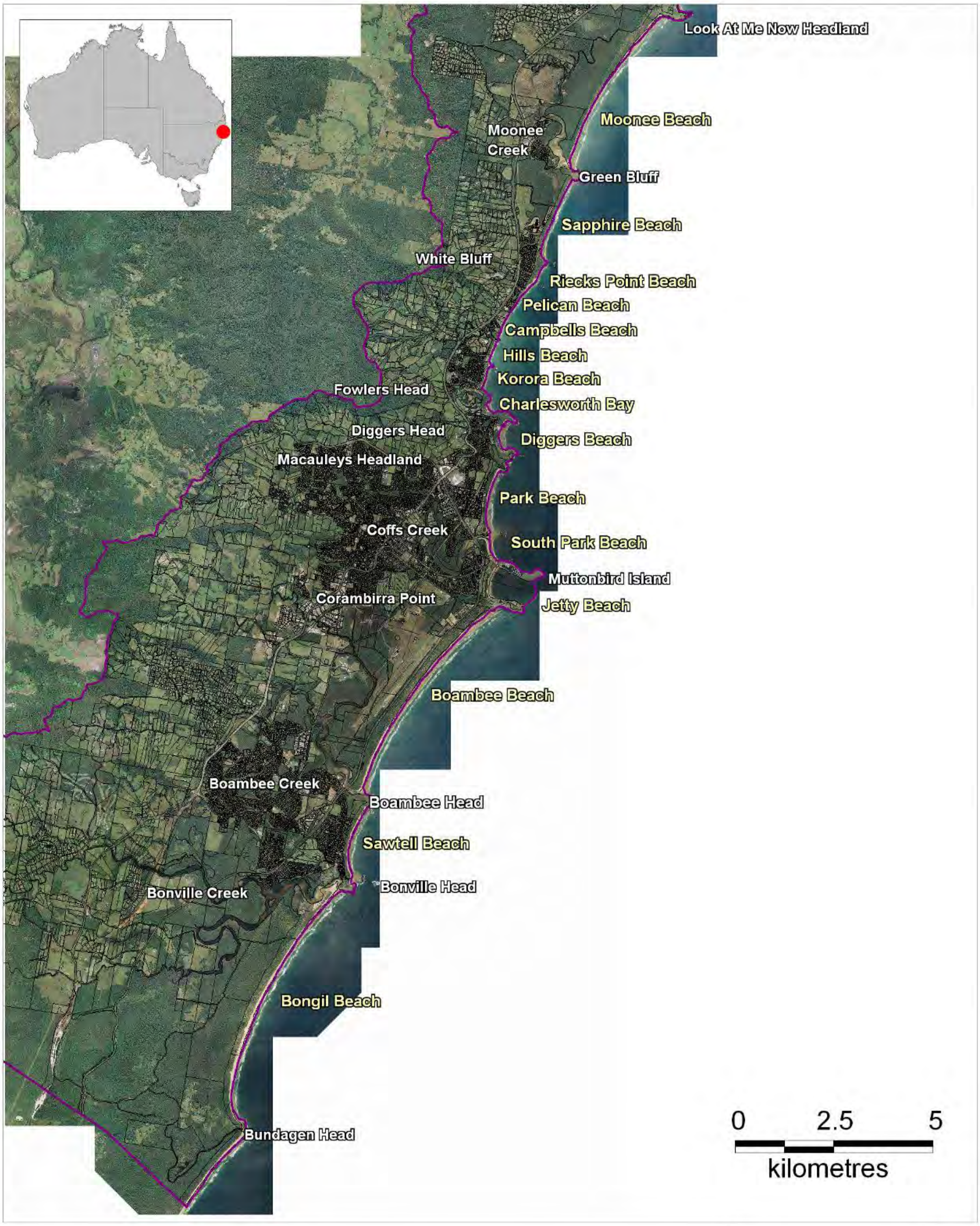
Rev:
A

N

BMT WBM
www.wbmpl.com.au

Filepath :

Figure 1-1 Coffs Harbour LGA Study Area North



Title:

Coffs Harbour LGA Study Area
Southern Half

N

Figure:

Rev: A

www.wbmpl.com.au

Filepath :

Figure 1-2 Coffs Harbour LGA Study Area South

2 REGIONAL OVERVIEW

2.1 Introduction

Regional geology determines the orientation of the coastline, the width and slope of the continental shelf, the type and location of headlands, reefs and other structures, embayment width and sediments. The interaction of coastal processes, sea level and regional geology determines the shape of the past, present and future shorelines and coastal barriers.

This section contains information on the geological and geographic constraints on coastal evolution of the Coffs Harbour regional coastline. There have been few coastal and marine geological studies specifically on the Coffs Harbour LGA region. Most of the related marine geological studies on the evolution of the continental shelf and shoreface bathymetry and sediments have been conducted on the NSW Central to Lower North Coast (Newcastle to Tuncurry) and on the north coast (Yamba to the Queensland border, Roy, 1982). Available data for the Coffs Harbour coastline includes an overview of the Quaternary coastal geology presented in Troedsen et al. (2004). The coastal and marine geomorphology and sediment distribution of the Coffs Harbour coastline was reported by Roy and Stephens (1980a and 1980b), and the Quaternary Geology of the coast and inner shelf specifically along the Coffs Harbour regional coast is reported in Stephens and Roy (unpublished draft NSW Geological Survey report).

2.2 Regional Geology

Broadly, the NSW coast is described as being strongly controlled by bedrock, which outcrops as headlands, rock platforms and cliffs. The bedrock outcrops are interrupted by embayments and valleys which are filled to various amounts with unconsolidated sediments, mostly of Quaternary (Pleistocene and Holocene) age.

Moving northwards along the NSW coast, there is a general increase in the embayment length, extent of Quaternary barrier deposits and width of the continental shelf. However, within the Coffs Region, this is less apparent. Coffs Harbour is within the New England Fold Belt province (Troedson et al, 2004), unlike the regions immediately north and south. Bedrock in the Coffs region is a highly deformed paleozoic meta-sedimentary rock (Troesden *et al.,* 2004). The coastal embayments of the Coffs region are described as small to narrow, to medium sized. Either side of the Coffs region, the coastal embayments are medium to large and broad. This highlights the role of bedrock geology in controlling the character of the Coffs Coast, and consequently, the beach morphology which has evolved.

The Coffs coastline is shaped by the meta-sedimentary bedrock, which outcrops as headlands, cliffs, rock platforms, and low relief rock reefs (Skene and Roy, 1985), as they spur from the coastal ranges to the coastline, forming numerous beach embayments. North of Red Rock, there is an obvious change in the coastline character, in line with the change in geology. North of Red Rock, there are very few headland protrusions, and instead, the low relief coastline comprises long stretches of sandy beach and mostly infertile Pleistocene coastal dunes (Short, 2007).

The coastal plain of Coffs Harbour is traversed by a number of small streams, which originate in the coastal ranges and flow across the narrow alluvial plains towards the sea. Most of these streams form lagoons and swamps behind the beach and dunes, with the mouths of the streams closed to the sea by accumulated marine sediment (Binnie and Partners, 1987).

The continental shelf of NSW is the narrowest continental margin along the entire Australian coast (Short, 2007), up to 50 km in width (Troesden et al, 2004). This affects the dissipation and shoaling of waves as they are transformed from deep water into the nearshore zone. (Troedson et al, 2004).

2.2.1 Coastal Evolution due to Sea Level in the Late Quaternary

Sea level fluctuations during the late Quaternary period have impacted upon the Australian continental margin and subsequently shaped the coastline observed today. The last sea level high stand occurred during the Pleistocene around 120,000 years ago (the Last Interglacial period, 117,000 to 133,000 yr BP), with sea levels around 5 m above their present levels (Troedson *et al.*, 2004).

The last glacial period between 25,000 and 15,000 years ago saw sea levels around 110-130 m below their present level. After this, sea levels rose rapidly and reached the present level around 6,500 years ago, in the Holocene. Sea levels have remained within 1 -2 m of their present levels since this time (Troedson *et al.,* 2004). The ~ 1 m fluctuation of sea levels during the late Holocene has also played a role in the current coastal character, as described in Section 4.1.1.

Typically, coastal barriers evident on the coast today have formed in response to the Pleistocene and Holocene sea level high stands. The barriers formed during the Pleistocene are still evident in some locations along the NSW coast, having formed during higher sea levels than present, and are termed inner barrier deposits. Holocene beach barrier systems are typically termed the outer barrier. (Troedson *et al.,* 2004).

2.2.2 Shoreface and Shelf Bathymetry

The active shoreface (or nearshore zone) is said to extend from the shoreline to water depths of 20 – 30 m. Shoreface bathymetry is divided into 3 zones:

i) surf zone from 0 to 5 m water depth, extending from the beach berm to the outer bar;

ii) inner nearshore zone from 5 to 12 m depth; and

iii) outer nearshore zone from 12 to between 20-30 m depth.

The boundary between the nearshore zone and the inner shelf is said to extend seawards from depths of 20-30 m. The boundary between nearshore and inner shelf sediments is said to be the boundary between the active and relict shoreface.

The nearshore zone has a typical concave up profile with slopes of 9%, whilst the inner shelf is a gently sloping plain with slopes of 1% (Stephens and Roy, unpublished Geological Survey of NSW, 1980 report). Lord and Van Kerkvoort (1981) also stated the nearshore bathymetry from Sawtell to White Bluff to be flatter than in other regions of similar exposure and orientation in NSW. WP

Geomarine (1998) state that the Campbells Beach nearshore zone between the 0 and 20 m contour has slopes of 1:100 to 1:175, and is one of the flattest nearshore zones in NSW.

Other studies in the area have suggested boundary between Inner and Outer Nearshore sands (relative to AHD) (which is taken to be analogous to the depth of closure) to be:

- 11 m in vicinity of Coffs Harbour (PBP (2004) quoting Stephen, 2004)
- 10 m in Byron Bay area (PBP (2004) quoting Nielsen, 1994)
- 11 m in Lennox Head area (PBP, 2004)
- 11 m in Evans Head area (PBP, 2004)

2.2.3 Regional Coastline Alignment and Sub-Compartments

The regional coastline alignment trends south west to north east with a south easterly orientation of 120 to 130°, and a more easterly orientation (90 to 100°) between Bare Bluff and Arrawarra Headland. The regional coastline is divided into four sub-compartments for analysis in this report. The division was based on the alignment and sediment budget data. These are:

- Sub-compartment 1 – Urunga (south of Bundagen Head) to Corrambirra Point;
- Sub-compartment 2 – Corrambirra Point to Look at Me Now Headland;
- Sub-compartment 3 – Look at Me Now Headland to Arrawarra Headland; and,
- Sub-compartment 4 – Arrawarra to Station Beach.

The sub-compartments are illustrated in Figure 2-1.

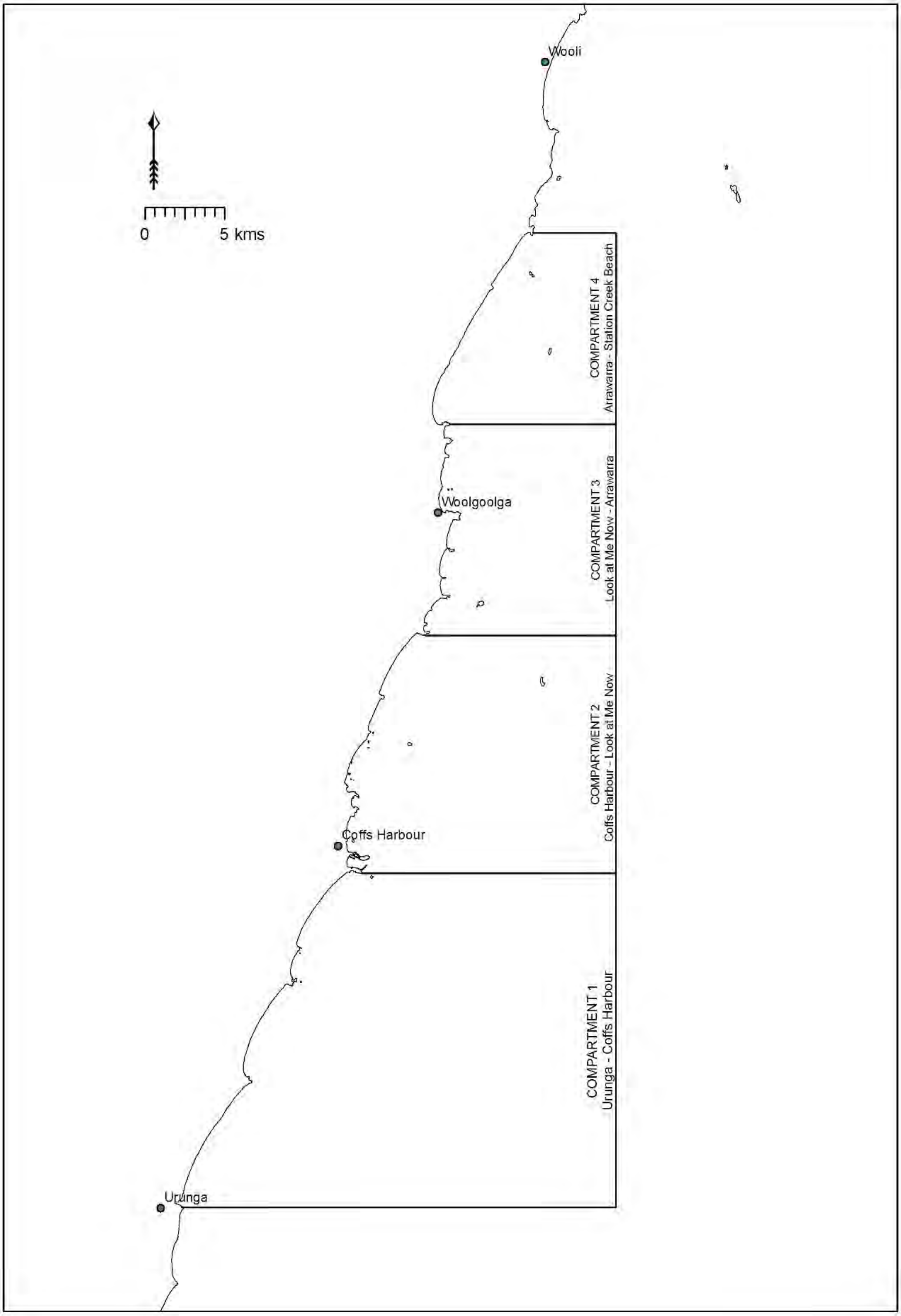


Figure 2-1 Sub-compartments of the Coffs Coastline

2.2.4 Coastal Geomorphology and Sediments

The Quaternary coastal geology of the four sub-compartments is shown in Figure 2-2 to Figure 2-6, from Troedsen *et al.* (2005). The Coffs regional coastline is typically:

- a multiple sand barrier and estuary type coastline with extensive outcrops of rock reefs offshore from the headlands between Bundagen Headland and Coffs Harbour (sub-compartment 1);
- smaller pocket or embayed beaches, with an increase in offshore rock reefs north of Coffs Harbour to Arrawarra Headland (sub-compartments 2 & 3); and
- Between Arrawarra Headland and Station Creek Beach (sub-compartment 4) the sand barrier and estuary type coastline is dominant

Although no dates have been obtained, the outer sand barrier at Bonville Beach is most probably of Holocene age, based on its stratigraphy, sand characteristics and morphological relationships that are consistent with Holocene barriers in this region (Troedsen *et al.,* 2005). Holocene origin sediments also exist to the outer barrier at Sawtell and Boambee Beach.

Holocene beach, dune and shoreface deposits are minimal in depth and spatial extent north of Coffs Harbour in sub-compartment 2, and the nearshore profile is characterised by semi-continuous bedrock reefs. Lord and Kerkvoort (1981) describe the nearshore bathymetry between Sawtell and White Bluff to be dominated and controlled by bedrock. They noted that the extensive offshore reefs and prominent headlands, that may also form a barrier to northerly sediment transport in some locations. The observation of offshore reefs may also suggest a lack of available sediment supply for the upper beach face from the nearshore zone.

In contrast, south of Coffs Harbour (sub-compartment 1), Holocene dune barrier sands are more extensive, with thicker dunes and semi-continuous sand deposits across the shoreface.

The Holocene -age sand barrier deposits overlie extensive estuarine clay deposits that were formed in a prior estuary of assumed Pleistocene age (ie., 117,000 to 133,000 years ago, Roy and Stephens, 1980).The associated Pleistocene-aged beach barrier-dune deposits have been eroded, prior to the late Holocene (ie, in the past 3,000 years). The underlying Pleistocene estuarine deposits are least developed inland of Boambee, Park and Moonee Beaches. At the latter site, Pleistocene dune sands may be found beneath the coastal heath plains behind Moonee Beach (Binnie and Partners, 1987 citing Soil Conservation Service, 1980).

2.2.4.1 Nearshore sediments

In a seaward direction, the inner nearshore sand unit thins and overlies a basal transgressive sand sheet, which is said to be of variable thickness and either Pleistocene or Holocene in age. The inner nearshore sand unit does not continue across Coffs Harbour mouth, and is also restricted around Macauleys and Diggers Headlands (Lord and Van Kerkvoort, 1981).

The surf zone and inner nearshore sand unit comprises fine to coarse grained (1.9 to 2.35 phi, or 0.27 to 0.20mm), occasionally gravelly, fawn coloured, with 20 to 40% of quartz grains iron stained and ranging from angular to rounded. The sands comprise 0-5% shell, 0-1% heavy minerals, and 1-3% rock particles (Stephens and Roy, unpublished Geological Survey of NSW, 1980 report).

The outer nearshore sand unit is said to be continuous across the region (Lord and Van Kerkvoort, 1981). The outer nearshore unit comprises fine grained (2.4 to 2.5 phi, or 0.19 to 0.18mm), grey coloured sand with 10-30% of the quartz grains iron stained (Stephens and Roy, unpublished Geological Survey of NSW, 1980 report).

The entire Holocene nearshore sand unit is a thin mobile cover over a coarse grained, light brown shelly inner shelf sand, as well as bedrock, gravels and clay (Lord and Van Kerkvoort, 1981; Stephens and Roy, unpublished Geological Survey of NSW, 1980 report). The inner shelf is typically composed of a sand and gravel deposit that outcrops in the nearshore zone as patches of gravel and sandy gravel. Inner shelf sands comprise very angular to sub-rounded grains, with 0-5% shell, 0-2% heavy minerals (up to 20%) and 1-3% rock particles (Stephens and Roy, unpublished Geological Survey of NSW, 1980 report). Within the gravel patches, the inner shelf sediments are light brown with 20-50% of grains iron stained, very angular to well rounded, with 0-20% shell, 0-1% heavy minerals and up to 15% rock particles (Stephens and Roy, unpublished Geological Survey of NSW, 1980 report). The gravel patches exhibit bedforms indicating modern reworking by wave energy to at least 30 m water depth (Roy and Stephens, 1980). Pleistocene estuarine mud deposits underlie the offshore sand and gravel deposits along much of the coast.

It was noted during field observations by BMT WBM personnel in 2008 that there is extensive occurrence of gravels on beaches between Sawtell and White Bluff, as consistent with the nearshore sediments described above. Coarse-grained deposits also underlie the Holocene sand barriers at Bonville and Boambee Beaches.

The nearshore sediment profile describes discontinuity with the modern wave climate. The outer nearshore sands are most extensive in Sub-Compartment 1, and are patchy in Sub-Compartments 2, 3 and 4, with extensive areas of outcropping hard-bottom reef and occasional islets. Stephens and Roy (unpublished Geological Survey of NSW, 1980 report) report sediment texture of 2.3 to 2.4 phi (0.2 to 0.19mm) is typical of the outer nearshore sands that they conclude are transported northwards by littoral currents. Beach and surf zone sediments along drift aligned north coast compartments have similar grain sizes of 2.3 phi (0.20 mm).

In terms of sedimentation and coastal processes on beaches, the influence of the Solitary Islands zone has resulted in a higher carbonate content in beach sands, and larger coral fragments upon the beach in sub-compartment 3. This may influence the hydrodynamic behaviour of beach sediments in this sub-compartment.

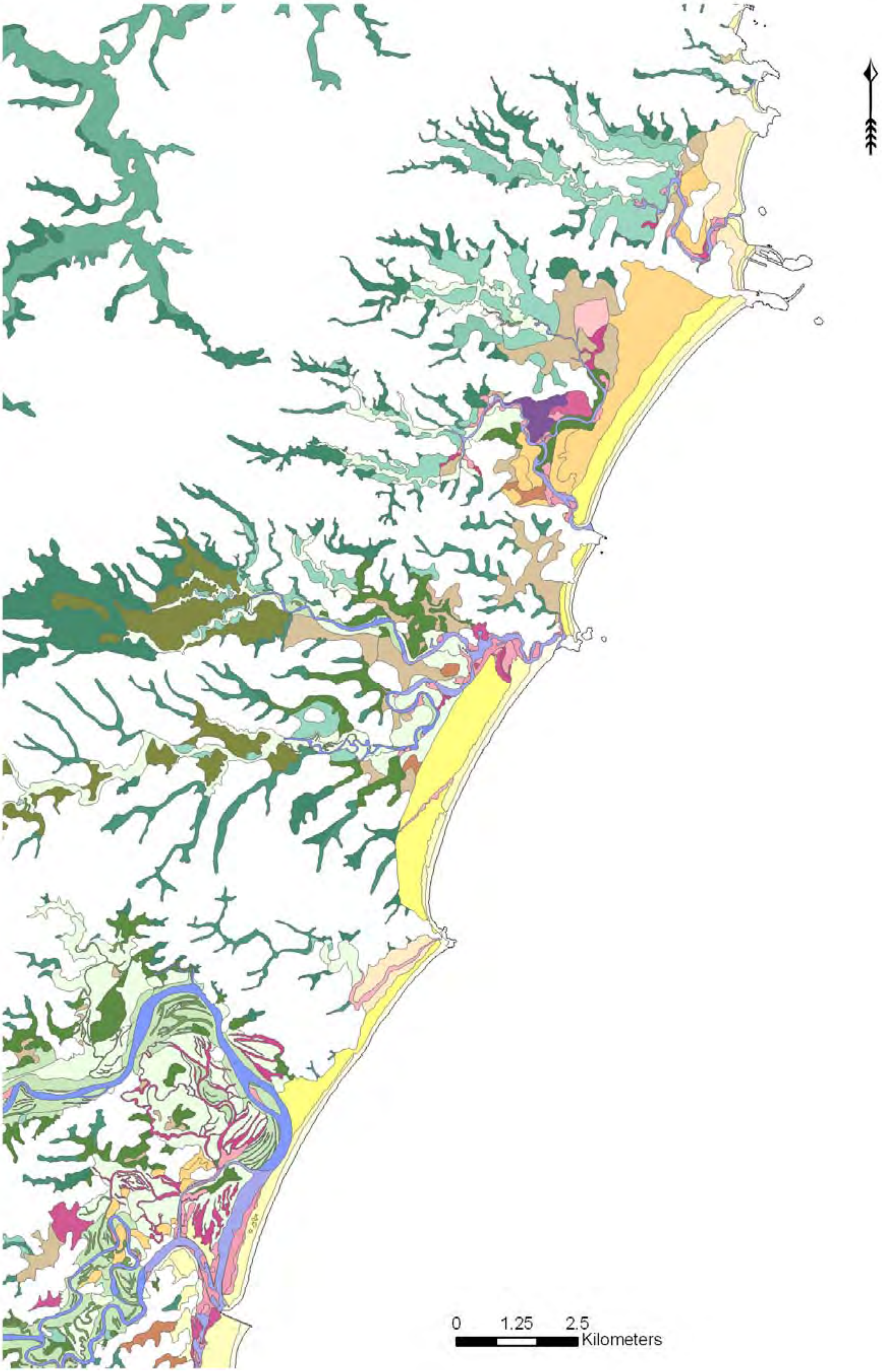


Figure 2-2 Quaternary coastal geology for sub-compartment 1 (after Troedsen et al., 2004)

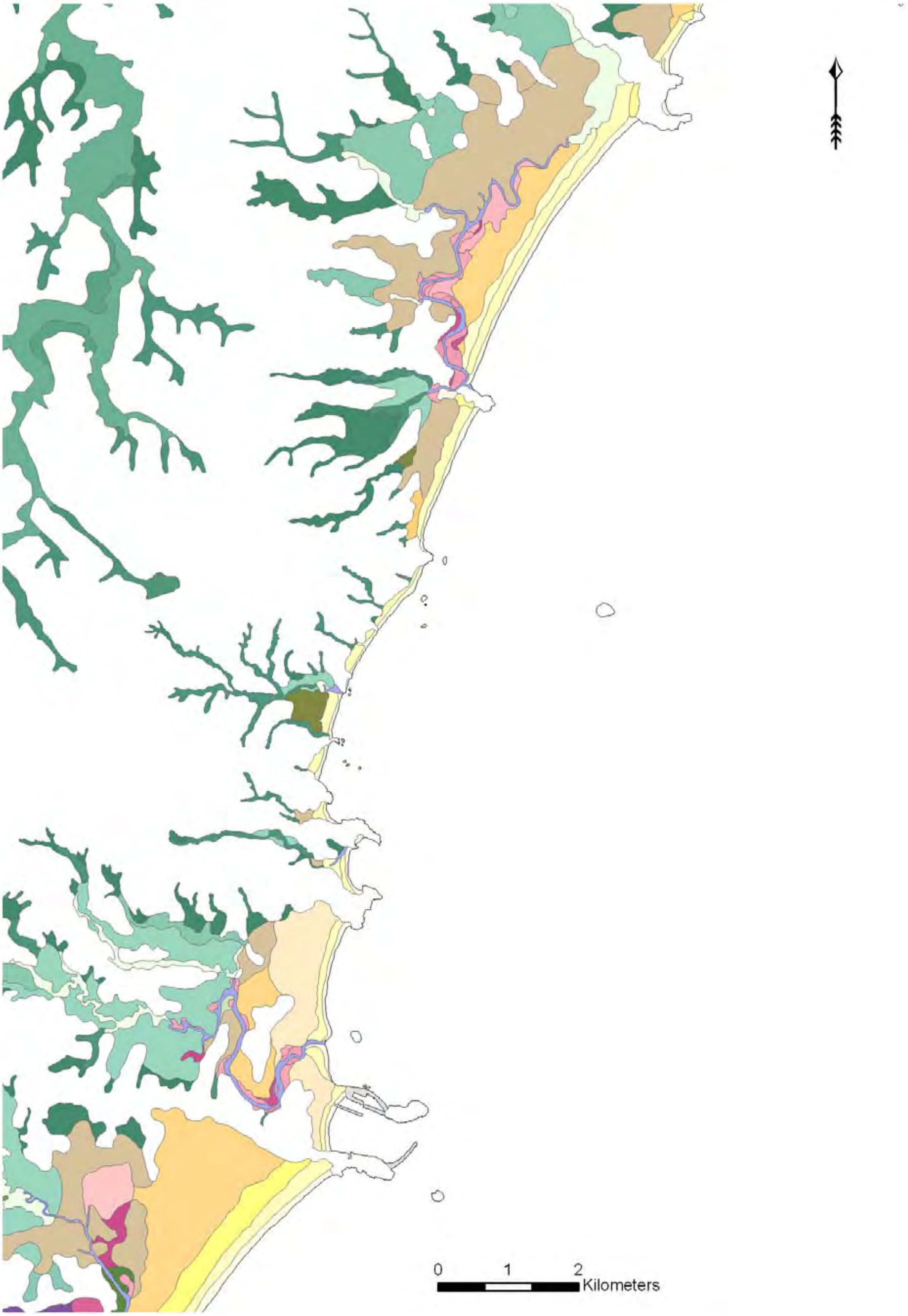


Figure 2-3 Quaternary coastal geology for sub-compartment 2 (after Troedsen et al., 2004)

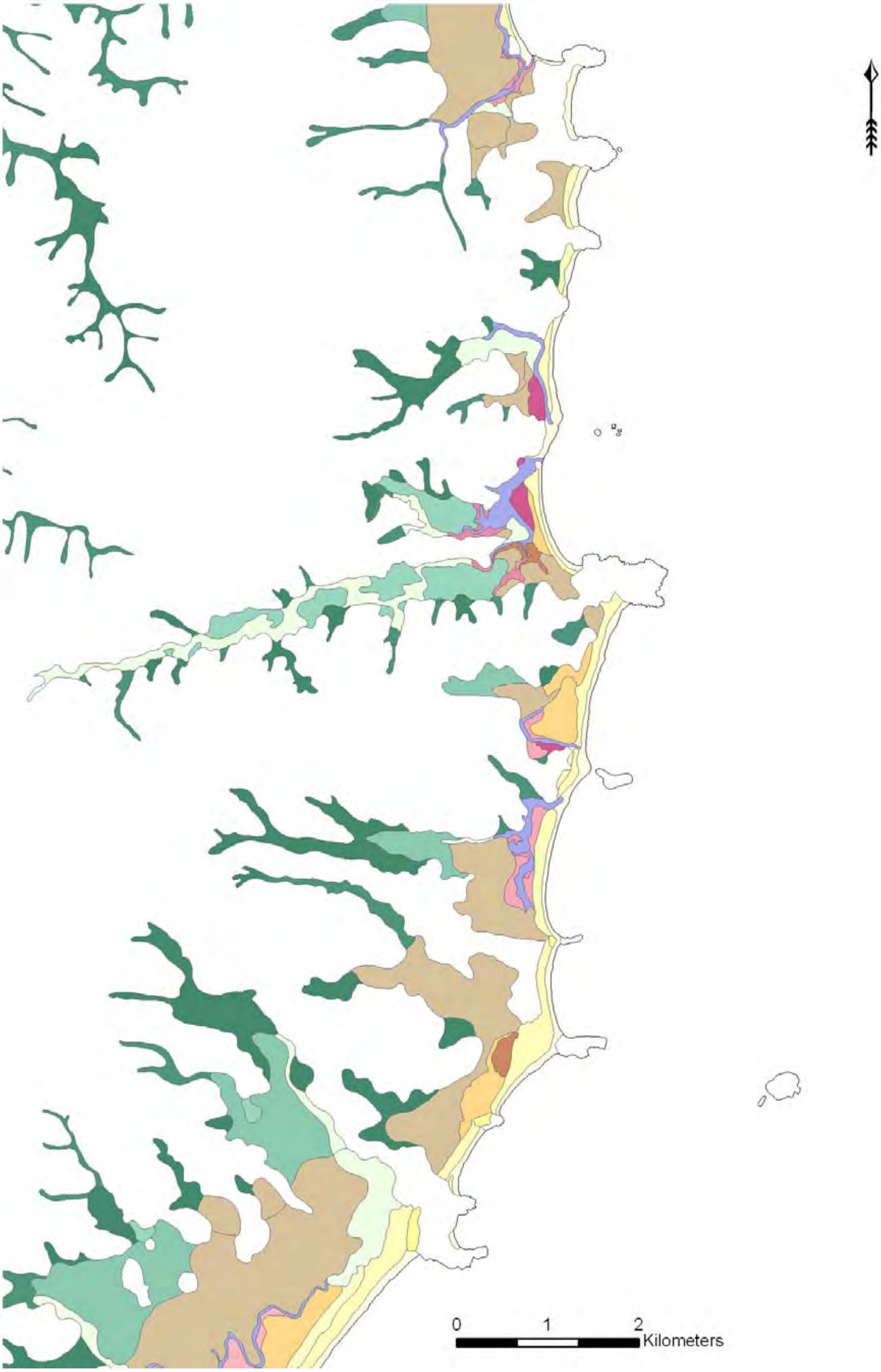


Figure 2-4 Quaternary coastal geology for sub-compartment 3 (after Troedsen et al., 2004)

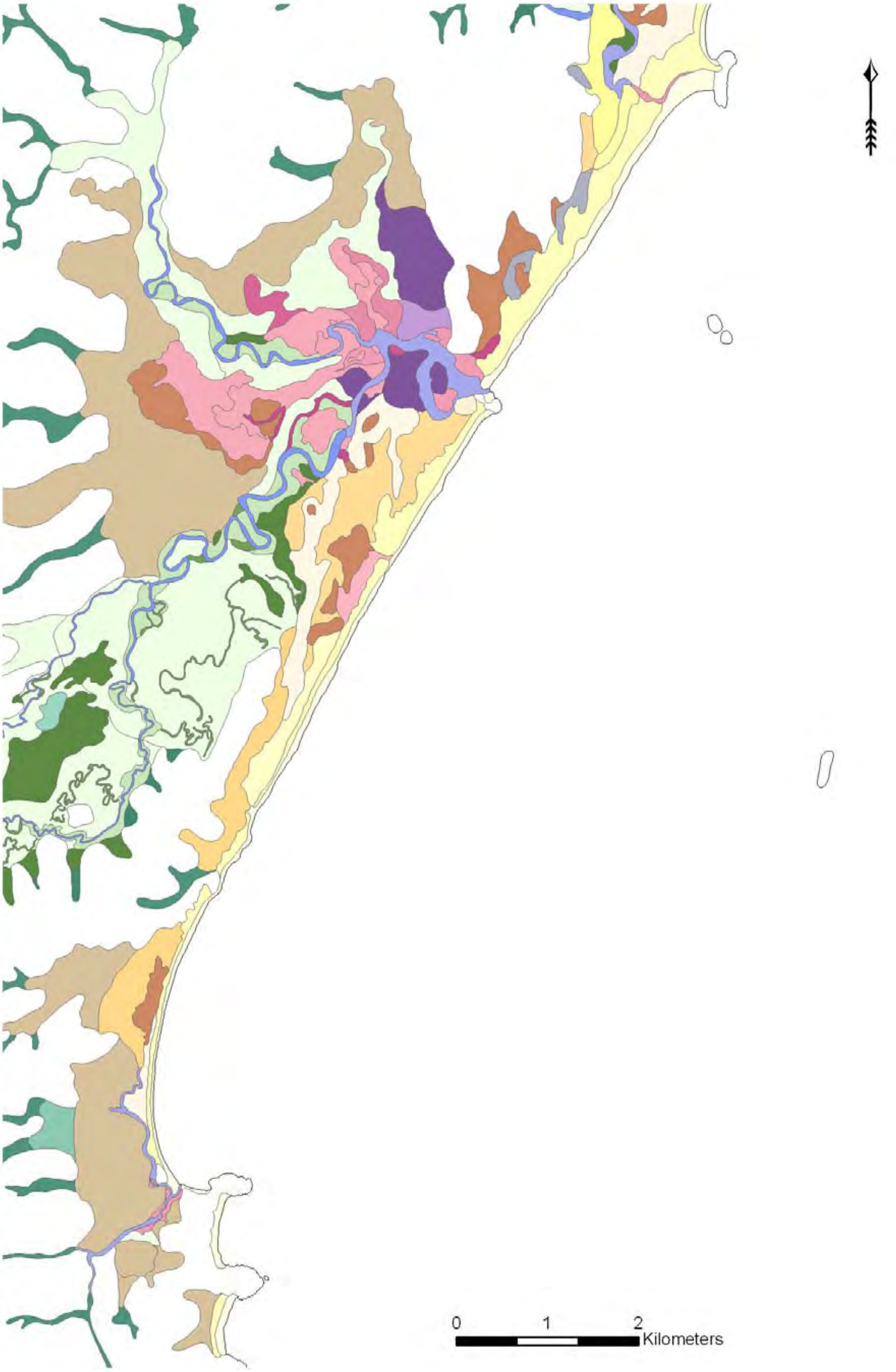


Figure 2-5 Quaternary coastal geology for sub-compartment 4 (after Troedsen et al., 2004)

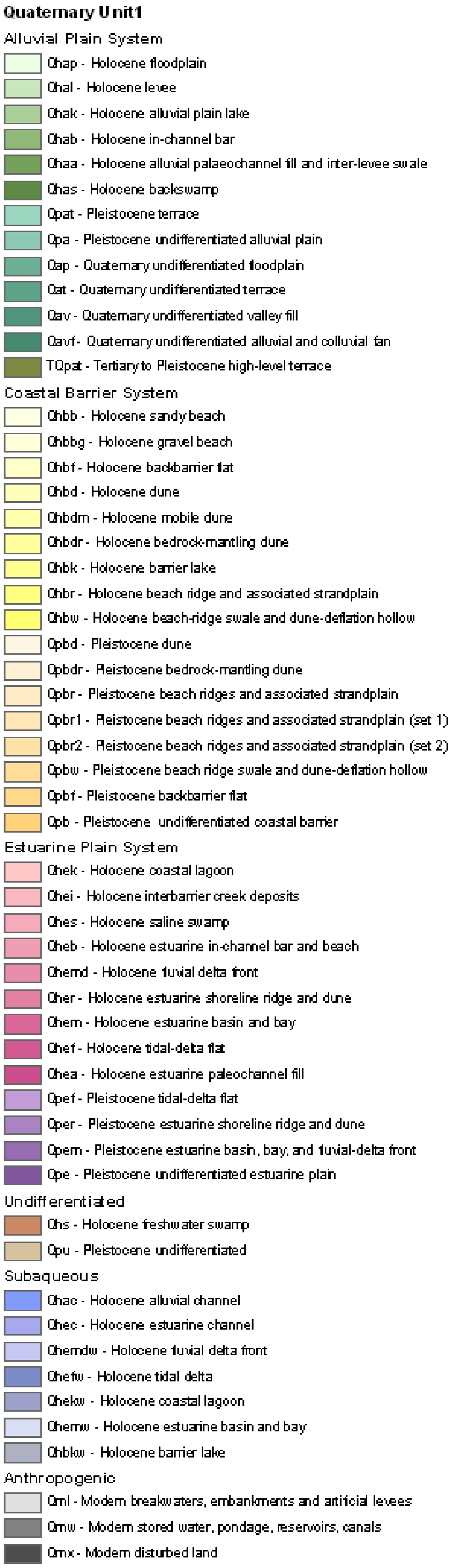


Figure 2-6 Legend for Quaternary coastal geology (after Troedsen et al., 2004).

2.2.5 Beach State

Wright and Short (1984) developed a beach classification system for wave-dominated coasts, based on wave energy exposure, beach and surf zone morphology and sediment grain size. Short (2007) has classified all of NSW's beaches into their respective beach types. Coffs coast beaches are typically intermediate beaches, which will oscillate between up to four beach states, depending on the wave height conditions. Intermediate beaches are typified by one to two roughly parallel sand bars cut by beach rips at regular intervals, medium to fine grained sand, and experiencing moderate to high wave conditions. The beach state classification system of Wright and Short (1984) with example beaches in the Coffs Region are discussed in Table 2-1. Individual beaches in Coffs Harbour are discussed in greater detail in Chapter 6.

Table 2-1 Beach State Classification and Coffs Beaches

Beach State	**Identifier**	Description / typical conditions	Example Coffs Beach
Reflective	**R**	Steep upper beach face which reflects waves, no sand bars, deeper water immediately offshore, Low wave energy (0-1 m height), coarser grain sizes	Korora Beach, Charlesworth Bay
Low Tide Terrace (Intermediate)	**LTT**	Single shallow bar or terrace exposed at low tide, Low wave energy (0.5 – 1 m height), possible weak rips at high tide	Woolgoolga Beach, Arrawarra Beach
Transverse Bar Rip (Intermediate)	**TBR**	Attached bars cut by frequent beach rip troughs/channels (150 – 300 m spacing) which can have strong currents, Moderate wave energy (1 – 1.5 m height)	Emerald Beach, Diggers Beach
Rhythmic Bar & Beach (Intermediate)	**RBB**	Undulating (rhythmic) sand bars separated by a trough from shoreline which feeds into strong rips, often heavy shore break due to troughs, Moderate wave energy (1.5 – 2.0 m height)	Boambee Beach Woolgoolga Back Beach.
Longshore Bar & Trough (Intermediate)	**LBT**	Shore parallel sand bar(s) with deep trough inshore and moderately steep beach face causing heavy shore break. Typically strong currents in trough feeding widely spaced, strong rip currents. Moderate to High wave Energy (1.5 – 2.0 m height)	Red Rock Beach (North Corindi)
Dissipative	**D**	Wide surf zone with multiple shore parallel bars and troughs, High wave energy (2 – 3 m) generating wave set up/set down and undertow currents	None in Coffs Harbour

3 COASTAL PROCESSES

3.1 Introduction

In this section, the coastal processes which have shaped the morphology of the Coffs region coastline will be described. Each of these coastal processes are related or interact with each other to some degree, with such interactions also described as required.

3.2 Wave Climate

3.2.1 Wave Generation Sources

The wave climate of the south east Australian coastline has a strong seasonality due to the seasonal dominance of the major wave generation sources. These sources are outlined below (Short and Trenaman, 1992; Short, 2007).

- Tropical cyclones: can occur from November to May, but occur most frequently during February and March. When tropical cyclones track down into the Tasman Sea (usually well offshore of the NSW coast), they will generate north easterly swell directions arriving on the coast.
- East coast cyclones: may occur at any time of the year, but are most likely to occur in May, June and July. These systems generate the strongest winds, heaviest rainfall and largest waves experienced on the NSW Coast. East coast cyclones tend to form over the centre of the NSW coast, generating waves which arrive from an easterly direction.
- Mid-latitude cyclones: occur throughout the year, particularly March to September, and these systems generate the predominant south-easterly swell experienced along the coast. Mid-latitude cyclones tend to form closer to the southern Australian continent in winter, and further south in summer. Thus, during winter (when they are closer to the coastline), higher waves will be experienced on the coast, and these systems may directly impact NSW weather (ie, wind and rainfall on land).
- Fine, warm weather on the NSW coast is produced by the subtropical anticyclone (STAC, or high pressure system) which moves from west to east over the Australian continent throughout the year, and is located further south in summer and further north in winter. In summer, on clear warm/hot days the land heats faster than the ocean. As the hot air rises over the land, cooler air from the ocean moves in to replace it, forming onshore sea breezes along the coast (and the opposite may occur over night. The onshore winds arrive from the NE rather than directly E due to the Coriolis effect, which deflects air and water movement to the left I the southern hemisphere). Persistent NE to E onshore winds over days may generate a weak wind swell on the coast.
- East coast low cyclones are more likely to form closer to the Coffs Harbour coastline than the other wave generation mechanisms, such as tropical cyclones, which are more likely to occur some distance north of the region, and mid latitude cyclones forming south of the region.

It is worth noting that, while there is some seasonality to the wave climate with respect to the wave generation sources and storm patterns, in terms of wave height experienced at the shoreline, it is possible for storm waves of significant height to occur at any time of the year at Coffs Harbour.

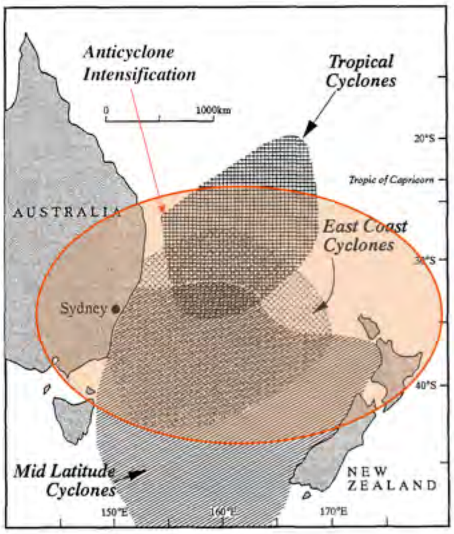


Figure 3-1 Wave generation sources on the SE Australian Coast (after Short and Trenaman, 1992). The subtropical anticyclonic intensification area is represented by the orange ellipse.

3.2.2 Offshore Mean Wave Climate

Wave data for Coffs Harbour and Bryon Bay was provided by the Department of Commerce Manly Hydraulics Laboratory (MHL). The wave data collection was funded by the Department of Environment and Climate Change (DECC). The wave data collected by the wave rider buoys defines the mid-shelf wave climate as the buoys are moored in ~ 85 m water depth, ~ 10 km offshore. In this report we will refer to all wave rider buoy data as indicative of the offshore or mid-shelf wave climate. Modelling of the nearshore wave climate is discussed in Section 3.2.5.

The Coffs Harbour wave rider buoy is not directional, and so wave height and period analysis only is possible with data from this buoy. The Byron Bay waverider buoy has been directional since 1999, and the Sydney waverider buoy since 1992. Mean wave direction data for the Coffs Harbour region has been interpreted from the Sydney and Byron Bay data. Byron Bay is 240 km north of Coffs Harbour, while Sydney is 540 km south.

3.2.2.1 Offshore Significant Wave Height

A statistical analysis of significant wave height (the highest one third of all wave heights, H_S) was provided by MHL for wave data from the wave rider buoys at Coffs Harbour and Byron Bay. The data recording period at Coffs Harbour spans 31 years from May 1976 to December 2007. Wave height exceedance statistics for Coffs Harbour are shown in Table 3-1 and for Bryon Bay in Table A.1 Appendix A.

Table 3-1 Significant Wave Height Exceedance Percentage Statistics, Coffs Harbour

H_s (m)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
0 → 0.5	100	100	100	100	100	100	100	100	100	100	100	100	100
0.5 → 1	99.99	99.98	99.97	99.89	99.69	99.87	99.87	99.81	99.98	99.97	99.96	99.90	99.91
1 → 1.5	82.29	82.66	90.85	87.09	84.59	83.10	84.40	79.15	80.66	83.40	83.58	80.37	83.45
1.5 → 2	41.73	42.24	56.92	49.09	54.32	48.55	51.57	40.84	39.40	38.00	40.16	36.06	44.79
2 → 2.5	17.93	21.54	26.26	22.82	27.05	24.52	24.46	18.57	15.91	15.88	18.05	14.22	20.49
2.5 → 3	6.39	9.72	11.33	10.10	11.81	10.34	12.14	7.97	6.66	6.56	8.65	5.25	8.86
3 → 3.5	1.66	4.09	5.63	4.58	4.80	5.28	5.28	3.41	2.75	2.81	4.01	2.40	3.87
3.5 → 4	0.55	2.04	2.56	1.98	2.34	2.90	1.86	1.31	1.14	1.34	1.83	0.99	1.72
4 → 4.5	0.20	0.90	0.97	0.77	1.30	1.43	0.52	0.44	0.31	0.55	0.72	0.44	0.71
4.5 → 5	0.04	0.32	0.44	0.27	0.60	0.72	0.24	0.20	0.05	0.16	0.32	0.18	0.29
5 → 5.5	0.02	0.14	0.11	0.09	0.20	0.38	0.14	0.10	*0.00*	0.02	0.11	0.04	0.11
5.5 → 6	*0.00*	0.10	0.06	0.02	0.02	0.20	0.07	0.04	*0.00*	0.01	0.01	0.01	0.04
6 → 6.5	*0.00*	0.05	0.01	0.01	*0.00*	0.14	0.05	0.01	*0.00*	0.00	0.01	*0.00*	0.02
6.5 → 7	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	0.08	0.01	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	0.01
7 → 7.5	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	0.01	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*
Average	1.46	1.52	1.66	1.56	1.61	1.63	1.61	1.47	1.48	1.47	1.48	1.40	1.57
Max	5.28	6.47	6.21	6.22	5.72	7.36	6.84	6.39	4.88	5.69	6.03	5.80	7.36
Min	0.46	0.47	0.29	0.26	0.34	0.38	0.40	0.44	0.38	0.48	0.44	0.29	0.26

The mean H_s experienced at Coffs Harbour is 1.57 m. This is slightly lower than the mean for Bryon Bay of 1.65 m, and 1.61 m at Crowdy Head. The north coast sector of NSW (Smoky Cape to the NSW-Queensland Border) has been described as having generally lower storm activity than other parts of the NSW coastline (BBW, 1985; Lawson and Treloar, 1986).

Seasonally at Coffs Harbour, H_s is largest in autumn, then winter, summer and the lowest wave heights occur in spring. The highest measured H_s of 7.36 m was recorded in the month of June, during which east coast low cyclones or mid-latitude cyclones may occur.

An analysis of storm wave height/duration return periods has been provided by MHL, as illustrated in Figure 3-2. The analysis uses the DECC owned data collected from the waverider buoy at Coffs Harbour between May 1976 and December 2007.

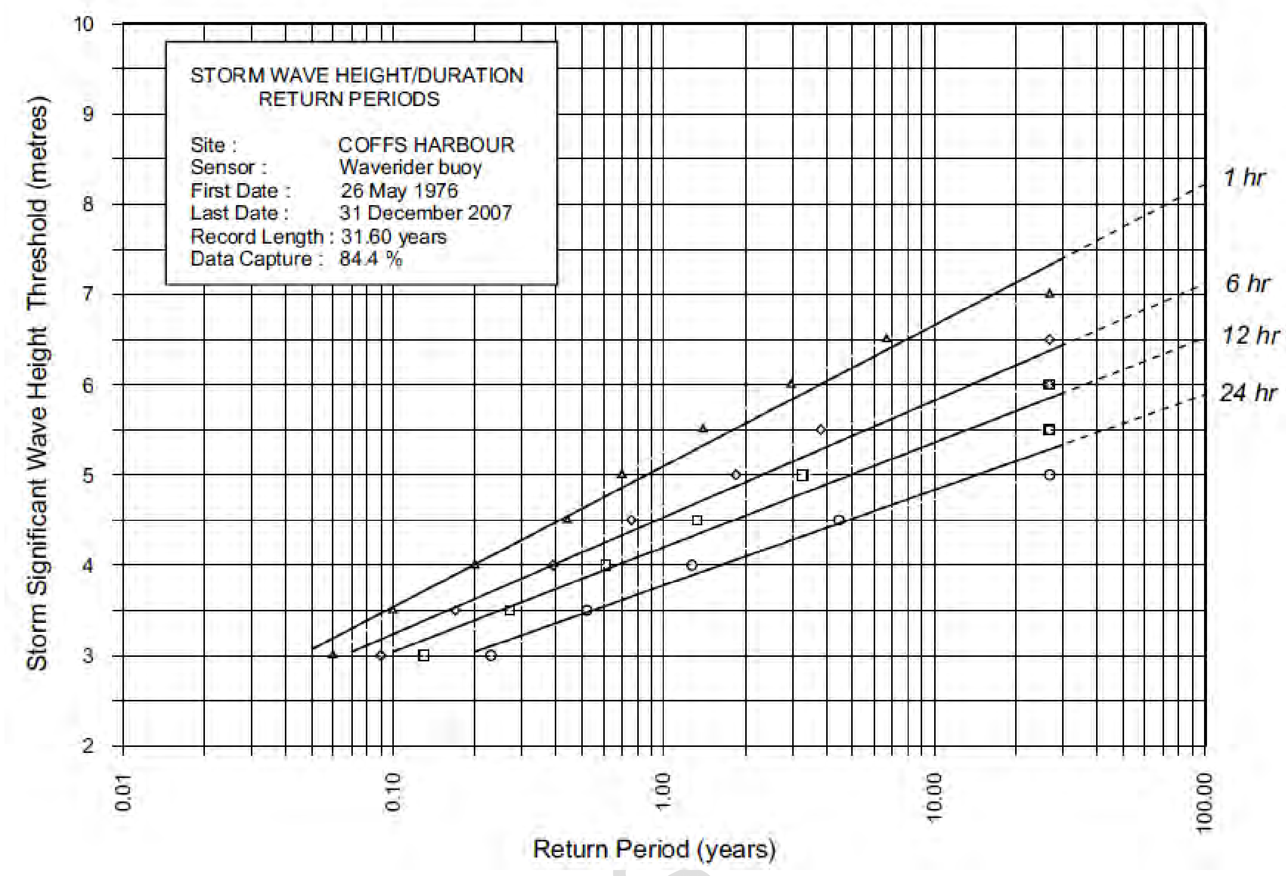


Figure 3-2 Storm Wave Height / Duration Curves for Coffs Harbour

3.2.2.2 Seasonal Variability in Offshore Wave Direction

Wave direction statistics data from the directional buoy at Byron Bay and Sydney may be used to infer likely direction at Coffs Harbour. Percentage occurrence by wave direction for Byron Bay is tabulated in Table 3-2. The Sydney mean wave direction statistics are shown in Table 3-3. The frequency histogram of mean wave direction for Byron Bay, Sydney and Batemans Bay is shown in Figure 3-3, from data supplied by Mark Kulmar, MHL.

Table 3-2 Percentage Occurrence Wave Direction, Byron Bay (1999 to 2007)

Dir'n	Degrees	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
N	348.75 - 11.24	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.000
NNE	11.25 - 33.74	1.82	0.07	0.10	0.40	0.97	0.85	0.17	1.49	6.71	5.48	3.78	6.16	2.603
NE	33.75 - 56.24	3.32	0.14	0.00	0.43	0.45	0.80	0.52	2.49	6.10	5.24	3.31	4.07	2.415
ENE	56.25 - 78.74	5.14	4.19	3.46	9.55	3.28	5.57	2.52	1.06	2.59	4.43	4.41	6.58	4.374
E	78.75 - 101.24	18.79	24.82	23.14	25.03	7.96	12.50	9.06	6.56	9.46	17.64	11.87	12.63	14.073
ESE	101.25 - 123.74	19.99	28.26	23.21	22.14	11.76	10.85	17.67	10.03	8.48	8.04	14.69	13.37	14.818
SE	123.75 - 146.24	15.56	17.02	15.97	15.98	19.45	23.30	25.02	18.52	14.70	12.52	22.74	17.53	18.493
SSE	146.25 - 168.74	19.20	15.53	23.35	17.64	34.76	31.51	32.75	41.75	32.96	24.90	22.09	25.39	27.402
S	168.75 - 191.24	15.44	9.33	10.05	8.09	20.61	13.73	11.58	15.94	17.11	19.56	15.32	13.05	14.579
SSW	191.25 - 213.74	0.56	0.58	0.62	0.43	0.52	0.39	0.54	1.01	0.71	1.54	1.42	0.88	0.791
SW	213.75 - 236.24	0.06	0.00	0.03	0.00	0.15	0.06	0.05	0.06	0.09	0.12	0.08	0.22	0.085

WSW	236.25 - 258.74	0.06	0.00	0.00	0.00	0.02	0.06	0.00	0.00	0.05	0.00	0.00	0.00	0.017
W	258.75 - 281.24	0.00	0.00	0.07	0.00	0.04	0.12	0.07	0.11	0.02	0.00	0.00	0.00	0.037
WNW	281.25 - 303.74	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.03	0.02	0.00	0.00	0.00	0.006
NW	303.75 - 326.24	0.00	0.07	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.006
NNW	326.25 - 348.74	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.000
Mean	Degrees	128.3	122.1	124.9	123.5	140.8	133.7	135.4	135.44	131.9	124.7	130.0	125.8	130.18

Table 3-3 Percentage Occurrence Wave Direction, Sydney 1992 – 2007

Dir'n	Degrees	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
N	348.75 - 11.24	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.000
NNE	11.25 - 33.74	0.16	0.01	0.06	0.12	0.02	0.05	0.04	0.12	0.09	0.23	0.03	0.09	0.088
NE	33.75 - 56.24	4.22	2.95	2.37	2.23	1.48	1.17	0.72	1.64	4.95	5.76	4.53	5.17	3.090
ENE	56.25 - 78.74	16.71	14.64	8.03	7.03	7.04	3.35	3.56	4.98	9.56	11.03	13.76	11.72	9.034
E	78.75 - 101.24	17.99	18.47	16.80	10.93	10.60	7.82	9.81	6.05	7.50	9.61	9.81	10.56	11.028
ESE	101.25 - 123.74	10.10	13.51	12.34	11.92	10.14	9.63	12.90	7.73	6.37	7.65	8.71	9.08	9.919
SE	123.75 - 146.24	12.15	11.50	17.27	18.65	16.87	17.08	19.30	20.78	17.20	13.10	14.09	14.36	16.191
SSE	146.25 - 168.74	19.35	19.07	25.97	31.68	33.53	41.32	36.08	40.11	33.53	30.05	24.11	24.80	30.434
S	168.75 - 191.24	18.17	19.27	16.19	16.88	19.40	18.83	16.27	17.16	19.28	21.22	23.20	22.72	19.046
SSW	191.25 - 213.74	1.13	0.57	0.95	0.47	0.37	0.40	0.50	0.81	0.82	1.12	1.72	1.37	0.851
SW	213.75 - 236.24	0.00	0.00	0.01	0.04	0.08	0.01	0.12	0.03	0.14	0.03	0.00	0.02	0.043
WSW	236.25 - 258.74	0.00	0.00	0.00	0.00	0.03	0.01	0.06	0.04	0.12	0.04	0.02	0.01	0.031
W	258.75 - 281.24	0.01	0.00	0.00	0.03	0.05	0.11	0.25	0.13	0.11	0.04	0.01	0.02	0.069
WNW	281.25 - 303.74	0.00	0.00	0.00	0.00	0.11	0.08	0.20	0.10	0.19	0.11	0.01	0.03	0.074
NW	303.75 - 326.24	0.00	0.00	0.00	0.00	0.18	0.10	0.14	0.20	0.08	0.02	0.00	0.02	0.066
NNW	326.25 - 348.74	0.00	0.00	0.00	0.00	0.07	0.03	0.06	0.09	0.01	0.00	0.00	0.01	0.024
Mean	Degrees	122.8	122.6	129.8	136.2	137.9	145.3	142.0	143.9	137.2	133.9	132.2	133.1	135.01

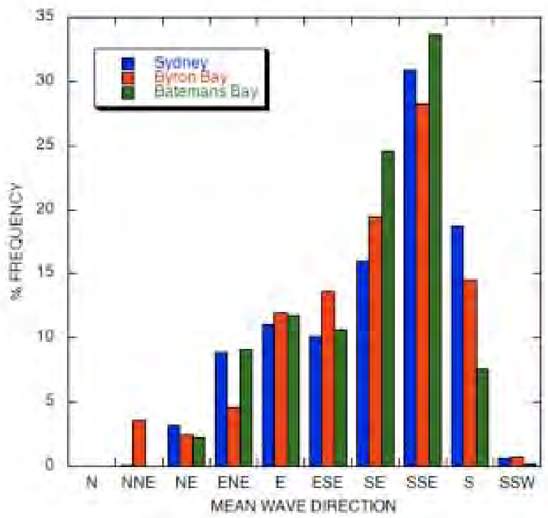


Figure 3-3 Percentage Frequency and Mean Wave Direction, from Mark Kulmar, MHL, 2006.

The record length for wave direction at Sydney spans 15.5 years from March 1992 to December 2007. At Byron Bay, the data record length is only 8 years, from October 1999 to December 2007. The shorter record length for wave direction at Byron Bay may have had an impact upon the outcomes of the statistical analysis. Further, it should be noted that the Byron Bay directional buoy has experienced occasional long periods of missing data, some of which occurred during storms. The missing data have been repaired and validated (pers. comm., Mark Kulmar, MHL, 28/07/2008), providing some reliability to the statistics.

Sydney and Byron Bay wave direction statistics confirm the discussion of the main wave generation sources (Section 3.2.1). The dominant wave direction at both Bryon Bay and at Sydney is south-south-east (SSE). 60% of waves arrive from the SE to S quadrant at Byron Bay, 27% of which are from the SSE alone. At Sydney, 65% of waves arrive from the SE to S quadrant, and 30% from the SSE alone.

Seasonally at both Sydney and Byron Bay, SE quadrant waves are at their most dominant during winter, and are slightly less, but still the most dominant wave direction during spring. Thus, for Coffs Harbour, SE quadrant waves are the dominant wave direction during winter and spring.

Over the summer to early autumn months in both locations, the incoming the wave direction shifts north slightly. However, there are notable differences in the wave climate between Byron and Sydney during summer-autumn. At Byron Bay, east (E) and east-south-east (ESE) waves are the dominant wave directions during January to April. Over summer at Sydney, the waves are more northerly in direction than at Byron Bay, however the percentage occurrence of NE quadrant waves is less and SE quadrant waves remain the dominant wave direction throughout the summer to autumn months.

East coast low weather systems are known to be the dominant storm generation mechanism for the Coffs Coast, and such systems are likely to occur east of Byron Bay (generating E to ESE waves), compared with Sydney (generating E to ENE swell). In addition, tropical cyclones will be more dominant in the wave record at Byron Bay than Sydney due to the proximity of Byron Bay to the tropics, strengthening the easterly signal in the Byron record. Hotter summer temperatures at Byron compared with Sydney may also initiate north to east sea breezes earlier in the day, and for more consecutive days, which may also increase the occurrence of ENE waves in the record to a small degree. The Byron Bay directional data appears to match the analysis of wave generation sources, and the wave climate described for the north coast by BBW (1985).

Based upon the assessment of measured wave directional data over the previous 15 years, the pre-dominant wave direction at Coffs Harbour is SSE, with SE quadrant waves the dominant wave origin during winter and summer, and waves dominantly from the ENE to ESE during January to April.

3.2.3 Inter-annual variability in Mean Wave Climate

In addition to the seasonal (annual) variability, significant variability in the SE Australian wave climate is observed over inter-annual to inter-decadal time scales. That is, between different years there are more or less storms, and wave directions are more southerly or northerly relative to the predominant south easterly wave direction.

Correlation has been found between the SE Australian wave climate and the El Nino Southern Oscillation (ENSO), which may explain some of the variability of the wave climate (height and direction) on an inter-annual (2 – 8) year basis (Short *et al.,* 2000; Ranasinghe *et al*., 2004; Goodwin 2005; You and Lord, 2008).

ENSO is the aperiodic fluctuation of the large-scale atmospheric circulation system across the Indian-Pacific Ocean region. The phase of warming of central and eastern tropical Pacific Ocean waters is known as El Nino, while the phase of cooler central and eastern tropical Pacific Ocean waters is termed La Nina. During El Nino phases, the warmer eastern equatorial Pacific tends to cause a reduction in rainfall and a drier, hotter eastern and northern Australia. During the La Nina phase, warmer waters above northern Australia result in an increase in the occurrence of tropical cyclones and east coast low cyclones, resulting in increased rainfall and cooler temperatures over eastern and northern Australia (Goodwin 2005; Phinn and Hastings, 1992; Hemer *et al.,* 2008, CSIRO, 2007). The Southern Oscillation Index (SOI) is used to define the phase of ENSO (i.e., El Nino or La Nina), and is determined by the relative difference in mean sea level pressure (MSLP) between Darwin (131W 12S) and Tahiti (149W 17S) by the Bureau of Meteorology. Negative SOI values indicate El Nino phases and positive values indicate La Nina phases of the Southern Oscillation.

The modulation of the occurrence of tropical cyclones and east coast low cyclones, and subsequently the relative dominance of mid-latitude cyclones (which generate the predominant SSE swells) by ENSO has implications for mean wave direction and wave heights along the NSW coast, at the inter-annual time scale over which ENSO phases typically occur.

Throughout both the El Nino and La Nina phases, the predominant wave direction remains south east along the NSW coast. However, comparison of mean monthly wave direction and mean monthly SOI has illustrated there is a subtle shift, slightly to the north or slightly to the south, around the predominant south east wave direction which has been correlated with the phase of the SOI. The La Nina phase has been associated with more northerly (easterly) wave directions (Short, *et al.,* 2000; Goodwin 2005; Ranasinghe *et al.,* 2004), and this is due to the increased occurrence during La Nina of tropical cyclones, which generate north easterly swells, and east coast low cyclones, which generate easterly swells (Phinn and Hastings, 1992; Hemer *et al.,* 2008; CSIRO, 2007). Likewise, during the El Nino phase, there are fewer tropical and east coast cyclones, and mid-latitude cyclones remain dominant, resulting in a more southerly mean wave direction (Ranasinghe *et al.*, 2004; Goodwin, 2005). Hopkins and Holland (1997) found a strong tendency for east coast low cyclones to occur especially when an El Nino is followed by a La Nina year.

Mean wave power has also been positively correlated with the phase of the SOI, likely due to the greater frequency/intensity of tropical and east coast cyclones during the La Nina phase in addition to the predominant mid-latitude cyclones. Phinn and Hastings (1992) compared the wave energy flux at Sydney (yearly from February to March) with the SOI and found greater wave power during the positive SOI (La Nina) phase and lower wave power during the negative SOI (El Nino) phase. Ranasinghe *et al*. (2004) calculated the number of storms (defined as significant wave height H_s> 2.5m for at least one day) between 1987 and 2001 at Sydney, and found on average double the number of storms during the La Nina compared with the El Nino phase. You and Lord (2008) compared yearly storm severity (January to December) with yearly mean SOI and found there to be good positive correlation, that is, the storm severity was increased during La Nina compared with El Nino phases.

3.2.4 Decadal Variability of Mean Wave Climate

Climate variability on interdecadal time scales (10-30 years) is an intrinsic characteristic of the Australian regional climate (Power et al., 1999). This interdecadal variability is thought to originate from complex feedbacks between the tropical and extratropical atmosphere and ocean. It modulates the severity and persistence of the ENSO behaviour. The interdecadal oscillation in sea surface temperatures across the entire Pacific Ocean is known as the Inter-decadal Pacific Oscillation (IPO) (Power *et al*., 1999). Positive values of the IPO index describe warmer sea surface temperatures in the central tropical Pacific and lower sea surface temperatures in the sub-tropical and mid-latitude south west Pacific Ocean. Negative IPO values indicate cooler sea surface temperatures in the central Pacific and higher sea surface temperatures in the south west Pacific Ocean (Power *et al.,* 1999; Goodwin, 2005).

Power *et al*. (1999) illustrated that when the IPO index is negative (La Nina-like) and higher sea surface temperatures are experienced in the sub-tropical and mid-latitude south west Pacific, the year to year variability in the Australian climate is found to be closely associated with year to year variability in ENSO. There is also a tendency for the variability of ENSO and the climate itself to increase during this negative IPO phase (Power *et al.,* 1999). Goodwin (2005) found that NSW wave climate is more closely associated with ENSO during the IPO La-Nina-like phases, creating persistent interannual wave climate. This has an important impact on both cross-shore and alongshore sediment transport. The relationship between storm severity and ENSO is also noted to have periods of good and poor correlation.

Decadal scale variability in the wave climate and shoreline response has been noted in other Hazard Definition studies in the northern NSW coast region. A period of dramatic erosion and shoreline retreat is reported to have occurred between 1954 and 1974, while a relatively calmer period of beach recovery and lower storminess has persisted since 1974 to the present (WBM, 2003). It is unfortunate, then, that the period of data instrumentation to accurately measure wave data has occurred during the period of relative quiescence.

Goodwin (2005) hindcast monthly mean wave direction for Sydney, and recently in an additional study (Goodwin and Blackmore, 2008) has hindcast Coffs Harbour and Byron Bay monthly mean wave direction for the past 60 years, that encompasses the two IPO periods.

The method for hindcasting the wave data was based on 12 characteristic synoptic climate types, determined from Self Organised Mapping (SOM) techniques applied to the NCEP-NCAR Reanalysis Sea-Level pressure data from 1948 to 2008. The mean mid-shelf (offshore) wave data for Sydney, Coffs Harbour and Byron Bay from the waverider buoy data were calculated for each monthly synoptic type. The hindcast mean wave data for the two IPO periods, namely, 1948 to 1976 La Nina-like and 1977 to 2007 El Nino-like, were then calculated from the monthly frequency of each synoptic type. This data was used to distinguish the mean wave climate differences between the two IPO periods as a background to understanding the historical shoreline behaviour determined from observations and from photogrammetry. For wave direction at Coffs Harbour, the mean monthly wave direction time series was taken as the average of the Byron and Sydney wave time series, as Coffs Harbour is located between the two sites.

Mean monthly wave data are listed below in Table 3-4, for each of the two phases of the Interdecadal Pacific Oscillation: the La Nina-like phase from 1948 to 1976; and the El Nino-like phase from 1977 to 2007.

There are no significant differences in mean monthly wave height between the IPO periods. The hindcast mean monthly data do not contain information on the frequency and severity of East Coast storm events, and provide instead a measure of the changes in the mean wave climate states for each month. The two extreme ends of the seasonal wave climate occur in winter and summer for *both* IPO periods. For Coffs Harbour, the average mean wave direction during summer (January, February, March) and winter (July, August, September) is 120° and 133°, respectively. This is consistent with the assessment of measured wave data discussed in Section 3.2.2.2, which indicated the seasonal wave direction at Coffs Harbour to be SE during both winter and spring.

However, the data do show subtle differences in mean wave directions associated with the IPO. The most significant directional differences at Coffs Harbour between the two IPO periods are a 7.6 ° more southerly mean wave direction in October during the El Nino-like IPO period. With a notable difference in wave direction between summer and winter, the data suggest that the El-Nino period tends to extend the ‘winter’ wave behaviour into October, whereas during the La-Nina, October experience a more ‘summer’ wave climate. This is highlighted in Figure 3-4. A more southerly mean wave direction in October means an increased occurrence of oblique waves incident along the surf zones, which will drive longshore sediment transport between compartments, and therefore may modify the beach morphology, most importantly, beach width and curvature. The potential impacts of mean wave direction upon beach morphology are discussed in greater detail in Chapter 4.

Table 3-4 Hindcast Mean Monthly Wave Data separated into the two IPO Phases*

MULTI-DECADAL PERIOD 1948-1976												
Wave Parameter	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Coffs TP1 (s)	9.15	9.29	9.30	9.59	9.68	9.82	9.82	9.72	9.70	8.96	8.94	8.96
Coffs H_s (m)	1.52	1.57	1.57	1.57	1.54	1.56	1.55	1.52	1.53	1.43	1.43	1.45
Coffs H_{max} (m)	2.61	2.70	2.69	2.69	2.65	2.66	2.66	2.61	2.63	2.47	2.46	2.49
Sydney MWD (^{o})	125.77	124.89	125.73	133.49	137.72	139.04	139.70	139.81	138.50	129.48	128.74	127.39
Byron MWD (^{o})	114.03	116.98	114.99	119.82	124.23	127.32	127.52	127.41	126.24	113.52	109.21	110.20
Coffs MWD** (^{o})	119.90	120.93	120.36	126.65	130.97	133.18	133.61	133.61	132.37	121.50	118.98	118.79
MULTI-DECADAL PERIOD 1977-2007												
Wave Parameter	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Coffs TP1 (s)	9.08	9.29	9.45	9.79	9.91	9.89	9.87	9.81	9.62	9.36	9.08	8.88
Coffs H_s (m)	1.49	1.57	1.61	1.58	1.58	1.57	1.56	1.54	1.51	1.48	1.48	1.43
Coffs H_{max} (m)	2.57	2.69	2.75	2.72	2.71	2.69	2.67	2.65	2.59	2.55	2.54	2.46
Sydney MWD (^{o})	126.43	125.82	127.64	135.30	138.17	139.01	139.77	140.27	139.53	136.96	130.95	128.70
Byron MWD (^{o})	112.43	115.85	115.15	123.52	126.89	127.45	127.76	127.79	125.48	121.34	112.61	107.81
Coffs MWD** (^{o})	119.43	120.83	121.40	129.41	132.53	133.23	133.77	134.03	132.51	129.15	121.78	118.25

**Where: TP1 is Peak Wave Period; H_s is Significant Wave Height, H_{max} is Maximum Wave Height; MWD is mean wave direction.*

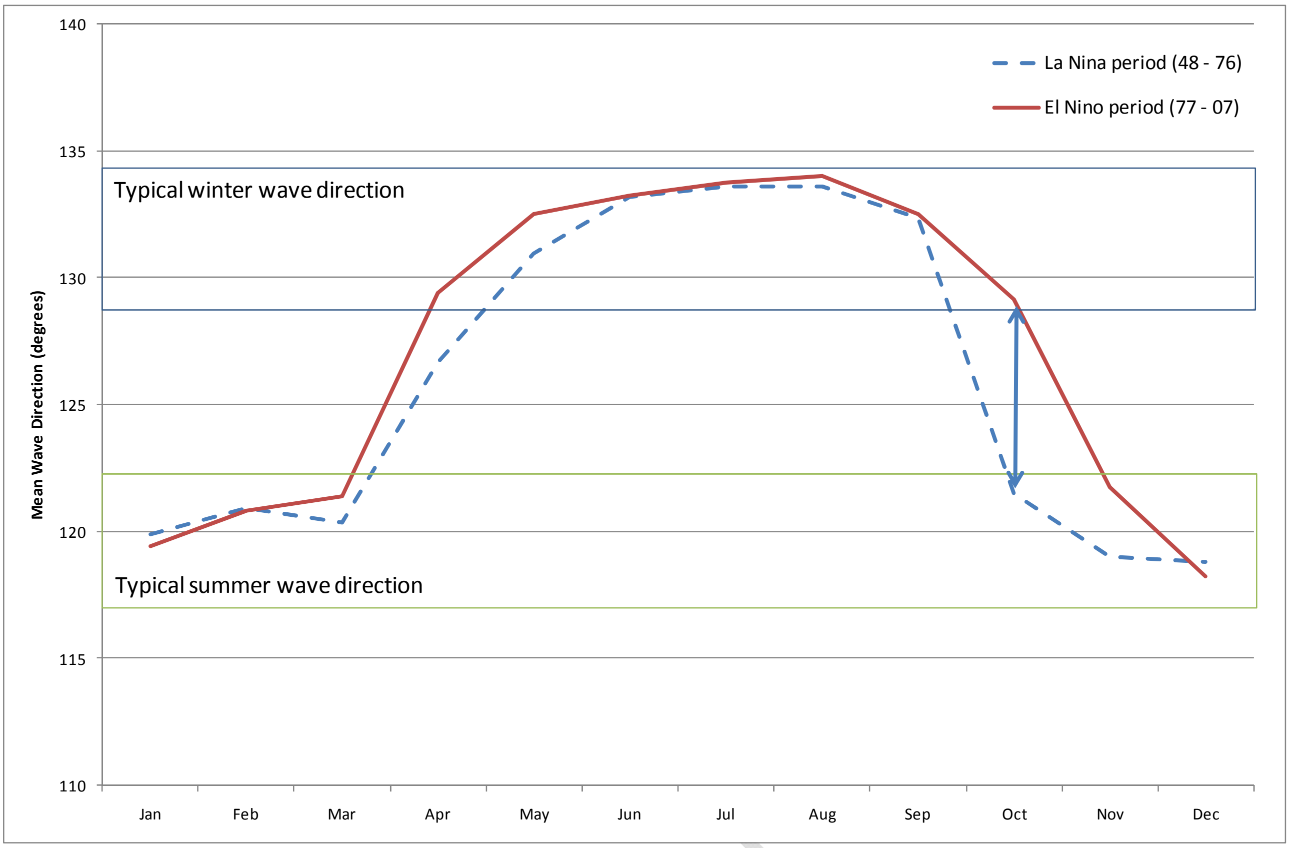


Figure 3-4 Decadal variability in MWD at Coffs Harbour

3.2.5 Nearshore Wave Climate

The assessment of beach and nearshore behaviour due to wave climate variability requires the generation of nearshore wave data. That is, the waves must be transformed from offshore into the nearshore zone, to take account of changes in wave direction and height due to refraction and diffraction as waves approach the coastline.

The offshore data were transformed to nearshore values using the MIKE 21 Spectral Wave Transformation software package from the Danish Hydraulics Institute (DHI). The MIKE 21 model transforms the offshore data for wave refraction and diffraction processes in the nearshore zone.

The wave transformation model was applied to a bathymetric model that was interpolated to a mesh with finer resolution nearshore than offshore. The bathymetric data used in the model was derived from all available data, including: Aus chart 812, PWD (1983), MHL (1983, 1986, 1987) and RAN survey data. The bathymetric grid was a variable mesh (variable element size) and extended from the coastline to 300 m AHD water depth.

The nearshore wave model was used to investigate the sensitivity of the Coffs Harbour coastline to changes in mean wave direction under average significant wave height (H_S) conditions. Based upon the review of mean wave direction data as described in Section 3.2.4 above, the winter and summer wave climates were taken as representative of the extreme ends of the directional wave climate over the long term. Model simulations were conducted for the winter and summer conditions described in

Section 3.2.2. The summer and winter nearshore H_s and mean wave direction patterns for each sub-compartment are shown in Figure 3-5 to Figure 3-12.

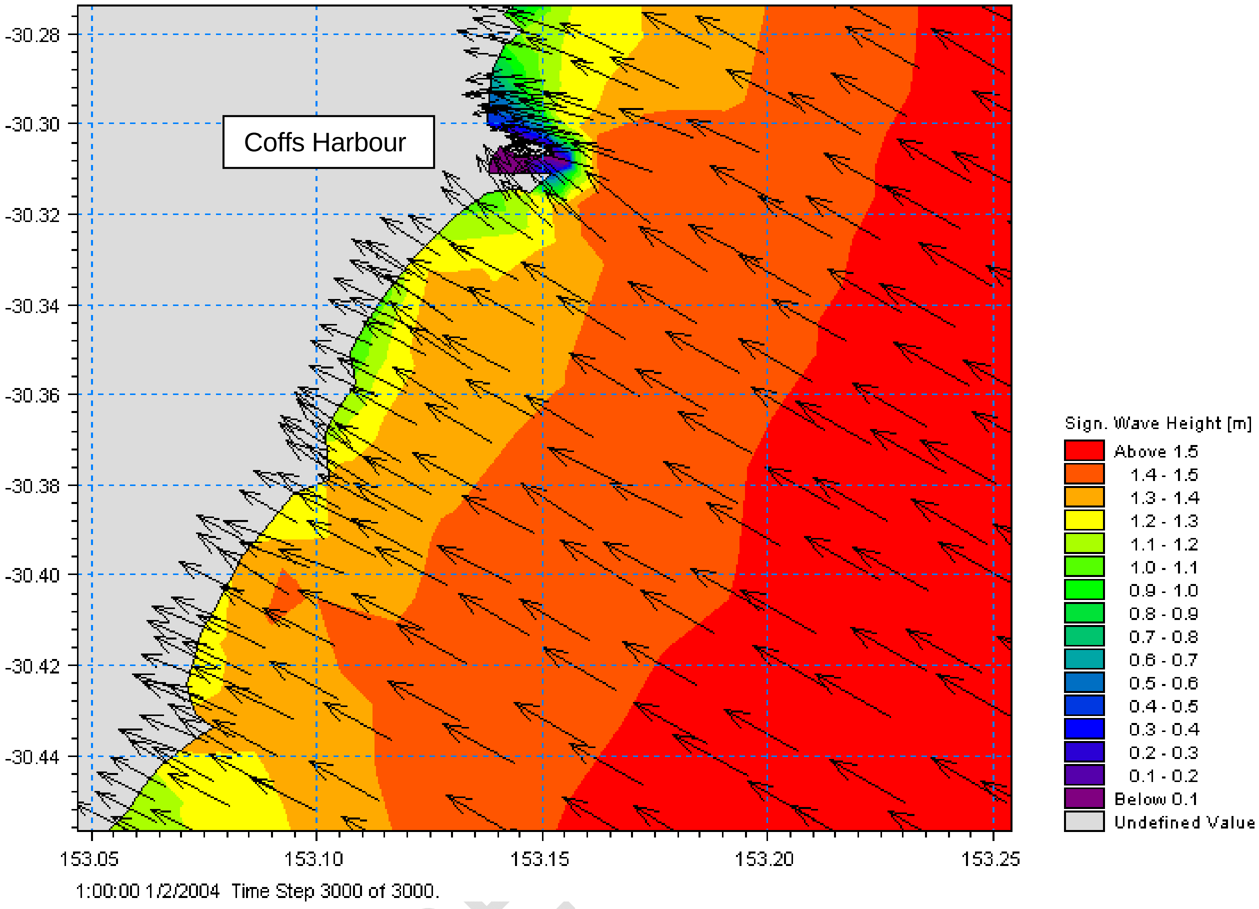


Figure 3-5 Summer nearshore H_s and MWD patterns for Sub-compartment 1 (Bundagen Head to Coffs Harbour).

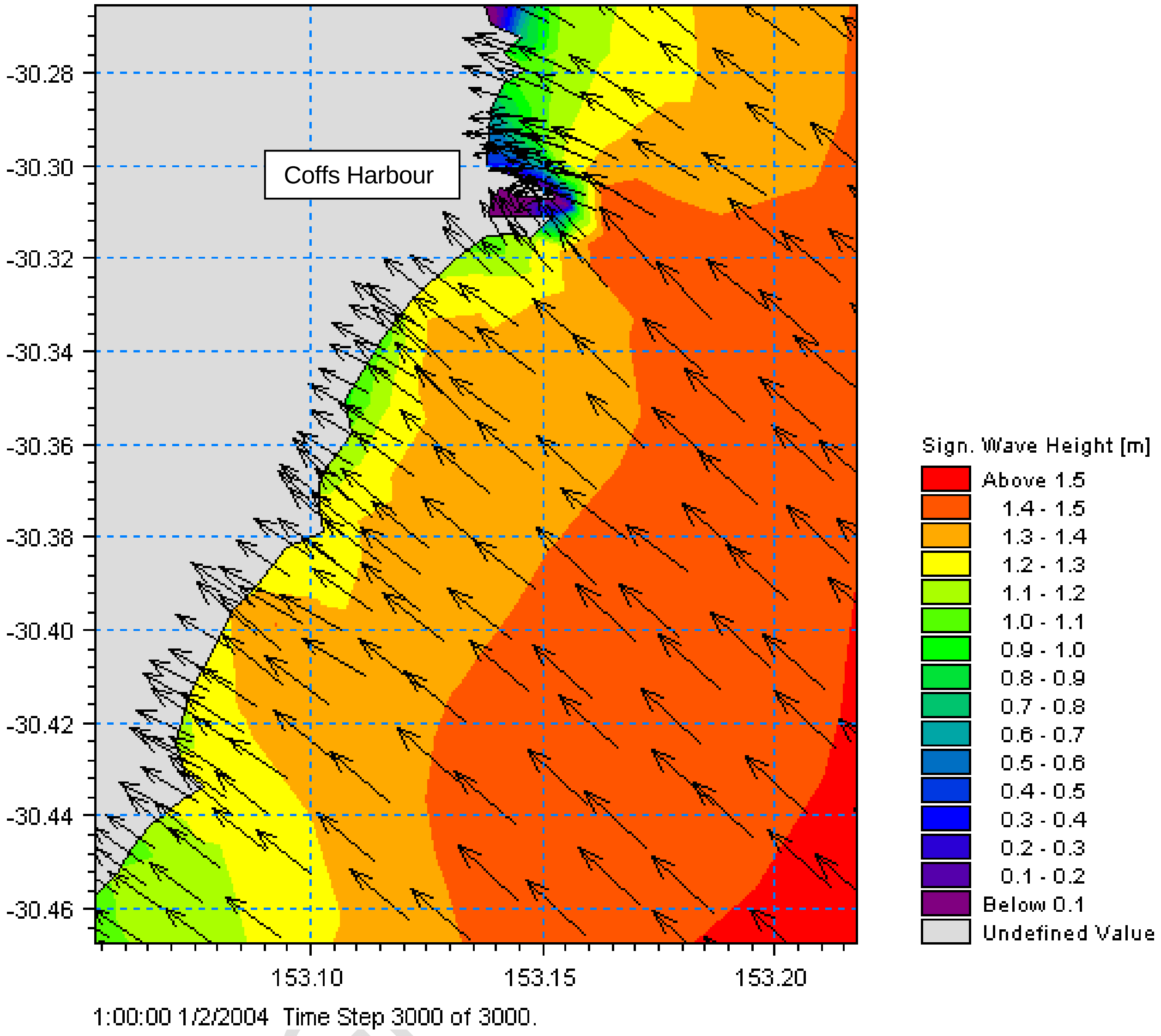


Figure 3-6 Winter nearshore H_s and MWD patterns for Sub-compartment 1 (Bundagen Headland to Coffs Harbour).

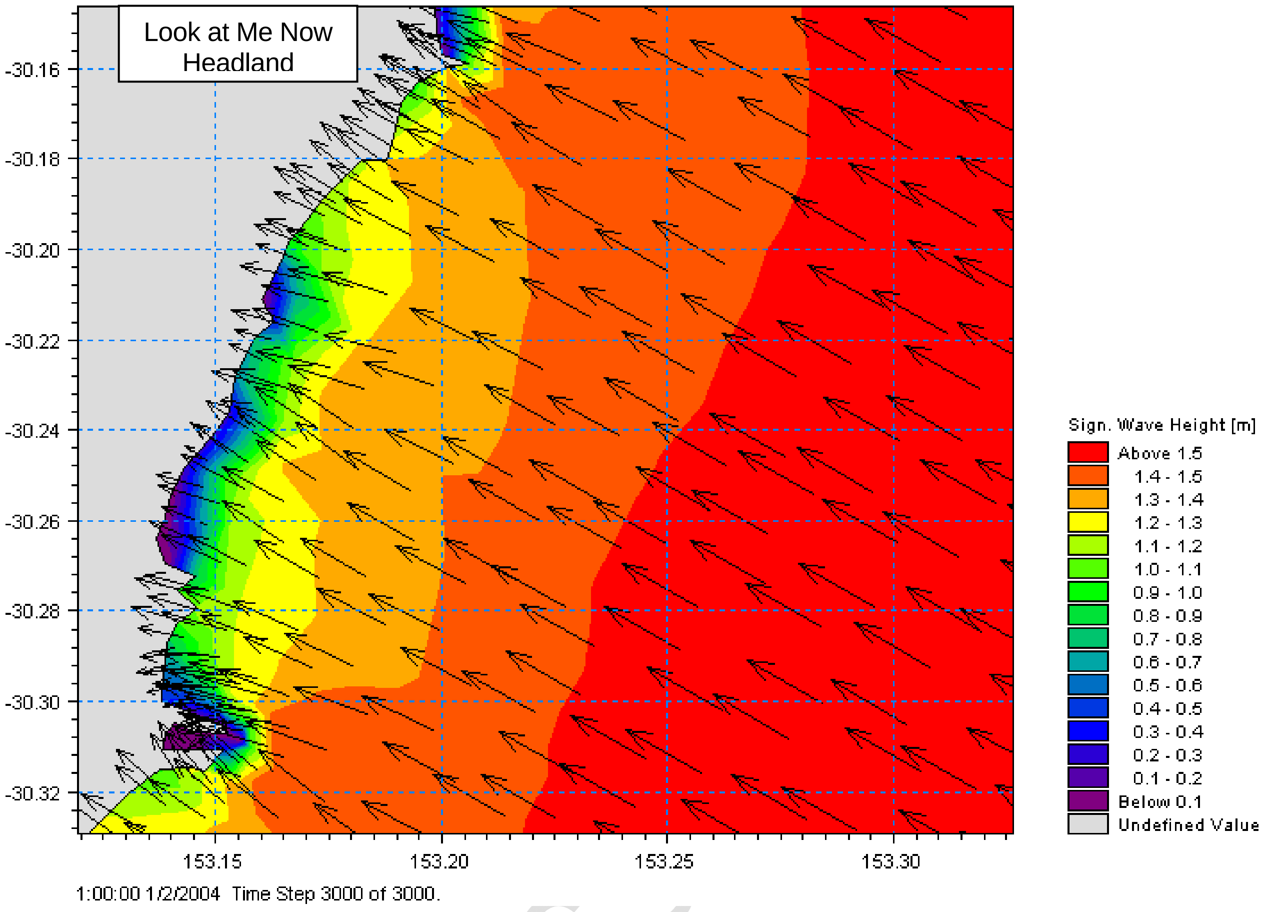


Figure 3-7 **Summer nearshore H_s and MWD patterns for Sub-compartment 2 (Coffs Harbour to Look at Me Now Headland).**

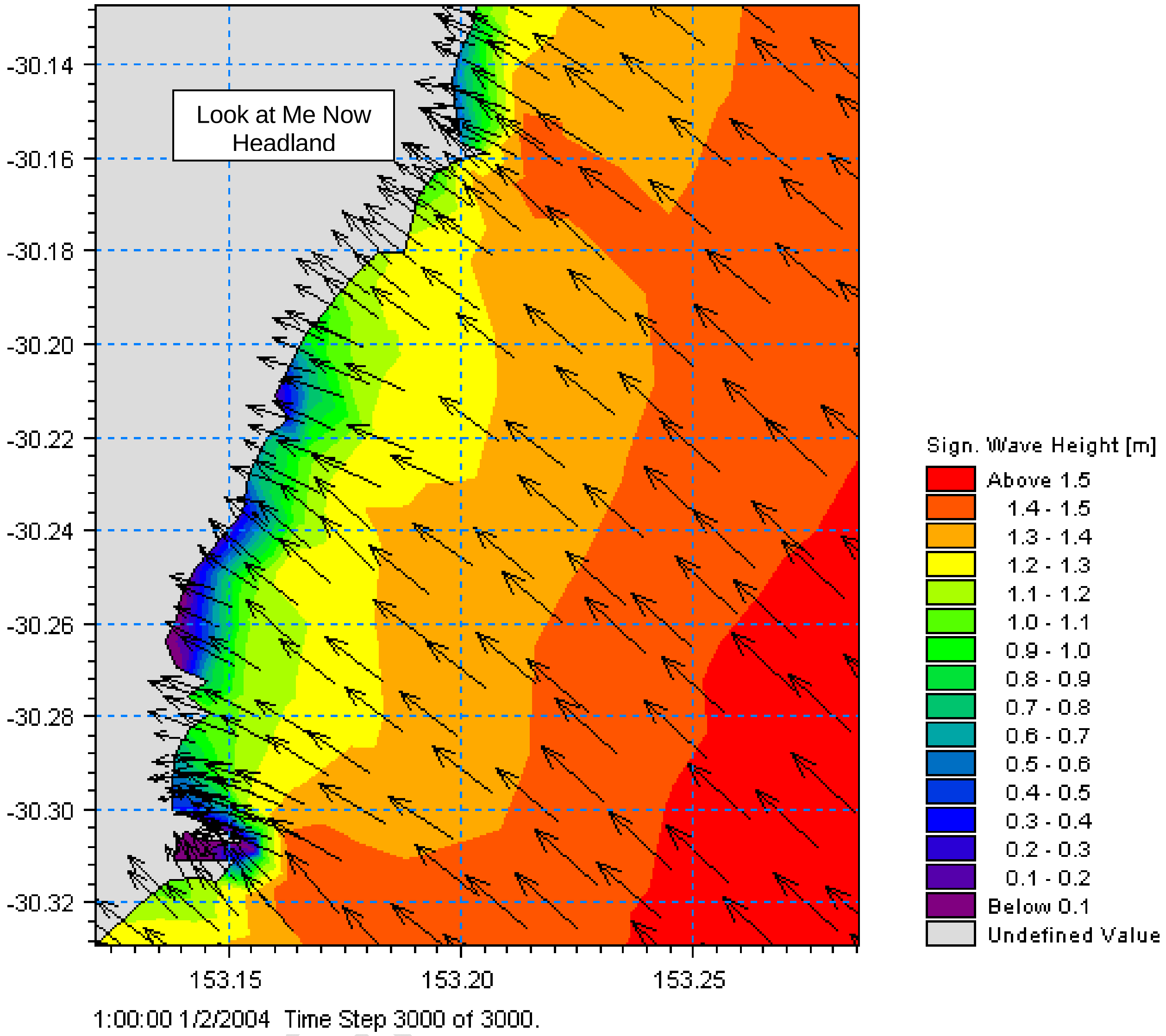


Figure 3-8 Winter nearshore H_s and MWD patterns for Sub-compartment 2 (Coffs Harbour to Look at Me Now Headland).

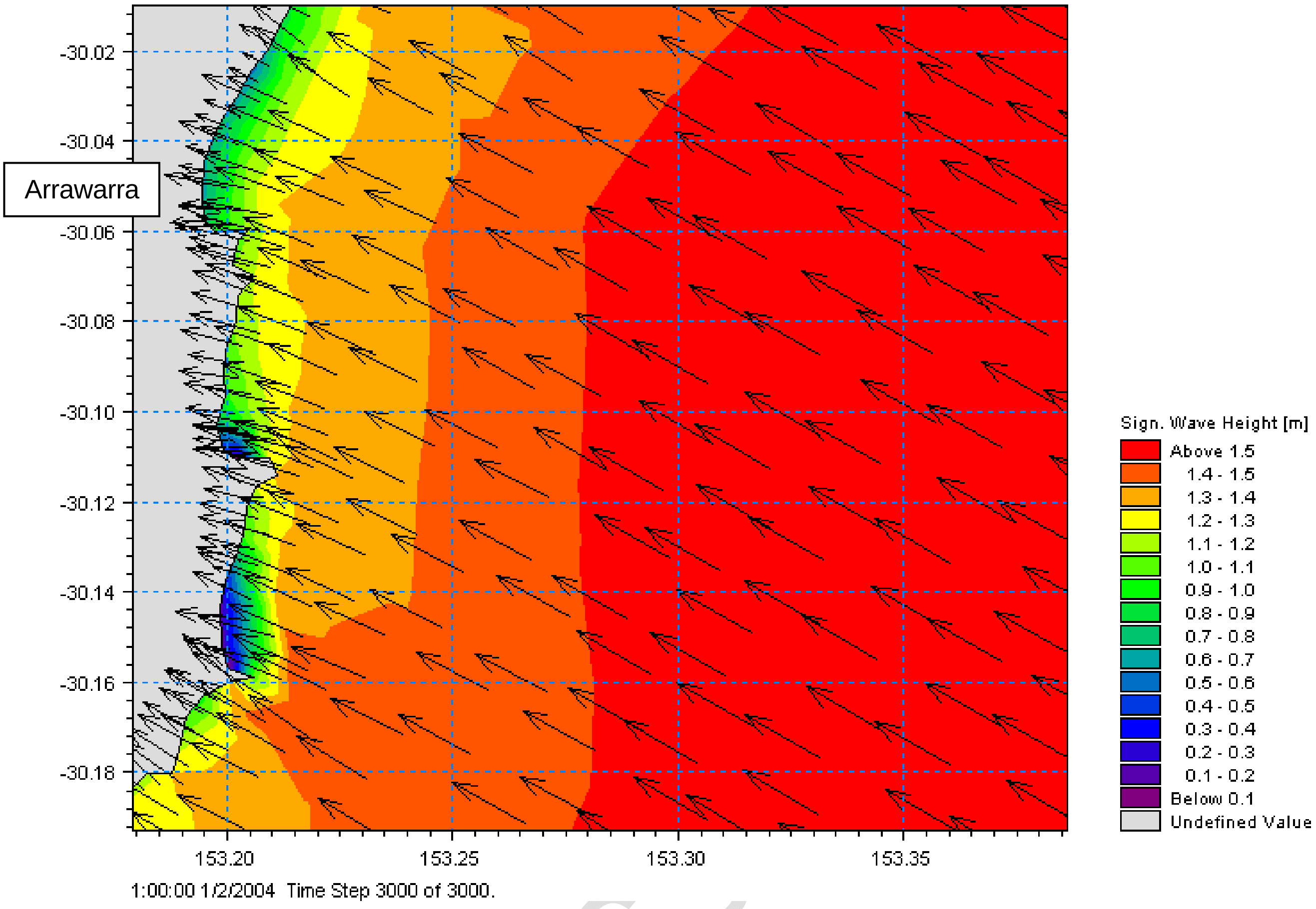


Figure 3-9 Summer nearshore H_s and MWD patterns for Sub-compartment 3 (Look at Me Now Headland to Arrawarra Headland).

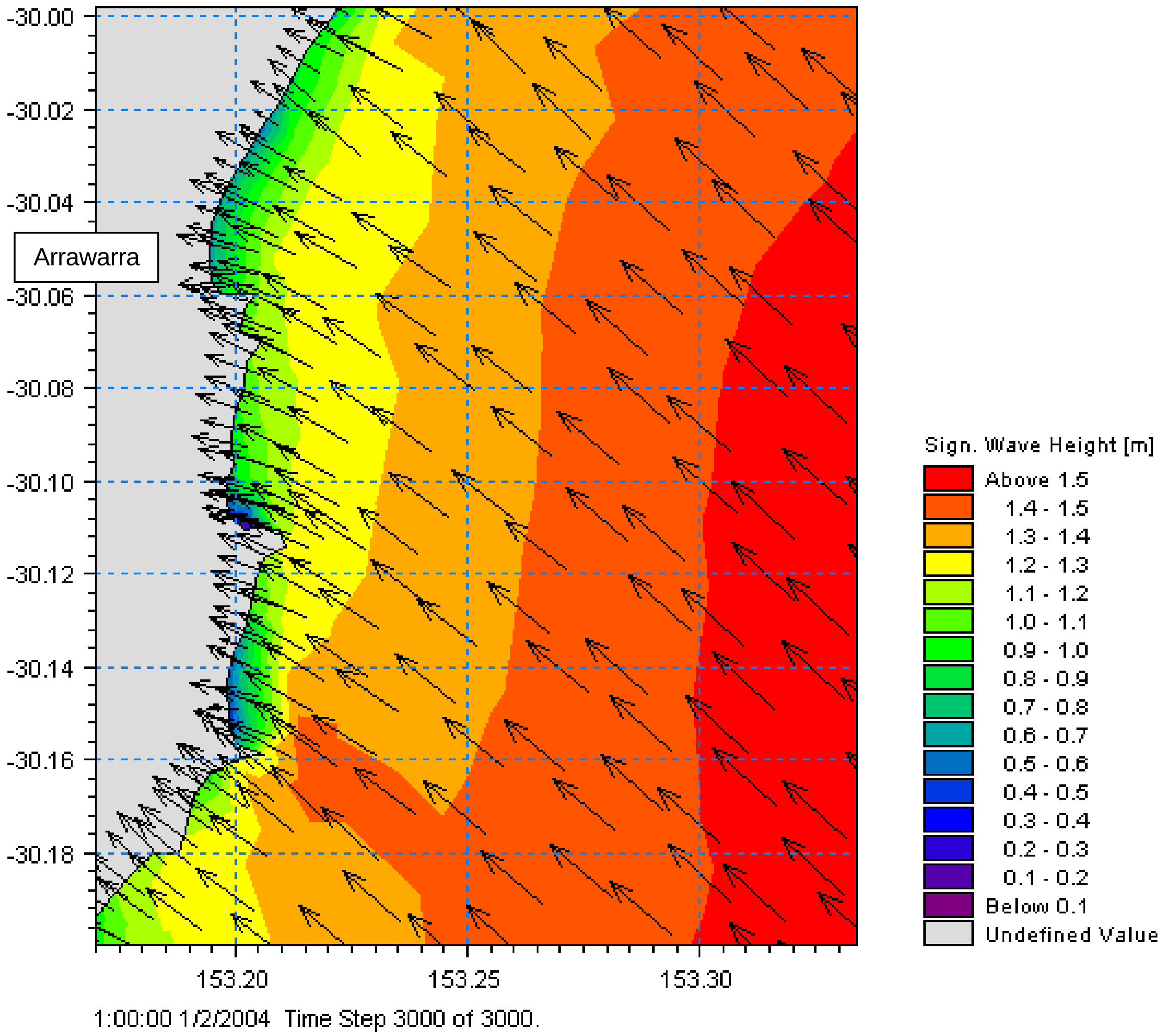


Figure 3-10 Winter nearshore H_s and MWD patterns for Sub-compartment 3 (Look at Me Now Headland to Arrawarra Headland).

.

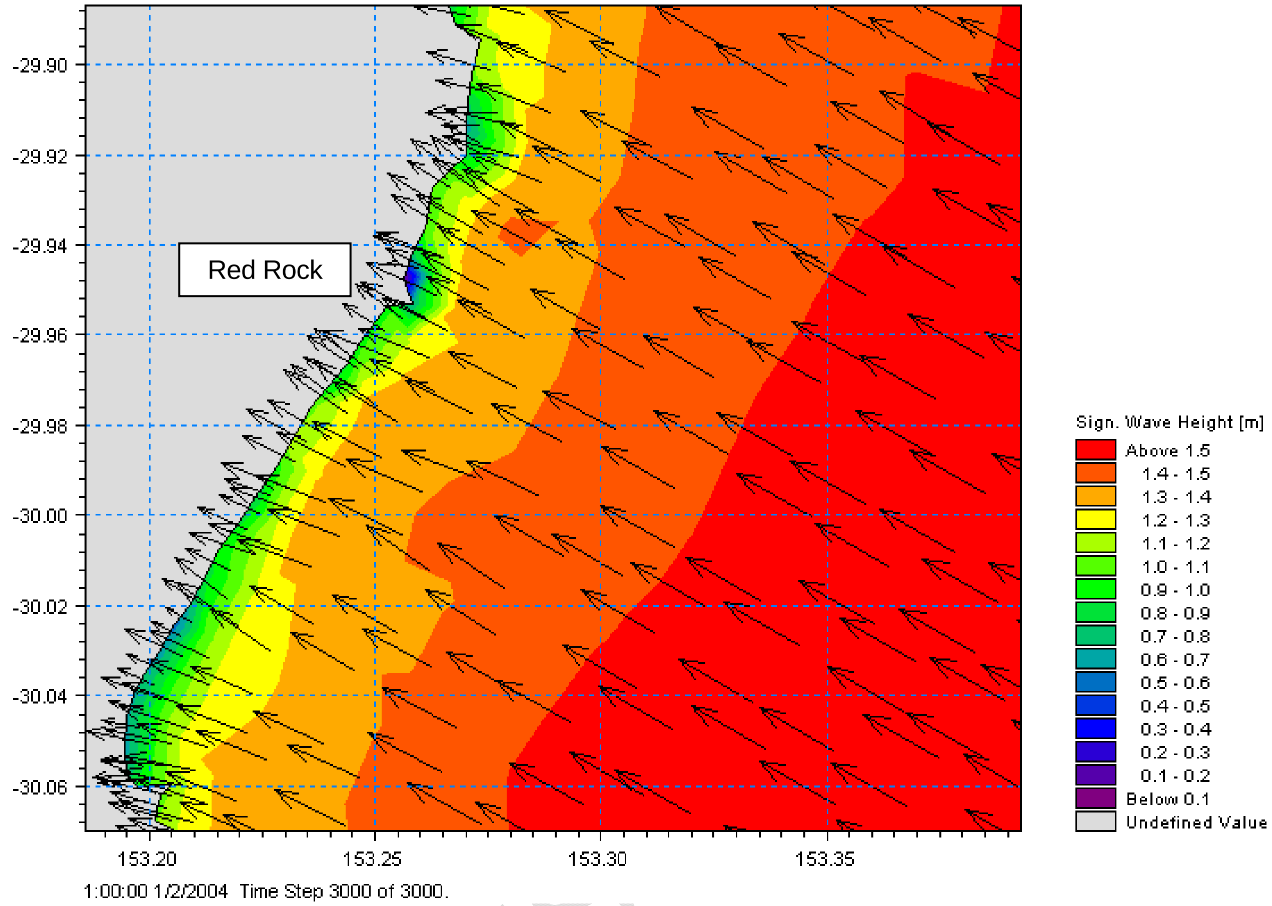


Figure 3-11 Summer nearshore H_s and MWD patterns for sub-compartment 4 (Arrawarra Headland to Station Creek Beach)

.

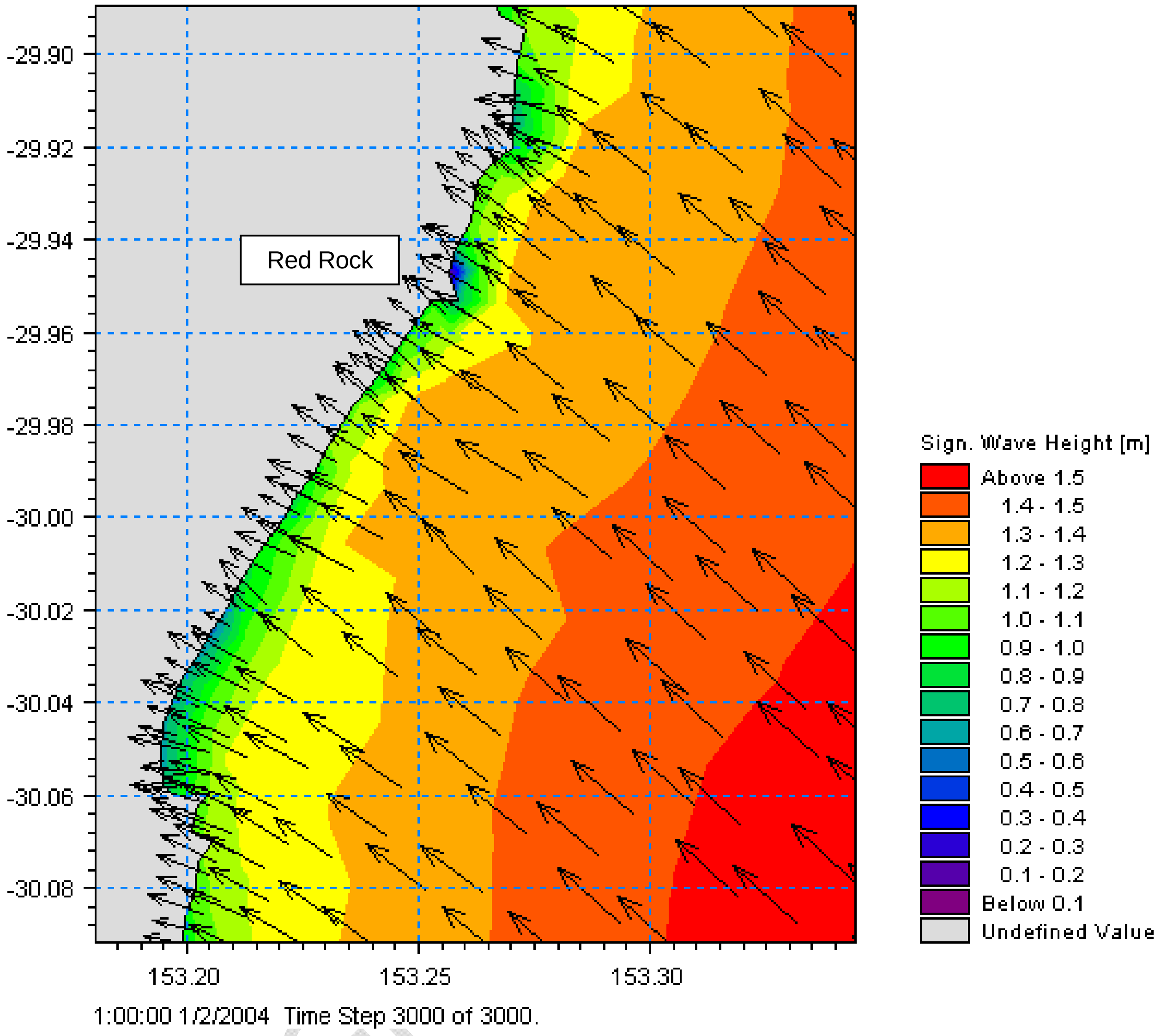


Figure 3-12 Winter nearshore H_s and MWD patterns for Sub-compartment 4 (Arrawarra Headland to Station Creek Beach).

3.2.6 Storm History

3.2.6.1 Storm History Prior to Wave Measurement

For the period prior to 1977 when wave data measurements commenced, the storm history provided in sources such as BBW (1985, 1986) and in other hazard studies in the region has been utilised. The number of storms and some characteristics for each year taken from BBW (1985; 1986) prior to 1977 has been summarised in Table A.2, Appendix A. Reports on the northern NSW coast have described significant storm activity to have occurred in 1954, 1967 and to a lesser degree, 1974, 1990 and 1999 (WBM, 2003).

The historical data indicates that while the number of storms may be greater in some years, the intensity may be lower, with large category X storms (of $H_s > 6.0$ m) occurring in years with low storm frequency (eg, 1926 and 1937). It is also apparent that most of the storm activity and the largest wave heights are produced by east coast low cyclones (44%) and tropical cyclones (42%) on the north coast (BBW, 1986). The highest waves determined for the north coast were generated by east coast low cyclones (BBW, 1986).

The year 1967 was the stormiest year from the historical data, with the largest number of storms and of the largest wave height. This included two category X storms of 9.9 m and 6.1 m H_s in February and March 1967 (tropical cyclones), followed by a storm of 10.1 m H_s generated by an east coast low cyclone in June 1967. In addition to the extreme wave heights, the June storm is expected to have caused the greatest damage as it occurred in conjunction with spring high tides, and when the beach was already in an eroded state.

The year 1954 also experienced a Category X storm of 9.1 m H_s during a tropical cyclone in February of that year. Other regional reports have described this as another notable year for storminess on the north coast, although unfortunately there is only limited data in BBW (1985) on storms in this year. The years 1929, 1942, 1955 and 1971 are also noted as being stormy years from the BBW (1985) storm history, due to the occurrence of Category X storms in addition to a more frequent storm occurrence.

Interestingly the May-June storms of 1974, which are generally taken to be the 1 in 100 year storm level for the central, Sydney and south NSW Coasts (McLean and Shen, 2006) were not reported to be as severe in terms of wave height on the north coast. Only one of the events which occurred during the seven week period from May to June 1974 was reported on the North coast (of 4.4 m on 3-5 June, 1974).

A number of the storm events are known to have coincided with high water levels on the NSW coast. While wave heights may have been lower, additionally elevated water levels are likely to have resulted in greater damage from these storms than may be anticipated from wave height alone. These events are listed below.

- Storms in February 1954, February 1974 and June 1967 (as noted above) coincided with the occurrence spring high tides (PBP, 2004).
- The May 1974 storm coincided with the highest water level recorded on the NSW coast, of 2.37 m (above ISLW) measured at Fort Denison (May 25, 1974), which included 0.24 m of unpredicted astronomical tide on top of 0.23 m of storm surge and 1.9 m of predicted tide (Foster *et al.,* 1975).
- The May 1997 storm (peak H_s of 5.6 m) coincided with an elevated water level 0.7 m higher than the predicted tide. Water levels during the May 1997 storm were found to be 1.2 - 1.9 m higher than three other storms of greater wave height (August 1986, June 1989 and April 1989), and so, the storm was described as more damaging. When storm duration was also accounted for, this storm was considered the 7th largest between 1976 and 2001. The storm caused damage to the eastern breakwater of Coffs Harbour (PBP, 2004).

3.2.6.2 Storm Severity Analysis

Storm severity calculations have been performed for the period of measured wave data (1977 to 2007). This allows a comparison of the wave power between years based on the number of storms and the storm wave heights. The storm severity value was calculated using the method of You and Lord (2008), with some minor modifications. You and Lord (2008) calculated yearly storm severity using the following equation:

$$\Omega = \left[\frac{1}{\lambda} \sum_{i=1}^{i=n} H_i^2 \right]^{0.5} = \left(\frac{n}{\lambda} \right)^{0.5} \times \left(\frac{\sum H_i^2}{n} \right)^{0.5} = f \times H_{rms}$$

Where: Ω *is storm severity (m);*
λ *is the number of storms per year averaged over many years,*
n *is the number of storms in one year,*
H_i *is storm peak wave height,*
H_{rms} *is the root-mean-squared wave height and*
f *is the relative frequency of occurrence of storms.*

The storm severity (Ω) presents the total wave energy of n storms scaled by λ (You and Lord, 2008).

You and Lord (2008) defined a storm as $H_s > 3$ m for more than one hour duration. The measured wave data consisted of 6 hourly H_s measurements for the period 1977 – 1985, and hourly H_s measurements for 1985 – 2007. For 1985 onwards, the storm threshold of 3 m advocated by You and Lord (2008) was used. However, given the lower sampling frequency for the pre-1985 data, a storm was defined as $H_s > 2.5$ m, for use in the equation. This is consistent with the definition used by BBW (1985) in their storm analysis.

You and Lord (2008) assumed that storms of a longer duration would have a larger peak storm wave height, and so, they stated that storm duration could be adequately represented by the peak storm wave height in the storm severity calculation. However, during the processing of the wave data (1977-2007), it was apparent that in many cases the storm wave height did not necessarily indicate the duration of the storm. Storms of larger H_s sometimes occurred for a shorter duration than storms with a lower peak wave height. To account for storm duration in determining storm severity, the number of hours of storms per year have been substituted, rather than the number of storm events per year, within the equation of You and Lord (2008). The results were found to more accurately reflect the relative storm severity (and wave power) occurring in each year.

Unfortunately, there are notable periods of missing data from the Coffs waverider buoy time series. In order to account for this, periods of missing data in the Coffs time series were substituted with measured wave data from the Byron Bay wave rider buoy. Compared with Coffs Harbour, average wave heights are slightly higher at Byron Bay, but the 100 ARI 1 hour storm is lower (refer Sections X and X). This is likely due to periods of equipment failure at both sites, in particular, the Byron buoy is documented to have failed during a number of severe storms (Kulmar *et al.*, 2005). Replacing missing data from Coffs with Byron data is likely to provide a good indication of the *regional* storm severity count for the entire Coffs LGA coastline. For large storm events, the two places are considered sufficiently close that the Byron Bay buoy will capture the occurrence of a storm at Coffs Harbour. The periods of data replacement are outlined in Table A.3, Appendix A.

The storm severity calculations indicate that the years 1988, 1989 and 1990, and 1999 were notably stormy years on the Coffs Coast. Other regional reports have also indicated 1990 and 1999 years to be notable for storms (WBM, 2003). To a lesser degree, 1984, 1995 and 2006 were also relatively stormy. The storm severity time series is given in Figure 3-13.

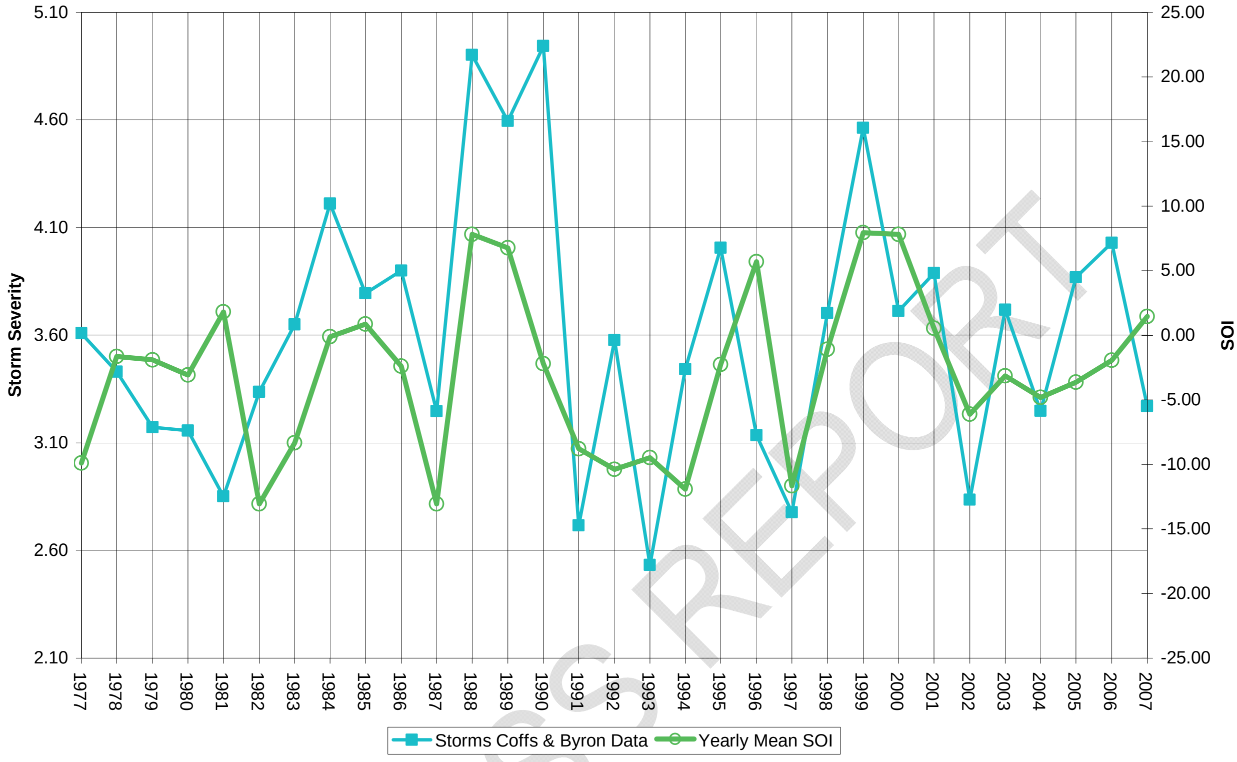


Figure 3-13 Storm Severity and Yearly Mean SOI

Storm severity calculated for Coffs Harbour has been compared with the yearly mean SOI (from January to December) in Figure 3-13. A correlation coefficient of 0.53 (p-value 0.0023) was calculated for the storm severity and SOI yearly values. When data from 1985 to 2007 only was compared (which is considered to be of better quality), the coefficient of correlation increased to 0.62 (p-value of 0.0016). This indicates there to be reasonable to good correlation between the storminess in any one year and the yearly SOI value.

3.3 Water Levels

3.3.1 Tides

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

Coffs Harbour tidal water levels are given in Table-3-5, as provided by MHL using data from 1987 – 2007. Coffs Harbour has a maximum tidal range of 2.04 m. The highest predicted tidal level, or highest high water solstice spring tide (HHWSS), is 1.084 m above AHD. Indian spring low water tide (ISLW) is -0.955 m below AHD, which is the lowest predicted tidal level.

The ocean tidal regime is uniform along the NSW Coast which means high tide occurs close to simultaneously at all locations along the coast. As such, shore-parallel tidal currents along the coastline are negligible. Near the larger entrances of estuaries, creeks, harbours and lakes/lagoons, tidal driven currents may be generated by the tidal volume flowing through such entrances on the falling and rising tide, resulting in local currents in the surf zone.

Table-3-5 Coffs Harbour Tidal Levels*

	HHWSS	MHWS	MHW	MHWN	MSL	MLWN	MLW	MLWS	ISLW
Level (m AHD)	1.084	0.695	0.547	0.399	0.009	-0.381	-0.529	-0.677	-0.955
Level (m ISLW)	2.040	1.651	1.503	1.355	0.965	0.575	0.426	0.278	0.000

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

3.3.2 Elevated Water Levels

Elevated water levels typically comprise a combination of:

- **barometric pressure set up** of the ocean surface due to the low atmospheric pressure of the storm;
- **wind set up** due to strong winds during the storm "piling" water upon the coastline;
- **Astronomical tide,** particularly the HHWSS; and
- **Wave set up.**

Wave set up is defined as the elevation of the water surface due to the release of energy by breaking waves. Wave set up is directly related to wave height, and so will be greater during storm conditions when wave heights are also larger. Wave set up occurs within the nearshore zone, and so is often calculated separately, then added to elevated still water levels. Storm surge calculations typically comprise the component of the elevated ocean level due to barometric pressure set up and wind set up, through a complex assessment of storm synoptic types and measured data.

At the present time, three assessments of elevated ocean levels and storm surge are available for use for the Coffs Harbour region. The BBW (1986) and McInnes *et al*., (2007) assessments are specific to Coffs Harbour. Discussions with MHL have indicated that a more comprehensive assessment of recurrence intervals for water levels in the Coffs region is being completed at present, but will not be completed in time for this progress report (pers. comm., Anne Glackin, MHL, November 2008). Until such time, design elevated water levels analysed for Sydney (Fort Denison), have been provided for use by DECC (pers. comm., Phil Watson, DECC, 2009), in Table 3-6.

The elevated ocean levels given by BBW (1986) are based upon a probabilistic assessment of water levels from an extreme storm and include the highest astronomical tide, storm surge and wave set up in the output. The BBW (1986) elevated ocean levels were generated using the storm history of east coast low and tropical cyclones at Coffs Harbour, which generate the largest storms wave heights and number of storms. The recurrence interval of the central pressure values from tropical cyclones and east coast low cyclones were then converted to an elevated ocean level, and estimated return interval wave heights to a wave set up. The values determined by BBW (1986) are given in Table 3-6.

McInnes *et al*. (2007) conducted an assessment of storm surge levels at Coffs Harbour for use in their assessment of the Wooli estuary, north of Coffs Harbour. The levels given for Wooli estuary in the report were converted back to surge heights for Coffs Harbour (using the regression equation given in the report). The McInnes *et al*. (2007) values are based upon hourly sea level data with the astronomical tide removed at Coffs Harbour, for the period 1996 – 2005. This 10 year time series was then extended back to 1971, by adding larger storm surges (> 0.32 m) documented by MHL for the period between 1971 and 1990, and then repeating the smaller storm surge events (< 0.32 m) from the original 1996-2005 storm series for the period 1971 – 1995. For the purpose of comparison with the other assessments by BBW (1986) and DECC (2009), the highest tide level (HHWSS) was added to the storm surge levels of McInnes *et al*. (2007), and are given in Table 3-6.

Wave set up is typically taken to be approximately 15% of the offshore significant wave height at the shoreline (WBM, 2003; WP Geomarine, 1998). MHL has provided the most recent return interval analysis of storm wave heights using the 31 years of data at Coffs Harbour (May 1976 to December 2007, refer Figure 3-2). The 1 hour storm duration wave heights have been utilised in the assessment of wave set up, as these are higher wave values, and so give the highest wave set up values that may occur during a storm. The 1 hour storm duration wave heights and subsequent wave set up values are given in Table 3-6.

Final extreme ocean level values that include storm surge, the astronomical tide and wave set up are summed in Table 3-6 for Coffs Harbour and Sydney. We have used the values from Coffs Harbour provided by McInnes et al. (2007), as these values are specific to Coffs Harbour and are more conservative than the other values. However, there are limitations in the methods used to derive this data, as such, it is anticipated that values specific to Coffs Harbour will be available from MHL for use in the Coffs Harbour LGA Hazards Study project.

Table 3-6 Elevated Water Levels, Coffs Harbour

	Extreme Water Level (Storm Surge + HHWSS)				**Extreme Water Level + Wave Set up**		
Recurrence Interval (years)	**Coffs Harbour (McInnes *et al.,* 2007) (m AHD)**	**Sydney (DECC, 2009) (m AHD)**	**1 hr duration wave height (m)**	**Wave Set up (m)**	**Coffs Harbour (BBW, 1986) (m AHD)**	**Coffs Harbour (McInnes et al, 2007) (m AHD)**	**Sydney (DECC, 2009) (m AHD)**
10	1.60	1.35	6.7	1.01	2.0	2.60	2.36
20	1.65	1.38	7.1	1.07	2.2	2.72	2.45
50	1.74	1.42	7.8	1.17	2.4	2.91	2.59
100	1.81	1.44	8.2	1.23	2.6	3.04	2.67

3.3.3 Wave Run-up

Wave run-up is the vertical distance on shore that the uprush of water from a breaking wave reaches, and for an extreme condition, is added to the tide, storm surge and wave setup. It is the wave run up mechanism that results in the overtopping of coastal barriers, resulting in coastal inundation of areas behind these barriers. It is generally considered that wave overtopping at an extreme level is likely to occur for a limited time (several hours) around the high tide.

Wave run-up is highly variable between storms and locations, and will depend on factors including wave height, wave period, beach slope, shape and permeability, the roughness of the foreshore area and wave regularity. Hence, it is difficult to predict wave run-up, and instead, actual measured values from other NSW locations are typically used. The largest measured wave run-up level is 7.3 m (AHD) at Narrabeen in 1986. This measurement was based on debris lines and so includes the elevated water levels during the storm in the measurement.

Wave run up is typically greater on steeper beaches. For Coffs Harbour regional beaches, calculations of run up using the steepest and flattest photogrammetric profiles gave a run up of 10.3 and 7.0 m AHD (WP Geomarine, 1998). In some locations along the Coffs coast, such as Campbells Beach, wave uprush may already reach the foredune crest during typical king high tide or high wave conditions.

In lieu of actual measurements from Coffs Harbour regional beaches, 7.0 m AHD is taken to have a lower bound probability of occurrence, 7.3 m AHD is the median probability of occurrence and 10.3 m AHD is the upper bound probability of occurrence wave run-up levels during a storm, as shown in Table 3-7.

Table 3-7 Predicted Wave Run Up Levels

	Wave Run up Level (m AHD)		
	Lower Range	**Median**	**Upper Range**
Existing Timeframe	7.0	7.3	10.3

3.3.4 Currents

3.3.4.1 East Australian Current

The major offshore oceanic current along the south eastern Australian coast is the East Australian Current (EAC). This is series of anti-clockwise eddies of warm water which originate in the Coral Sea and are observed as a continuous, strong current travelling slowly down the western side of the Tasman sea, just off the continental shelf of Australia. At a point along the NSW Coast, often at Smoky Cape, the EAC turns left and heads towards New Zealand before turning north and ebbing out (MHL, 1987; WPGeomarine, 1998).

Occasionally, eddies of the water break from the EAC and travel south unpredictably, and may travel as far as Tasmania. At times, the current may encroach as far shoreward as the 20 m depth contour, and when this occurs, high currents may be generated. The continental shelf is relatively narrow in the Coffs Harbour area, and strong southerly currents have been observed offshore in this region, believed to be the EAC (MHL, 1987; WPGeomarine, 1998). It is unknown what effect encroachment of the EAC near to shore has upon surf zone processes

The tropical characteristics of SIMP are tied to the East Australian Current (EAC), which brings tropical water south along the NSW coast, usually at a distance of a few km offshore. The extent, strength and persistence of this current varies, as it travels as a series of eddies, but overall, the current increases average temperatures sufficiently to allow tropical species to exist in the SIMP region. The EAC also likely carries eggs and larvae of tropical species, which may not easily reproduce in local waters (Binnie and Partners, 1987).

3.3.4.2 Longshore currents

Waves arriving at oblique angles on the coast generate a current which travels along the shore. This current is the key process in the longshore transport of sediment. Longshore currents may also be observed as feeder channels for rip currents, and may also be generated by longshore variations in water levels due to nearshore wave conditions and wind stresses (Coastline Management Manual, 1990).

Longshore currents may be generated in any direction along the coastline, depending upon the incoming wave direction. Where the angle of wave attack is close to perpendicular to the shore, there is little to no generation of a longshore current.

The predominant angle of wave attack on the NSW coast is from the SE. This oblique angle of approach relative to the orientation of the NSW coastline (including the Coffs coast) generates a net northerly longshore sediment transport along the entire NSW coast.

However, the strength of net northerly transport is thus largely dependant on the prevailing wave climate. During southerly wave directions, longshore currents will be strongly directed towards the north. During more easterly wave conditions, there may be little to no longshore transport. During northerly wave conditions, currents will be directed to the south. It is apparent, then, that the prevailing wave climate controls the strength and direction of longshore currents, and thus, longshore sediment transport.

3.3.4.3 Cross-shore currents / rip currents

The main cross-shore currents of interest within the surf zone are rip currents. Rip currents facilitate the offshore flow of water from the surf zone, which has been delivered by breaking waves. Rip currents are dominant upon intermediate beach states, particularly the transverse bar and rip state, which are the most common beach state along the Coffs Coast. The spacing of rips is dependant upon the wave energy conditions, such that, during large waves, fewer rips will form at greater distance apart, however the currents are also wider and stronger. Feeder currents and troughs into the rips will also develop in width and current strength during high waves.

Rip currents contribute to the extent of beach erosion during severe storms (Nielsen *et al.*, 1992), both in terms scarping of the upper beach face, as well as transporting offshore the sand mobilised by wave breaking. Gordon (1987) estimated erosion of 230 m^3/m above 0 m AHD at a rip current scarp at Wamberal Beach following a storm in 1978.

On the open beach length, rips may form at any location along the beach. Topographically constrained rip currents form at headlands or along reefs, to facilitate the offshore flow of water from breaking waves at headland constrained beaches. Topographic rips at headlands assist in the bypassing of sediment around headlands, by delivering sediment beyond the headland constraint during high waves. Headland bypassing is a key feature of longshore transport in the Coffs Region (refer Section 3.6.2).

On heavily embayed beaches, the wave height and energy may exceed the natural spacing of rip currents, and instead “mega rips” at the topographic headland constraint may form. Mega rips may export sand up to 1 km offshore. The water depths 1 km offshore are likely too deep to enable such sand deposits to be reworked back onshore during calm conditions.

3.3.4.4 Currents at Headlands

A series of current measurement exercises were conducted by MHL throughout the 1980s (MHL, 1983; 1986; 1987) at a number of headlands to investigate current speed and directions, and the generation mechanism for these currents (eg, wind, waves). MHL (1983; 1986; 1987) tracked currents at Woolgoolga Headland, Look At Me Now headland and Green Bluff. The current measurement exercises aimed to determine a suitable headland location for an ocean outfall. However, some of the conclusions regarding current dynamics at headlands have some relevance to this study.

The control that headlands may place on current movement and the relative dominance of wind or waves under certain conditions has implications for our understanding of sediment bypassing around headland features (as discussed in Section 3.6.2). In certain locations, wind currents were dominant, while wave driven currents were more dominant at others, and not surprisingly this related to water depth immediately offshore of the headlands.

At the large headlands with deeper water offshore, namely Look At Me Now and Woolgoolga, the dominant mechanism driving currents was found to be wind. At Look At Me Now and Woolgoolga, current measurements indicated that for 85 – 90% of the time, the current direction matched the wind direction (MHL, 1986; 1987). MHL noted that when the wind changed direction during the experiment, there was an almost immediate shift in the current direction with the wind. The current monitoring also demonstrated that beyond the surf breaking zone, wave generated currents had little to no influence on water currents at these headlands.

MHL (1987) noted that due to the deep water at Look At Me Now and Woolgoolga (> 8 m), under typical wave conditions waves remain unbroken until they reach the rock shelf of the headlands. During storm events, waves break further from the shore throughout the beach region, and significant currents may be generated. MHL (1987) suggested that given water depths off the headlands are typically > 8 m, waves will only begin to break when they reach a height of 6 m, although this assumption does not take into account rip currents generated along headlands during high wave conditions (MHL, 1987).

Headlands such as Green Bluff and Diggers Headland were found to have shallower water depths (2 – 3 m), rock reefs and boulders immediately around the headland. The results of current monitoring by MHL (1983) near Green Bluff over the summer of 1982-83 indicated a greater role for wave driven currents. It was found that when wave height was greater than 1 m, wave induced currents dominated the water movement at Green Bluff, typically within a narrow band of broken water along the rocky bluff shoreline. Further offshore (20 – 30 m) however, wind-induced currents were dominant. During times of low wave activity wind-induced currents were also dominant. The experiments illustrated a mean current speed of 0.1 m/s (+/- 0.05 m/s), with little difference in current speed due to waves or wind (MHL, 1983).

Lord and Van Kerkvoort (1981) reported findings of a sand tracer experiment at Diggers Head. Diggers Head was selected for the experiment as it is one of the major protruding headlands in the Coffs region. The experiment involved placing sand tracer in a rip current on the southern side of the headland (ie, at Diggers Beach) under ~ 4 m wave heights. The offshore water depths were noted to be ~ 2 - 3 m around the headland. The experiment indicated significant bypassing of Diggers Head, with tracer collected at Campbells Beach within two days of placement at Diggers Beach. Thus, while Diggers Head is a key protruding feature of the Coffs coastline, the shallower water depths enable sediment bypassing at this location.

MHL (1987) concluded that headlands have a large bearing on local current patterns, including forcing currents to increase speed at the headland to flow around it. Sharp changes in shoreline orientation may lead to current separation, which is often observed as streak lines emanating from headlands, generation of eddies, and 'shadow zones' in the lee of headlands. In the experiments at Woolgoolga and Look At Me Now headlands there were a number of unusual current anomalies, such as when the current further offshore of the headlands ran counter to the wind direction, or when complex eddy structures were observed. Current separation at the numerous islands in the region may also generate eddies and counter currents in the region (MHL, 1987).

3.4 Wind Climate

In the coastal region, the prevailing winds are directly responsible for the general *sea* state, and in some instances may generate noticeable currents. Assessment of 30 years of wind data from Coffs Harbour Airport indicated there to be a diurnal variation in wind direction during warmer months (November to March). Winds are generally offshore in the morning (due to the cooler land mass relative to the sea), and onshore winds form from the east to north east direction in the afternoon, as the land mass is heated during the day and the overlying air is heated and rises causing cool air to flow in from the sea to replace it. During the cooler months, winds tend originate from the west to south directions. Occasional afternoon sea breezes occur during cooler months, however these are of lesser strength than those in summer months (MHL, 1983; Binnie and Partners, 1987).

3.5 Regional Rainfall, Runoff and Fluvial Discharge

The Coffs regional climate is humid sub-tropical, and Coffs typically experiences warm to hot summers, and generally mild winters. Average annual rainfall is 1800 mm, of which, around 60% occurs between December and April. The average rainfall is higher east of the coastal range than the western areas inland, due to moist sea air rising over the coastal range, and falling as precipitation. (Binnie and Partners, 1987). Binnie and Partners (1987) estimated the average surface water runoff (per unit area per year) for the area between Bungaree Head and Red Rock to be more than double the average runoff for coastal NSW south of Sawtell, and nearly nine times the average for the State.

Rainfall typically falls as occasional high intensity bursts, and the creeks and lagoons are noted to respond rapidly to rainfall (WP Geomarine, 1998).

The Bellinger/Kalang River system is the largest fluvial contribution to the Coffs Harbour regional coastline. The other major rivers and creeks with outflow to the regional coastline are: Bonville Creek, Boambee Creek, Coffs Creek, Moonee Creek, Woolgoolga Creek, Arrawarra Creek, and the Corindi River.

3.6 Sediment Transport

3.6.1 Longshore and Cross-shore Sediment Supply

The stability and recovery of coastal embayments in the Coffs region will be governed by the available sediment supply, both from updrift regions (ie, longshore sediment transport from beaches to the south) and in the nearshore zone (ie, cross-shore sediment transport). Investigation of the sediment transport to the north and south of Coffs Harbour and from the nearshore zone is discussed herein.

It has been widely observed that a significant volume of sand has prograded along Boambee Beach, as a result of sand trapped by both the land bridge between South Coffs and the mainland since 1926, and the eastern breakwater off Corambirra Point breakwater, completed in 1946. Accretion on Boambee beach indicates that there is a nearshore sediment supply, and that where planform accommodation space occurs between headlands, reefs or breakwaters, beach profiles will prograde. The planform accommodation space is controlled by the shoreline curvature and its relationship to the nearshore wave refraction pattern, and the steepness of the nearshore to offshore depth profile. For example, the construction of the southern land bridge at Coffs Harbour has created planform accommodation space for the subsequent seaward progradation of Boambee Beach.

The probable sources of sediment on Boambee Beach are:

- Upcoast (south), delivered by longshore transport;
- Sand transported across the shoreface from the nearshore zone; and
- sand reworked from the fluvial flood tidal deltas (ie, Bonville and Boambee Creeks) into the nearshore littoral zone by fluvial flood discharge.

Roy and Stephens (1980) estimate that approximately 100 m of shoreline progradation (~2,750,000 m^3) along Boambee Beach has occurred between 1940-1980. This is equivalent to 68,750 m^3/yr and is comparable to calculated longshore sediment transport for the South West Rocks to Nambucca Heads mega-compartment, located to the south of Coffs Harbour.

If the longshore headland bypassing rate for Corambirra Point (37,500 m^3/yr from Roy and Stephens 1980 work) is indicative of the Coffs Harbour regional rate, then the across-shore sand transport rate would be ~6 m^3/m of shoreline/yr to supply all of this volume without contributions from eroding updrift compartments. Along the South West Rocks to Nambucca Heads mega-compartment centennial average sand supply rates to the shoreline have varied between 0.5 to 4 m^3/m of shoreline/yr, over the past 2000 years (Goodwin and Blackham, in prep). At Iluka, centennial average sand supply rates to the shoreline have varied between 0.5 to 5 m^3/m of shoreline/yr, over the past 2000 years (Goodwin *et al.* 2006). These rates indicate that an across-shore sand supply exists for much of the NSW north coast, since the modern and historical sand supply has not been associated with an equivalent sand loss due to recession of updrift (ie to the south) beach compartments (Cowell *et al.*, 2003, Goodwin, in prep).

North of Coffs Harbour, the thin offshore sand deposits (refer Section 2.2.4.1) do not provide an extensive source for sand barrier progradation. During the mid Holocene (7,000 to 3,000 yr B.P.), prior sand barrier deposits located seawards of the modern coast were eroded to supply the present coast. Roy and Stephens (1980) have reported that shell lag deposits in the inner shelf sands taken from water depths of 10 to 30 m have yielded late Holocene ages (2670± 92 and 3245± 218 years BP). They record at least 1 m of surface sand reworking shorewards and exposure of underlying sediments and substrate. The occasionally exposed underlying coarse sand and fine gravel has migrated onshore, allowing the northern beaches to become coarser and steeper (with one beach in fact prograding) over this time. The gravelly lag deposits and active sand bedforms of the inner shelf sands indicate that during the late Holocene to modern period, wave action has mobilised and transported sand landwards and alongshore to supply the nearshore zone. However, this also suggests the lower shoreface sand supply in the Coffs Harbour region may now be exhausted.

Nearshore sediment supply is the most important source of sand for much of the Coffs region coast particularly in years where the mean wave direction is more easterly. This is because a more easterly wave direction does not drive longshore sediment bypassing of headlands, which may replenish some beach compartments, and these events become rare to episodic.

In addition, higher wave heights and longer wavelengths which may be associated with more easterly storm conditions (eg, east coast lows) result in waves mobilising a greater volume of sand from deeper water. Hence fluctuations in wave height are also an important control on the across-shore sand supply. The more extensive Holocene sand barrier deposits that have formed at Bonville and Boambee Beaches may indicate that these compartments have trapped a significant proportion of the longshore sediment supply throughout the late Holocene.

It is possible that the reworking of flood tidal delta sands during the late Holocene relative sea level fall has also provided a source of sand, since many of the late Holocene sand barrier deposits, such as Boambee and Bonville Beaches, are situated adjacent to or downdrift of the major river and creek outlets. However, there is no available data to investigate the significance of flood tide deltas and hence, fluvial sediment discharge as a significant source of sediment to the coastline.

3.6.2 Longshore Sediment Transport

Waves approaching the shoreline from an oblique angle generates a current alongshore which transports sediment. Depending on the prevailing wave and wind direction, the sediment transport may be directed either north or south. On NSW beaches, the net longshore sediment transport is to the north, due to the dominant south east wave climate relative to the general north to south orientation of the NSW coast. The net northerly transport is considered to be more pronounced in northern NSW because the headlands are less prominent.

Longshore sediment transport is episodic along the Coffs Harbour coast due to the physical interruption of bedload transport by bedrock reefs and headlands in the littoral zone, and the constraints of wave climate variability. The longshore sediment transport is dependent on storm events to activate bypassing around the headlands (Lord and Van Kerkvoort, 1981). In simple terms, storm waves (during short term storm events) transport sand around headlands as episodic slugs of relatively large quantities of sand. Topographically constrained rip currents at headlands may assist with the offshore transport of sediment around headlands during storm conditions. However, depending on the incident wave direction, headland bypassing may be more or less effective. For example during easterly wave conditions, the near perpendicular incoming wave direction (relative to the shoreline) generates little to no longshore current. Rip currents at headlands would still generate offshore transport, but without the longshore current, the sediment would be deposited offshore of the beach. This highlights the susceptibility of the Coffs coastline to shoreline impacts (such as erosion) in response to wave climate variability.

3.6.2.1 Estimated Longshore Transport Rates from Coffs Harbour Bathymetric Changes

The construction of the Coffs Harbour breakwaters between 1914 and 1927 has resulted in the termination of longshore sand transport north of Muttonbird Island (Carley et al., 2006). Prior to the harbour construction, longshore sand transport was continuous between Boambee Beach and Park Beach to the north (Lord, 1984). The estimated rate of longshore sand transport along the Coffs Harbour coast prior to harbour construction is 75,000 m^3/yr, based on calculated updrift sand volumes trapped between 1942 and 1979. The calculations are based on the cumulative sand volumes from: Boambee Beach upper shoreface progradation; offshore of the harbour; inside the harbour (25,000 – 50,000 m^3/yr); south of the harbour; and from sand extraction (Lord and van Kerkvoort, 1981; Carley *et al.*, 2006).

Analysis of the 1890 AD bathymetric chart indicates that a natural sediment bypassing route occurred around the eastern side of South Coffs Island, then between Muttonbird Island and the mainland shoreline, and along Park Beach. The bathymetric charts illustrated the passage between the western tip of South Coffs Island and the mainland coast to be shallower than 2 m water depth, and to be comprised of a sub-aqueous tombolo and outcropping reef that allowed longshore sediment bypassing during high tide and storm wave conditions.

The 1890 AD bathymetry indicates that the pathway for sand bypassing of South Coffs Island is in 7 to 8 m water depth, with a shallow salient formed off the inshore (western) tip of Muttonbird Island. This salient, or bar of outer nearshore sand extended around Muttonbird Island and into deep water offshore of South Park and Park Beach. The orientation of the sand salient formed off the western tip of Muttonbird Island indicates that it has formed from a wave refraction/diffraction pattern with a nearshore mean wave direction ~120° T, that is close to the modern MWD for summer.

These headland sand bypassing routes were terminated by the construction of the southern, eastern and northern breakwaters. Roy and Stephens (1980) and Lord (1984) concluded that the construction of the Coffs Harbour breakwaters has artificially resulted in the trapping of sediment immediately to the south along Boambee Beach, with some bypassing around South Coffs Island and the eastern breakwater, resulting in accretion within the harbour mouth, Jetty Beach, and inner Coffs Harbour. There is no evidence to suggest that any significant sand bypassing around the eastern side of

Muttonbird Island is a regular occurrence today. Carley *et al.* (2006) have calculated the downdrift shoreline recession and the equivalent sand budget deficit along the 10 km of beaches to the north of Coffs Harbour between 1942 and 1986 or 1993 to be ~73,000 m^3/yr, which is equivalent to the volume trapped by the harbour breakwaters. Sediment on the beaches north of the harbour including Campbells Beach has been observed to be coarsening over time (Lord and van Kerkvoort, 1981). This is because the finer fraction of the sediment is more easily transported by longshore transport processes under typical wave conditions, and thus is winnowed out over time.

The interpreted natural longshore sand transport rate at Coffs Harbour is comparable to rates determined at other locations on the regional coast, such as along the South West Rocks to Nambucca Heads coast (75,000 m^3/yr), both in the recent decades and during the past 1000 years (Goodwin and Blackham, 2009 in prep). The recent increase in the sand infilling rate in the harbour during the 1990's to rates of 50,000 m^3/yr (Carley et al., 2006) may be associated with bathymetric shoaling along Boambee Beach, and/or, with the region-wide trend towards higher longshore sand transport rates during the El Nino-like phase of the Interdecadal Pacific Oscillation (IPO) from 1977 to 2006 (Goodwin, 2006). On the basis of the various estimates, the longshore sand transport rates along the Coffs coast could reliably be estimated to vary between 50,000 to 100,000 m^3/yr, depending upon wave climate variability, particularly between the IPO phases.

3.6.2.2 Aeolian (windborne) Sediment Transport

Aeolian, or windborne sediment transport originates from the aerial beach, specifically from the dry beach berm and dry upper beach face, and unvegetated incipient dunes and foredunes. Aeolian transport is the key builder of foredunes. Aeolian transport is specific to particular sediment grain sizes, such that sediments which are too coarse or heavy are not able to be transported by the wind. Vegetation of incipient and foredune regions is also a key factor in the transport of sediment by the wind. Vegetation may consolidate sediment in dunes, which negates transport by wind, and vegetation may also capture and retain wind blown sediment in foredunes and incipient dunes.

Thus, aeolian transport is likely to be important within particular regions of Coffs, and insignificant in others, based upon the constraints of grain size, dry upper beach regions and vegetation on dunes. The most notable location of windblown transport is between Fiddamans Beach and Sandys Beach, across Bare Bluff. At this location, aeolian transport is likely to be a key mechanism for sediment transport between these beaches. Although in recent years, effort to stabilise this region has been undertaken by dune care groups. It is unknown what effect the stabilisation of this sand blowout has had upon sediment transport for these beaches.

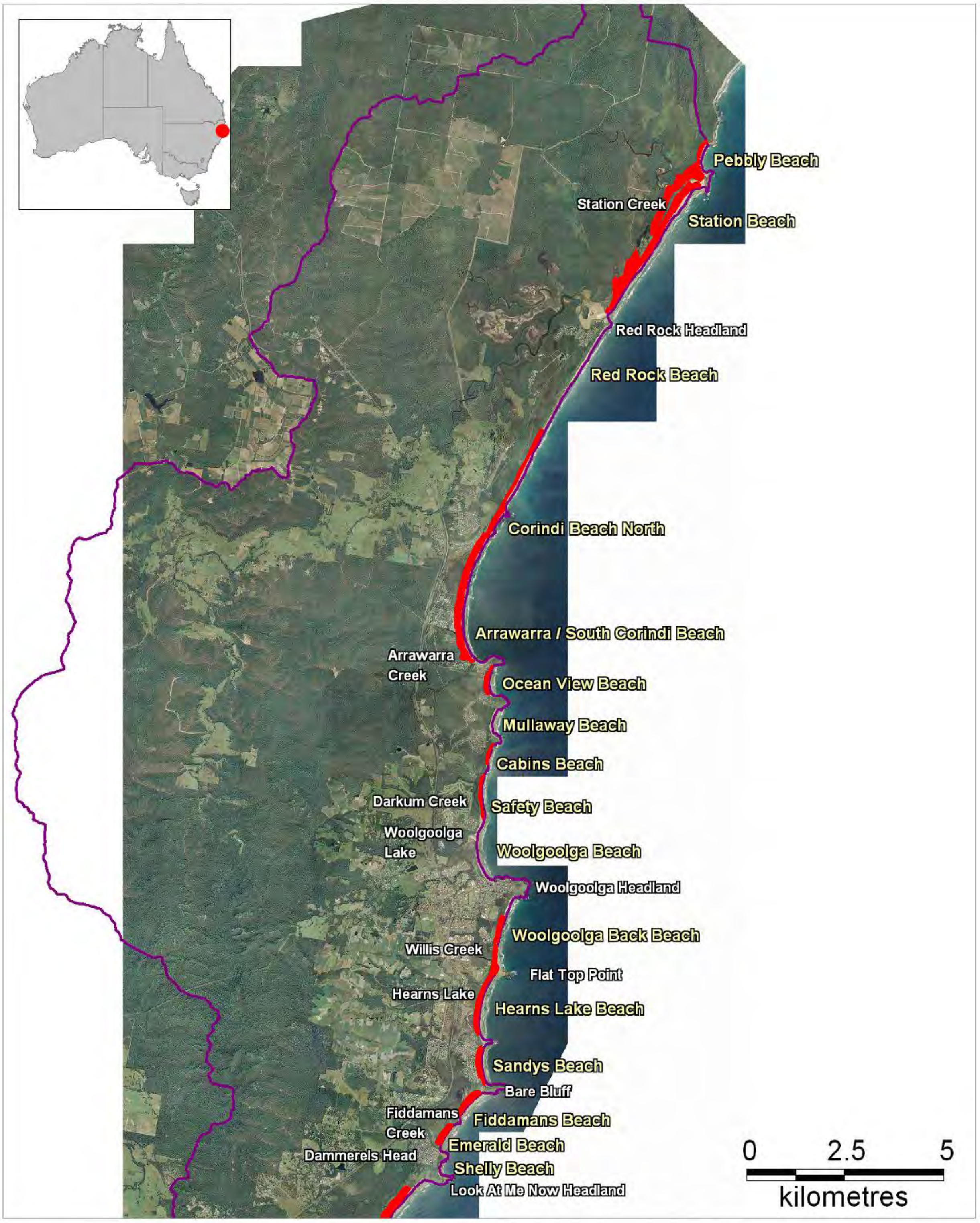
In other locations, for example Campbells Beach, aeolian transport is insignificant, due to coarse sediments as well as the wetting of the upper beach face during high tide, which hampers the transport of significant volumes of sediment.

Aeolian transport is a natural process, and allows the building of foredunes and storage of beach sediments in the upper beach. Aeolian transport is considered an issue in relation to the coastal hazard of sand drift. Sand drift is a minor nuisance in most cases, but may present a notable hazard where significant volumes of sediment are being removed from the beach system by wind, and/or coastal developments are being overwhelmed by windborne sediment. Changes to wind regimes under a future climate may present a change in Aeolian transport characteristics, most importantly, wind direction, which may modify the direction of transport, and the duration of strong winds, which may modify transport volumes.

Further, changes to the vegetation on sand dunes, such as by overuse and the creation of informal tracks by walkers or four-wheel drive vehicles, may initiate a sand blowout and subsequent destabilisation of the dune system. This may have consequences for the storage of sediment within foredunes, and therefore, the protection available to beaches during periods of erosion by waves and high water levels.

3.6.2.3 Sand Mining Impacts

The Coffs Harbour regional coast has supported an intensive sand mining industry during the 1950's to 1980's. The sand mining was largely confined to the outer sand barriers and was most extensive between Arrawarra Creek and Corindi Beach, south of Woolgoolga Headland, and along Moonee Beach. The locations of sand mining are shown in Figure 3-14 and Figure 3-15. It is probable that post-mining dune reformation may have had an impact on the subsequent beach and dune behaviour, and may be difficult to distinguish from natural beach variability due to interannual wave climate and sediment supply fluctuations. Photogrammetric analysis has identified the sites where dune reformation occurred.



Title:

Sand Mining Map (from CCA Dataset)
Coffs Harbour Study Area, Northern Half

Figure:

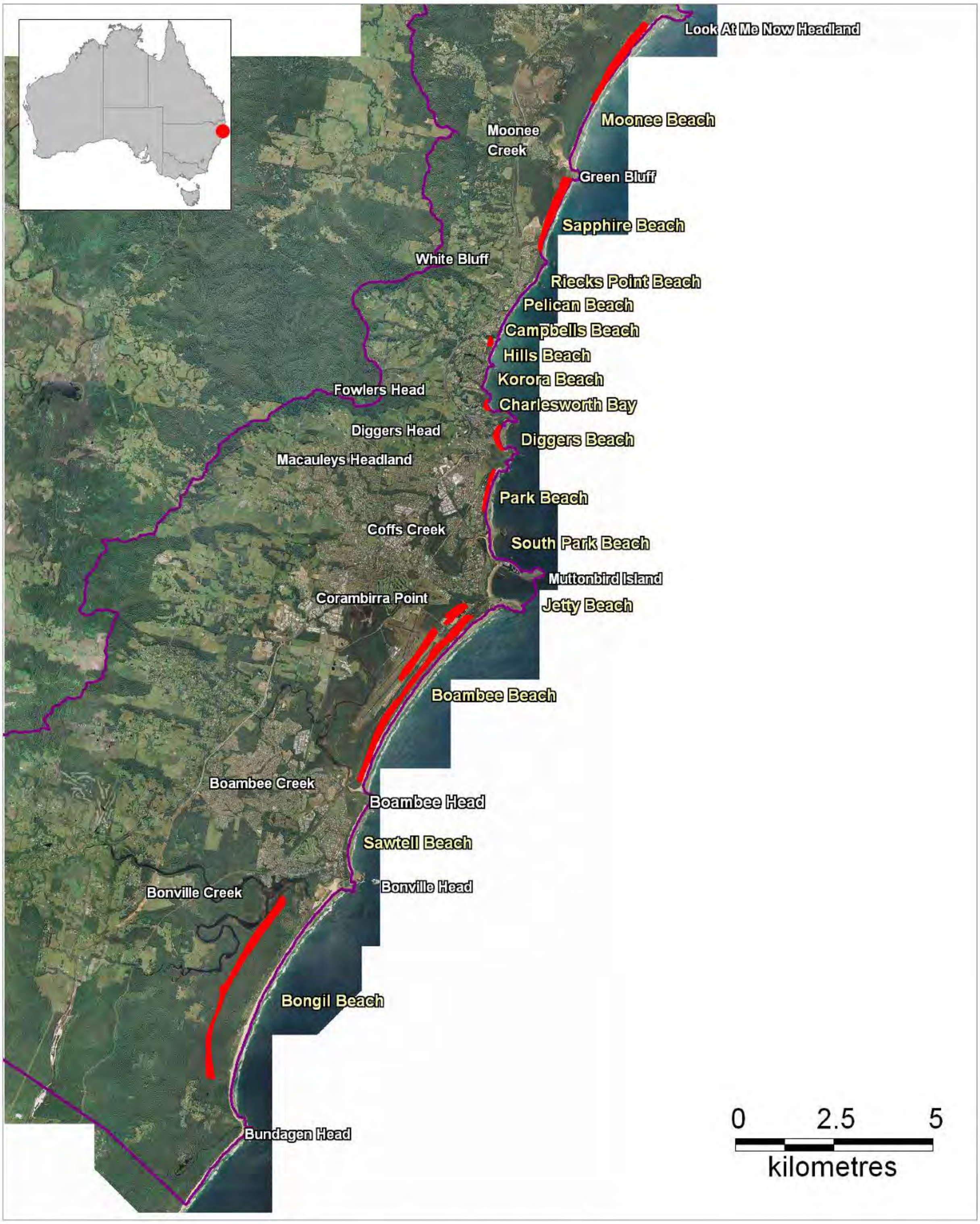
Rev:
A

N

BMT WBM
www.wbmpl.com.au

Filepath :

Figure 3-14 Sand Mining Paths, Northern Coffs Study Area



Title:

Sand Mining Map (from CCA dataset) in the Coffs Harbour Study Area, Southern Half

Figure:

Rev: A

N

BMT WBM
www.wbmpl.com.au

Filepath :

Figure 3-15 Sand Mining Paths, Southern Coffs Study Area

4 SHORELINE RESPONSE TO COASTAL PROCESSES

4.1.1 Long-term Trends in Regional Coastline Behaviour (Recession / Progradation) due to Sea Level Change

Over the late Holocene (past 3,000 years), relative sea-level along the northern NSW coast has fallen by ~0.5 to 1 m due to geodynamic processes (Lambeck, 2002), before rising ~0.15 m in the past century (White *et al.*, 2005). The relative sea level fall of ~0.5 to 1 m over the past ~3,000 years has probably contributed to the progradation of the coastline during this period in locations where there was a positive sand supply. These include Bonville, Boambee, Moonee and Station Beaches.

Whilst sea-level has risen along the NSW coast by ~0.15 m during the past century (Fort Denison, Sydney, Church *et al.*, 2004), sea-level has been observed to fluctuate monthly at Coffs Harbour and other sites along the northern NSW coast by up to 0.38 m, and by ±0.15 m on interannual periods due to ocean basin changes associated with ENSO, and by ±0.03 m on interdecadal periods associated with the IPO. The natural shoreline responds to these fluctuations by translating the dune-beach-shoreface profile seawards and landwards as the sea level falls and rises. Simple modelling tools such as the Bruun Rule, and variants such as the Cowell Shoreface Translation Model are used to estimate the shoreline and profile response to sea-level rise and fall, as discussed further in section 5.5

4.1.2 Coastline Planform and Wave Climate Variability

The sea level anomalies associated with ENSO and IPO are coupled with the fluctuations in wave climate (wave direction and wave height) associated with ENSO and IPO. High sea level anomalies are coupled with east south easterly mean wave direction, which drives a reduced northward flowing longshore sand transport and an apparent anticlockwise rotation in the shoreline alignment (broadly described by accretion at the southern end and erosion at the northern end of the embayment). And low sea-level anomalies are coupled to south-south easterly mean wave direction changes that drive an enhanced northward flowing longshore sand transport and an apparent clockwise rotation in the shoreline alignment.

The coastline can experience a range of responses to wave climate variability, including:

- Shoreline planform or beach rotation;
- Shoreline planform or beach oscillation; and,
- Shoreline planform curvature change.

Apart from the southern hooks of the larger beach compartments, the most susceptible beaches to interannual to interdecadal wave climate changes are those beach alignments that are controlled by ephemeral salients and tombolos attached to offshore headlands and reefs. These are unconsolidated sand deposits that immediately respond to shifts in the wave refraction and diffraction patterns, and are vulnerable to storm wave erosion.

4.1.2.1 *Interseasonal and Interannual Shoreline/Beach Rotation and Beach Oscillation Processes*

Beach rotation is the apparent clockwise-anticlockwise shift in the beach planform, typically between opposing erosion and accretion cycles at the northern and southern ends of embayed beaches. Most research on beach rotation has been conducted on embayed beaches where significantly oblique incident waves and longshore currents are small.

Short *et al*. (2000) assessed monthly beach profile survey data from Narrabeen/Collaroy Beach in Sydney between 1976 and 1999, to determine short and long term variations in the beach profile width. There was found to be a significant negative correlation between the two southern profiles and the two northern profiles, such that when the northern profiles were accreted, the southern profiles were eroded, and vice versa. The beach was also observed to pivot around a profile at about the centre of the beach. Beach rotation was linked with the incident wave direction, and so, the phase of the SOI. Short *et al*. (2000) showed there to be a strong correlation between the phase of the SOI and beach rotation. During the El Nino phase, the more southerly wave direction resulted in more accretion at the northern end and more erosion of the southern end of the beach, and a clockwise rotation of the beach. In contrast, during periods of more northerly (easterly) wave direction, associated with La Nina, the southern end of the beach experienced accretion and the northern end eroded, with an anti-clockwise rotation of the beach (Short *et al.,* 2000). This is also evident on interdecadal time scales.

The cause of the apparent shift in the beach planform is in dispute, it is currently not defined whether the rotation occurs in response to differential cross-shore transport or differential longshore transport forced by the wave climate variability, although it is likely to be some combination of both. However, the general concept of beach rotation applies for drift aligned coasts like the Coffs Harbour region, although the processes are not as well understood as for embayed beaches like Narrabeen-Collaroy.

Beach oscillation is a different process driven by the storm cycle, with sand eroded from beaches and deposited in offshore storm bars during storm wave attack (usually rapidly, i.e. in the first 12 hours of storm duration), with subsequent onshore transport and beach volume accretion and recovery over weeks to years, depending upon the severity and frequency of storm wave events (Short, 1999). In their assessment of storms and the SOI, Ranasinghe *et al*. (2004) found that storm wave heights during an individual storm could be equally large during a La Nina or El Nino period. However, the beach is more or less able to withstand storm attack depending on whether it is in a relatively accreted or eroded state. The relative state of the beach (eroded or accreted) is related to the frequency of storm events, not simply the wave height during one storm, as this modifies the length of time between storms during which the beach may recover.

Throughout the first half of 2009, significant beach erosion has been observed along the Coffs coastline. Erosion escarpments have been estimated to be at or close to the erosion extents experienced during the highly stormy decade of the 1970s. While we have no wave data to fully analyse this erosion event, it is known that there has been no single storm (eg, 1-in-100 year) event over this period that may be linked with the observed erosion. There have, however, been a number of storm events during the January to July period, at least one of which coincided with a high spring high tidal phase. In this case, it is likely that the frequency of storm events coupled with high tide water levels has resulted in the significant extent of beach erosion observed. The wave direction during the storms may also be a factor in the observed erosion.

In terms of predicting future beach erosion, it is apparent that beach rotation is an important process which needs to be accounted for in determining the probable extent of long-term beach erosion, particularly at the ends of the beach compartment, whilst the potential beach oscillation is due to storm wave events is taken into account through the definition of a storm demand volume.

4.1.2.2 Interannual Shoreline/Beach Curvature Change Processes

Sustained shifts in the offshore mean wave direction result in regionally variable nearshore wave approach angle to the shoreline. Typically, along the Coffs harbour regional coast, a shift in offshore mean wave direction to a more easterly direction results in the wave approach angle being more normal (i.e. perpendicular) to the shoreline. This results in greater planform curvature, with greater landward indentation in the middle of the beach compartment. In contrast, a shift in offshore mean wave direction towards more southerly direction results in reduced curvature through the middle and northern sections of the beach planform, with more indentation at the southern end.

For beaches where longshore sediment supply occurs, the increased sediment supply together with a more oblique mean wave direction (relative to the shoreline) under more southerly conditions, results in a flattened shoreline planform throughout the beach compartment. On the north coast of NSW, increased shoreline curvature tend to form during the La Nina-like wave climate, with flatter curvature occurring during the El Nino-like wave climate (Goodwin, in prep, 2009).

4.1.2.3 Interannual and Interdecadal Shoreline/Beach Planform Curvature and Rotation Variability in the Coffs Harbour Region

Shoreline position and curvature was assessed at each of the beaches in the Coffs Harbour region, using temporal sequences of photogrammetrically-derived data. This was compared to the wave refraction sensitivity analysis (S_{MWD}) conducted using the wave model (Section 3.2.5). The beaches that were found to be significantly sensitive to wave climate change are:

- Bongil Beach;
- Sawtell and Boambee as one compartment;
- Korora Bay and Charlesworth Bay;
- Northern half of Moonee Beach;
- Emerald and Fiddamans Beach;
- Woolgoolga Back Beach and Hearnes Lake Beach as one compartment;
- South to Middle Corindi Beach and Redrock Beach; and,
- North Redrock Beach

Beaches with S_{MWD} values > 0.3 (that is, > 30% of the total offshore mean wave direction change is observed in the surf zone) are determined to be sensitive to offshore mean wave direction changes, whilst beaches with S_{MWD} values < 0.3 are shown to be insensitive to offshore mean wave direction changes.

The high sensitivity of the above beaches to wave climate changes on multi-decadal to centennial time scales is suggested by the high concentrations of heavy mineral sands that were sought by sand mining operations during the previous century. These heavy mineral sand deposits are formed from prolonged beach and dune erosion associated with sustained shoreline alignment changes, over multi-decades to centuries (Goodwin, in prep 2009).

4.1.3 Multi-decadal Trends in Coastal Behaviour due to Sediment-Budget Imbalance

The main influences on the sediment budget imbalance of individual beach compartments are: storm erosion frequency; the natural variability in longshore sediment supply associated with wave climate; the available offshore sediment supplies, and; the anthropogenic interruption and trapping of longshore sediment by the Coffs Harbour breakwaters.

Following the analysis of individual beaches, which shall be compiled for the Hazards Definition phase of the project, more detailed calculations of the regional sediment budget will be determined.

4.1.4 Conceptual Coastal Processes Overview

Discussion and overview of the coastal processes operating within and between the four sub-compartments (refer Figure 2-1) will be compiled as part of the final Hazards Definition assessment. The conceptual processes overview will be interpreted from the observations of coastal processes and beach change from the past century, and will also consider longer term (multi-decadal to centennial) coastal behaviour given from review of the onshore and offshore coastal geological evidence.

5 CLIMATE CHANGE AND COASTAL PROCESSES

5.1 Introduction

In this section, we will outline the most up-to-date climate change projections available and relevant to the Coffs region. This chapter also outlines recent work to project future wave climate, using the most recent climate modelling data. A discussion of projected changes to coastal processes, in particular, sea level, wave climate and elevated water levels, due to climate change will be given. Last, a broad overview of the likely change to the shoreline alignment and planform of the coastline in response to changes to coastal processes with climate change will be given.

In the final Coastal Processes and Hazards Definition Study, we plan to outline the impacts of climate change in terms of the severity and frequency of the coastal hazards as part of our assessment of each of the coastal hazards, for the current, 50 year and 100 year timeframe. This chapter provides the background to the understanding of future coastal hazards due to climate change.

5.2 Sea Level Rise

The NSW Government recently released a Draft Sea Level Rise policy, which stated a value of 0.4 m sea level rise by 2050 and 0.9 m by 2100 should be used in coastal assessments for planning purposes. The NSW Government policy estimate is essentially a combination of the highest estimates of 0.59 m by 2090-99 (IPCC, 2007), 0.2 m due to the dynamics of ice sheet flow (IPCC, 2007) by 2100 and 0.12 m by 2100 due to regional processes particular to the East Australian Current (McInnes, *et al*., 2007).

Regional impacts of sea-level rise are also depend upon the relative movement of the land to the ocean, caused by sedimentation, land subsidence, tectonism and millennial scale geodynamics (Goodwin, 2003). The latter has and will cause a small ongoing, relative sea-level lowering along the NSW coast of ~0.5 mm/yr which reduces the relative sea-level rise along the regional coastline by the same amount.

Spatial variability in mean sea level rise exists across the latitudinal extent of the south east Australian coast. Church *et al.* (2004) indicate that maximum rates of sea level rise in Australia in excess of 2 mm per year are observed between Sydney and Brisbane, and rates of between 1 and 1.5 mm per year along the southern NSW coast. McInnes *et al.* (2007) examined projections of the relative mean sea level rise along the NSW coast due to thermal expansion in two CSIRO global climate models. In both models the mean sea level rise along the NSW coast due to thermal expansion (and uncorrected for land motion) was greater than the global average values, and indicated considerable spatial variability due to the warming of sea surface temperatures in this region, and the strengthening of the East Australian Current, and thus derived the 0.12 m by 2100 projection. The projected sea level rise estimate of IPCC (2007) differed by up to 4 cm from present to 2030 (approx 1 mm per year) between Batemans Bay and Wooli Wooli on the NSW coast. However it is thought that with respect to coastal behaviour, this differential in mean sea level rates of rise is probably insignificant on multi-decadal time scales.

5.3 Rainfall, Wind and Wave Climate Change

Climate change projections have been also been determined for the impacts of climate change on rainfall, storm surge, storm frequency and wave direction and wave height, such as given by McInnes *et al*. (2007).

The climate change predictions of McInnes *et al*. (2007) are based upon the output of two CSIRO models, CCM2 and CCM3. Both CSIRO models are forced with the same emission scenario, A2, where CO_2 rises from 370 parts per million (ppm) at present to 880 ppm by 2100. The A2 scenario was considered sufficiently conservative, given CO_2 has grown at 2 ppm/year over the past 10 years. The CCM2 and CCM3 models exhibited distinctly different climate change responses with respect to wind speeds, and thus were used to investigate predictions further.

The predicted changes to wave height and direction were based upon the CCM2 and CCM3 model output for wind speed and direction. The modelled wind speeds and directions were converted to significant wave height (H_s) and wave period (T_p) using empirical relationships. Winds near to the coast were used to generate storm waves and winds further offshore to generate swell waves. The calculations for storm surge were based upon changes in the frequency of storm waves from a south to south-easterly direction, as this direction was found by McInnes *et al.* (2007) to be responsible for nearly all of the extreme sea level events recorded in the past. The storm surge calculations do not include wave set up.

For predictions for wind change, it was found that the 45° resolution for direction used in the modelling was too coarse to indicate evidence of changes in direction away from the most dominant direction. It was assumed that modelled changes in annual or seasonal wind direction (away from the dominant direction) were therefore less than 45°**.** Therefore, as seen in Table 5-1, the seasonal dominant wind direction remains the same at 2030 and 2070. Some predictions for changes in wind speed were derived, however. The changes are given relative to the dominant wind direction (McInnes *et al.,* 2007; Macadam *et al*., 2007). The wind speed changes predicted in the future are relatively similar to the present, and there is no available predictions regarding future wind direction change.

Given the wide range in predictions given in Table 5-1, particularly for storm wave frequency and extreme rainfall events, it is apparent that a sensitivity approach within a risk based format is appropriate for assessing the predictions and their impact upon each of the coastal hazards. Using the range of predicted values, a probability of hazard impact, rather than a discrete, single value hazard impact, will be estimated and provided in the subsequent Coastal Hazards report for the Coffs coastline.

Table 5-1 Climate Change Predictions

Prediction	Year	2030	2050	2070	2100	Reference
Sea Level Rise			**0.40 m**		**0.90 m**	DECC (2008)
Extreme rainfall events	Wooli Wooli	-10 % to 0 %		-10% to +10%		Macadam *et al*. 2007
Average total Rainfall	Wooli Wooli	-6 % to 0 %		-19% to 0%		Macadam *et al*. 2007
Storm Surge	100 year return period	+/- 1%		-3% to +4%		McInnes *et al*. 2007. Actual change is 1 -

Prediction	Year	2030	2050	2070	2100	Reference
						3 cm
Storm Wave Frequency	S + SE direction	-8% to +13%		-20% to + 48%		McInnes *et al*. 2007. Ranges based upon output from CCM2 & CCM3 models
	NE Direction	-40% to +100%		-73.3% to 0%		
	E Direction	-49.5% to +2.7%		-54.5% to +35.1%		
	SE Direction	-35.6% to -23.6%		-34.4% to +50%		
	S Direction	+3.9% to +34.1%		-13.7% to +46.3%		
Storm Maximum Wave Height (Hmax)	S + SE direction	0% to +3%		-15% to +9%		McInnes *et al*. 2007. Ranges based upon output from CCM2 & CCM3 models *Predictions given by CCM2 & CCM3 in agreement – no range required.
	S + SE direction	5.3-6.9 m		5.6-5.8 m		
	NE Direction	3.5-3.6 m		3.6-3.9 m		
	E Direction	6.0-6.2 m		5.3-7.8 m		
	SE Direction	4.9-6.4 m		5.9* m		
	S Direction	5.5-7.1 m		5.5-5.7 m		
Swell Waves from predominant SSE direciton (135-180 Deg TN)	Mean Direction	158.6-159.6 ^{o} TN		159.4-160.6 ^{o} TN		McInnes *et al*. 2007. Ranges based upon output from CCM2 & CCM3 models
	Change in direction	-0.8 to +0.3 ^{o}		+0.1 to +1.2 ^{o}		
	Occurrence	25.7 - 26.3 %		25.3 - 28.0%		
	Mean Hs	1.3-1.4 m		1.3-1.4 m		
Swell Waves from full directional range (10-190 ^{o} TN)	Mean Direction	101.3-106.1 ^{o} TN		99.4-105.9 ^{o} TN		McInnes *et al*. 2007. Ranges based upon output from CCM2 & CCM3 models
	Change in Direction	-3.1 to +0.6 ^{o}		- 3.3 to -1.3 ^{o}		
	Mean Hs	1.2 m		1.2-1.3 m		
Changes to percentage of wind direction **days** with average wind speed: **4 - 8 m/s**	**Annual** SE (112.5 – 157.5°)	-2 to +1 %		-1 to +2 %		Macadam *et al.* 2007 for ocean near Wooli, based on McInnes *et al*. 2007 output from CCM2 & CCM3 models
	Summer SE (112.5 – 157.5°)	-3 to -2 %		-2 to 0 %		
	Autumn SE (112.5 – 157.5°)	-3 to +4 %		-2 to +4 %		
	Winter S (157.5 – 202.5°)	-3 to -1 %		-5 to -3 %		
	Spring N (337.5 – 22.5°)	*No change*		-1 to 0 %		
Changes to percentage of wind direction **days** with average wind speed: **8 - 12 m/s**	**Annual** SE (112.5 – 157.5°)	-1 to +2 %		-1 to +2 %		Macadam *et al.* 2007 for ocean near Wooli, based on McInnes *et al*. 2007 output from CCM2 & CCM3 models
	Summer SE (112.5 – 157.5°)	0 to +2%		-1 to +1 %		
	Autumn SE (112.5 – 157.5°)	-4 to +3%		-3 to -1 %		
	Winter S (157.5 – 202.5°)	*No change*		0 to + 2%		
	Spring N (337.5 – 22.5°)	0 to +1%		*No change*		
Changes to percentage of wind direction **days** with average wind speed: **12 - 16 m/s**	**Annual** SE (112.5 – 157.5°)	0 to +1%		0 to +1%		Macadam *et al.* 2007 for ocean near Wooli, based on McInnes *et al*. 2007 output from CCM2 & CCM3 models
	Summer SE (112.5 – 157.5°)	+ 2 %		0 to +2%		
	Autumn SE (112.5 – 157.5°)	-1 to +1 %		-1 to +1 %		
	Winter S (157.5 – 202.5°)	+ 2 %		+1 to +2 %		
	Spring N (337.5 – 22.5°)	0 to +1%		0 to +1%		
Changes to percentage of wind direction **days** with average wind speed: **>16 m/s**	**Annual** SE (112.5 – 157.5°)	*No change*		*No change*		Macadam *et al.* 2007 for ocean near Wooli, based on McInnes *et al*. 2007 output from CCM2 & CCM3 models
	Summer SE (112.5 – 157.5°)	*No change*		*No change*		
	Autumn SE (112.5 – 157.5°)	*No change*		0 to +1 %		
	Winter S (157.5 – 202.5°)	0 to +1 %		*No change*		
	Spring N (337.5 – 22.5°)	*No change*		*No change*		

5.4 Projected Impacts on Elevated Ocean Water Levels

The storm systems that produce elevated sea levels are east coast lows, cut-off lows and southward moving tropical cyclones. The latitudinal difference in extreme water levels has an important effect on the spatial variability of coastal response on decadal timescales, and is coupled to wave direction changes (eg; Storm waves with east mean wave direction are coupled to frequent extreme high water levels). While hazards are not explicitly discussed in this report, the combination of large waves and elevated water levels results in greater erosion on beaches.

The available climate change predictions (Table 5-1) indicate there are likely to be minor changes in storm surge height and maximum (storm) wave height in the future due to climate change. This will modify the elevated water levels that may be expected during a storm. Future elevated water levels in 50 and 100 years will also include the predicted increase in sea level.

We have compiled an estimate of future elevated water levels using the available climate change predictions. In addition, the future elevated water level estimate also takes into account probable changes in the frequency and intensity of east coast lows storm systems, which are typically responsible for extreme water level events. This is discussed in detail below.

The upper and lower range of percentage change in storm surge and storm wave heights given by McInnes *et al.* (2007) have been used to calculate an upper and lower range of future storm surge and wave set up levels, as given in Table 5-2. Predicted sea level and astronomical tidal levels were then added to these values, at the 50 and 100 year planning periods.

Table 5-2 Predicted Elevated Water Levels for 50 & 100 year Planning Periods

Planning Period (years)	Wave Height (H_s m AHD)		Wave Set Up (100 year ARI)		Storm Surge (100 year ARI)		HHWSS	Sea Level Rise	Elevated Water Level (100 year ARI)	
	Lower	Upper	Lower	Upper	Lower	Upper			Lower	Upper
Existing	8.20	8.20	1.23	1.23	0.72	0.72	1.08		3.04	3.04
50	8.20	8.45	1.23	1.27	0.71	0.73	1.08	0.40	3.42	3.48
100	6.97	8.94	1.05	1.34	0.69	0.75	1.08	0.90	3.72	4.07

5.4.1 Future Wave Run Up

Due to the complexity of the wave run up calculations (refer Section 3.3.3), it is not presently possible to determine a future wave run up due to future storm conditions under climate change. The most basic assessment available is to add the estimates for sea level rise, storm surge and wave set up for the 50 and 100 year periods to existing wave run up levels. The 50 year and 100 year wave run up level estimates are summarised in Table 5-3.

Table 5-3 Future Predicted Wave Run Up Levels

Planning Period (years)	Wave Run up Level (m AHD)		
	Lower Range	Median	Upper Range
Existing	7	7.3	10.3
50	7.4	7.7	10.7
100	7.7	8.2	11.3

5.5 Projected Impacts on Shoreline Position, Alignment and Curvature

Generic models to project shoreline response to sea-level rise, wave climate change are in their infancy, despite the four decades of application of the Bruun Rule (Bruun, 1962) which has little use on wave-dominated coasts with oblique to the shoreline MWD, and hence, variability in longshore gradients and sediment transport. Although effects on shoreline curvature and rotation relate primarily to changes in direction statistics of the wave field, other factors need also to be taken into account in their study. These include effects of variations in mean sea level, changes in seabed geometry that may act as a source or sink of sand for beaches, storm-wave erosion events, and disturbances to alongshore sand transport budgets not associated with the directional statistics of the wave field, such as increased losses to estuaries due to sea-level rise or reduced supply from rivers due to changes in terrestrial hydrology. The challenge is to discriminate between the effects of these forcings relative to those driven by changes in the wave climate. In this study, we applied a third-order shoreface translation model (Cowell et al., 2003) that is capable of including variations in wave climate-induced sediment supply. In addition, to assess the possible range of shoreline/beach curvature responses to potential wave climate changes we have applied the planform geometry model of Hsu and Evans (1989) and Hsu et al. (2008) to characteristic sections of the Coffs Harbour coast. These landward-seaward translations in the beach and dune profile will be used to constrain the coastline recession hazard definition.

6 COFFS REGION INDIVIDUAL BEACH DATA REVIEW

6.1 Introduction

In this chapter, a description each beach, including its geomorphologic beach state, headland, reef and other feature of the Coffs LGA coastline is given. In addition, a summary of existing studies available to date (in particular, coastal processes and hazards information) is given where available for each beach embayment and headland. This information provides a background summary for each beach from which the updated hazards outcomes will build and expand.

It is interesting to note in this summary the varying estimates of sea level rise over time, and also, the increasing consideration of other climatic elements in the assessment of coastal processes and hazards during the period of coastal assessment to present. It is also worth nothing the sometimes contradicting assessments of coastal erosion, recession and accretion at various beaches, as new photogrammetric data becomes available. In fact, the varying conclusions over time only serve to provide further evidence of the natural variability in beaches, our increasing understanding of how coastal processes will manifest as beach change, and finally, the need to include uncertainty and variability in our definition of the beach erosion and recession hazards in particular.

6.2 North Beach and Bundagen Head

North Beach runs for 8.75 km from the northern entrance wall of the Bellinger River to Bundagen Head. The northern 2 km of this beach, north of Tucker Rocks, lies within the study area. This section also lies within Bongil Bongil National Park (NP), which extends north to Bonville Beach.

The beach is a double barred system, facing east-south east into the prevailing swell. The beach is composed of fine sand. The inner bar is generally a continuous attached bar (low tide terrace), occasionally crossed by rips. A deep, wide trough which is generally swept by strong currents separates the inner bar from an outer bar further offshore (Short, 2007).

Bundagen Head is a fairly low headland, separating North Beach and Bonville Beach. The small **Bundageree Creek** entrance lies amongst the rocks on the northern side of Bundagen Head. Both lie within the Bongil Bongil NP.

6.3 Bongil Beach and Bonville Headland

Bongil Beach (NSW 115, Short 2007) extends from Bundagen Head to Bonville Head for a length of 5.8 km. The beach is composed of fine grained beach sand. It faces southeast and receives the full extent of the prevailing wave climate. As such, a well maintained double barred surf zone has developed. There are often many rips (up to 30) across the inner transverse bar. A deep trough then separates this from the outer rhythmic bar, which has more widely spaced rips. At the far southern end at the rocks surrounding Bundagen Head, waves are reduced slightly, although rips still form here.

The entrance to **Bonville Creek** is located at the northern end of the beach, flowing along Bonville Head. Flows from the creek develop deep channels and strong tidal currents. And there is a tidal rock pool located on Bonville Head, along which lies a strong permanent rip (Short, 2007).

The beach is largely backed by Bongil Bongil National Park and remains relatively isolated and untouched. There is no regular vehicle access to the beach, and surfers occasionally access the beach by crossing Bonville Creek.

Bonville Head is a ~ 15 m high headland, separating Bongil Beach, Bonville Creek and Sawtell Beach. Approximately 600 m offshore of the Headland are two rock reefs known as Sawtell Island. The lower back of the headland is likely to have experienced disturbance by clearing in the past, and largely consists of dune sands. A car park and lookout is located on top of the headland.

6.4 Sawtell Beach

Sawtell Beach lies between Bonville Head and Boambee Head in the north. The beach is 2.1 km in length. The majority of the beach is exposed to the predominant wave climate, although the southern end of the beach is largely protected by Sawtell Island and the headland, and a reflective beach has developed in the lee of this protection. A sandy tombolo forms between the reefs of the island and the shore, under accretionary conditions. This southern part of the beach may be accessed from Bonville Headland, where there is also a boat ramp and some sheltered rock pools.

For the remainder of the beach, under normal wave conditions the beach experiences a transverse bar rip morphology, with frequent rip channels (~ 8). In higher wave conditions, a second outer bar is also apparent, cut by more widely spaced rips. (Short, 2007)

The beach is backed by a well vegetated foredune, with the township (~15000 people) of Sawtell located behind the beach. The Sawtell Surf Life Saving Club (SLSC) is also located immediately behind the beach on top of the foredune at the middle to southern end of the beach.

Lord and Van Kerkvoort (1981) noted Sawtell as having a wide, fine grained beach berm backed by a large Holocene foredune, and described the beach to be eroding slowly. They note that Sawtell Beach is the only beach [apart from Bongil Beach] that is unaffected by the harbour construction.

PWD (1995), as part of their Coffs Harbour City Coastal Assessment, determined the following design Coastline Hazard Design Parameters for Sawtell Beach:

- Beach Erosion: 0 m
- Shoreline Recession: 0 m/yr
- Recession due to Sea Level Rise: 14 m
- 50 year Hazard Zone: 14 m
- Development within 50 year Hazard Zone: Nil
- Coastal Inundation Risk: Nil

The design parameters were derived by PWD (1995) as follows.

- Assessment of recession due to sea level rise was calculated with the Bruun Rule (1962) and utilised the IPCC sea level rise estimates from 1990. The low, medium and high sea level rise predictions for the 50 year planning period were thus 0.14, 0.28 and 0.44 m respectively. Discussion of the anticipated effect of climate change upon wind and wave climates was also provided, however detailed information as to the likely changes or their impact upon the coast was not possible at that time.
- Storm erosion demand was estimated by measuring the maximum movement of the erosion escarpment between the most eroded and most accreted dates of aerial photography.
- The shoreline recession rate was calculated as movement of the erosion escarpment between first and last photography dates (metres) divided by the length of time between the first and last photography dates (years).
- Broad comments only as to the susceptibility of each beach to coastal inundation in the 50 year horizon were given. Detailed estimates were not provided, due to the complexity of estimating wave run up on beaches.

There are some limitations to the methodologies used in the PWD (1995) report. The first limitation is obviously the more recent sea level rise predictions and adopted value of 0.9 m by 2100 (DECC, 2009), which requires a re-evaluation of recession due to sea level rise.

The application of the Bruun Rule (1962) to determine recession due to sea level rise was also problematic (although the authors did note the limitations of the Bruun Rule, such as three dimensional aspects such as headland features and longshore transport which are not considered by the Bruun Rule). PWD (1995) assumed one beach slope value for all Coffs beaches to determine recession with the Bruun Rule, and nominally adopted a ratio of horizontal recession to sea level rise of 50:1. Each of the 1990 low, medium and high sea level rise scenarios (for the 50 year period) were assessed, but only the mid level sea level rise recession outcome of 14 m recession in 50 years was adopted. PWD (1995) then labelled all beaches of the Coffs Coastline with a design value of 14 m for recession due to sea level rise. The use of the Bruun Rule (1962) to define one recession value has more recently been determined to be inadequate for future coastal planning (Ranasinghe *et al.,* 2007, Cowell *et al.,* 2006).

There are also limitations to the assessment of shoreline recession based upon the movement of the erosion escarpment divided by the time (years) between the first and last date of photography, which was the methodology applied by PWD (1995). Limitations to this approach which may notably skew the outcomes, include:

- The choice of photographs, namely the absolute first and last dates of photography, does not consider the relationship of the photos with storm events, and so, whether the profiles are eroded, average or accreted. As such, the assessment incorporated short term, natural fluctuations in the profile, namely erosion/accretion and rotation cycles due to mean wave height and wave direction, and which may generate an over or under exaggeration of actual recession rates.
- Variations in spatial characteristics along the beach (for example, sediment fluctuations between the northern and southern ends such as describes beach rotation) were not considered, and the recession rate determined was adopted for the entire embayment.

- The approach does include volumetric changes to the beach, which means that vertical movement (erosion / accretion) of the beach not accounted for in the assessment.
- The assessment did not discuss the accuracy of the aerial photography (and so photogrammetric data) used to calculate recession. In particular, the early aerial photographs were typically high level, and so of limited accuracy, which may skew the recession calculation.
- Similarly, the impacts of anthropogenic events on beach and dune profiles, such as sand mining, extraction or levelling for development were not explicitly considered in the assessments.

PBP (2004) assessed carefully the outcomes of the PWD (1995) report based on the likely beach states (ie, accreted or eroded) in relation to the history of coastal storms, and concluded the long term recession rates by PWD (1995) to be:

- Over-estimated at Park, Macauleys, Charlesworth Bay, Hills, and Campbells Beach due to the initial profiles being average or accreted, and the last photo dates being eroded profiles;
- Under-estimated at Sawtell Beach due to a severely eroded initial beach state and eroded or average final beach state.

PBP (2004) determined the remaining beaches (Sapphire, Woolgoolga, Ocean View, Corindi) were less likely to be affected, as the start and end profiles were both relatively eroded.

The PWD (1995) are presented for these beaches in various sections in this report, however, it is worth noting the limitations which apply to the design parameters derived for that report.

6.5 Boambee Head and Boambee Beach

Boambee Head is 60 m in height (Short, 2007).

Boambee Beach is a 5.7 km stretch of sandy beach from Boambee Head and the mouth of Boambee Creek to Corambirra Point. The beach is composed of fine grained sand. It faces the south-east and receives the full extent of the predominant wave climate, with waves said to average 1.6 m. This has resulted in a well-developed double sand bar system. The inner transverse bar has regular rips across its length. A broad deep trough has developed between this and the outer bar. The outer bar is generally continuous. In the south, the permanent outlet of Boambee Creek produces strong tidal currents in the creek mouth and beach shoals (Short, 2007).

The very northern end of Boambee Beach between a small rock outcrop and Corambirra Point is often called **Gallows Beach**, a 150 m stretch of beach which is at times eroded back to form a cobble beach and exposing the underlying bedrock and rock wall of the southern Coffs Harbour land bridge with Corambirra Point. The surfzone of Gallows is a continuation of the Boambee Beach surfzone, with a large permanent rip running along Corambirra Point (Short, 2007).

Boambee Creek flows behind the southern half of the beach and out to the ocean against Boambee Head. It typically remains open (Short, 2007).

Extensive foredunes back Boambee Beach, (of ~ 10 – 20 m in height), with sand mining of the hind dune ridges during the 1960s and 1970s. Coffs Harbour Airport, the Northern Railway line and Coffs Harbour Sewage Treatment Plant are located behind the northern half of Boambee Beach. The ocean outfall is located off Corambirra Point from Boambee Beach. Access is only possible from the northern end of the beach.

Gallows Beach is backed by a gravel and bitumen car park servicing a boat ramp into Coffs Harbour. There is no natural vegetation, and the car park is less than 6 m above sea level. In large seas, waves overtop the car park. Gallows and the northern end of Boambee Beach are accessible from this car park. The southern end of Boambee Beach is accessible from a car park and track on top of Boambee Head, then crossing Boambee Creek.

Boambee Beach has been measured to be accreting, due to the interruption of northerly littoral transport by southern breakwater and landbridge between the Mainland and Corambirra Point (also known as South Coffs Island) and the eastern breakwater adjoining Corambirra Point (PWD, 1995). An accretion rate of 38,000 m^3/yr above 0 m AHD has been stated for the beach (PWD, 1995), or, of up to 5m/yr (Lord and Van Kerkvoort, 1981). However, PBP (2004), in their review of the PWD (1995) report, noted that no particular study or reference was cited in deriving this rate of accretion. The PWD (1995) report also assessed the beach to have no 50 year hazard zone as related to the hazards of beach erosion, shoreline recession or long term recession due to climate change, due to the high rate of accretion upon this beach.

In more recent times, mining of the low tide beach face at Gallows Beach and the northern end of Boambee has occurred. There is a current licence permitting the take of 8,000 m^3/year (although, this amount may be as high as 16,000 m^3/yr, pers. comm.., Robert Kasmarik, DECC, February, 2009). The licensed contractors provided information to Department of Lands as to the volume of sand they have extracted, which they said to be 151,000 m^3 over the last 10 years. However, there are no weigh bridges at the site (Boambee), so these volumes are not checked after extraction, but rather, the information is provided in good faith to Department of Lands (pers. comm.., Robert Kasmarik, DECC, February, 2009).

The contractors take the sand from intertidal zone at low tide, that is, the low tide beach face and not the dune system. Observers of the extraction have seen 20 truck loads removed within one day, and by the next day it is impossible to see where the sand was taken from. The contractor's extraction licence expired on 22 Dec 2008, however, the extraction volume reporting to Dept of Lands was likely part of the process of renewing this. As Boambee Beach lies just south of the Solitary Islands Marine Park (SIMP, which extends north of Muttonbird Island), this extraction is not believed to be an issue for ecology (pers. comm., Robert Kasmarik, DECC, February, 2009).

6.6 Coffs Harbour, Corambirra Point and Muttonbird Island

Corambirra Point extends for 800 m seaward, comprising the southern land bridge to South Coffs Island out to the point. The eastern breakwater of Coffs Harbour is attached to the end of Corambirra Point, and is oriented roughly north east, thus offers protection from the predominant south east swell. Muttonbird Island offers protection to the harbour mouth from north east swell. Waves frequently break upon the eastern breakwater, and damage to the breakwater has been sustained during large storms, for example, in 1996.

The only known significant Aboriginal site near to Park Beach is at Corambirra Point. Ceremonies were regularly performed here by Aboriginal groups (RDM, 1998). In European times, Corambirra Point has been heavily quarried, with a large scarp evident on its northern edge.

Coffs Harbour is bounded by a land bridge between the mainland and South Coffs Island (Corambirra Point), the eastern breakwater extending 400 m off Corambirra Point, and a northern breakwater attaching Muttonbird Island with the mainland. The inner harbour is outlined by a small southern breakwater inside Muttonbird Island and the northern breakwater, inside which there are marina berths (Short, 2007).

The safe inner harbour for small craft was built in the mid 1970s. And a small basin was cut in the causeway between South Coffs Island and the mainland to create a protected boat launching ramp facility on the southern side of the harbour (RDM, 1998a).

Prior to causeway and breakwater construction, South Coffs Island and Muttonbird Island were separated from the mainland by a nearshore channel, through which it is assumed that net northerly littoral drift from Boambee Beach to Park Beach could proceed uninterrupted (RDM, 1998a).

Coffs Harbour or **Jetty Beach** is the 1.4 km stretch of beach inside the breakwaters and Corambirra outcrop. This beach is heavily protected by the breakwaters and land bridge and breakwaters of Corambirra Point. Thus waves are rarely greater than 0.5 m in height. The beach has a wide, low attached bar with no rips, and displays a low tide terrace morphology (Short, 2007).

Behind Jetty Beach there is a limited width of dune vegetation, then car parking and a large park and picnic area. Not surprisingly there is also a jetty upon the beach, which extends out to the mouth of the inner harbour. A small creek / drainage line exits onto the beach on the northern side of the jetty.

A recent paper by Carley *et al*. (2006) provides a discussion of the history of construction of Coffs Harbour, and the effects of the harbour breakwaters upon northerly littoral transport. Points of interest from the Carley *et al*. (2006) paper are outlined below.

- Prior to the breakwaters, the northerly littoral transport rate was estimated at 75,000 m^3/yr, and passed both behind (via wave and wind processes) and around South Coffs Island (Corambirra Point), then between Muttonbird Island and Jetty Beach into Park Beach and beyond.
- The northern breakwater is approximately 1 km long, joining with Muttonbird Island. It was commenced in 1914 and completed in 1924.
- The channel between South Coffs Island (and Corambirra Point) and the mainland was reclaimed between 1915 and 1927. The reclamation closed off what is believed to be the main sand pathway from Boambee Beach into Jetty Beach and beyond to Park Beach.
- The eastern breakwater (off Corambirra Point) was commenced in 1919 and completed in 1946. This construction obstructed what is believed to have been the secondary pathway for sediment bypassing from Boambee Beach, around the eastern side of Corambirra Point, then between Muttonbird Island and the mainland into Park Beach.
- Thus, the eastern and northern breakwaters and land reclamation forming the southern land bridge are said to have intercepted virtually all of the northerly littoral transport, including transport around Muttonbird Island.

- Similar littoral drift barriers (ie, Tweed Breakwaters at Tweed River) are reported to affect beaches up to 10 km downdrift.
- Based upon hydrographic survey of the harbour, a tidal shoal has developed at the mouth of Coffs Harbour, which is moving landward and slowly decreasing water depths between the eastern breakwater and Muttonbird Island. Based upon the 1999 hydrographic survey, there has been a possible increase in the infilling rate of the harbour, from 25,000 m^3/yr (given by Lord and Van Kerkvoort, 1981) to up to 50,000 m^3/year.
- Carley *et al.* (2006) used the recession rates calculated by PWD (1995), which are based upon photogrammetry up to 1988/89, to estimate littoral losses for the beaches north of the harbour.
- Via this method, the overall rate of loss from beaches north of the harbour to Moonee Beach (but not including Moonee and Korora, as they were not assessed in the PWD (1995) report) was calculated to be ~ 73,000 m^3/yr, which is similar to assumed net littoral transport of 75,000 m^3/yr for the region.

Council periodically undertakes dredging at the mouth of the inner harbour of Coffs Harbour. The dredging is typically undertaken with an excavator at low tide. On rare occasions, the dredge boat from Moreton Bay (QLD) is utilised. In this case, Council acquires permission to dump the dredged sand at a location around 400 m north of Muttonbird Island opposite Park Beach. Observation of this process has noted that the dumped sand does get transported back onto Park Beach, although it is not known how long the sand remains on the beach (pers. comm., Robert Kasmarik, DECC, February, 2009).

PWD (1995) has indicated Jetty Beach is accreting at a rate of 1,800 m^3/yr above 0 m AHD, and thus determined there to be no risk of erosion, shoreline recession, or recession due to sea level rise. The PWD (1995) outlined the following Coastline Hazard Design Parameters for Jetty Beach:

- Beach Erosion: none
- Shoreline Recession: none
- Recession due to Sea Level Rise: none
- 50 year Hazard Zone: none
- Development within 50 yr Hazard Zone: Nil
- Coastal Inundation Risk: Nil

However, a review of this report by PBP (2004) found no particular study or reference for the stated accretion rate. Readers are also advised to review the limitation of the PWD (1995) report.

6.7 South Park Beach and Park Beach

South Park Beach lies between the northern breakwater adjoining Muttonbird Island and the mouth of Coffs Creek and sandy cuspate foreland which has formed in the lee of Litte Muttonbird Island. The beach is 600 m long. Waves are typically small (average < 1 m) at the beach, as it is protected by the 600 m northern breakwater. The beach exhibits a low tide terrace morphology, maintaining an attached sand bar which may be cut by rips during high wave conditions (Short, 2007).

The northern breakwater extends into a rock revetment wall immediately behind South Park Beach, extending near to Coffs Creek mouth. Between the wall and the water line is a narrow beach strip which is typically inundated at high tide. Reflected waves and currents along the seawall and breakwater are common. There is a car park at the southern end, around the port and sailing club, from which a small ramp offers access to the beach.

South Park beach has experienced significant recession in relation to the Harbour breakwaters, and this process is outlined further in discussion of Park Beach below. Inundation of the rock revetment is likely to occur during storm conditions (RDM, 1998a).

On South Park Beach, RDM (1998a) found that the maximum erosion between successive years of photography was 12 m, between 1969-1975 (excluding the 1996 photogrammetry, which was said to have been affected by storms in 1995). Trends in erosion are said to have been masked by the meandering of Coffs Creek entrance and rock protection works constructed at the southern end of the beach (RDM, 1998a).

The rock wall at the southern end of Park Beach was apparently constructed to protect the southern corner adjacent to the northern breakwater. The stability of the wall (armour size, toe depth, filter requirements) was not assessed. Without assessment, it was assumed that some slumping of the rock armour and erosion may occur with storm wave attack.

A long term recession rate was not explicitly established by RDM (1998a) for South Park Beach due to the effects of the meandering Coffs Creek mouth, which has overprinted potential beach recession. In 1942, the creek meandered and exited adjacent to the northern breakwater. The beach has since prograded and the southern end is now stabilised by rock protection works approx 200 m long. Thus, in the absence of other data, it was assumed that this whole embayment would recede and form an alignment in response to the overall recession trend established for Park Beach, north of Coffs Creek. The average recession rate of 0.5m/yr found for Park Beach was adopted for South Park Beach.

As part of the RDM (1998a) Park Beach Coastline Hazard Definition and Management Study, mapping of dune vegetation species was conducted. South Park Beach, adjacent to Jetty Park, was found to be characteristically flat open grassland, with some recent shrub and tree plantings (behind bicycle footpath).Typical species include: black she-oak (*Allocasuarina littoralis*), coast banksia, screw pine (*Pandanus tectorius var. australianus*), coastal rosemary (*Westringia fruticosa*) and coastal wattle (*Acacia sophora*). East of footpath comprised dense grasses and herbs, many exotic. This vegetation was separated from the beach by the rock revetment wall. Beyond the wall on the incipient dunes and foredunes was found to be actively colonised by hairy spinifex, climbing Guinea flower, *Scaevola calendulacea*, and *Ipomoea pes-caprae subsp. brasiliensis* at the ocean front, and coastal wattle and coast banksia as low juvenile shrubs further back.

The higher ground had vegetation density of 10-100%, with a sparse to absent shrub layer. Species noted include mature coast banksia, three veined laurel, Chinese elm (*Celtis sinensis*) and tuckeroo. Exotic species included Dense infestations of lantana camara in some places and dense patches of fishbone fern (*Nephrolepsis cordifolia*). A former Coffs Creek channel was noted to have similar vegetation plus mature coast banksia, as well as a range of exotic species.

Park Beach extends from the cuspate foreland in the lee of Little Muttonbird Island and the mouth of Coffs Creek for 1.5 km to Macauleys Head in the north. Both Little Muttonbird and Muttonbird Islands provide slight protection from south east waves, although the beach faces east, and receives the majority of the prevailing swell particularly at the northern end. A transverse bar and rip morphology is typically evident, with up to 10 beach rips, and a permanent rip along Macualeys Headland. In summer, strong rips may form adjacent to the sandy foreland at the southern end under north east wind and wave conditions (Short, 2007). Long term recession is a key feature Park Beach since the Harbour breakwaters were constructed.

Park Beach is the main beach for the township of Coffs Harbour. An access road runs behind the length of the beach. There is extensive parking, many pedestrian accessways, a picnic area between the southern car park and creek, a caravan park, hotel and the Coffs SLSC. The Coffs Harbour SLSC was established in 1923. The southern end of the beach is patrolled for most of the year. (Short, 2007)

Coffs Creek exits to the ocean at the southern end of Park beach, with training walls to enable the creek mouth to remain open for the majority of the time. Behind the beach lies a fenced foredune (largely vegetated), which is occasionally undercut by storm waves, leaving a high erosion escarpment.

PWD (1995) assessed the following Coastline Hazard Design Parameters for Park Beach:

- Beach Erosion: 15 m
- Shoreline Recession: 0.5 m/yr
- Recession due to Sea Level Rise: 14 m
- 50 year Hazard Zone 54 m
- Development within 50 yr Hazard Zone: Nil
- Coastal Inundation Risk: Nil

Coastal Hazard Parameters of RDM (1998a)

The outcomes of the coastal hazard assessment by RDM (1998a) are summarised below:

	50 year	100 year
Long term Recession (m)	25	50
Sea Level Rise	14	22
Erosion (m)	15	-
Total (m)	40-54	50-72

The setbacks were based on assumed 0.5 m/yr shoreline recession rate, with allowance for short term erosion events/beach fluctuations in the 50 year period only, as it was assumed that these fluctuations would be accounted for in the long term average movement specified for the 100 year period. The derivation of these parameters is discussed herein in detail.

Beach Erosion

RDM (1998a) determined beach erosion using the 1997 photogrammetry. The method for determining beach erosion was to take the largest extent of movement between successive years of photograph. The largest extent of movement was 20 m, which occurred in the section of beach between the Park Beach Bowling Club and Park Beach CP, between 1969 and 1975. Erosion of up to 10 m occurred on the northern end of the beach over this period also. This approach has limitations, the most notable being the lack of investigation of the cause of the erosion extents, and which then assumes that 20 m of erosion may occur in response to one, or a series of closely spaces storms. This is a simplification of the actual processes which generated the eroded shoreline in 1969. The accuracy of photography and other anthropogenic effects which may skew the erosion measurements were also not discussed.

At Park Beach, a series of storms between March and August 1995 resulted in severe beach erosion at 9 of the 11 beach accessways, with escarpments of up to 5 m in height between the accessway and the beach. Much of the seaward dune fencing was also washed away. The 1996 photogrammetry was largely excluded from assessment, due to the effects of these storms which may skew the results.

Photography for 1994 to 1996 indicated movement of the dune of up to 18 m (132m^3/m) in the area north of Park Beach Caravan Park, where the dune had been reconstructed in 1993. The northern end only suffered minor erosion of its escarpment during the 1995 storms.

Figure 6-1 Erosion of foredune at the southern end of Park Beach, January 1973, from ERA (1973)

Shoreline Recession

RDM (1998a) noted other studies have found there to be negligible bypassing of sand around the harbour. They stated that sediment continues to move north around Macauleys Head at ~ 11,000-18,000 m^3/yr.

RDM (1998a) concluded that the interruption of net northerly longshore sediment transport had resulted in ~ 25 - 30 m of erosion of the Park Beach dunal system since the earliest photographic records (1942).

They observed high steep erosion escarpments to be left following storms, with little beach left at high tide. This equates to an average rate of ~0.5m/yr shoreline recession on Park Beach. RDM (1998a) found this rate to be confirmed by studies in 1984 and 1995 by PWD, which also established a long term recession rate of 0.5m/yr for Park Beach. Thus, an overall average recession rate of 0.5 m/yr was adopted for the Hazard study (RDM, 1998a).

Recession was likely to have been exacerbated by past sand and gravel extraction from the northern end of Park Beach. Once extraction ceased, beach replenishment works were undertaken to restore the eroding dunal system.

Higher recession rates of up to 1.4 m/yr (such as to south of the Bowling Club) were identified to occur over shorter periods of time (eg, 1969-96), but this was thought to describe the addition of individual storm events. As such, the longer term average was considered more appropriate as the long term trend (RDM, 1998a)

The southern end of Park Beach, particularly between the caravan part and the SLSC, was identified as having lower recession rates, and it was thought this may be due to the training wall constructed to stabilise the creek entrance and dunal works in 1988.

The first aeroplanes to visit Coffs were once landed upon Park Beach, and this was said to indicates a wider, finer grained beach than present. The present beach berms (from Park Beach to White Bluff) are said to be narrow and coarse grained. The beaches exhibit gravel layers after storms, with finer sediments having been transported offshore (Lord and Van Kerkvoort, 1981).

At the time of the site inspection by BMT WBM (July, 2008), the erosion escarpment on the foredunes revealed a cross-section of interspersed layers of gravel and finer sand, particularly at depth in the dunes, as seen in Figure 6-2. Furthermore, it is known that Park Beach was mined for gravel, as well as sand. The evidence of gravel within the foredunes suggests that gravelly sediments upon Park Beach are not peculiar to the present time, but have been present upon the beach during past wave and water level conditions. In fact, the existence of gravel deposits is consistent with the offshore sedimentology described for the Coffs Region (refer Section 2.2.4.1).

The evidence of gravel in the foredunes and suggestion of a natural cycle of gravel deposits upon the beach face at first appears to contrast with the historical observations reported by Lord and Van Kerkvoort (1981) of a wide, fine grained beach berm at Park Beach. Previous authors have used such historical observations as evidence of recession due to harbour construction. There is little question that the Coffs Harbour breakwaters have caused significant recession at Park Beach. However, the contrasting evidence of gravel deposits in the foredunes and an observed wide fine grained beach in fact suggest that Park Beach has experienced (and adapted to) quite different cycles of wave and water level climate in the past. That is, the beach has experienced a more receded, reflective state in the past under what was presumably a different wave climate and water level scenario compared with the wave and water level climate during which a fine grained wide beach berm developed, during the more recent historical past.

Figure 6-2 Gravel layer evident in erosion escarpment in Park Beach Foredunes, July 2008

Sand nourishment has been conducted on Park Beach at various dates, as outlined below.

- In 1988, the main access road to the Coffs Harbour SLSC at Park Beach had to be relocated (to the western end of the main car park) as it had been threatened by erosion and sand drift. At this time, 20,000 m^3 of sand was imported from Boambee Beach to re-establish the dunes in front of the SLSC to an area ~ 500 m to the north (RDM, 1998a).
- In 1993, sand nourishment again commenced from the SLSC to ~ 500 m north, with 25000 m^3 of sand pumped from Coffs Creek (near the porpoise pool) (RDM, 1998a).
- In 1995, 27,000 m^3 of sand was pumped from the harbour (adjacent to boat ramp) to re-establish the dunes and beach in front of the SLSC and Park Beach Caravan Park (RDM, 1998a).
- In 1997, beach replenishment works undertaken by the State and Local Government involved pumping 28,000 m^3 of sand from Coffs Harbour onto the beach between the SLSC and the northern end of the Caravan Park. North of the SLSC, the sand was shaped to fit against the eroding dune and sloped to the adjacent beach in a uniform alignment.
- In 1998, 16,000 m^3 of sand was trucked from Boambee Beach to Park Beach, using a front end loader at low tide (at a forecasted cost of \$6-8/m^3 plus ~ \$180 000 to stabilise and shape the

sand once on Park Beach). The excavation was estimated to require 2000 total truck movements between the Harbour and Beach (RDM, 1998a).

- Spoil from period dredging of the mouth of the inner harbour of Coffs Harbour by Council has on occasion been placed upon Park Beach
- On the rare occasions that the dredge boat from Moreton Bay (QLD) is utilised to dredge Coffs Harbour, this sand has been dumped at a location around 400 m north of Muttonbird Island opposite Park Beach. Observation of this process has noted that the dumped sand has been transported onto Park Beach, although it is not known how long the sand remains on the beach (pers. comm., Robert Kasmarik, DECC, February, 2009).
- A recent sand nourishment operation with dredged Harbour sand took place during autumn of 2009. Again, the material was placed in the vicinity of the Park Beach SLSC, to protect this key site of erosion in the past, and to avoid the sediment being transported into Coffs Creek (pers. comm., Robert Kasmarik, April, 2009).

Recession due to Sea Level Rise

Predicted sea level rise at the time of the RDM (1998a) report were used with the Bruun Rule (1962). A ratio of 50:1 was adopted for this area to calculate a likely shoreline recession for the 50 and 100 yr planning horizons. The best estimate sea level rise scenarios of 0.28 and 0.44 m by 50 and 100 years were used. This gave a recession due to sea level rise of 14 and 22 m for the 50 and 100 year periods. This is also consistent with the PWD (1995) 50 year estimate.

Sand Drift

RDM (1998a) noted that any loss of dune vegetation or exposure of dune sediments would enable sand drift to exacerbate both short term erosion and long term recession. Most of the pedestrian and vehicle accessways comprise board and chain construction, and this assists in reducing damage to vegetation and potential for sand movement. Where minor uncontrolled pedestrian access tracks exist, there is potential for degradation of the dune system.

At the northern end of the beach, the dune system has been lowered to provide access and possibly to improve the view from the car park. Sand may be blown into this car park here. It was also thought that unvegetated areas on the southern side of Coffs Creek may also cause nuisance sand drift into the nearby SLSC car park and adjacent reserve.

It was also noted that sand nourishment activities will be less effective where sand placement in dunes is not shaped, stabilised or planted with vegetation, as the unconsolidated sand is more susceptible to windborne transport and erosion. Sand drift from uncoordinated sand nourishment activities may also cause a nuisance to nearby residential and recreational development (RDM, 1998a)

Coastal Inundation

The stillwater open coast water levels estimated by BBW in 1986 were taken as applicable to the central and northern parts of Park Beach. These levels were thought to be conservative in the southern part of the beach due to the sheltering effect of the harbour RDM, 1998a).

The RDM (1998a) report assessed coastal inundation due to water levels and wave run up, and determined the following areas to be susceptible to inundation:

- A stormwater outlet at the northern end of the beach
- various dune fences and access ways along beach
- the training wall on the northern side of Coffs Creek
- The extent of land likely to be affected by inundation was thought to be limited to the car park areas at the northern and southern ends of the beach and low lying areas adjacent to Coffs Creek entrance, such as Ocean Parade and the SLSC carpark. RDM (1998a) said the limit of wave penetration was difficult to assess, but assumed that the Orlando Sreet Road Bridge would be the limit.
- It was noted that as the beach recedes, inundation will affect a greater area.

This assessment is in contrast to the findings of PWD (1995), likely due to the more detailed assessment conducted by RDM (1998a).

Coffs Creek Entrance

The entrance to Coffs Creek has been found to migrate considerably across the beach face in the past. Survey from 1890 (by the Royal Navy) and aerial photographs from 1942 show the creek exiting adjacent to the northern breakwater of the harbour. At one time, an accumulation of sand in the tombolo in the lee of Little Muttonbird Island appeared to be pushing the entrance to the south. In subsequent years, the creek entrance migrated to the north of Little Muttonbird Island (RDM, 1998a).

A small training wall in Coffs Creek was constructed west of the SLSC carpark in 1977. In 1988, the wall was extended as part of beach improvement works. The creek has formed a channel adjacent to the training wall and only minor changes in entrance position have since occurred, mainly seaward of the wall. It is thought unlikely that significant movements will occur with the training wall in place. The stabilisation of the entrance was also thought to prevent scour by the creek scour and subsequent storm wave attack to the coastal dunes on the immediate northern and southern sides of the creek (RDM, 1998a).

In spite of the stability of the creek entrance due to the training walls, storm waves and elevated water levels may still penetrate through the creek entrance, resulting in inundation and erosion of the dunes, for example, the dune on the southern side of the creek and east of the railway line may be potentially affected by erosion during a storm event (RDM, 1998a).

Stormwater Hazard

There is only one stormwater outlet discharging across the beach, at the northern end of the beach adjacent to Macauleys Headland. RDM (1998a) noted the potential for severe erosion at this outlet particularly during southerly wave attack. Hazards associated with this stormwater outlet included erosion to the beach berm and surrounding nearshore area caused by stormwater discharge, and which would also enable erosion by larger waves at the berm and dune areas next to the outlet. The accumulation of debris and ponding of water and pollutants under low flow conditions when the beach berm reforms in front of the outlet was also noted. These observations were confirmed during the BMT WBM site inspection (July 2008).

There are also several minor discharges from Ocean Parade street drainage into hind dunes, although these were not considered to present a hazard at Park Beach (RDM, 1998a).

RDM (1998a) suggested that, in the medium term, scour protection should be installed to prevent the stormwater outlet from undermining the pedestrian access, and in the longer term, the outlet should be extended out to the rock shelf.

Dune Vegetation

Significant assessment of the ecology of the dunes (both flora and fauna) were undertaken for the RDM (1998a) report. These detailed assessments are available within this report, with only brief summary of findings presented here.

The vegetation zones recognised on Park Beach include vegetation of foredunes and an expanse of littoral rainforest behind the dunes. Differences in vegetation for north compared with south of Park Beach are related to the different geomorhological processes occurring at each end, for example, the foredunes of north Park Beach were found to be eroding while those at south Park Beach were accreting.

The dune vegetation zone is generally vegetated with mature coast banksia on its ocean side and tuckeroo (*Cupaniopsis anacardioides*) and other littoral rainforest species dominating the inland slopes.

Prior to the caravan park, a continuous belt of littoral rainforest between Coffs Creek and Macauleys Head would have existed. The best developed rainforest area is now occupied by the eastern part of the caravan park and a day picnic area next to the creek. A remnant of littoral rainforest is located between the SLSC and the north western end of the SLSC carpark. There are known to be exotic and weed species amongst the remnant native species. Another well developed area of littoral rainforest also exists north of Park Beach Hotel Motel and between the lee of the hind dunes and Ocean Parade.

Park Beach coastal strip was concluded to be well vegetated, with generally healthy and vigorous vegetation. Minor die-back in the zone of mature banksias, at the crest and immediately behind the dunes in the past, plus other disturbance was noted to have allowed the rise of exotic (weed) species, which comprise large amount of vegetation. In spite of the exotics, a large number of wildlife were noted to be supported by the dune and rainforest vegetation, including a large population of nectar dependant birds.

A detailed fauna investigation concluded Park Beach to be an important component in the wildlife corridor network, particularly that existing in the urban zone of Coffs Harbour. It provides a more or less continuous strip of close to natural habitat which links the natural habitats to the north and south, and also links with habitat of Coffs Creek.

Bird surveys noted a large number of nectivores to be found along the length of beach and headland and within forest and shrubs particularly those dominated by coast banksia. Common species included the Brown Honeyeater (*Lichmera indistincta*), Brush Wattlebird (*Anthochaera chrysoptera*) and especially the white cheeked Honeyeater (*Phylidonyris nigra*). Only two shorebird species were found, namely Little tern (*Sterna albifrons*) and most commonly the Silver Gull (*Larus novaehollandiae*).

Human Usage

Park Beach and immediate surrounds are the hub of activity for tourists and local residents of Coffs Harbour, particularly during summer. The beach is one of the main attractions to the area and is regarded as having a very high recreational amenity. Furthermore, Park Beach is the most accessible surf beach for Coffs Harbour residential area and is the main surfing beach for the city. The beach is the base for the Coffs Harbour SLSC, and is patrolled over summer and school holidays.

According to data provided by CHCC in May 1997 (cited in RDM, 1998a), visitors to Coffs Harbour generate > $196 million per year. Tourism is the most important industry in Coffs Harbour in terms of income and employment generated. The tourist base at that time was largely oriented towards the domestic family market, with 518,000 domestic visitors to Coffs Harbour in 1988/89, making it the most preferred holiday destination on the NSW north coast.

A survey of visitors to the North Coast in 1991 (Pitt, cited in RDM, 1998a) indicated > 60% nominated the pleasant climate, no beach pollution and scenic beaches as their major reasons for visiting the North Coast. The sample consisted of 95% of genuine holiday makers, as opposed to visitors in the area for business, education or other personal reasons.

The survey indicated the most likely activities for visitors to the North Coast region were surf swimming, sunbathing, walking and looking at scenery. The survey also found that different activities were favoured at different beaches/coastal areas, therefore requiring different amenities at each location to maintain or raise the visitor experience (Pitt, 1991).

The survey of visitors to the North Coast indicated "without doubt" that natural dunes and trees are a highly rated features of the beach and this backdrop is a central component of the perception of a scenic beach. Rocky headlands were also highly rated. High rise buildings, 3-4 storey buildings and advertising displays were found to be annoying, unpleasant backdrops to the beach (Pitt, 1991).

The survey is of interest to this background data review for the following reasons:

- It highlights the importance of natural backdrops and scenery, particularly healthy extents of coastal dune vegetation, to the tourism revenue potential of Coffs Harbour
- It also illustrates the need for careful and considered coastal development in the coastal zone, in order to promote tourism, which is a key industry for the Coffs Harbour economy
- It demonstrates that strict planning controls which prevent development in areas of potential coastal hazard are also likely to enhance the tourism and economic potential of the region, in addition to mitigating (or avoiding) the damaging effects of coastal hazards.

A detailed history of settlement of the Coffs Harbour area is discussed in the RDM (1998a) study, and readers are referred to this document for more information. The RDM (1998a) also provides a detailed description of recreational usage of Park Beach.

Hazard Management

Specific management strategies of interest from the Coastline Hazard Management Plan (RDM, 1998b) included:

- Undertake emergency management works to ensure public safety during and after major storms or king high tides where damage occurs to dunes or accessways;
- Implement road closures at Ocean parade railway underpass and SLSC car park when inundated due to high tides, or creek floods. And additional action was to investigate long term solutions;
- Dune management was proposed to maintain and enhance existing vegetation, such as by maintaining pedestrian tracks and fencing to protect vegetation, and planting with endemic species, and continue existing dune management programs. This insl
- Beach and dune nourishment was proposed, to occur every 5 -10 years (a total of 100,000-200,000 m^3 sand, based on a loss of 20,000 m^3/yr due to shoreline recession) with the shaped to reform a dunal system, and revegetated and fenced to prevent wind blown losses
- Improvements to beach amenity around the stormwater outlet next to Macauleys Headland were outlined, including maintenance to remove litter and debris, signage about hazards from pollutants and stormwater velocities, and undertaking a study of options to improve the outlet, such as by constructing a training wall or extending the outlet.

A suggestion of extending the eastern breakwater of Coffs Harbour towards Muttonbird Island and to orient it further seaward at an angle in order to deflect sand around the island toward Park Beach were indicated by this study to be inappropriate. Studies cited from PWD were said to illustrate that sediment is not presently bypassing Muttonbird Island and is unlikely to do so in the next 100 years, due to the deeper water depths and extensive reefs off the island. Extension of the breakwater further east would thus result in greater sand accumulation on its southern side (RDM, 1998a).

RDM (1998a) also concluded that suggestions to remove a section of the Northern breakwater of the harbour, or to install pipes to allow accumulated sand from the harbour to move northward was also found to be unfeasible. This was because the construction of the harbour breakwaters has reduced the wave energy to a level that was no longer sufficient to mobilise and transport sediment, particularly through a narrow entrance. Further, a breach in the breakwater would require large changes to the inner harbour and marina in order to maintain safety, and may have large impacts upon land based activities and facilities such as the Yacht Club and the NSW waterways building.

Forms of coastal protection, such as seawalls, groynes and offshore breakwaters were noted in the RDM (1998a) study, but none were considered appropriate or suitable, due to:

- the requirement for a seawall to run the entire length of the embayment, to negate edge effects, whereby erosion is exacerbated at the ends of the seawall due to increased turbulence and reflected waves. There are also issues of beach amenity associated with seawalls
- groynes have little effect on cross-shore sand movement in storms, and thus would not be effective in managing short term erosion. We also note that groynes encourage rip formation, as they act as a topographic constraint upon the embayment width, and so may actually worsen erosion during storms
- offshore breakwaters may significantly reduce the surf zone amenity; and
- all of these structures are very costly to construct and maintain.

6.8 Macauleys Headland and Diggers Beach

Macauleys Headland forms a wide, high headland and cliffs. A 30 m wide beach is wedged between the high cliffs on the southern side of Macualeys Headland. The beach consists of a mixture of sand, cobbles and boulders. It is fronted by rocks and reef, and is likely to be popular for rock fishing (although dangerous and unsuitable for swimming or surfing).

Diggers Beach, also known as Macauleys Beach, is bounded by Macauleys Headland in the north and Diggers Head in the south. **Jordans Creek** exits to the ocean across the beach immediately south of a small rocky outcrop around the centre of the beach. The beach is sometimes considered as two beaches, due to the minor separation by the small, rocky outcrop at Jordans Creek entrance.

The southern part of Diggers Beach extends for 800 m long and faces east, with wave heights decreasing towards the south. The beach evolves from a lower energy low tide terrace morphology in the south to a transverse bar and rip morphology in the north in the north to a. Permanent rips may be found against the northern rock outcrop and the southern headland, and there is typically a rip occurs in the centre of the beach (Short, 2007).

Residential and tourist development including Aanuka Beach Resort is located behind Diggers Beach. The beach has two car parks at its southern end (Short, 2007). Access is also possible from Aanuka Beach Resort by a foot bridge across Jordans Creek and to the beach.

The northern portion of the beach between the small rock outcrop and Digger Head is 300 m in length, and faces east. The predominant south-easterly wave climate has resulted in typically higher waves at this northern end of the beach, and the beach exhibits a transverse bar and rip morphology. Permanent rips occur along the northern headland and southern rock outcrop (Short, 2007). This section of beach is accessed by walking along the beach from the south.

Preliminary assessment suggests the northern half of the beach has a low risk of erosion and recession by 2105, while the southern half of the beach has a medium risk for erosion/ recession by 2105 likely due to the relatively high level of development behind the beach (DECC, 2005).

PWD (1995) assessed Coastline Hazard Design Parameters for Macauleys Beach (ie Diggers Beach) as follows:

- Beach Erosions; 10 m
- Shoreline Recessions: 0.3 m/yr
- Recession due to Sea Level Rise: 14 m
- 50 year Hazard Zone: 39 m
- Development within 50 year Hazard Zone: Carpark at southern end of beach
- Coastal Inundation Risk: Nil

Lord and Van Kerkvoort (1981) assessed photogrammetry at Diggers Beach between 1969 and 1980, and determined there to have been 3 - 19 m of recession over this period (11 yrs). This was calculated to equate to a loss of 35,000 m^3 of sand from the dunes. They also determined a loss of 70,000-140,000 m^3 associated with the landward translation of the beach profile, giving a total loss of 105,000-175,000 m^3 for Diggers Beach over the 11 years between 1969 and 1980.

Lord and Van Kerkvoort (1981) noted the history of heavy mineral sand mining and sand and gravel extraction from Diggers Beach. The heavy mineral sands mining occurred in 1967. And there was known to be removal of 170,000 m^3 of sand and gravel from the beach berm between 1959 and 1973, of which 70,000 m^3 was removed between 1969 and 1973.

Taking mining extraction into account, Lord and Van Kerkvoort (1981) determined natural erosion processes to have resulted in 35,000 to 105,000 m^3 volume loss between 1969 and 1980, or a natural recession rate of 0.4 - 0.75 m/year for Diggers Beach.

At the time of Lord and Van Kerkvoort (1981) paper, the beach was described as narrow, backed by a single foredune which had a prominent erosion escarpment.

It was thought that the inner nearshore sand unit (observed on the beaches near to the Harbour) did not continue around Diggers Headland. Offshore coring was inconclusive, as it was found that the sediment depth was thin overlying clay/gravel/bedrock. The thinness of this layer suggested it would probably be totally mobilised during a storm (Lord and Van Kerkvoort, 1981).

A report by ERA (1973) aimed to assess the effect of gravel mining on the strandline of Macauleys (now Diggers) Beach. Although mining was no longer taking place, the report found an uneven pattern of accretion and denudation and considerable loss of the vegetated foredune, which it was concluded was the ongoing consequence of beach mining. Photos of Macauleys Beach from the 1973 report by ERA are reproduced below.

The commercial gravel source was thought to be a deep surface layer at the northern end of the beach, which was replenished during mining activities by the action of the sea under high tides and storms. The effects of beach mining upon Macualeys (Diggers) beach were noted to have been exacerbated by human access upon the dunes and wind erosion of undermined foredunes (ERA, 1973)

.

Figure 6-3 View looking north along Diggers Beach, with former area of mining in the flat area in the right middle distance. Photo from ERA (1973)

Figure 6-4 Southern end of Diggers Beach, showing vegetation and scarping, 1973, photo from ERA (1973)

Figure 6-5 Erosion escarpment and spring high tide water level at southern end of Diggers Beach, January 1973, photo from ERA (1973)

Figure 6-6 Diggers Beach, illustrating gravel on inner sand bar. Photo from ERA (1973).

6.9 Diggers Head and Charlesworth Bay

Diggers Head is a high, large outcrop of bedrock. There are some rocks immediately offshore of the headland, however the surrounding sea bed is largely clear of bedrock. The headland protrudes ~ 250 m from the shoreline of Diggers Beach (MHL, 1983). In relation to Charlesworth Beach in the lee of the headland, Diggers Head extends nearly 1 km from the shoreline, and this provides significant protection to beaches to the north from the predominant south easterly waves.

Site inspection suggested water depths near the rock shelf of 2 - 3 m along the northern face, and greater depths potentially along the north east face of the headland. Water depths were said to be much shallower on the southern side of the headland (MHL, 1983).

A sand tracer experiment was conducted which involved dumping 11.8 tonnes of sand at the southern side of Diggers Headland in the surf zone (the sand was tagged with Neo-Zappon blue dye) during wave conditions of 3-4 m height from the south east. The sand was dumped on falling tide. Sampling was conducted for 6 days following the dump, then regularly for the following 3 months. Diggers Headland was selected, as based upon its length and orientation, it was postulated to be the most likely bedrock headland to interrupt sediment movement north of Coffs Harbour (Lord and Van Kerkvoort, 1981).

The results of the sand tracer experiment indicated significant bypassing of Diggers Headland occurred within the first day of dumping. The coarser sand fraction was transported in the high energy surf zone close to the headland; and the finer fraction was dispersed offshore and to the north. The tracer sand was found on Charlesworth Beach within one day and within two days, the sand had travelled up to 1 km north. Tagged sediment was still detectable on beaches to the north up to 3 months later. The experiment established that bypassing could occur around the large, protruding Diggers Headland under moderate energy conditions (Lord and Van Kerkvoort, 1981).

Given the shallower water depths surrounding Diggers Head, as compared with Muttonbird Island or other of the northern headlands, waves of smaller wave height will break, and so, mobilise sediment for bypassing at this location.

Charlesworth Bay is a 500 m long, curved, northeast facing beach. It is very well protected from the predominant south easterly swell by Diggers Head at its southern end, with waves typically < 0.5 m. There are also known to be many reefs and bedrock outcrops on the sea bed around this location, which provide further dissipation of incoming wave energy at this location. The northern boundary of the beach is Fowlers Head.

Not surprisingly, then, Charlesworth Bay exhibits a typical reflective beach morphology, with a steep upper beach face of coarse sand and cobbles, and a wider bar exposed at low tide. A rip may form against the northern headland under higher wave conditions (Short, 2007).

The valley behind the beach is mostly occupied by the Novotel Pacific Bay resort. A road runs to the southern end of the beach. An old boat shed exists at the southern end of the beach

Charlesworth Bay is considered likely to have a low risk of erosion and recession by 2105 (DECC, 2005).

PWD (1995) determined the following Coastline Hazard Design Parameters for Charlesworth Bay:

- Beach Erosion: 0 m
- Shoreline Recession: 0 m/yr
- Recession due to Sea Level Rise: 14 m
- 50 year Hazard Zone: 14 m
- Development within 50 year Hazard Zone: Nil
- Coastal Inundation Risk: Nil

An historical photograph of Charlesworth Bay is illustrated in Figure 6-7.

Figure 6-7 Charlesworth Bay, with revegetated area of former mining in foreground to right. Photo from ERA (1973)

6.10 Fowlers Head, Korora Beach, Hills Beach, Campbells Beach, Pelican Beach and Riecks Point Beach

Korora Beach, Hills Beach, Campbells Beach, Pelican Beach and **Riecks Point Beach** are classified as reflective beaches (Short, 2007). The beaches are composed of medium to coarse grained sand, rounded gravels and cobbles, comprising both shell and rock fragments. The coarser gravels/cobbles are deposited more thickly on the high tide (upper) beach face by surging breakers and swash processes. All of the beaches exhibit a narrow beach face and beach berm.

The reflective beach morphology results in plunging waves breaking close to the shore at low tide and surging breakers onto the upper beach face at high tide. Such wave breaking conditions are dangerous to swimmers and are unsuitable for surfing, as the waves plunge in a heavy shore break.

In typical low wave conditions, the beaches have one sand bar attached to shore. During high wave conditions, this sand bar may migrate further offshore under the process of cross-shore sediment transport, and thereby offer greater dissipation of incoming wave energy. In the subsequent period of beach recovery, the sand bar will migrate shoreward and attach to the shoreline, due to onshore sediment transport driven by the regular swell waves.

Rip currents, which provide the offshore component of surfzone circulation, regularly form adjacent to the headlands and rock reefs under moderate to high wave conditions. Rip currents may be associated with greater offshore sediment transport under storm conditions, resulting in a scarp at the landward end of the current. One such scarp has been observed at the southern end of Campbells Beach (refer Figure 6-8).

Figure 6-8 Erosion formed by rip current, southern end of Campbells Beach

Behind this compartment of beaches, the coastal ranges are noted to be close to the shore, making for narrow and small back barrier deposits behind these beaches. The beaches are composed of quaternary deposits, and there are thought to be no remnant Pleistocene deposits remaining in the small embayments.

The compartment from Korora to Riecks Point beaches is oriented towards the predominant south easterly swell. The protrusion of Diggers Head affords a large measure of protection to the beaches between this head and White Bluff. A number of reefs in the nearshore zone also assist in dissipating and refracting incoming wave energy. Diggers Head protrudes approximately 1 km seaward relative to the beaches.

Fowlers Head, located between Charlesworth Bay and Korora Beach may also refract incoming wave energy to a lesser degree. Fowlers Head is said to be coarse grained metamorphic rock (ERA, 1973).

Riecks Point Reef is the largest reef in the compartment, and extends from ~ 650 m offshore towards the shore in a north east direction. A tombolo has formed between the reef and shore, separating Pelican and Riecks Point Beaches.

Another large reef formation extends from 700 m offshore of the southern end of Korora Beach toward the shore in a north east direction, and a tombolo has also formed between the reef and shore, separating Hills and Korora Beaches.

Campbells Beach has a number of smaller rock reefs in the nearshore zone immediately offshore of the beach. These minor reefs will also provide some dissipation of incoming wave energy, and may trap and contain sediment during storm conditions, which is then readily available for beach recovery during calm conditions.

In addition to the headlands and reefs discussed, a bathymetric chart given in WP Geomarine (1998) shows bedrock high points offshore of White Bluff and at Riecks Point Reef to the north. These high points will dissipate wave energy arriving from a north-east direction on Campbells Beach. The bathymetric chart also shows smaller reefs offshore of Macauleys Headland to the south of Campbells Beach, and these features may also assist in dissipating wave energy from the south east. The reefs plus the protruding Diggers Head have resulted in these beaches typically experiencing a smaller average wave height. This combined with coarser sand and gravels have resulted in the reflective beach morphology.

The headlands which separate the five beaches in the Campbells compartment have only a minor protrusion, with attached rock platforms and reefs. Access between the beaches is easily possible around the headlands at low tide. The minor separation provided by the headlands indicates there is likely to be sediment exchange between the beaches under typical wave conditions. This will be important for assessing beach erosion and long term recession.

The Coffs Harbour breakwaters form a highly important control on sediment supply to the beaches north of the harbour including Campbells Beach, as discussed in Section 3.6.2.1.

A paper by Lord and Van Kerkvoort (1981) focused on the longshore sediment transport and coastal processes of the beaches between Sawtell and White Bluff, which includes Korora, Hills, Campbells, Pelican and Riecks Point Beaches. The following findings from the Lord and Van Kerkvoort (1981) paper are relevant to this study.

- Beaches north of the Harbour were noted to be in a poor condition at the time of the report. There was little to no growth of incipient features and the high water run-up reached the toe of the erosion escarpment at most beaches between the Harbour and White Bluff. The site assessment coincided with a period of low storm activity and so, the authors stated that the beaches should have exhibited a more accreted (recovered) profile.
- Various historical activities (such as plane landings on Park Beach and motorcycle racing on beaches between Diggers and White Bluff) were said to indicate that significant narrowing of the beaches between Coffs Harbour and [at least to] White Bluff had occurred since the Harbour construction. The historical information was also said to indicate there had been a change in sediment type to the present day coarse grained and gravelly beach berms.
- It was postulated that for beaches north of the Harbour, erosion during storm events will continue to the point where the beaches become sufficiently compartmented to prevent sediment bypassing around the intervening headlands, and the loss of littoral "throughput" will extend the length of time for beach recovery after the storms.
- It was noted that north of Macauleys Headland [to White Bluff] the coastal ranges abut close to shore, resulting in relatively narrow beach embayments comprised mainly of Holocene sediment deposits.

- The nearshore bathymetry between Sawtell and White Bluff is said to be flatter than that found at other regions of the NSW coast. Further, the nearshore zone is controlled by bedrock, with a number of offshore reefs and prominent headlands forming a barrier to northerly longshore sediment transport.
- The outer nearshore sand unit is said to be continuous across this region while the inner nearshore sand unit is not believed to be continuous, but rather is restricted around Macauley and Diggers Headlands. The boundary between these inner and outer nearshore sands is said to be in 5 - 10 m water depth.
- The nearshore sand unit is said to be thin and overlies bedrock, clays and gravels. Gravels were found to occur extensively on beaches between Sawtell and White Bluff, particularly on beaches north of Diggers Head. This is also the region where the inner nearshore sand unit is discontinuous.

A summary of previous reports relating to the individual beaches (Korora, Hills, Campbells, Pelican and Riecks Point) is detailed below.

On **Korora Beach**, SMEC (2005) found the design parameters of PWD (1995) to be inadequate, and instead utilised the storm erosion modelling program SBEACH to determine the likely risk of coastal hazards at Korora Beach, as part of a coastal engineering assessment for a proposed development at 15 Shell Cove Lane Korora.

Using a 0.1 % AEP design storm wave height, which was taken to be H_s of 10.5 m and peak wave period of 16 s (based upon data from Port Kembla) SMEC (2005) determined a storm erosion profile from SBEACH that was well seaward of 1943 photography profile.

The sea level rise predications at the time of report were 0.15 m for the 50 year period and 0.4 m for 100 year period. SMEC (2005) calculated the nearshore slope to 17 m water depth to 1:82.8. Using this slope in the Bruun Rule, a recession due to sea level rise of 33 m for 100 yr planning period was determined.

Wave run-up was calculated with the ACES modelling program, utilising the design wave height parameters given above, and was determined to be 4.8 m in this location.

Assessment of photogrammetry indicated no signature of long term recession on Korora Beach. This was assessed using all photogrammetric profiles. SMEC (2005) then removed the 1986, 1989 and 1996 profiles from their assessment, as the photogrammetry from these dates was considered potentially spurious. The subsequent assessment indicated a very low to negligible rate of recession of 0.05m/yr. Thus no overall long term recession was assumed for Korora Beach.

Thus, the design long term recession for Korora beach was stated to be 33 m for the 100 yr planning period (comprising 0 m long term recession and 33 m recession due to sea level rise).

Hills Beach was determined by PWD (1995) as having the following Coastline Hazard Design Parameters:

- Beach Erosion: 0 m
- Shoreline Recession: 0 m/yr

- Recession due to Sea Level Rise: 14 m
- 50 year Hazard Zone: 14 m
- Development within 50 year Hazard Zone: Nil
- Coastal Inundation Risk: Nil

John Allen & Associates (1988) confirm the reflective beach morphology at Hills Beach, describing a steep, narrow beach face, and surf conditions which are typically dangerous for swimming, due to the surging waves and deep inshore channel. Rips were noted to form commonly along the north and south ends of the beach. The John Allen & Associates (1988) site inspection coincided with a 1.9 m high tide and swash was observed regularly running up to the top of the beach foredune.

The beach is mostly composed of fine to medium grained sands, with some coarser sands and fine gravels. The grain size increases towards the surf zone, and is finer along the back of the beach. The report stated the Foredunes and hind dunes were said to consist of sand of Holocene age (John Allen & Associates 1988).

At time of report, a low insipient foredune had formed in front of a former erosion scarp in the frontal dune and had become established with primary dune species. The foredunes, located between the back of the beach and the start of the relatively flat hind dunes consist of two low foredunes running parallel for the length of the beach, and cease in front of the lagoon (John Allen & Associates, 1988).

Pine Brush Creek Lagoon lies behind Hills Beach with its entrance adjacent to the northern headland. The lagoon is generally closed, except under high flow conditions when a channel is cut to the beach alongside the headland. The area of the lagoon behind the beach is said to be gently sloping and the lagoon is said to remain shallow for a considerable distance in this area (John Allen & Associates, 1988).

The headland to the north of the lagoon contains a well preserved stand of SEPP 26 Littoral Rainforest. A reserve of approximately 400 m in length lies between the southern shoreline of Pine Brush Creek lagoon and Normal Hill Drive in the south and adjoins the reserve at Korora Beach (John Allen & Associates, 1988). Opal Cove Resort comprises the majority of development at Hills Beach, located ~ 100 – 200 m behind the beach and dunes.

Dune vegetation was described as good in south to poor in the northern area of reserve, due to trampling by people accessing the beach, and clearing of hind dunes for a former caravan park. Across the beach, the rear of the foredune is almost cleared of natural vegetation, has a low grass cover, and there were many exotic species noted in the dune system. The profile of the foredunes is relatively low at Hills Beach. John Allen & Associates (1988) provided a comprehensive description of incipient and foredune species present at the time of the report. Readers are referred to this document for further details of dune vegetation species.

Figure 6-9 Hills Beach upper beach face and dunes, from John Allen & Associates in 1988

Figure 6-10 Pine Brush Creek Lagoon entrance in 1988, from John Allen & Associates (1988)

Opal Cove resort was under construction at the time of the report. Prior to the development of Opal Cove resort, based upon interviews and questionnaire surveys, it was found that Hills Beach and reserve was primarily used for: quiet uncrowded picnics / barbeques; sheltered swimming in the lagoon; access to Hills Beach for surfing and Korora Beach for swimming; sunbaking and strollling along the uncrowded beach; access to fishing from the northern headland. The users at this time were typically local residents of the Korora region, attracted by the uncrowded and relatively undeveloped nature of the beach. Other users included holidaymakers from nearby resorts, who also visited the area to avoid the crowds found at other Coffs beaches and reserves. The management plan described in the report sought to retain the low key, quiet, and uncrowded nature of the reserve which existed prior to the development of Opal Cove (John Allen & Associates, 1988).

An Aboriginal site of significance exists in the vicinity of Hills Beach and the site is associated with rites for the increase of crayfish (John Allen & Associates, 1988).

Campbells, Pelican and Riecks Point Beaches have typically considered to be one beach in past assessments, and this is worth noting in the summary of findings given below.

For **Campbells Beach**, PWD (1995) defined design coastline hazard parameters of:

- Beach Erosion: 10m;
- Shoreline Recession: 0.3m/yr equating to 15 m over 50 years;
- Recession due to Sea Level Rise: 14 m.
- 50 year Hazard Line: 39 m.
- Four properties on Emerald Avenue fall within this 50 year hazard line.

Once again, readers are advised to refer to the methodologies used by PWD (1995) and their limitations for determining these design parameters.

Lord and Van Kerkvoort (1981) described the original survey of land at Campbells Beach in 1884 to record a reserve of crown land of 5 chain widths (~ 100 m) between the high water mark and the residential subdivisions. In 1981, the beach erosion escarpment was located approximately along the subdivision boundary. Lord and Van Kerkvoort (1981) note that, even allowing for some leniency in the definition of the high water mark in 1884, the original survey indicates a loss of 50-100 m of beach since 1884, which is an average of 0.5 - 1.0 m per year between 1884 and 1981.

A Coastal Processes and Hazard Definition Study was completed by WP Geomarine (1998) as Stage One of a Coastline Management Plan for Campbells Beach. The study aimed to further understand the threat of erosion and inundation which has existed for properties particularly along Campbells Beach for at least 20 years. WP Geomarine (1998) defined Campbells Beach as including Pelican Beach and Riecks Point Beach, in their determination of processes and hazards, and which they termed the southern, middle and northern ends of the beach. *Actual* names of the beaches have been used to describe the findings of this report below.

Beach Erosion

A design storm cut of 140 m^3/m above 0 m AHD was assumed, and which was calculated to equates to the landward movement of the 1996 erosion escarpment of 10 m at Campbells Beach and 6 m at Pelican and Riecks Point Beaches. It was not clear how the 10 m erosion value was calculated. The

10 m allowance was recommended as the immediate beach erosion hazard line for the entire beach length.

The beach erosion value (140 m^3/m) was based upon assessment of photogrammetry between 1942 and 1996 which indicated this rate occurred less than 2 % of the time. The beach was assessed to have experienced an average of 100 – 120 m^3/m erosion seaward of the erosion escarpment.

It is also interesting to note that WP Geomarine (1999a) compiled a coastal engineering report which indicated a lower storm demand of 80m^3/m for a property at the southern end of Campbells Beach. This was stated to be because the southern end of the beach in this location comprised beach sand interspersed with bedrock, and because the southern ends of beaches receive lower wave energy. While this is true, it is widely recognised that the southern ends of beaches along the NSW Coast experience greater erosion due to longshore transport processes driven by the predominant south-easterly swell. Further, a topographically constrained rip current tends to develop at the southern end of Campbells beach, increasing the likelihood of offshore sand transport and erosion in this region.

Shoreline Recession due to sediment deficit

The report adopted the PWD (1995) recession rate of 0.3 m/yr as a conservative design value, resulting in linear recession of 15 m in 50 years and 30 m in 100 years of the erosion escarpment.

However WP Geomarine (1998) also conducted a volumetric analysis of photogrammetric data between 1942 and 1996, and obtained recession rates which differed from the PWD (1995) assessment. WP Geomarine (1998) calculated 0.21 m/yr recession at Campbells Beach, 0.08 m/yr recession at Pelican Beach, and 0.11 m/yr accretion at Riecks Point Beach, equating to 0.08 m/yr recession across all three beaches between 1942 and 1996. The recession rates were calculated from the difference between the most accreted and eroded beach volumes from the photogrammetric data.

PBP (2004) determined the Campbells profile in 1942 and 1996 to both be average (ie, not accreted or eroded), and so considered the photogrammetric analysis by WP Geomarine (1998) to be reliable. The volumetric analysis given by WP Geomarine also contrasted with rates of 0.5 – 1.0 m/yr recession between 1884 and 1981 described by Lord and Van Kerkvoort (1981). The accuracy of long term recession values given in all assessments (i.e., Lord and Van Kerkvoort, 1981; PWD, 1995; and WP Geomarine, 1998) is discussed and clarified in Section xxx.

Longshore Sediment Transport

WP Geomarine (1998) calculated the rate of net longshore transport for Campbells Beach using a recession rate of 0.3 m/year and an assumed active nearshore profile between +5 m AHD to -10 m AHD. The rate determined was a 9,000 m^3/year contribution by Campbells Beach to the net northerly longshore transport. That is, Campbells Beach was estimated to be losing 9,000 m^3/year more sediment around White Bluff than received from Hills Beach.

Carley *et al.* (2006) determined a higher rate of loss of 12,600 m^3/year (compared with the estimated rate of 9,000 m^3/yr by WP Geomarine (1998)) based upon values given by PWD (1995).

Recession due to Sea Level Rise

Using the Bruun Rule, linear recession of the erosion escarpment of 4.5 m for the 50 year period and 11 m for the 100 year period was calculated, for sea level rise of 0.225 m and 0.538 m in 50 and 100 years (from 1998), respectively.

The beach slope value used in the Bruun Rule was taken as the slope from the toe of the surfzone to the top of the dune crest, because this is the area of beach to be impacted by sea level rise. The beach slope used was taken as the average of Campbells, Pelican and Riecks Point Beaches (of 1:10, 1:20, 1:50 respectively) equalling 1:20. It should be noted that the nearshore zone was stated to be very flat by WP Geomarine (1998) (between 1:100 and 1:175), and that flatter shoreline slopes produce greater recession with the Bruun Rule.

Behind the beach face at Campbells, excavations conducted for developments (swimming pools and buildings) did not reach bedrock. Further, borehole data obtained for the WP Geomarine (1998) study found no significant bedrock outcropping above -1 m AHD. This suggests that shallow bedrock outcrops below the foredunes (and which form reefs in the nearshore zone) are limited, and should not be relied upon to provide protection from long term shoreline recession in the future (WP Geomarine, 1998).

Cliff and Dune Stability

An assessment of the wave impact zone, the zone of slope adjustment, and the zone of reduced foundation capacity was conducted by WP Geomarine (1998) using the accepted methodology defined by Nielsen *et al.* (1992). There was no information indicating the maximum depth of scour to be anticipated from an extreme storm event, hence the scour level recommended for NSW beaches by Nielson *et al.* (1992) of -1 m AHD was adopted (WP Geomarine, 1998).

There was no available geotechnical data defining the soil properties landward of the beach, therefore WP Geomarine (1998) assumed that the back beach material was compacted, moderately strong, dune sand with an angle of internal friction (phi) of 35^0 to conduct the assessment. WP Geomarine (1998) state that where geotechnical assessment indicates the back beach material varies from this assumption, the zone of slope adjustment and zone of reduced foundation capacity given below should be recalculated and adjusted accordingly.

- The *Wave Impact Zone*, which is the area subject to wave attack during a storm, was defined on Campbells to include all of the beach seaward of the erosion escarpment. This gives a *Distance Landward of the Vertical Escarpment Crest in Storm* of 0.0 m.
- *Zone of Slope Adjustment* is the zone of slumping of the erosion escarpment after the storm has passed. WP Geomarine (1998) defined this zone to extend 2.0 m landward of the vertical escarpment crest. Property foundations within this zone must extend into the stable foundation zone, with piles designed for lateral soil loadings.
- *Zone of Reduced Foundation Capacity* is defined by taking a line, of the same slope as phi (35^0), from the limit of wave scour up to intersect with the ground surface. The horizontal extent between the vertical erosion escarpment crest and the intersection with the ground surface is taken as the zone of reduced foundation capacity. Using an assumed back beach level of 5 m AHD, WP Geomarine calculated this zone to be 12 m landward of the vertical erosion

escarpment crest. However, it was stated that in the case of an intended construction, a site specific assessment should be undertaken to ensure proper founding for proposed structures.

Each of these zones is to be applied on top of the hazard lines (immediate, 50 and 100 years) as defined above. Most importantly, the 12 m Zone of Reduced Foundation Capacity needs to be added to each of the immediate, 50 and 100 year hazard lines.

Coastal Inundation

WP Geomarine (1998) calculated wave run up for the flattest measured profile (0.13) and steepest (0.23), giving 10.3 m AHD and 7.0 m AHD, respectively. The 10.3 m height was considered overly conservative because of the beach's generally flat offshore slopes and reefs, which would enable extensive wave dissipation. Thus a design level of 7.0 m AHD was adopted, and this is consistent with other measurements on the NSW coast.

Sand Drift

There was assessed to be no significant loss of sediment from the beach due to aeolian processes. Sand drift is also not seen as a threat to adjacent development (WP Geomarine, 1998; 1999b).

Dune vegetation

Vegetation on Campbells Beach was noted to be sparse during the site inspection, however, development was said to form the main groundcover along the foredune.

Coastal Entrances

The natural scouring of creek entrances during floods and subsequent infilling is not thought to affect the long term sediment budget or beach stability of Campbells Beach. The creek entrances on Campbells, Pelican and Riecks Point Beaches are thought to be stable (WP Geomarine, 1998).

Hazard Lines

The beach erosion, long term recession and recession due to sea level rise were combined to give the following hazard lines in the WP Geomarine (1998) assessment. The hazard lines given here are measured from the 1996 erosion escarpment:

- An immediate hazard line of 10 m
- A 50 year hazard line of 29.5 m
- A 100 year hazard line of 51 m

Based upon these hazard lines, WP Geomarine (1998) found:

- one property within the immediate hazard line;
- an additional 6 properties within the 50 year hazard line; and
- a further 4 properties within the 100 year hazard line.

WP Geomarine (1998) clearly noted that the hazard lines given above did not include the slope instability zones associated with dune slip following beach erosion. This indicates that there are additional properties to those specified that are at risk from coastal processes. The additional hazard due to dune instability is described below.

WP Geomarine (1999b) also developed a Campbells Beach Coastline Management Plan, which utilised the hazard lines and other hazard assessments defined in the Coastal Processes and Hazards Definition Study (WP Geomarine, 1998), as outlined above. The Coastline Management Plan provided options for mitigating and addressing the various coastal hazards. Additional points of interest regarding coastline hazards in the Plan are given below.

- The Coastline Management Plan (WP Geomarine, 1999) further defined the coastal entrance hazard, noting that some properties adjacent to Hayes and South Creek banks experience inundation at times of heavy rainfall and/or severe coastal storms when waves may overtop the beach berm and wash into the creek.
- A seawall for the properties along Emerald Avenue was one strategy option given in the Plan. The proposed seawall was required to extend from the banks of South Creek to Middle Head, at a height of 6 m AHD and to a toe depth of -1 m AHD. The wall was stated to be made from tipped/placed rock, with primary and secondary armour layers, armoured toe, crest and drainage works (WP Geomarine, 1999). A seawall that has been constructed at 13 Emerald Avenue falls far short of the required design specifications given by WP Geomarine (1999) to properly protect properties on Campbells Beach.

6.11 White Bluff and Sapphire Beach

White Bluff forms the southern headland of Sapphire Beach. The bluff is ~ 30 m above sea level, with sheer cliffs falling to the beach (MHL, 1983).

The headland consists of bedrock outcrops which form a short projection into the surf zone. Water depths are shallow at the end of this bluff. There is extensive bedrock immediately offshore of the Bluff in shallow water depths. Lobster Rocks is an outcrop of bedrock ~ 130 m offshore of White Bluff, surrounded by deeper water on its northern edge (MHL, 1983).

This site is exposed to swell from all directions which are attenuated on the bedrock reefs and extensive shallow bedrock immediately offshore of White Bluff (MHL, 1983).

Sapphire Beach is 2.3 km in length, lying between Green and White Bluffs. The beach faces southeast, however due to Split Solitary Island located 2.5 km offshore of White Bluff the beach has slightly lower waves than nearby Moonee Beach. The beach has a double barred system, of transverse bar rip morphology for the inner bar and rhythmic bar and beach for the outer bar. Up to 10 rips may cross the inner bar, which become stronger during those times when the outer bar attaches to the inner bar. (Short, 2007)

Sapphire Beach has been described as a receding beach, with rates of recession around 33 % lower at the northern end compared with the southern end (WPGeomarine, 1999a).

The northern end of Sapphire Beach was thought to have a medium risk of erosion / recession, and the southern end an extreme risk of erosion / recession by 2105 (DECC, 2005). The majority of the beach length is thought to have a low risk of overwash by 2105 (DECC, 2005).

In the coastal assessment conducted by PWD (1995: refer to Section X for limitations in methodology used in this report), the following design parameters were determined:

- Beach erosion: 10 m
- Shoreline recession: 0.3 m/yr
- Recession due to sea level rise: 14 m
- 50 year Hazard Zone: 39 m
- Development within 50 year Hazard Zone: Nil
- Coastal inundation risk: Nil

A surf environmental analysis was conducted at Sapphire Beach (commissioned by PWD and summarised into a report in 1992), between 7 August 1980 and 5 August 1985 (with no data collected between early April 1984 to August 1984). The analysis involved volunteers taking twice daily observations of wind, wave height and wave period characteristics, breaker type and beach usage counts. Summary information of interest to current project is reproduced in Table 6-1 and Table 6-2.

The summary of beach usage data (which included sunbathers, swimmers and surfers) indicated that overall: on weekdays, average usage was 14 people, with a maximum of 378 recorded (in January); and on weekends/holidays the average usage was 22 and maximum was 298 people (in January) (PWD, 1992).

Based upon the total observations of wave breaker type, 66.37 % of observed breakers were spilling, 6.13 % were plunging, 0.00 % were surging and 27.46% were a combination of spilling and plunging breakers.

Table 6-1 Wind Direction Observations, from PWD (1992)

Wind Direction	**Morning Dominant**	Morning Secondary	**Evening Dominant**	Evening Secondary	**Total Dominant**	Total Secondary
Summer	S	SSW & SSE	NE	SE	NE	SE & SSE to S
Autumn	S	SW	SE	SSE	S	SE
Winter	NW	S & SW	SSE	SE	SSE	SE & S
Spring	S	NW	NE	SE, SSE & N	NE & N	S & SSE
Total	S	SW	SSE & SE	NE	S to SE	

Table 6-2 Wave Height and Period Observations from PWD (1992)

Wave height (m)	**Probability of exceedance (%)**	**Wave period (s)**	**% occurrence**
4	0.0	4-6	6
3.5	0.0	6-8	28
3.0	0.08	8-10	40
2.0	3.0	10-12	19.5
1.5	11.0	12-14	6
1.0	46	14-16	0.5
0.5	89	>16	6

The Sapphire Beach settlement lies behind the beach. The northern end of the beach may be accessed by Moonee Beach. A small caravan park lies on the beachfront at the southern end, providing beach access, a small car park and picnic facilities (Short, 2007).

6.12 Green Bluff and Moonee Beach

Green Bluff is a 200 m wide headland which projects 150 m seaward of the line of adjacent beaches (Moonee, Sapphire). Its highest point is ~ 20 m above sea level. The lower edge of Green Bluff headland consists of steep rocky slopes and gullies. Above the 10m contour, the land slopes gently. (Laurie, Montgomerie & Pettit Pty Ltd 1983).

Green Bluff is an outcrop of the metamorphic Coramba Beds geology. A number of basaltic dykes are visible on the seaward edge of the Bluff. Most of the basaltic lava in these dykes has been weathered away, particularly where in contact with the sea. Sand transported from the adjacent beach sand dunes is said to have created a raised area on the middle of the headland (Laurie, Montgomerie & Pettit Pty Ltd 1983).

Hydrosurvey indicated that 3 m water depth contour continues seawards of Green Bluff. Offshore bed slopes are constant to the 11 m water depth contour, which is 360 m offshore. Offshore contours are aligned approximately north - south. Sand in transit during hydrosurvey suggested that sea bed levels should not be assumed constant (MHL, 1983).

Dives conducted in December 1982 and February 1983 noted that the sea bed material was sandy with shell fragments and pebbles and a few isolated shoals. Outcrops of bed rock and large boulders were noted to litter the seabed just offshore of the Bluff, at around 2 - 3 m water depth. Fine bed material was evident in suspension, and being propagated along the bed in the direction of the swell (MHL, 1983).

Not surprisingly given the shallow water depths immediately offshore of Green Bluff, MHL (1983) determined that ocean waves and swell were an important influence on currents in vicinity of the headland. Waves of Hs > 1 m will break in shallow water offshore of the headland.

Moonee Beach is said to be one of the longer stretches of beach in the Coffs area, running 4.6 km between Look At Me Now Headland and Green Bluff. The beach experiences the full prevailing wave climate, facing east-south-east. The beach displays a well developed double barred system for its full length. The inner bar typically has numerous rips (up to 16), with rips more widely spaced across the outer bar due to the higher wave energy. The inner bar is noted as a transverse bar and rip, and the outer bar a rhythmic bar and beach morphology. (Short, 2007)

Moonee Creek exits to the ocean at the southern end (along the northern side of Green Bluff), before flowing northwards behind the beach. Moonee Creek typically has a wide open entrance and at high tide, access to Moonee Beach is typically cut off by the Moonee Creek entrance. There is also a minor drainage channel at the northern end of the beach, east of Lighthouse Crescent (John Allen & Associates, 1990).

Moonee Creek has a catchment of ~ 41 km^2. It drains east from the coastal range towards Emerald Beach then deviates south west parallel and behind the dunes of Moonee Beach, and eventually feeds to a lagoon east of Moonee Village. Sugar Mill Creek joins with Moonee Creek near to the entrance to the ocean at Green Bluff. The Creek is open to the ocean, assisted by a shallow rock shelf under the entrance channel, which keeps tidal velocities high enough to prevent sand accumulation. The entrance area is popular for recreation, while access to the beach from the village of Moonnee Beach is via wading across the creek and entrance compartment (which can be difficult, especially at high tide). The whole creek eco-system is diverse and locally significant (Laurie, Montgomerie & Pettit Pty Ltd 1983; Binnie & Partners, 1987).

Preliminary work by DECC (2005) has determined there to be a low risk of erosion / recession and an extreme risk of overwash by 2105 at the southern end of Moonee Beach.

The beach is backed by Moonee Beach Nature Reserve, which is said to state significant habitat value. The reserve is relatively undisturbed, providing valuable habitat for small mammals and birds. There is evidence of Aboriginal usage of the area at Moonee Beach, including scattered middens and a tool factory (Binnie and Partners, 1987).

An assessment of dune vegetation by P. Baker & Associates in 1984 described the dominant species on the dune ridge to be *Acacia sophorae*, said to be dense, vigorous and moderately resistant to trampling. Areas of the dunes not covered by this species are covered with spinifex and blady grasses. The western edge of the dune is flanked with scattered *Banksia integrifolia*, *Casuarina equisetifolia*, *Acacia saligna* and *Carpobrotus glaucescens* (pigface). The area behind the dune ridge was apparently undergoing regeneration following sand mining, at the time of this 1984 report. The dune vegetation community was described as assist in binding dune soils and preventing erosion by wind.

Moonee Beach and Creek are relatively undeveloped, apart from a caravan park, a small residential area, and small collection of shops towards the Pacific Highway at the southern end of the beach. More recently, a commercial development has been constructed in the Highway, while extensive urban development is proposed to the south of Skinners Creek, between the highway and Moonee Creek.

Surfing is popular off Green Bluff headland and Moonee Beach (to the south) is said to provide some of the best surfing breaks in the area (Binnie and Partners, 1987). The northern headland ("Back Emerald") is a left hand break, which is popular in summer as it is protected from the prevailing north east winds. The only beach access to the northern end of the beach is via a vehicle track from Emerald Beach, or down the Look At Me Now headland escarpment. At the southern end of the beach behind the Moonee Creek entrance, there is a car park.

6.13 Look At Me Now Headland, Shelly Beach, and Dammerels Head

Look At Me Now Headland is a large headland feature which forms the northern boundary of Moonee Beach. The headland is steeply cliffed up to ~10 m above sea level, then rises gently to form a dome shaped crest on the southern portion of the headland, at 20 – 30 m above sea level. Rock outcrops form small islands off the north eastern edge of the headland (Binnie and Partners, 1987). A low rock platform exists below the steeply cliffed drop (MHL, 1983). Bathymetric data taken by MHL (1983) has been used within the nearshore wave model (refer Section 3.2.5).

The headland is composed of Coramba Beds, which are likely Late Carboniferous. These metamorphic rocks have undergone at least two stages of regional metamorphism and three stages of deformation (PWD, 1987). The rock mass is likely to be of lesser strength due to bedding and fractures, and the headland is described as intensely jointed and fractured, and sheared in some places (Binnie and Partners, 1987). One dyke on the south east side has weathered to below low tide level, resulting in a narrow rocky embayment with large boulders projecting from a coarse sandy bed (MHL, 1983).

Look At Me Now Headland is used for walking, fishing and scuba diving, but access to the water from the headland is not easy. Local divers have laid an underwater rope trail around the point, which links points of interest. Marine ecology is typical of the region and isolated corals have been reported, although no rare or unique species or communities were noted (Binnie and Partners, 1987).

Look At Me Now headland is of significance to the local Gumbaingirr people. It is stated to be the mythical point of entry of the ancestral being Ulitarra, who founded the Gumbaingirr people. The area shows evidence of usage and a stone tool factory (John Allen & Associates, 1990).

On both Look At Me Now and Dammerels Headlands, areas of seepage and impeded drainage occur which have given rise to the presence of sedgelands, predominantly on the northern sides. Rare and endangered species (at the time of the report) sited across the headland include: Little Tern, Rainbow Bee Eater, White Breasted Sea Eagle and Osprey (although not a nesting site) (John Allen & Associates, 1990).

Shelly Beach is a 600 m east facing beach between Dammerels Head and Look At Me Now Headland. It is moderately protected by the headland, with waves generally < 1 m. It has a low continuous sand bar and a cobble/boulder beach face at high tide at its southern end, forming a low tide terrace beach. A permanent rip exists along Dammerels Head (Short, 2007).

Directly abutting the steep escarpments and slopes of the bedrock outcrop of Dammerels to Look at Me Now Headland, there is some exposed rock on the beach itself (John Allen & Associates, 1990). It is likely that the upper beach may be completely removed under certain storm conditions.

Shelly Beach is a generally safe and protected swimming area year round, however, its usage is reported to be low, likely due to the proximity of Emerald Beach which has parking, toilets, and picnic and play facilities. Fishermen, divers and snorkelers use the rock platforms of the headlands (Dammerels and Look At Me Now) and Shelly Beach (John Allen & Associates, 1990).

Two memorial plaques for two unidentified sailors who died following the collision of the Keilwarra and Helen Nicoll in 1886 are located immediately behind Shelly Beach (John Allen & Associates, 1990).

Dammerels Head forms the southern end of Emerald Beach with a shallow rock zone immediately offshore. A headstone from the grave of the Dammerels, the original white settlers of this area, has been relocated on Dammerel Headland, along with a damaged replica of the semaphore pole used to signal the Lighthouse on Solitary Island. A second semaphore pole is on LAMN headland (John Allen & Associates, 1990).

A small drainage channel occurs on the northern side of Dammerel Head near Fiddamans Road (John Allen & Associates, 1990).

Although not of direct significance to coastal processes, it is interesting to note that of a comparative assessment of 18 headlands from Wilsons Headland near Wooli to Nambucca Headland, Dammerels Headland was found to have the second highest species diversity of plants and animals, and contains a number of rare dwarf heath species. The native plants occur in communities described as low scrub, scrub heath, dwarf heath, grassy dwarf heath, headland grassland and sedgeland.

Dammerel Headland is a roosting site for Brahminy Kites. And a rare species of plant known as Zieria occurs on the headland (John Allen & Associates, 1990).

Across the headlands of Look At Me Know, Shelly Beach and Dammerels, the predominant vegetation communities are closed scrubland, scrub, dwarf heathland, grassy dwarf heathland, sedgeland and headland grassland. In these communities, 62 native plant species have been identified and 108 bird species recorded based on the headland vegetation complex, several of which are rare or endangered (John Allen & Associates, 1990).

Pedestrian Access to the headlands includes formal tracks and informal tracks, which should be rationalised to protect the endangered species present on the headlands of both Dammerels and Look At Me Now (John Allen & Associates, 1990).

6.14 Emerald Beach, Diggers Point and Fiddamans Beach

Emerald Beach is 800 m long beach which faces east-southeast and curves to south. It lies between Diggers Point and Dammerels Head. It is largely controlled by these bedrock headlands plus a reef towards the southern end, resulting in four permanent rips on the beach. In addition, shifting beach rips also occur. It is noted to be a double barred system, facing into the dominant swell direction, with a transverse inner bar and rhythmic outer bar (Short, 2007).

The beach is easily accessed at its the southern end, with a park, picnic area and amenities behind the beach at this end. Fiddamans Creek exits to the ocean between the middle and southern end of the beach. Recreation at Emerald Beach, and nearby Shelly Beach and Dammerels and Look At Me Know Headlands includes walking, surfing, swimming, rock fishing, diving and viewing of scenic points from headland (John Allen & Associates, 1990).A preliminary assessment by DECC (2005) considered Emerald Beach to have an extreme overwash potential along 15% of its length (due to dune heights of 6 – 8 m in height, DNR, 2006), and low potential for the remainder by 2105. Emerald Beach was considered to have a low risk of erosion and recession by 2105 (DECC, 2005).

An investigation into coastal processes and hazards was conducted for Emerald by PBP (1995) as part of assessment process for a proposed development of Lot 2 DP 840016 Pacific Highway, Emerald Beach. At that time, PBP (1995) described Emerald Beach as having a beach width (measured from 0 m AHD to the back beach escarpment) of ~ 15 to 25 m, and ~ 30 m at the entrance to Fiddamans Creek. Well rounded gravel / cobbles (30 -60 mm diameter average) were found scattered across beach, with a dense (30-40%) coverage immediately south of Fiddamans

Creek entrance, to sparse (1%) from 70 m north of entrance to northern end of beach. A similar scattering of cobbles was observed during the field inspection conducted by BMT WBM in July 2008.

At the time of the PBP report (1995), a well defined erosion escarpment was evident, cut into the densely vegetated dune, and thought to be relatively recent. The scarp face was composed weakly consolidated soil with trace organics. No incipient foredune was apparent. The toe of the erosion scarp was estimated at + 2 m AHD along full length of beach, and ranged in height from 0.5 m in southern end to a maximum of 3 m in the centre of the beach, to 1.5 m at northern end. While such features are interesting to note, they are likely to be transient features, such that at other times, recovery will accreted sand onto the beach, and fill in this erosion.

There was no data relating specifically to Emerald Beach, therefore PBP (1995) upon recommendation by the then Department of Land and Water Conservation (now DECC) adopted a conservative erosion rate from Park Beach of 15 m, as as this was the largest value determined for any beach in the Coffs Region by PWD in 1995.

Shoreline recession due to sea level rise was taken to be 30 m, using a sea level rise of 0.6 m (the then predicted mid level scenario) and a slope of 1:50 (as adopted by PWD, 1995).

PBP (2004) conducted a photogrammetric assessment of seven aerial photos between 1943 and 1993, from which they found Emerald Beach to be accreting. Using survey of the beach, they calculated long term accretion of Emerald Beach of between 0.1 - 0.9 m/yr. However, as this was said to be in contrast to other nearby beaches (and generally on the NSW coast at that time), a conservative shoreline recession rate of 0.2 m/yr was adopted, which is a similar rate to the average of 0.16 m/yr established for Coffs beaches by PWD (1995).

PBP (1995) determined a total design shoreline recession for the 100 yr period to be 65 m, incorporating: a conservative beach erosion estimate of 15 m; a conservative shoreline recession estimate of 20 m and; shoreline recession due to sea level rise of 30 m. The 65 m 100 yr hazard line was found to be between 19 and 38 m seaward of the seaward boundary of the subject property of the report.

It is interesting to note the contradicting assessment of erosion and accretion determined by PWD and PBP in 1995. In fact, these assessments suggest that there is likely to be some variation in the shoreline state over time, as opposed to a consistent erosionary or accretionary state.

Dune crest heights along Emerald Beach were measured at 7.2 m, 7.9 m and 7.7 m AHD at southern, middle and northern ends. Based upon the assumption of dune levels greater than 6 m to be sufficient to abate coastal inundation by PWD (1995), Emerald Beach was considered to have no coastal inundation hazard, and that this would continue for the planning period of 100 yrs (PBP, 1995). In considering the effects of sea level rise upon the likelihood of coastal inundation, PBP (1995) stated that the order of magnitude of potential impacts are within the range of the existing dune crest elevations, and that sea level rise coastal inundation impacts pose a small and acceptable level of risk.

Fiddamans Creek is typically open to the ocean, with its entrance controlled by a bedrock outcrop on the beach and reef in the water at its entrance. PBP (1995) described the plan position of the entrance to have remained stable over the 50 yrs prior to this report. The stability is thought most likely attributable to the bedrock outcrop, forming a hard edge along one bank over at least the lower 100 m of the creek channel.

This bedrock outcrop was estimated to be ~ 3 – 4 m AHD in height (PBP, 1995). PBP (1995) estimated the waterway width to be ~ 10 m to within 500 m of the ocean, with a depth of ~ 1 m within 100 m of the ocean a the time of inspection. PBP (1995) estimated a “design” configuration for the creek entrance during flooding to be a berm height of + 3.5 m AHD, and entrance width of 20 m.

Residential development adjoins the southern bank of Fiddamans Creek with a caravan park on the northern side. Recreational activity tends to occur at the mouth of the creek (Binnie and Partners, 1987).

Little is known about **Diggers Point**, which separates Fiddamans and Emerald Beaches. Site inspection revealed it to be a low headland which protrudes only a short way between the two beaches. A track across Diggers Point provides access to Fiddamans Beach. Otherwise, access across Bare Bluff is the only other access point to the relatively quiet Fiddamans Beach. Short (2007) reports few and occasional visitors (surfers and fishers) to Fiddamans Beach.

Fiddamans Beach is located between Bare Bluff and a smaller headland known as Diggers Point. It is 1 km in length, and faces southeast, thus is not protected from the dominant south-south east wave climate. This has resulted in a high energy double barred rip dominated beach. The outer bar displays a rhythmic bar and beach shape, the inner bar a transverse bar and rip beach state. The inner bar usually has more frequent rips (~ 5), with more widely spaced rip cells across the outer bar. Permanent rips exist along both bounding headlands.

Of particular note along Fidddamans Beach is the large, unvegetated sand blowout which traverses from Fiddamans Beach over the back of Bare Bluff onto Sandys Beach in the north. The high, vegetated sand dunes which extend a few hundred metres inland behind Fiddamans Beach, with some large blowout features caused by prevailing winds are also of interest. The sand blowout across the headland is likely to facilitate aeolian sediment transport between the two beaches. Fencing and areas of revegetation of the headland blowout are evident at present. Review of aerial photography in 1943 illustrates that the exposed sand across the headland and two other large blowout features in the dunes were active at this time. Compared with the 1943 photography, the headland blowout was significantly wider, as were the dune blowouts, which are now largely revegetated. Windblown sediment transport in this region is a natural process, and may also be an important pathway for the transport of sediment from the south into Sandys Beach and beaches to the north. In this case, revegetation of this feature may impact upon sediment supply for beaches to the north.

While there is evidence that sand mining occurred on Fiddamans Beach, the foredune and hinddune regions currently support a large area of undisturbed coastal wetland and dune species, which are likely to be of high ecological value. This area is part of the Moonee Beach Nature Reserve.

6.15 Sandys Beach and Bare Bluff, Hearnes Lake Beach and Woolgoolga Back Beach,

Bare Bluff is a headland standing approximately 30 m high and protruding 800 m to the east (Short, 2007). The bathymetry surrounding Bare Bluff Headland was surveyed by MHL in 1986, and has been incorporated into the bathymetry used in the nearshore wave model (refer Section 3.2.5). There is said to be an Aboriginal stone tool "factory" on the headland (Binnie & Partners, 1987)

The entire stretch of beaches from Bare Bluff to Woolgoolga Headland is ~ 5 km in length, with beaches separated by sandy, reef-bound cuspate forelands, including the spit between Flat Top point and the shoreline.

Sandys Beach extends 1.2 km in length, from the unnamed rocks and reef-tied foreland in the north to Bare Bluff in the south. The beach faces roughly east. Bare Bluff headland and Groper Island located 3 km offshore provide moderate protection for the southern end of the beach, resulting in typical waves of < 1 m and a continuous sand bar (without rips), forming a low tide terrace morphology. The beach is transverse bar and rip at its northern end, with typically 4 – 5 rips across the sand bar, and a permanent rip along the northern rocks and reef. There are noted to be a few rock outcrops in the surf zone. (Short, 2007)

The beach was said to have a low risk of coastal inundation and a medium risk of erosion and recession by 2105 (DECC, 2005).

PBP (2004) analysed photogrammetry at Sandys Beach for dates between 1964 and 1996. Volume change above the 0 and 3 m contour indicated that between 1964 and 1996, the southern end of the beach had receded, there was slight recession at the northern end, and the middle portion of the beach had accreted slightly. As an average across the length of Sandys Beach, there had been very little change, with between -0.08 and 0.5 m of positional change over the 1964 to 1996 period.

A surf environmental analysis was conducted at Sandys Beach (as commissioned by PWD and summarised into a report in 1991(b)), between August 14 1980 and November 17 1987. The analysis involved volunteers taking twice daily observations of wind, wave height and wave period characteristics, breaker type and beach usage counts. Summary information of interest to current project is reproduced in Table 6-3 and Table 6-4.

The summary of beach usage data (which included sunbathers, swimmers and surfers) indicated that overall: on weekdays, average usage was 17 people, with a maximum of 180 recorded; and on weekends/holidays the average usage was 38 and maximum was 360 people (in December) (PWD, 1991b).

Table 6-3 Wind Direction Observations, from PWD (1991b)

Wind Direction	**Morning Dominant**	Morning Secondary	**Evening Dominant**	Evening Secondary	**Total Dominant**	Total Secondary
Summer	S	NE	NE	SE	NE	S & NNE
Autumn	S	ESE	SE	NE & S	S & SE	NE
Winter	WSW	SW/S	SE	S	S	SE & SW
Spring	N	S	N	NE & SE	N	NE
Total	S	N	SE	NE	N, NE, SE, S	

Table 6-4 Wave Height and Period Observations from PWD (1991b)

Wave height (m)	Probability of exceedance (%)	Wave period (s)	% occurrence
4	0.08	4-6	1.5
3.5	0.1	6-8	12
3.0	1.0	8-10	46.5
2.0	7.0	10-12	31.5
1.0	30	12-14	7.5
0.5	80	14-16	1
		>16"	

The three beaches of Woolgoolga Back, Hearnes and Sandys offer good surfing conditions depending on prevailing waves. The breaks are typically beach (sand) breaks, but a right hand break can form along the northern side of Flat Top Point, under certain conditions (Short, 2007).

A shady reserve runs the length of the Sandys Beach, immediately behind the dunes, with two car parks for visitors further north along the beach. The beach is patrolled during summer. A boat launching ramp is located near the southern end of the beach. Access to Fiddamans Beach to the south is possible across the sand blow spilling onto the southern corner of the beach (Short, 2007).

Hearnes Lake Beach lies between Flat Top Point and an unnamed reef-tied foreland (i.e. sandy tombolo) to the south. Hearnes Lake and its associated wetlands are situated behind much of the beach length. The entrance to the lake is at the northern end of the beach, behind Flat Top Point. **Flat Top Point** is usually linked to the mainland via a sandy tombolo, which is typically accessible at low tide.

The beach is ~ 2 km in length and faces east, thus is exposed to waves from north to south along its lenght. A rip-dominated double bar system has evolved, with numerous (~8) rips across the inner bar and a rhythmic outer bar with fewer, more widely spaced rips. In high seas, the outer bar is evident, as waves break across it. The modal beach state is said to be a transverse bar and rip inner bar and rhythmic bar and beach outer bar. In the lee of the southern rocks and reef-tied foreland, waves are reduced slightly, and the system forms a continuous sand bar. A permanent rip is located against the southern rocks. (Short, 2007)

Hearnes Lake is an Intermittently Closed and Open Lake or Lagoon (ICOLL) with a typical surface area of 10 ha and a catchment of 6.8 km^2. Its main tributary is Double Crossing Creek. Much of its catchment has been cleared for agriculture, and other development in the catchment includes a small section of Sandy Beach village, and a caravan park on the lake's north-western shoreline. To the immediate north of the Lake lies SEPP 26 Littoral Rainforest, while areas to the south contain the Endangered Ecological Community Coastal Saltmarsh as well as tracts of mangroves and fringing sedgelands, all of high environmental value. Hearnes Lake is zoned as 'habitat protection' within the Solitary Island Marine Park (SIMP). (BMT WBM, 2009b)

Flat Top Point and its surrounding waters and rock reefs are said to contain the highest diversity of marine life within the whole SIMP and the area is protected as a 'sanctuary zone'. Flat Top Island is also part of the Coffs Coast Regional Park. (BMT WBM, 2009b)

While the beach and lake may be limited in accessibility, there is significant use of these regions for walking, swimming, fishing, dog exercising, bird watching, surfing, kite / wind surfing, picnicking and other leisure activities (BMT WBM, 2009b). Access to the beach is possible via the caravan park on the northern side of the Lake at the northern end of the beach, and at the southern end via Sandys Beach car park in the south.

A preliminary assessment by DECC (2005) has suggested the beach is at a high risk of recession and erosion, and a low risk of coastal overwash along the majority of its length, with an extreme risk of overwash for around 20% of its length by 2105.

A recent assessment of coastal hazards was undertaken as part of a development application for a property on the northern side of the beach by PBP (2004). The subject property was 45 Hearns Lake Road Woolgoolga, located on the northern edge of Hearnes Lake and behind the dunes at the northern end of Hearnes Lake Beach.

PBP (2004) utilised the erosion modelling package SBEACH to calculate the storm demand for Hearnes at the location of property. Model inputs included: 2004 survey of the beach above 0 m AHD to the subject property boundary; an assumed grain size of 0.15 mm, as consistent with sediment sampling at nearby Sandys and Woolgoolga beaches of 0.16 mm; a 100 yr ARI offshore wave height of 10 m Hs and wave period taken from Sydney and Port Kembla wave rider buoys, which is considered conservative because these locations have a larger wave climate than the north coast; a time series of spring tide plus known tidal anomalies for Coffs Harbour, giving a peak water level of 1.5 m AHD, timed to coincide with peak wave height.

The outcomes of the SBEACH modelling indicated erosion above 0 m AHD of between 34 and 46 m^3/m. The relatively small values are said to be related to the relatively flat profile of the beach (as taken from the 2004 survey data). However, a storm demand value of 200 m^3/m was assumed to remain conservative and consistent with other typical beach studies along the NSW coast (e.g. Gordon (1987) values of 230 m^3/m for NSW) (PBP, 2004).

Sea level rise predictions adopted for the study were for 0.2 m rise by 2054 and 0.5 m by 2104. PBP (2004) utilised the Bruun Rule (1962) to calculate shoreline recession due to sea level rise. Based upon studies for nearby areas in the Coffs Region (refer Section 2.2.2), a depth of closure of 11 m relative to AHD was used. Survey of Woolgoolga Headland (taken from MHL (1986)), which extended 650 m south of the headland near to Flat Top Point, indicated the 11 m contour to be at a distance of 600 m offshore. Assuming this distance for the adjacent Hearns Lake Beach gave a nearshore slope of 1:40. At a slope of 1:40 with the sea level rise values noted previously produced values of 8 m of shoreline recession by 2054 and 20 m by 2104. (PBP, 2004)

The report also discussed changes to storm frequency and intensity relating to climate change, however, the generic nature of predictions at that time meant numerical values relating to such changes were not able to be calculated. PBP (2004) assumed a modest to moderate increase in average and maximum cyclone intensities, noting that cyclones may be linked with ENSO although it was unknown how this may vary with climate change. Mid-latitude storms were predicted to increase in intensity but decrease in frequency, due to reduced equator to pole temperature gradients. PBP (2004) noted that such potential changes in weather patterns may result in a change in the angle of approach of the predominant wave climate, in turn resulting in a realignment of shoreline and change in recession/accretion patterns.

The wave run up value calculated for Hearnes Lake Beach was 5.8 m AHD. The dune levels at the property for which the report was commissioned were said to be greater than 9 m AHD, which was expected to be maintained in the future, thus a negligible coastal inundation hazard was assumed for next 100 yrs.

It was not considered appropriate to adopt the high recession rate of 0.5 m/yr for Park Beach (derived from other studies) for Hearnes Lake Beach because the recession is largely result of Coffs Harbour breakwaters, and which are nearly 20 km south of the Hearnes Lake Beach. PBP (2004) were uncertain if the harbour has impacted (reduced) sediment supply to Hearnes Lake Beach. However, it was suggested that rates of sediment bypassing of Look At Me Now Headland and Bare Bluff to the south are likely to be low and as such, Hearnes is likely to be accustomed to relatively low rates of sediment supply from the south.

Further, PBP (2004) cited studies for six beach locations near to Hearnes Lake Beach that found the beaches to be either stable or accreting over the period of record of 30-50 years, namely Campbells, Emerald, Sandy, Woolgoolga and Corindi beaches.

Analysis of the vegetation line in the aerial photography at Hearnes Lake Beach adjacent to the new development and Hearnes Lake entrance was investigated, and it was found that: the vegetation line migrated seaward 10 – 15 m between 1943 and 1973; there was further seaward migration of vegetation line between 1973 and 2004; the vegetation line to the south was generally stable. In 2000, the vegetation line was 15 m seaward of the southern end and 40 m seaward of the northern end of the subject property (45 Hearnes Lake Road) compared with the 1943 line. There was also said to be strong evidence of beach accretion between 2002 and 2004 (and generally at this location over last ~ 60 years). PBP (2004)

Hearnes Lake Beach, in vicinity of property (i.e. at the northern end of the beach just past the lake entrance) is thought to have been accreting in the 60 years prior to the PBP 2004 report. The relative stability is said to have occurred in spite of sand extraction at the northern end of the beach in the 1960s and 1970s. The PBP (2004) report stated that the stability of Hearnes Lake Beach was expected to continue into the future and net sediment loss would be negligible. However, a conservative long term recession rate of 0.05 m/yr was adopted, equivalent to shoreline recession of 2.5 m by 2054 and 5 m by 2104 (i.e. due to net sediment loss and not including sea level rise).

PBP (2004) also considered past sea level rise in their calculated recession rates. For the study, they adopted a rise of 0.86+/- 0.12 mm/year between 1915 and 1998 calculated from water level records at Sydney and Fremantle, equating to sea level rise of 0.052 m between 1943 and 2004. When corrected for beach slope, this accounted for 2.1 m of shoreline recession over the period, and which should be deducted from the long term recession rate. The calculation confirmed the assumed long term recession rate of 0.05 m/yr to be relatively conservative, compared with potential erosion due to measured sea level rise.

PBP (2004) cited Jones (1981) as stating sand extraction occurred at the Flat Top Point tombolo between the late 1960s to ~1976. Observation of aerial photography from 1969 and 1972 showed small scale extraction to be occurring at Hearnes Lake entrance. Further, observation of aerial photography indicated a well vegetated foredune, suggesting extraction took place on the active beach face, and not the foredune region.

An anecdotal account of sand mining at Hearnes Lake Beach (pers. comm.., Rhonda Atkins, Woolgoolga local for ~50 years) outlined the mining that occurred in the early 1970s. Basically, “dump trucks” were driven onto the beach via the old fishermans track (through Hearnes Lake). Sand was taken from the area to the north of Hearnes Lake, nearly opposite Flat Top Point and just south of the Willis Creek outlet. Sand was extracted from the front of the incipient dunes to fairly close to the front of the foredunes. More generally, the region from Hearnes Lake through to Sandy Beach was mined.

Hearnes Lake entrance typically closed, and generally recloses rapidly following a breakout event. Lake opening is said to typically to form a narrow channel approximately on the northern side of the entrance berm. Vegetated banks at the entrance are said to have been fairly stable since 1943 (from aerial photos), suggesting it is unlikely that the channel and entrance would meander significantly outside of these bounds (PBP, 2004).

No known significant stormwater outlets were noted to flow directly onto Hearnes Lake Beach (PBP, 2004).

PBP (2004) assessed the Zone of Slope Adjustment to lay seaward of the property boundary at 45 Hearnes Lake Road for all planning periods (existing, 50 and 100 yrs). In 2104, the Zone of Reduced Foundation Capacity extends over the SE corner of the property.

The well vegetated foredune noted by PBP (2004) to have been present over the period of aerial photography also suggests that the hazard of sand drift was not an issue at this location. However, should the dune vegetation be damaged or removed, there is potential for landward sand drift, which may be either a nuisance and low levels, or a permanent loss from the system at high volumes. PBP (2004) stressed that public access to the beach from the proposed development be restricted to the existing public access route (at the northern shoreline at Hearnes Lake entrance), to limit damage and erosion of the dunes.

Pockets of low open *Banksia intergrifolia* and *Cupaniopsis anacardioides* forests were found flanking beach dunes at Hearnes Lake and the southern end of Sandy Beach. Such species are known to stabilise coastal dunes and shelter surrounding areas from salt laden sea breezes (Binnie and Partners, 1987).

Woolgoolga Back Beach is located between Woolgoolga Headland in the north and and the sandy foreland in the lee of Flat Top Point in the south, stretching for 1.8 km. The beach has double sand bars in the north which join together into a single bar at the southern end of the beach. The outer bar has a rhythmic bar and beach morphology, and the inner bar has typically a transverse bar and rip morphology. Depending on the wave conditions, the inner bar is either attached or detached from the beach face, with many (~ 10) rips crossing it. When detached, a trough exists between the sand bar and beach face, and the inner bar is more rhythmic in morphology. Permanent rips are found adjacent to the headland in the north and along the reef at Flat Top Point, which extends 500 m offshore. The beach faces roughly east south east. (Short, 2007)

The length of Woolgoolga Back Beach is backed by vegetated dunes, with a low swampy area behind the dunes in the centre of the beach (Short, 2007). **Willis Creek** outlets to the beach at the southern end, adjacent to Flat Top Point. Prior to the ocean outfall at Corambirra Point, the sewerage treatment works (situated in the low swampy area behind the dunes) discharged to Willis Creek.

The beach length is considered to have a medium risk of erosion / recession by 2105 (DECC Int. Doc, 2005). The risk of coastal inundation by 2105 is considered to be extreme for 15%, Medium for 5 % and low for the remainder of the entire beach length (DECC, Int Doc, 2005).

Access is possible via Woolgoolga headland in the north, and an access point at the centre of the beach. Four wheel drive access is also located at the southern end of the beach, with driving permitted along the beach.

6.16 Woolgoolga Headland, Woolgoolga Beach and Safety Beach

Woolgoolga Headland is 50 m in height, and extends 1 km into the sea (Short, 2007). The headland is composed of rock of the Coramba Beds formation (Binnie and Partners, 1987). The rock mass is likely to be of lesser strength due to bedding and fractures, and the headland is described as intensely jointed and fractured, with a number of metamorphic shear zones of micro-brecciated rock. Due to the jointing and bedding, the rock mass is thought likely to be of lesser strength. (Binnie and Partners, 1987)

The headland topography begins at the waters edge as steep cliffs rising to 10 m, then more gently rises to 30 m to form a low ridge from the lookout to the township (Binnie and Partners, 1987).

Current monitoring at Woolgoolga Headland by MHL (1986) suggests that under typical conditions, wind is the dominant driver of headland currents. The headland may have an affect on current separation due to the sharp change in orientation of the coastline. This may have an impact on the frequency of sediment bypassing, and shadowing of the southern end of Woolgoolga Beach from longshore sediment transport.

Woolgoolga Headland is predominantly vegetated with grassland and heathland communities, and an area of Banksia scrub on the more sheltered northern side of the headland. Woolgoolga Headland was described as one of the best undisturbed headlands of its type (in terms of vegetation). There are also said to be Aboriginal middens on Woolgoolga Headland (Binnie and Partners, 1987).

Good water clarity and a range of species are noted to occur in the shoreline, intertidal zone and adjacent waters, which make the area of interest in terms of marine ecology/environment. The protected rock platform on the northern side provides for low wave marine communities and a number of coral stands (Binnie and Partners, 1987).

Next to the southern end of the headland lies Woolgoolga Shopping Centre, a caravan park and the Woolgoolga SLSC (est. 1933), with a grassy picnic area and car parking between the SLSC and the headland. There is also an access road behind Woolgoolga Beach to another caravan park situated next to the mouth of Woolgoolga Lake. (Short, 2007)

Woolgoolga Beach continues south from the sandy foreland at Woolgoolga Reef for 1.7 km to Woolgoolga Headland. The beach generally faces east, becoming curved towards its southern end. The beach is sheltered by the large Woolgoolga Headland and attached reef at its southern end. This has shaped the morphology, which is typically a shallow gradient beach face and attached sand bar at the southern end (low tide terrace), grading to a transverse bar and up to five rips towards its northern end where it is more exposed to the prevailing wave climate. A permanent rip runs against Woolgoolga Headland, which is strengthened during summer north easterly winds (Short, 2007).

The beach is composed of fine beach sand, of 0.16 mm mean grain size (Short,1993, cited in PBP, 2004). Vegetation immediately behind the beach is said to include open forest with Melaleuca quinquenervia (Broad Leafed Paperbark), and also areas of wet heath with Banksia aspleniifolia (Swamp Banksia) (Binnie & Partners, 1987).

Woolgoolga Lake is located behind the beach, and is typically closed to the ocean. Woolgoolga Lake is a popular location for swimming and other recreational activities, and also supports a range of wetland species.

On 12th and 13th May 1964, big seas accompanied by king tides removed foredune sands and almost undermined the front of the existing Woolgoolga-Grafton Surf Life Saving Clubhouse. The clubhouse was built in 1955-6, constructed by club members using donated materials. Old jetty piles which had been used to terrace the bank were washed out during the storm. The NE corner foundation pier of the building was also washed out. The dune area was re-established by an initial sand fill, then natural sand accumulation and also further sand and rock fill. (Sustainable Futures Planning & Design 1990; PWD, 1989)

In spite of rock protection placed in front of the clubhouse to protect it, by 1989, it was located seaward of the natural erosion escarpment line. The rock protection did not halt natural erosion which continued on either side of the site. (PWD, 1989)

During the cyclones of 1974, it is believed that storm seas and associated high tides eroded large quantities of sand from the beach and berm. The southern end of the beach was said to be the most affected (Soil Conservation Service of NSW, date unknown).

Assessment by PWD (1995) found the northern end of Woolgoolga beach to be stable between 1943 and 1986 (ie, no accretion or recession).

The beach contains a narrow dune system with both high and low sections (PWD, 1989). The risk of overwash by 2105 is considered to be low for most of the beach length, with perhaps ~30% of the beach length considered to have an extreme risk of overwash (DECC, 2005). The entire beach area is considered at extreme risk to coastal erosion and recession by 2105 (DECC, 2005).

There have been hazard studies conducted for this section of beach, as follows. Of particular interest is the changing conclusions regarding long term recession at Woolgoolga Beach, as new methods and data for assessing photogrammetry, beach erosion and recession became available.

PWD (1989) conducted an assessment of the photogrammetric data available at three blocks along Woolgoolga Beach. From the data, they calculated a linear regression to determine the rate of recession at the beach. They concluded that all profiles except two at the very southern end of the beach were undergoing recession, at rates of 0.14-1.27 m^3/yr/m. PWD (1989) concluded that the southern end of the beach was accreting due to protective works carried out in this area, the groyne effect of rock protection at the surf club and fill placed at the site.

A report by Sustainable Futures Planning & Design (1990) utilised a storm erosion demand of 150 m^3/run of beach above AHD. The value was deduced from storm erosion demands along other areas of NSW adjusted to generally local known conditions, provided by the then Public Works Office in the absence of a storm demand survey.

Analysis of photogrammetric data by Sustainable Futures Planning & Design (1990) found recession rates of 0.1 – 0.7 m per year at some locations, and accretion at others along Woolgoolga Beach. A present analysis of such data would likely conclude that the beach was experiencing little if any long term recession, but rather short term erosion in response to short term events.

To determine the effects of sea level rise, an escarpment recession rate of 0.14 to 0.35 m/year was calculated, based on the predictions available at that time. The design parameter long term recession trend was taken to be 0.1 m/yr plus 0.3 m/yr (as a conservative sea level rise factor), a total of 0.4 m/year (Sustainable Futures Planning & Design 1990)

In 1995, PWD updated their 1989 photogrammetric assessment with recent 1993 aerial photography. As part of the assessment, the following coastline hazard design parameters were developed (the limitations to methodology applied during this report are detailed in Section 6.19):

- Beach Erosion: 5 m
- Shoreline Recession: 0.2 m/yr
- Climate Change: 14 m
- 50 Yr Hazard Zone: 29 m
- Development within 50 yr Hazard Zone: Woolgoolga Surf Life Saving Club
- Coastal Inundation Risk: Low to moderate risk to 5 dwellings west of Hofmeier Close with erosion of frontal dune; and low to moderate risk to surf life saving club (SLSC) and adjoining caravan park.

A more recent coastal engineering assessment report was compiled by SMEC in 2004, however the report largely utilised the findings given in the PWD (1995) report. The report adopted a 5 m translation of the erosion escarpment during an extreme design storm event. While the design storm event adopted was the 100 yr ARI wave height/duration condition defined using measured wave data from MHL and DECC, the 5 m erosion value was taken from the PWD report of 1995. A long term recession rate of 0.2 m /year was also adopted based on the findings of PWD (1995).

SMEC (2004) utilised revised best estimate predictions for sea level rise by IPCC of 0.15 m within 50 years and 0.4 m in 100 yrs. From this, a total recession of 40 m within 100 years was determined, that is the natural long term recession plus sea level rise. .

SMEC (2004) calculated elevated water levels due to wave set up and wave run up, using a combination of models such as SWAN (a wave transformation model), SBEACH (a beach erosion model), and ACES (an irregular wave run up algorithm). Using a 0.5 m storm surge (there were no references for this value) and a 100 year average recurrence interval wave height of 8.4 m (supplied by MHL), they deduced a maximum wave run up of 4.3 m AHD. Interestingly, this was 1.0 m below the highest dune level of the proposed development for which the study was commissioned.

The Woolgoolga district was first settled by Europeans in late 1870s to early 1880s. Early farmer-settlers tended to settle along Woolgoolga Creek upstream of the tidal influence. Sea was favoured transport for goods, agricultural produce and logs. A jetty was constructed on Woolgoolga beach, starting in 1890 and completed in 1892. The Woolgoolga Jetty was 476 m, located approx 250 m N of Woolgoolga Headland. By the late 1940s and early 1950s the number of ships stopping at the jetty was very low and the structure fell into disrepair. The entire structure was removed by 1962. (PWD, 1989)

Safety Beach is long sandy stretch of 1.2 km extending from an unnamed bluff in the north to a sandy foreland formed in lee of Woolgoolga Reef. The beach grades from a transverse bar and rip to a low tide terrace morphology from north to south. As such, there is a single bar with a few rips crossing it, forming into an attached bar at the southern end. This is due to increasing protection from Woolgoolga Reef which dissipates the waves to typically < 1 m in height at the southern end. During high wave conditions, rips may form at the southern end, particularly near the reef. A permanent rip is located at the northern end of the beach against the bluff. (Short, 2007)

Sampling by Short (1993, cited in PBP 2004) at Safety Beach gave mean grain sizes in the swash zone of 0.16 mm

Darkum Creek runs south behind Safety Beach for 1 km before crossing the beach berm to the ocean at the southern end of Safety Beach. (Short, 2007)

Safety Beach is considered to have an extreme risk of inundation by overwash for 50 % of its length, a high risk of overwash for ~ 8% of the length, and a low risk for its remaining length (DECC Int Doc, 2005). Safety Beach is considered likely to have a low risk of erosion and recession in 2105 (DECC Int Doc, 2005).

Fishing and surfing are popular along the beach and headlands, assisted by the good access. (Short, 2007)

6.17 South Mullaway Beach, Mullaway Headland, and Mullaway Beach

South of Mullaway Headland lies **South Mullaway Beach**. This beach is 600 m in length, and extends to a small unnamed rocky bluff around 10 m high. The beach has one bar with usually two beach rips across it, forming a typical transverse bar and rip morphology. There are permanent rips adjacent to both headlands. A small creek crosses the dune and beach at its northern end. There is a caravan park is situated north of the creek. A car park exists at the top of the unnamed southern bluff. (Short, 2007)

Behind South Mullaway Beach there is a low, vegetated foredune. Around 10 % of the beach length is thought to have a high risk of coastal overwash, and a further 10% of the length to have a low risk of overwash by 2105 (DECC Int doc, 2005). The risk of erosion and recession on this beach in 2105 is considered high (DECC Int doc, 2005).

An unnamed sand and pebble beach of only 50 m in length is situated on the southern side of the unnamed low bluff (that forms the southern headland of South Mullaway). The beach is a reflective beach, with a steep beach face and coarse grained sand, surrounded by cliff and rocks. It is accessed via a steep walking track from the unnamed bluff car park. (Short, 2007)

Mullaway Headland is a metasedimentary rock outcrop around 15 m in height. (Short, 2007)

Mullaway Beach is a 700 m long stretch between Ocean View Headland in the north and Mullaway Headland in the south. The beach has single bar with usually 2 to 3 rip across it, as describes a transverse bar and rip morphology. Permanent rips exist against both headlands. Waves break along the southern rocks, in a point break. (Short, 2007)

A vegetated dune lies behind the beach. A small creek exits to the ocean at the southern end of Mullaway Beach. An access road runs behind the dunes giving access at both headlands. Parking for beach visitors is provided at the headlands. Some residential properties are situated behind both headlands (Short, 2007).

Mullaway Beach and Headland are considered to have a low risk of both coastal inundation and erosion / recession in the year 2105 (DECC, internal document, 2005).

6.18 Ocean View Headland and Ocean View Beach

Ocean View Headland is an outcrop of fine grained metasedimentary rock.

Ocean View Beach is a curving, 900 m long beach between Arrawarra and Ocean View Headlands. The beach faces east, but receives some protection from the dominant swell from Ocean View Headland. The beach is composed of medium sand, with rocks in the surf for the northern 300 m of beach. The beach is said to be transverse bar and rip type. It has a single sand bar, which is typically cut by 3 or 4 rips, a strong permanent rip along Arrawarra Headland in the north, and a lesser permanent rip along Ocean View Headland in the south. (Short, 2007)

Locally, the beach is sometimes known as Mullawarra, as it lies between Mulloway and Arrawarra Beaches.

The northern end of Ocean View Beach was noted to be stable (ie, no recession or accretion) over the period 1943 – 1993 (PWD, 1995). PWD (1995) provided design hazard parameters for Ocean View beach (the limitations for design parameters outlined in Section 6.19 apply):

- Beach Erosion: 0 m
- Shoreline Recession: 0 m/yr
- Recession due to Sea Level Rise: 14 m
- 50 Yr Hazard Zone: 14 m
- Coastal Inundation Risk: Nil

Ocean View Beach and Headland are considered to have a low risk of both coastal inundation and erosion / recession in the year 2105 (DECC, internal document, 2005).

Access to the beach is via a road along the rear of the beach to Arrawarra Headland. From this road, parking areas in the centre and southern ends of the beach are accessible. Residential housing is located behind the northern and southern sections of the beach, including some of Ocean View Headland. (Short, 2007)

6.19 Arrawarra Headland to Middle Corindi Beach

Arrawarra Headland comprises 250 million year old shales and slates, of the same geology seen in the headlands to Macauleys Headland. It is described as a low, grassy headland. Surfing is very popular at the point break formed by the headland. The University of New England has a zoology field station atop Arrawarra Headland (Short, 2007).

Corindi-Arrawarra Beach, or South Corindi Beach extends from the rocks in the north to the outlet of **Arrawarra Creek** in the south. The beach is increasingly protected toward the south, and this is evident in the beach type and sediment size. The beach sand becomes finer toward the south. The beach has a double bar system in the north to the centre of the beach. The outer bar has a rhythmic bar and beach morphology and the inner bar is transverse bar and rip morphology. Both bars have rips across the sand bars, and the two bars are separated by a deep trough. Moving south, the beach morphology grades into a wide, low gradient attached bar cut with occasional rips, typical of a low tide terrace beach type (Short, 2007).

The 750 m portion of **Corindi-Arrawarra Beach** between Arrawarra Creek and the headland is of shallow gradient and faces north east. The beach comprises very fine sand sediment, and possible silty sediment from the nearby Arrawarra Creek mouth, which, due to the low wave energy in the far southern corner of the beach, has deposited on the beach.

This beach is known for its point break, formed by waves from the south east refracting around Arrawarra Headland and into the beach. The headland provides considerable protection for this beach, with waves greatly dissipated upon reaching the shore. This in combination with fine sand has produced a wide beach and shallow attached sand bar without rips, that is, a low tide terrace beach type. When waves are large from the south east, a strong current along the beach flowing to the north is generated. (Short, 2007)

The beach is backed by low foredunes, which are frequently cut by access tracks from each of the caravan parks (Short, 2007). The foredunes are typically low (less than 6 m in some locations (DNR, 2006), and so the risk of overwash in these locations in 2105 is said to be high. The risk of erosion and recession by 2105 is also said to be high to extreme from north to south along this stretch of beach (DECC, internal doc, 2005).

The Coffs Harbour City Coastal Assessment by PWD (1995) outlined the following hazard design parameters for Corindi:

- Beach Erosion: 0 m
- Shoreline Recession: 0 m/yr
- Recession due to Sea Level Rise: 14 m
- 50 Yr Hazard Zone: 14 m
- Coastal Inundation Risk: Nil

Towards the south, there are a series of large beachfront caravan parks. Arrawarra point break has an access road with picnic area and boat launching ramp. Surfing is very popular at Arrawarra Headland, with beach breaks also offered along the beach. Fishing is also popular, off the headland, beach rips, and rocks at Corindi. (Short, 2007)

Middle Corindi Beach North extends from the beach rocks (which form the southern boundary of Red Rock beach) to another pile of rocks 350 m to the south. The beach has a reflective beach morphology. This is due to two shallow reefs offshore which are linked with irregular shore platforms, with rocks in the centre of the surfzone. Thus, wave breaking on this offshore rocky reef reduces the waves to typically < 0.5 m at the shoreline. Rips often form against the rocks. The sediment is typically medium to coarse sand with some gravel and cobbles. The coarser sediments in combination with the low waves have resulted in a steep beach face, typical of a reflective beach profile. (Short, 2007)

Under suitable wave conditions, well developed beach cusps may form, as evidenced in Figure 6-11.

Figure 6-11 Well developed beach cusps on Middle Corindi Beach

Behind this section of beach lies **Pipe Clay Lake**, which is known to be a site of continuous Aboriginal presence, and usage for food gathering. Not surprisingly, then Pipe Clay Lake and its surrounds are abundant in both registered and unregistered archaeological sites and special places. The unregistered sites include both known and unknown sites. (BMT WBM, 2009a)

This section of beach easily accessible at it is backed by a reserve and a caravan park, then Corindi township (population of ~ 600). (Short, 2007)

6.20 Red Rock Headland and beaches (South and North)

Red Rock Beach, Main Beach, or North Corindi Beach, extends from Red Rock for 5.2 km to a collection of rocks and reef, which forms the "boundary" with Middle Corindi Beach. The beach faces southeast, experiencing the full regional wave climate, and average waves of ~ 1.5 m. A double barred surf zone has developed. The outer bar is rhythmic in shape with widely spaced rips, of transverse bar rip / rhythmic bar and beach morphology. The beach sand is medium to coarse, and as such, the inner bar is often attached to the shore forming a steep beach face. The inner bar typically has a reflective to low tide terrace profile. Permanent rips were identified running along the northern headland, and may also form against a bedrock outcrop located in the surf around 200 m south of Red Rock headland. (Short, 2007)

PWD (1995) noted that Corindi Beach (Red Rock) appeared to be accreting, with the rate of accretion increasing towards the northern end. Review of the aerial photography is consistent with this, as there appears to be significant sand storage with little curvature in the beach planform towards Red Rock headland.

The Coastal Lands Risk Assessment (DNR, 2006) noted dune heights of greater than 8 m along Red Rock Beach, and recommended a setback distance of 15 m. The beach was considered to have a low risk of inundation and a low risk of erosion and recession for the 2105 horizon (DECC, 2005).

A surf environmental analysis was conducted at Red Rock Beach (as commissioned by PWD and summarised into a report in 1991(a)), between November 28, 1980 and December 8 1987, with no data from March to August 1986. The analysis involved twice daily observations (morning and afternoon) by volunteers of wind, wave height and wave period characteristics, breaker type and beach usage counts. Of interest to this study is the observational data for wind and waves within the nearshore zone of Red Rock Beach. A summary of the findings is provided below in Table 6-5 and Table 6-6.

Table 6-5 Wind Direction Observations, from PWD (1991a)

Wind Direction	**Morning Dominant**	Morning Secondary	**Evening Dominant**	Evening Secondary	**Total Dominant**	Total Secondary
Summer	S	SE	NE	SE	NE	S & SE
Autumn	S	SE	SE	S	S	SE
Winter	NW	S	S	SE	S	NW & SE
Spring	NW	S & SE	NE	SE	NE & SE	
Total	S	SE & NW	NE	SE	S	SE

Table 6-6 Wave Height and Period Observations from PWD (1991a)

Wave height (m)	**Probability of exceedance (%)**	**Wave period (s)**	**% occurrence**
4	0.05	**4-6**	1.5
3	0.5	**6-8**	16
2.5	0.9	**8-10**	45
2	5	**10-12**	27.5

1	50	**12-14**	8
0.5	85	**14-16**	2
		>16	0

Breaker types were estimated based upon the definition given in the Shore Protection Manual (CERC, 1984). In summary, 27.70% of waves observed were spilling, 28.03% were plunging, 20.12 % were surging and 22.38 % were a mixture of spilling and plunging.

The report found an overall weekday average usage of 4 people and maximum of 49, and overall weekend/holiday average usage of 8 people and maximum of 80 (during April) (PWD, 1991a). Beach usage was defined to include sunbathers, swimmers and surfers, at the time of observation.

Red Rock Beach is accessible via the caravan park and car park at Red Rock in the north, and via Corindi Beach in the south. A small holiday community of ~ 300 people live at Red Rock. There is a riverfront caravan park with a small local shop on the south side of the Corindi River mouth. Red Rock Beach is patrolled over the summer (weekends, Christmas and Easter holidays), with a relatively new surf club (formed in 1991). Boat launching in the creek is possible, with fishing popular in the creek and off the headland. (Short, 2007)

An assessment by Peter Parker Environmental Consultants (1988) reproduced a number of photos of the beaches adjacent to Red Rock headland from 1929, and which may offer evidence of the beach conditions at this time. The photos are reproduced in Figure 6-12 to Figure 6-14.

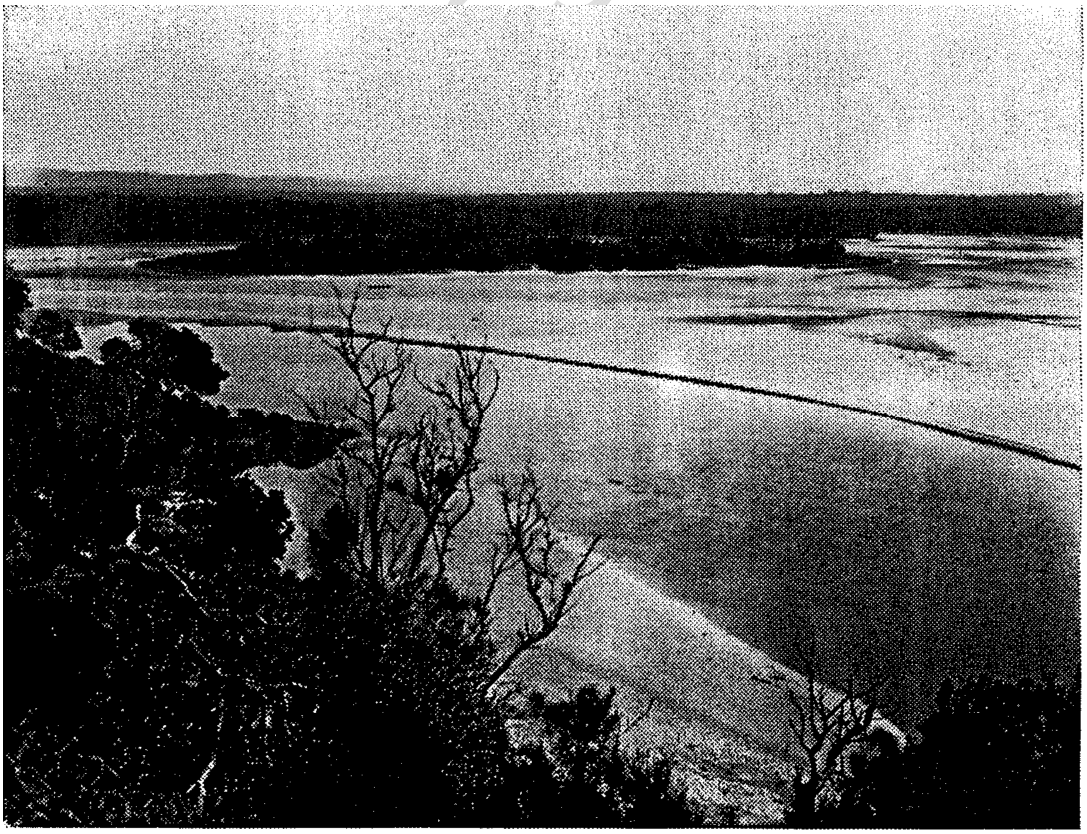


Figure 6-12 Corindi River illustrating the sand flats and island in 1929 (reproduced from Peter Parker Environmental, 1988)

Figure 6-13 Red Rock Headland and Beach, 1929 (reproduced from Peter Parker Environmental, 1988)

Figure 6-14 Main Beach Red Rock with views south to Corindi, 1929, (reproduced from Peter Parker Environmental, 1988)

Red Rock headland is a 20 m high red and white coloured outcropping of well bedded jaspers and chert, interbedded with altered basaltic lava. The geology of the headland is known locally as the Redbank River formation (Peter Parker Environmental Consultant 1988), and the headland geology is around 300 million years old (Short, 2007). The **Corindi River** exits to the ocean along the northern side of this headland. There is a large sea cave on the north east face of Red Rock (Peter Parker Environmental Consultants, 1988).

There is a rich history of Aboriginal usage and spiritual connection throughout the Red Rock and Corindi regions, with a continuous connection with the land to this day of the local Gumbainggirr people.

Red Rock is known to have a high significance to the local Gumbaingirr people, although the tenor of this significance has changed since European settlement. Red Rock itself was known as a clever place, named "Mirrel" to highlight the specialness of the place. Red Rock also served as a traditional gathering place where red ochre and white and yellow pigments were exchanged and used in ceremonies and initiations. Nearby Jewfish Point is said to contain ceremonial areas and camping grounds, with the dance of the Brolga danced here. The Brolga is said to have learnt its dance from that performed at Jewfish Point (according to interviews by Cane, 1988, cited in Peter Parker Environmental Consultants, 1988).

European settlers known to have reached Red Rock by 1827, as part of great pastoral expansion of NSW (Peter Parker Environmental Consultants, 1988). Sadly, Red Rock headland is now remembered for the Blood Rock Massacre during the early period of contact with European settlers, with many Aboriginal people driven off the headland (now known as “Blood Rock”). Gumbaingirr descendants, especially women, still avoid this location.

Other sites of known Aboriginal archaeological material include: a midden located on the south west side of Jewfish Point; middens at Corindi Head; a scar tree located adjacent to Corindi River; and an ochre site on lower north face of Red Rock, as based on oral testimony as to the use of this site and the high quality ochre available (Peter Parker Environmental Consultants, 1988).

Red Rock North Beach, or Little Beach is a small section of beach between Red Rock and Corindi River. It is also known as Little Beach. It is a short compartment of 200 m between the headland and the river mouth. The beach is protected from south-east swell by Red Rock headland, however, strong tidal flows from the Corindi River mouth form deep channels through the surf zone particularly when the tide is ebbing out. The small beach is therefore very unsafe for swimmers, in spite of being easily accessible (by a short walk from the caravan park and town and a small car park at the eastern end). The beach usually has a wide low bar and tidal shoals, as well as outflow channels. The modal beach type is said to be Low Tide Terrace. (Short, 2007)

6.21 Station Beach and Pebbly Beach

Station Beach faces south at its northern end in lee of rocks in the surf zone, which is also where **Station Creek** exits to the ocean. The beach then trends southeast for 4 km to Red Rock and Corindi River mouth. The beach is exposed to waves, and has developed a double bar configuration, with rips across the inner bar, and more widely spaced rips cutting the outer bar. As such, the beach state of the inner bar is transverse bar rip (TBR), and the outer bar is rhythmic bar & beach (RBB). (Short, 2007)

Station Beach is also situated in the Yuraygir NP. Access to the beach is possible through the southern section of Yuraygir NP (Barcoongere Forest Way), from which Station Beach is a 1 km walk or 4WD away. However, 4WD access on the beach is not permitted. (Short, 2007)

The northern end of the beach is offshore in a north-easterly wind, making it sought out by surfers during typical summer onshore (north easterly) wind conditions. (Short, 2007)

There are no existing processes or hazard studies available for this beach. There is photogrammetry for the beach for various dates between 1966 and 2007.

Pebbly Beach is an east facing arc of 900 m length. Rocks at its southern end separate it from the outlet of Station Creek and subsequent beach. The beach is composed of coarse sand and gravel. The northern half of Pebbly Beach has a continuous sand bar which is occasionally cut by rips. The bar narrows to the south, while the beach face steepens, as wave energy decreases towards the south in lee of the southern rocks. Pebbly Beach lies within the Yuraygir National Park (NP) (Short, 2007).

7 REFERENCES

Baker, R.G.V., Haworth, R. J., Flood, P.G. (2001). Inter-tidal indicators of former Holocene sea levels in Australia: a summary of sites and a review of methods and models. *Quaternary International* **83-85** (2001), pp. 257-273

BBW [Blain, Bremner and Williams], (1985). *Elevated Ocean Levels, Storms Affecting the NSW Coast 1880-1980*, prepared for the NSW Public Works Department Coastal Branch in conjunction with Weatherex Meteorological Services, PWD Report No. 85041

BBW [Blain, Bremner and Williams], (1986). *Elevated Ocean Levels, Coffs Harbour*, prepared for the NSW Public Works Department Coastal Branch in conjunction with Weatherex Meteorological Services, PWD Report No. 86005.

Binnie & Partners Pty Ltd (1987), Northern Areas Wastewater Scheme Environmental Impact Statement prepared for Public Works Department NSW on behalf of Coffs Harbour Shire Council, June 1987.

Blackham, D. (2006). Late Holocene shoreline evolution and mean wave direction, mid North Coast, New South Wales. Unpublished B Sc. honours thesis, University of Newcastle, 102pp.

Blackmore, K. and Goodwin, I.D. (2009). Hunter, Central and Lower North Coast regional climate change project. Report 3. Climatic change impacts or the Hunter, Central and lower North Coast region of NSW. Environment Division, Hunter Councils, pp99.

BMT WBM (2009a), *Pipe Clay Lake Draft Estuary Management Plan*, prepared for Coffs Harbour City Council, June, 2009.

BMT WBM (2009b), *Hearnes Lake Estuary Management Study and Plan*, Final Draft, prepared for Coffs Harbour City Council, August 2009.

Browning, S. and Goodwin, I. 2008. A 700 year reconstruction of East Coast Cyclone Frequency. *Risk Frontiers Report* , Macquarie University.

Bruun, P., (1962). Sea-level rise as a cause of shore erosion, *Journal of Waterways and Harbors Division*, American Society of Civil Engineers, **88**, 117-130.

Carley, J.T., Wyllie, S.J., Lord, D.B. and R.J. Cox, (2006). *Coastal Processes in the Coffs Harbour Region*, Proceedings of the 15th NSW Coastal Conference

CERC (1984) [reference details to come]

Church, J.A., N.J. White, R. Coleman, K. Lambeck and J.X. Mitrovica (2004), Estimates of the Regional Distribution of Sea Level Rise over the 1950 to 2000 Period. Journal of Climate, 17, 2609-2625.

Cowell, P.J., Roy, P.S., and R.A. Jones, (1992). Shoreface Translation Model: computer simulation of coastal-sand-body response to sea level rise, *Mathematics and Computers in Simulation*, **33**, 603-608.

Cowell, P.J., Roy, P.S., and R.A. Jones, (1995). Simulation of Large-scale Coastal Change Using a Morphological Behaviour Model, *Marine Geology*, **126**, 45-61.

Cowell , P.J., et al. 2003. The Coastal-Tract (Part 1): A conceptual approach to aggregated modelling of low-order coastal change.*Journal of Coastal Research*, 19, 828-848.

Cowell, P.J., Thom, B.G., Jones, R.A., Everts, C.H., and Simanovic, D., (2006). Management of Uncertainty in Predicting Climate-Change Impacts on Beaches, *Journal of Coastal Research*, **22**, 232-245.

CSIRO (2007). *Climate Change in Australia Technical Report 2007*. CSIRO Marine and Atmospheric Research and Bureau of Meteorology, Melbourne, VIC, Australia.

DECC (2005), INTERNAL DOCUMENT *New South Wales Coastal Lands Risk Assessment,* prepared by Patterson Britton & Partners and Department of Environment and Climate Change

DECC (2009) [reference details to come]

Danish Hydraulics Institute, (2008). Mike 21 Spectral Wave Model FM software. Danish Hydraulics Institute.

DNR (2006), *NSW Coastal Lands Risk Assessment*, prepared for the Comprehensive Coastal Assessment (Department of Planning) Project 06, June 2006.

DP (2009), *Mid North Coast Regional Strategy*, Final, NSW Department of Planning, March 2009

DP (2009) *How the Mid North Coast Strategy Will Help the Coffs Coast Subregion* Fact Sheet, Department of Planning, March 2009.

ERA (1973), *Study of Shoreline Stability Macauleys Beach and Charlesworth Bay Coffs Harbour New South Wales* prepared by Environmental Resources of Australia, March 1973.

Floyd, A. G. (1991), *Vegetation Survey of Proposed Pipeline Look-At-Me-Now Headland,* prepared for Department of Public Works, October 1991.

Folland CK, Renwick JA, Salinger MJ, Mullan AB. 2002. Relative influences of the Interdecadal Pacific Oscillation and ENSO on the South Pacific Convergence Zone. *Geophysical Research Letters* **29**(13): 21-1 – 21-4.

Foster, D. N., Gordon, A. D., and N. V. Lawson, (1975). The Storms of May-June 1974, Sydney, N.S.W, *2nd Australian Conference on Coastal and Ocean Engineering*, Gold Coast, Queensland, April 27- May 1, 1975.

Goodwin (2003) [ref to come]

Goodwin, I.D., (2005). A mid-shelf, mean wave direction climatology for southeastern Australia and its relationship to the El Nino-Southern Oscillation since 1878 A.D., *International Journal of Climatology*, **25**, 1715-1729

Goodwin, I.D., Stables, M. A. and Olley, J. (2006). Wave climate, sand budget and shoreline alignment evolution of the Iluka–Woody Bay sand barrier, northern New South Wales, Australia, since 3000 yr BP *Marine Geology* 226, 127-144.

Goodwin & Blackmore (2008) [reference details to come]

Gordon, A.D., (1987). Beach Fluctuations and Shoreline Change - NSW, reprints of Papers, *8th Australasian Conference on Coastal and Ocean Engineering*, 30 November to 4 Dec, Institution of Engineers Australian National Conference Publication No 87/17 pp 103-167

Haines P. E. and B. G. Thom, (2007). Climate change impacts on entrance processes and behaviour of intermittently open/closed coastal lagoons in NSW, Australia, *Journal of Coastal Research* **SI 50,** (Proceedings of the 9th International Coastal Symposium), 242-246.

Hanslow, D. J., (2007). Beach Erosion Trend Measurement: A Comparison of Trend Indicators, *Journal of Coastal Research* **SI 50** (Proceedings of the 9th International Coastal Symposium), 588 – 593. Gold Coast, Australia

Hemer, M. A., McInnes, K., Church, J. A., O'Grady, J., and J.R. Hunter, (2008), *Variability and Trends in the Australian Wave Climate and Consequent Coastal Vulnerability*, Final Report prepared for Department of Climate Change Surface Ocean Wave Variability Project, September 2008.

Hopkins and Holland (1997) [reference details to come]

Hsu, J.R.C., Evans, C., 1989. Parabolic bay shapes and applications. Proc. Institution of Civil Engineers, London (Part 2), 87, 556 - 570.

Hsu, J.R.C et al.., 2008. Appreciation of Static Bay Beach Concept for Coastal Management and Protection. J. Coastal Research, 24 (1), 198-215.

IPCC (2007), *Climate Change 2007: Synthesis Report*, Intergovernmental Panel on Climate Change key findings and uncertainties contained in the Working Group contributions to the Fourth Assessment Report.

John Allen & Associates (1988), *Hills Beach Reserve, Korora Plan of Management*.

John Allen & Associates (1990), *Look-At-Me-Now Headland Draft Plan of Management* prepared for Department of Lands, January 1990.

Jones, C., (1981), *Coffs Harbour Coastal Planning Study - Working Paper 10: Coastal Geomorphology*, NSW Department of Environment and Planning, Report No 80/08, Grafton, July 1981.

Lambeck, K. (2002). Sea level change from mid Holocene to recent time: an Australian example with global implications. In: *Ice sheets, sea level and the dynamic earth*. Geodynamics series 29, American Geophysical Union, Washington D.C, pp. 33-50.

Laurie, Montgomerie & Pettit Pty Ltd (1983), *Moonee Beach Sewage Outfall - Review of Feasible Methods for Headland Discharge at Green Bluff*, prepared in association with Lewis & Duvivier, for the Public Works Department of NSW, June 1983.

Lawson & Treloar, (1986). *Elevated Ocean Levels, Storms Affecting the NSW Coast 1980-1985*, prepared for the NSW Public Works Department Coastal Branch in conjunction with Weatherex Meteorological Services, PWD Report No. 86026

Lord, D.B, and A. Van Kerkvoort, (1981). *A Coastal Process Investigation, Coffs Harbour*, NSW, Proceedings of the 5th Australian Conference on Coastal and Ocean Engineering, Perth, Institute of Engineers Australia.

Lord (1984) [reference details to come]

Macadam, I., McInnes, K. and J. O'Grady, (2007). *Climate Change Projections for the Wooli Wooli Estuary and Batemans Bay*, prepared by CSIRO for the Department of Environment and Climate Change [DECC].

McInnes, K. L., Abbs, D.J., O'Farrell, S.P., Macadam, I., O'Grady, J. and R. Ranasinghe, (2007). *Projected Changes in Climatalogical Forcing for Coastal Erosion in NSW*, prepared by CSIRO for the Department of Environment and Climate Change [DECC].

McLean, R., and J. Shen, (2006). From Foreshore to Foredune: Foredune Development Over the Last 30 Years at Moruya Beach, New South Wales, Australia, *Journal of Coastal Research*, **22**, 28-36.

MHL (1983), *Moonee Ocean Outfall Investigation* prepared by Manly Hydraulics Laboratory PWD Public Works Department, Report No. 376, August 1983.

MHL (1986), *Coffs Harbour Northern Areas Outfall Investigation - Stage 1 Report* prepared by Manly Hydraulics Laboratory Report No. 462; PWD Public Works Department NSW Report No. 86039, August 1986.

MHL (1987), *Coffs Harbour Northern Areas Outfall Investigation - Design Stage Report* prepared by Manly Hydraulics Laboratory [MHL] Report No. 494; PWD Public Works Department NSW Report No. 87018, June 1987.

Nielson, A.F., Lord, D.B., and H.G. Poulos, (1992). *Dune Stability Considerations for Building Foundations* , Institution of Engineers, Civil Engineering Transactions Vol CE34, No.2, June 1992, pp. 167-173.

NSW Government (1990). *Coastline Management Manual*, prepared September 1990.

P. Baker and Associates (1984), *Environmental Land Capability Study Moonee Development Area* August 1984.

PBP (1995), Proposed Development of Lot 2 DP 840016 Pacific Highway Emerald Beach prepared by Patterson Britton and Partners [PBP], November 1995.

PBP, (2004). *45 Hearns Lake Road Woolgoolga Coastline Hazard Definition and Lake Entrance Processes*, prepared by Patterson Britton and Partners [PBP], October 2004.

Peter Parker (1988), *Red Rock Recreation Reserve Draft Plan of Management* prepared by Peter Parker Environmental Consultant for Department of Lands (Crown Lands Office), April 1988.

Phinn, S.R. and P.A. Hastings, (1992). Southern Oscillation Influences on the Wave Climate of South-Eastern Australia, *Journal of Coastal Research*, **8**, 579-592.

Pitt, M.W. (1991). *Tourism and Coastal Land Management - Survey of Visitors on the North Coast of NSW*.

Power, S., Casey, T., Folland, C., Colman, A., and V. Mehta, (1999). Inter-decadal modulation of the impact of ENSO on Australia, *Climate Dynamics*, **15**, 319-324.

PWD (1983), *Coffs Harbour Shire - Northern Areas Sewerage Moonee Sewage Treatment Works: A Review of Treatment Works Sites and Effluent Disposal Options* prepared by Public Works Department NSW [PWD] for Coffs Harbour Shire Council. Report No. CH002; PWD Report No 8302, October 1983.

PWD (1986), *Moonee Development Area Draft Local Environment Plan* prepared by Public Works Department NSW, 1986.

PWD (1987), *Coffs Harbour Northern Areas Wastewater Scheme Geological Feasibility Investigation for Proposed Outfall Sites at Woolgoolga Headland and Look At Me Now Headland* prepared by Public Works Department NSW Geotechnical Centre. Report No. G87006, April 1987.

PWD (1989), *Woolgoolga Beach Examination of Recession Trends*, Preliminary Copy prepared by Public Works Department NSW, March 1989.

PWD (1991a), *Red Rock Beach Surf Environmental Analysis* prepared by Public Works Department NSW [PWD] Coast and Rivers Branch, October 1991.

PWD (1991b), *Sandys Beach Surf Environmental Analysis* prepared by Public Works Department NSW [PWD] Coast and Rivers Branch, October 1991.

PWD (1992), *North Sapphire Beach Surf Environmental Analysis* prepared by Public Works Department NSW [PWD] Coast and Rivers Branch, September 1992.

PWD (1995), *Coffs Harbour City Coastal Assessment Report*, prepared by Public Works Department NSW [PWD] Coast and Flood Policy Branch, Report No. 94066, March 1995.

Ranasinghe, R., McLoughlin, R., Short, A. D., and G. Symonds, (2004). The Southern Oscillation Index, wave climate and beach rotation, *Marine Geology*, **204**, 273-287.

Ranasinghe, R., Watson, P., Lord, D., Hanslow, D. and P.Cowell, (2007). *Sea Level Rise, Coastal Recession and the Bruun Rule*, Proceedings of the Coasts and Ports Conference '07, Engineers Australia

RDM (1998a), *Park Beach Coastline Hazard Definition and Management Study* prepared by Resource Design & Management [RDM] for Coffs Harbour City Council and Department of Land & Water Conservation, December 1998.

RDM (1998b), *Park Beach Coastline Hazard Management Plan* prepared by Resource Design & Management [RDM] for Coffs Harbour City Council and Department of Land & Water Conservation, December 1998.

Roy, P.S. and Stephens, A.W. (1980). Regional geological studies of the N.S.W. inner continental shelf. summary results. Geological Survey Report No GS 1980/028. Geological Survey of New South Wales, Department of Mines.

Roy and Stephens (1980b) [reference details to come]

Roy (1982) [reference details to come]

Short, A. D. and N. L. Trenaman, (1992). Wave Climate of the Sydney Region, an Energetic and Highly Variable Ocean Wave Regime, *Australian Journal of Marine and Freshwater Research*, **43**, 765-91

Short, A.D, (1993) *Beaches of the NSW Coast*, Australian Beach Safety and Management Program

Short (1999) [reference details to come]

Short, A.D., Trembanis, A., and Turner, I., (2000). *Beach oscillation, rotation and the southern oscillation - Narrabeen Beach, Australia*, Proceedings of the 27th International Coastal Engineering Conference, ASCE: Sydney, pp. 2439-2452

Short, A.D. and A.C. Trembanis, (2004). Decadal Scale Patterns in Beach Oscillation and Rotation Narrabeen Beach, Australia - Time Series, PCA and Wavelet Analysis, *Journal of Coastal Research*, **20**, 523-532.

Short, A.D., (2007). *Beaches of the New South Wales Coast A guide to their nature, characteristics, surf and safety*, 2nd Edition, February, 398p.

Skene, D.L. and P.S Roy (1985), *The Quarternary Geology of the Coast and Inner Shelf At Wooli, Northern NSW*, prepared for the Geological Survey of New South Wales Department of Mineral Resources Geological Survey Report No. 1986/216, December 1985.

SMEC (2004), *Coastal Engineering Advice, 14 Hofmeier Close, Woolgoolga*, prepared for Lesiuk Architects, August 2004.

SMEC (2005), *Lot 216 DP 228582 15 Shell Cove Lane Korora, Coastal Engineering Advice*, February 2005.

Soil Conservation Service of NSW (Date Unknown), *Beach Dune Management Woolgoolga Beach Reserve* (date not stated on report)

Stephens, A.W. and Roy, P.S. (unpublished 1980). Quaternary geology of the coast and inner continental shelf at Coffs Harbour, northern New South Wales. Unpublished report of The Geologcal Survey of New South Wales, Departmet of Mines, New South Wales.

Sustainable Futures Planning & Design (1990), *Report on Proposed Woolgoolga-Grafton Surf Life Saving Club*, May 1990.

Thom and Short (2006), Introduction: Australian Coastal Geomorphology, 1984 – 2004, *Journal of Coastal Research* **22**, 1, January 2006, p1-10.

Troedson, A., Hashimoto, T.R., Jaworska, J., Malloch, K., Cain, L. (2004), *New South Wales Coastal Quaternary Geology*, prepared for the Comprehensive Coastal Assessment (DoP) by the NSW Department of Primary Industries, Mineral Resources, Maitland.

Troedsen, A. and Hashimoto, R. 2005. NSW Coastal Quaternary Geology Data Package. Geological Survey of NSW.

WBM (2003) [reference details to come]

White, N.J., Church, J. A., and Gregory, J. M. (2005). Coastal and global averaged sea level rise for 1950 to 2000. *Geophysical Research Letters*, **32**, 2005.

WP Geomarine (1998), *Campbells Beach Coastline Management Study Stage One Coastal Processes and Hazard Definition Study*, December 1998.

WP Geomarine (1999a), *Coastal Engineering Advice, Lot 4 DP 774491, Coachmans Close, Sapphire*, prepared for Newnham Karl and Partners, May 1999.

WP Geomarine (1999b), *Campbells Beach Draft Coastline Management Plan Stage Three* prepared for Coffs Harbour City Council, October 1999.

Wright and Short (1984) [reference details to come]

You, Z. and D. Lord, (2008). Influence of the El-Nino-Southern Oscillation on NSW Coastal Storm Severity, *Journal of Coastal Research*, **24**, 2B, 203-207.

APPENDIX A: WAVE AND STORM DATA

Table A.1 Significant Wave Height Exceedance Statistics, Byron Bay

H_s (m)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
0 → 0.5	100	100	100	100	100	100	100	100	100	100	100	100	100
0.5 → 1	99.96	99.95	99.98	99.92	99.76	99.76	99.93	99.77	99.84	99.86	99.93	99.91	99.88
1 → 1.5	84.74	87.62	93.62	92.43	88.96	87.68	85.48	84.57	83.12	83.36	83.85	80.69	86.11
1.5 → 2	48.75	50.26	66.30	62.14	56.43	56.50	53.91	44.99	43.50	43.12	39.20	35.86	49.65
2 → 2.5	22.42	27.31	35.50	32.13	32.16	29.59	29.36	22.60	19.76	18.54	18.68	14.73	24.94
2.5 → 3	7.72	12.61	18.77	14.81	15.44	13.22	14.22	10.60	8.74	8.29	10.12	5.12	11.51
3 → 3.5	2.14	5.59	8.72	5.53	7.05	6.04	6.20	4.75	4.07	3.20	4.38	1.64	4.91
3.5 → 4	0.70	2.26	4.34	2.80	2.93	2.41	2.37	2.03	2.03	0.77	2.06	0.76	2.10
4 → 4.5	0.10	1.18	1.93	1.11	1.14	0.78	0.74	0.71	0.89	0.19	0.89	0.46	0.83
4.5 → 5	0.01	0.44	0.85	0.47	0.34	0.19	0.24	0.17	0.26	0.04	0.26	0.10	0.27
5 → 5.5	0.00	0.15	0.18	0.17	0.05	0.03	0.06	0.02	0.09	0.00	0.05	0.02	0.07
5.5 → 6	0.00	0.01	0.04	0.06	0.04	0.01	0.00	0.00	0.04	0.00	0.01	0.00	0.02
Average	1.56	1.69	1.81	1.78	1.71	1.74	1.62	1.53	1.52	1.49	1.53	1.37	1.65
Max	4.53	5.85	5.80	5.86	5.96	5.59	5.48	5.17	5.95	4.70	5.65	5.21	5.96
Min	0.44	0.38	0.48	0.39	0.38	0.34	0.44	0.38	0.40	0.38	0.44	0.43	0.34

Table A.2 Storm History from Blain Bremner and Williams (BBW), 1985, 1986.

Year	Number storms	Largest storm descriptions	Reference
1921	5	Largest storms in April (5.5 m Hs, tropical cyclone) and July (5.1 m Hs, East Coast Low). No Category X storms	BBW 1985
1922	3	East coast low in Jan (4.1 m Hs) is largest storm	BBW 1985
1923	3	Largest storms in April (5.0 m Hs, tropical cyclone) and June (5.0 m Hs, continental low). No Category X storms	BBW 1985
1924	5	Storm wave heights generally smaller, with largest in April of 4.0 m (southern low)	BBW 1985
1925	5	Storm wave heights generally large, with three storms Hs > 5 m (east coast lows, STAC)	BBW 1985
1926	2	Category X east coast low in May producing 7.8m Hs	BBW 1985
1927	2	East coast low in April produces 5.3 m Hs	BBW 1985
1928	3	Tropical cyclone in Feb produces 4.9 m Hs, other storms relatively small	BBW 1985
1929	5	Large category X east coast low in June of 7.1 m Hs	BBW 1985
1930	0	Storms elsewhere on NSW coast are relatively small	BBW 1985
1931	1	Tropical cyclone in Feb produces 5.0 m Hs, other storms on NSW coast are small	BBW 1985
1932	2	Largest is 4.0 m Hs from a continental low	BBW 1985
1933	6	Two of the storms had Hs > 5 m, in March (tropical cyclone), and July (east coast low cyclone).	BBW 1985
1935	4	Low storm wave heights, maximum of 4.2 m due to intensification of the STAC, March	BBW 1985
1936	2	Moderate strength, 4.6 m Hs due to tropical cyclone in March	BBW 1985
1937	3	Category X tropical cyclone in Feb producing 8.1 m Hs	BBW 1985
1938	5	Lower Hs in storms, with maximum of 4.6 m in April (east coast low cyclone)	BBW 1985
1939	2	Maximum of 4.8 m in March, tropical cyclone	BBW 1985
1940	2	East coast low producing 5.2 m maximum in March	BBW 1985
1941	1	East coast low producing 5.3 m maximum in May	BBW 1985
1942	5	Category X east coast low in October producing 9.1 m Hs	BBW 1985
1943	1	STAC intensification producing 4.2 m Hs in May	BBW 1985
1944	0		BBW 1985

Year	Number storms	Largest storm descriptions	Reference
1950	1	Inland trough low produces Category X storm of 6.6 m in January	Only selected storms listed for 1945 to 1966 in BBW (1985)
1952	1	Continental low produces 4.8 m in June	Only selected storms listed for 1945 to 1966 in BBW (1985)
1954	1	Category X tropical cyclone in Feb producing 9.1 m Hs	Only selected storms listed for 1945 to 1966 in BBW (1985)
1955	5	Category X tropical cyclone producing 7.5 m in January	Only selected storms listed for 1945 to 1966 in BBW (1985)
1960	5	Hs in March up to 5.0 m	BBW 1985 + 1986
1961	4	Hs of storms are < 5.0 m	BBW 1985 + 1986
1962	3	Two of the storms had Hs > 5 m (April and July)	BBW 1985 + 1986
1963	5	Most storms < 5.0 m Hs	BBW 1985 + 1986
1964	5	Hs of storms are < 3.5 m	BBW 1985 + 1986
1965	3	Category X storm in July with Hs > 7.5 m	BBW 1985 + 1986
1966	1	June storm up to 5.0 m Hs	BBW 1985 + 1986
1967	13	Three Category X storms, of 9.9 m Hs in January and 6.1 m in February (both tropical cyclones) and 10.1 m Hs in June (east coast low cyclone)	BBW 1985 + 1986
1968	3	Largest wave height of 5.2 m in August	BBW 1985 + 1986
1969	3	Lower Hs in storms, with maximum of 4.2 m in February (tropical cyclone)	BBW 1985 + 1986
1970	1	Southern low producing 5.3 m Hs in Mar-Apr	BBW 1985 + 1986
1971	6	Category X of 6.1 m Hs in July from continental low	BBW 1985 + 1986
1972	6	Up to 5.3 m Hs in April tropical cyclone	BBW 1985 + 1986
1973	5	Up to 5.8 m in July east coast low cyclone	BBW 1985 + 1986
1974	6	Tropical cyclones in Jan, Feb and Mar (Hs 5.3 - 5.4m). Only 1 listing for May-June period, of 4.4 m on 3-5 June	BBW 1985 + 1986
1975	7	Storm wave height generally lower (< 4.0 m Hs)	BBW 1985 + 1986
1976	12	storms generally lower (< 4.5 m), largest Hs of 5.5 m in January (tropical cyclone)	BBW 1985 + 1986

Table A.3 Coffs Wave Time Series Data Gaps and Replacement for Storm Severity Analysis

Year	%age missing data per year	Start Date	Hs (m) at start date	Outage Duration (days)	Replacement Details
1979	13.42%	18/09/1979 15:00	1.98	49.00	Missing period replaced with Byron Data
1980	0.00%				
1981	8.97%	1/04/1981 21:00	2.022	32.75	Available data to 1/05/81 from Byron used as replacement
1982	0.00%				
1983	0.00%				
1984	17.02%	26/04/1984 9:00	1.412	62.13	Byron only had data from 18/05/1984 (ie, also missing data). Available Byron data was used.
1985	9.51%	9/07/1985 19:00	6.571	34.71	Malfunction during storm, unsure if this is peak, and storm data missed. Data also missing from Byron file (between 30/06/85 to 27/08/85)
1986	0.00%				
1987	12.71%	1/02/1987 8:00	0.633	46.38	Missing period replaced with Byron Data
1988	0.00%				
1989	23.34%	28/07/1989 5:00	2.951	59.21	Wave heights reducing prior. Data replaced with Byron data (until 22/09/89 23:00, when data missing from Byron)
		6/12/1989 0:00	1.241	28.38	Majority of data also missing from Byron Record, not replaced
1990	27.87%	25/02/1990 11:00	1.595	44.96	Missing period replaced with Byron Data
		31/05/1990 6:00	2.4	54.38	Wave heights reducing prior. Data replaced with Byron data
1991	4.49%	5/02/1991 23:00	1.26	16.38	Missing period replaced with Byron Data
1992	3.14%	20/12/1992 13:00	1.196	29.79	Missing period replaced with Byron Data
1993	10.25%	3/06/1993 8:00	1.148	19.08	Only to 18/06/93 available and used from Bryon Data
1994	0.00%				
1995	14.59%	12/01/1995 22:00	1.142	14.71	Missing period replaced with Byron Data
		16/05/1995 12:00	1.48	22.92	Missing period replaced with Byron Data
		14/11/1995 16:00	1.635	15.63	Missing period replaced with Byron Data
1996	19.06%	28/01/1996 10:00	1.007	46.04	Missing period replaced with Byron Data
		2/07/1996 22:00	1.141	23.54	Missing period replaced with Byron Data
1997	18.17%	28/01/1997 0:00	1.907	17.46	Missing period replaced with Byron Data
		22/07/1997 5:00	1.278	23.21	Missing period replaced with Byron

Year	%age missing data per year	Start Date	Hs (m) at start date	Outage Duration (days)	Replacement Details
					Data
1998	4.74%	6/12/1997 8:00	1.275	42.96	This period also missing from Bryon record
1999	0.00%				
2000	7.49%	4/12/2000 16:00	1.035	44.92	Missing period replaced with Byron Data
2001	11.88%	31/03/2001 1:00	2.217	24.38	Missing period replaced with Byron Data
		30/12/2001 14:00	1.144	16.75	Missing period replaced with Byron Data
2002	14.05%	27/10/2002 15:00	2.451	35.96	Wave height slowly decreasing. Missing period replaced with Byron Data
2003	0.00%				
2004	0.00%				
2005	5.81%	11/03/2005 4:00	1.31	21.21	Missing period replaced with Byron Data
2006	11.23%	5/06/2006 23:00	1.524	21.46	Missing period replaced with Byron Data
2007	6.70%	21/07/2006 4:00	3.368	19.54	Potential to have missed storm data. Missing period replaced with Byron Data**.**
		1/07/2007 22:00	1.696	24.46	Missing period replaced with Byron Data

BMT WBM Brisbane
Level 11, 490 Upper Edward Street Brisbane 4000
PO Box 203 Spring Hill QLD 4004
Tel +61 7 3831 6744 Fax +61 7 3832 3627
Email wbm@wbmpl.com.au
Web www.wbmpl.com.au

BMT WBM Denver
14 Inverness Drive East, #B132
Englewood Denver Colorado 80112 USA
Tel +1 303 792 9814 Fax +1 303 792 9742
Email wbmdenver@wbmpl.com.au
Web www.wbmpl.com.au

BMT WBM Melbourne
Level 5, 99 King Street Melbourne 3000
PO Box 604 Collins Street West VIC 8007
Tel +61 3 9614 6400 Fax +61 3 9614 6966
Email wbmmelbourne@wbmpl.com.au
Web www.wbmpl.com.au

BMT WBM Morwell
Cnr Hazelwood Drive & Miners Way Morwell 3840
PO Box 888 Morwell VIC 3840
Tel +61 3 5135 3400 Fax +61 3 5135 3444
Email wbmmorwell@wbmpl.com.au
Web www.wbmpl.com.au

BMT WBM Newcastle
126 Belford Street Broadmeadow 2292
PO Box 266 Broadmeadow NSW 2292
Tel +61 2 4940 8882 Fax +61 2 4940 8887
Email wbmnewcastle@wbmpl.com.au
Web www.wbmpl.com.au

BMT WBM Perth
1 Brodie Hall Drive Technology Park Bentley 6102
Tel +61 8 9328 2029 Fax +61 8 9486 7588
Email wbmperth@wbmpl.com.au
Web www.wbmpl.com.au

BMT WBM Sydney
Suite 206, 118 Great North Road Five Dock 2046
PO Box 129 Five Dock NSW 2046
Tel +61 2 9713 4836 Fax +61 2 9713 4890
Email wbmsydney@wbmpl.com.au
Web www.wbmpl.com.au

BMT WBM Vancouver
1190 Melville Street #700 Vancouver
British Columbia V6E 3W1 Canada
Tel +1 604 683 5777 Fax +1 604 608 3232
Email wbmvancouver@wbmpl.com.au
Web www.wbmpl.com.au

APPENDIX B: PHOTOGRAMMETRIC DATA & QUALITY

Table B-1 Photogrammetric Data Summary

Project #	Bongil (D24)			Sawtell (A43)			Boambee (BOA (Blocks 1 - 4); A69 (Blocks 7 - 9))				Jetty & South Park (B73)			Park (A42)		
Year	**Date**	**Scale**	**Vertical Accuracy**	**Date**	**Scale**	***Vertical Accuracy****	**Date (BOA)**	**Date (A69)**	**Scale**	***Vertical Accuracy****	**Date**	**Scale**	***Vertical Accuracy****	**Date**	**Scale**	***Vertical Accuracy****
1942				23/04/1942	22000	*0.6*		23/04/1942	22000	*0.4*	23/04/1942	22000	*0.6*	23/04/1942	22000	*0.4*
1943																
1954																
1956																
1964	12/08/1964	40000	0.6													
1966																
1967				12/12/1967	6000	*0.3?*										
1969							1/08/1969	1/08/1969	21000	*0.4*	1/08/1969	21000	*0.4*	1/08/1969	21000	*0.4*
1973	14/04/1973	40000	0.5				15/04/1973		25000	*0.4*	15/04/1973	25000	*0.4*	15/04/1973	25000	*0.4*
1974	18/08/1974	44000	0.5				23/06/1974		40000	*0.6*						
1976																
1977				12/10/1977	16000	*0.3*		29/10/1977	25000	*0.4*	12/10/1977	16000	*0.3?*	12/10/1977	16000	*0.3*
1978																
1980	1980*			4/04/1980	10000	*0.3*								4/11/1980	10000	*0.3*
1981	26/10/1981	16000	0.3													
1983				31/08/1983	10000	*0.3*										
1985																
1986							23/04/1986	23/04/1986	10000	*0.3*	23/04/1986	10000	*0.3*	23/04/1986	10000	*0.3*
1988				26/09/1988	10000	*0.3*										
1989														28/08/1989	10000	*0.3*
1993				17/06/1993	10000	*0.3*	17/06/1993	17/06/1993	10000	*0.3*						
1994														7/05/1994	10000	*0.3*
1996	28/06/1996	10000	0.3				28/06/1996	28/06/1996	10000	*0.3*	28/06/1996	10000	*0.3*	28/06/1996	10000	*0.3*
2000				16/05/2000	10000	*0.3*	16/05/2000	16/05/2000	10000	*0.3*	16/05/2000	10000	*0.3*	16/05/2000	10000	*0.3*
2004				7/08/2004	10000	*0.3*	7/08/2004	7/08/2004	10000	*0.3*	7/08/2004	10000	*0.3*	7/08/2004	10000	*0.3*
2006																
2007	11/01/2007	10000	0.3	11/01/2007	10000	*0.3*	11/01/2007	11/01/2007	10000	*0.3*	11/01/2007	10000	*0.3*	11/01/2007	10000	*0.3*
Data Quality / Issues	*Block 8 was run for 1980 instead of 1981, as 1981 photography didn't cover block 8. Based on other dates in area, could be 04/04/1980 or 04/11/1980			1942 photography not assessed (ie, there is no photogrammetric data for this date) - pers comm Christine Gray, DECC, 28/11/08.							1969 photogrammetric data was lost, and said to be very high photo scale at 1:58000 (pers.comm, Christine Gray, DECC, 28/11/08). There is now no photogrammetry for 1969			1942 photogrammetric data is not available for Block 5N. The data file was corrupted and not re-run ("unavailable"). "A42425n is corrupt and unavailable"		

Project #	Macauleys (Diggers &Charlesworth) (A79)			Korora (A24)			Hills (A24)			Campbells (inc Pelican and Riecks Point) (A01)			Sapphire (A29)		
Year	Date	Scale	*Vertical Accuracy**	Date	Scale	Vertical Accuracy	Date	Scale	Vertical Accuracy	Date	scale	*Vertical Accuracy**	Date	Scale	*Vertical Accuracy**
1942															
1943				9/03/1943	20000	0.6	9/03/1943	20000	0.6				9/03/1943	20000	*0.6*
1954															
1956															
1964	1/08/1964	46000	*0.6*	1/08/1964	46000	0.6	1/08/1964	46000	0.6	1/08/1964	46000	*0.6*	12/08/1964	47000	*0.6*
1966															
1967															
1969	1/08/1969	40000	*0.6*										1/08/1969	58000	*0.6*
1973	15/04/1973	25000	*0.4*	15/04/1973	25000	0.4	15/04/1973	25000	0.4	15/04/1973	25000	*0.4*	15/04/1973	25000	*0.4*
1974										18/08/1974	40000	*0.6*			
1976															
1977	12/10/1977	16000	*0.6*												
1978										4/04/1978	4000	*0.3*			
1980	4/11/1980	10000	*0.3*							4/11/1980	8000	*0.3*			
1981				27/11/1981	16000	0.3	27/11/1981	16000	0.3						
1983													31/08/1983	10000	*0.3*
1985															
1986	22/06/1986	10000	*0.3*	23/04/1986	10000	0.3	23/04/1986	10000	0.3	22/06/1986	10000	*0.3*			
1988										9/05/1988	10000	*0.3*	9/05/1988	10000	*0.3*
1989				20/08/1989	10000	0.3	20/08/1989	10000	0.3						
1993										17/06/1993	10000	*0.3*			
1994	7/05/1994	10000	*0.3*												
1996	28/06/1996	10000	*0.3*	28/06/1996	10000	0.3	28/06/1996	10000	0.3	28/06/1996	10000	*0.3*	28/06/1996	10000	*0.3*
2000	16/05/2000	10000	*0.3*	16/05/2000	10000	0.3	16/05/2000	10000	0.3	17/05/2000	10000	*0.3*			
2004	7/08/2004	10000	*0.3*	7/08/2004	10000	0.3	7/08/2004	10000	0.3	7/08/2004	10000	*0.3*	7/08/2004	10000	*0.3*
2006															
2007	11/01/2007	10000	*0.3*	11/01/2007	10000	0.3	11/01/2007	10000	0.3	11/01/2007	10000	*0.3*	11/01/2007	10000	*0.3*
Data Quality / Issues	1969 photogrammetric data is not available for Block 5. The data file was corrupted and not re-run ("unavailable") "The a79695 file is corrupt and unrecoverable although the line in the prof overlays seems fine but I can't find that .dat" (C.G., 23/01/09)						Pers.comm Christine Gray, DECC, 28/11/08 and 15/12/08: "Early data files lost or corrupt when tape backup failed many years ago. Graphic files tell the story see a24hp1.pdf attached."			1964 photogrammetry is not available - dat files lost and corrupted, not replaced.					

Project #	Moonee (D15)			Emerald (A72)			Fiddamans (B01)			Sandys (B01)			Hearns Lake (B100)		
Year	Date	Scale	Vertical Accuracy*	Date	Scale	Vertical Accuracy*	Date	Scale	Vertical Accuracy	Date	Scale	Vertical Accuracy	Date	Scale	Vertical Accuracy
1942															
1943				9/03/1943	16000	0.6	9/03/1943	16000	0.6	9/03/1943	16000	0.6	11/03/1943	23000	0.6
1954															
1956	26/04/1956	32000	0.6	1/05/1956	32000	0.6									
1964	12/08/1964	46000	0.6	1/08/1964	46000	0.6	1/08/1964	46000	0.6	1/08/1964	46000	0.6	1/08/1964	46000	0.6
1966															
1967															
1969				6/04/1969	40000	0.6									
1973	9/05/1973	25000	0.4	3/05/1973	25000	0.4	3/05/1973	25000	0.4	3/05/1973	25000	0.4	3/05/1973	25000	0.4
1974	18/08/1974	40000	0.6												
1976	2/12/1976	40000	0.6												
1977															
1978															
1980															
1981	27/11/1981	16000	0.3?	26/10/1981	16000	0.3?									
1983				31/08/1983	10000	0.3									
1985															
1986	22/06/1986	10000	0.3										22/06/1986	10000	0.3
1988				9/05/1988	10000	0.3	9/05/1988	10000	0.3	9/05/1988	10000	0.3			
1989															
1993				17/06/1993	10000	0.3	17/06/1993	10000	0.3	17/06/1993	10000	0.3			
1994	18/05/1994	10000	0.3												
1996							28/06/1996	10000	0.3	28/06/1996	10000	0.3	28/06/1996	10000	0.3
2000	17/05/2000	10000	0.3							17/05/2000	10000	0.3	17/05/2000	10000	0.3
2004				7/08/2004	10000	0.3				7/08/2004	10000	0.3	28/07/2004	10000	0.3
2006													26/11/2006	10000	0.3
2007	11/01/2007	10000	0.3	11/01/2007	10000	0.3	11/01/2007	10000	0.3	11/01/2007	10000	0.3			
Data Quality / Issues							1996 photogrammetry is not available for Block 1 - "FD961 is empty and unrecoverable" (C.G., 23/01/09) The "FB" Profile (across the sand spit separating Fiddamans and Sandys) was not observed for 1993 (pers. Comm., Christine Gray, 15/12/2008)								

Project #	Woolgoolga Back (B100)			Woolgoolga (A91)			Mullaway & South Mullaway (D16)			Ocean View (OV)		
Year	Date	Scale	Vertical Accuracy	Date	Scale	*Vertical Accuracy**	Date	Scale	Vertical Accuracy	Date	Scale	Vertical Accuracy
1942												
1943	11/03/1943	23000	0.6	11/03/1943	20000	*0.6*	11/03/1943	18000	0.6	9/03/1943	16000	0.6
1954												
1956				26/04/1956	32000	*0.6*	26/04/1956	32000	0.6	1/05/1956	32000	0.6
1964	1/08/1964	46000	0.6				12/08/1964	46000	0.6	1/08/1964	46000	0.6
1966				7/02/1966	16000	*0.5*						
1967												
1969												
1973	3/05/1973	25000	0.4	15/04/1973	25000	*0.4*	15/04/1973	25000	0.4	3/05/1973	25000	0.4
1974							23/06/1974	40000	0.6	21/05/1974	25000	0.4
1976												
1977												
1978												
1980												
1981				27/11/1981	16000	*0.3*	26/10/1981	16000	0.3	26/10/1981	16000	0.3
1983												
1985												
1986	22/06/1986	10000	0.3	22/06/1986	10000	*0.3*						
1988										9/05/1988	10000	0.3
1989												
1993				17/06/1993	10000	*0.3*				17/06/1993	10000	0.3
1994												
1996	28/06/1996	10000	0.3	28/06/1996	10000	*0.3*	28/06/1996	10000	0.3	28/06/1996	10000	0.3
2000	17/05/2000	10000	0.3	17/05/2000	10000	*0.3*				17/05/2000	10000	0.3
2004	28/07/2004	10000	0.3	28/07/2004	10000	*0.3*				7/08/2004	10000	0.3
2006	26/11/2006	10000	0.3	26/11/2006	10000	*0.3*	26/11/2006	10000	0.3	26/11/2006	10000	0.3
2007												
Data Quality / Issues	1986 and 1964 not complete for Block 9 (up to Pr 4 in 1964; to Pr 10 in 1986) - "The B100 files are at the limit of coverage by aerial photography" - C.G. 23/01/09. On 4/2/09, C.G further noted "Please delete profs. 11 & 12 of blk 9 for 1986, as edge of model has caused errors there". Only profiles 1 to 10 have been used in the photogrammetric analyses						1943 photogrammetry is not complete: Block 1 is not covered by the photography (pers. comm., Christine Gray, 10/12/08), Block 2 is missing the last two profiles and Block 3 is unavailable- "D16432 is missing the last two prfs and D16433 is empty. These would need to be reset to rerun them if necessary." (C.G., 23/01/09)			Block 1 is not covered on the 1974 photography (pers.comm Christine Gray, 10/12/08)		

Project #	**Corindi South (Arrawarra) (A71)**			**Corindi Beach Mid (D17)**			**Corindi North to Red Rock (D20)**			**Station (D21)**		
Year	Date	Scale	Vertical Accuracy	Date	Scale	Vertical Accuracy	Date	Scale	Vertical Accuracy	Date	Scale	Vertical Accuracy
1942												
1943	11/03/1943	16000	0.6									
1954												
1956	26/04/1956	32000	0.6									
1964	1/08/1964	46000	0.5	1/08/1964	46000	0.6	1/08/1964	46000	0.6			
1966										23/08/1966	40000	0.6
1967												
1969												
1973				3/05/1973	25000	0.4	14/04/1973	25000	0.4	14/04/1973	25000	0.4
1974	21/05/1974	25000	0.6	21/05/1974	25000	0.4						
1976												
1977												
1978										30/08/1978	25000	0.4
1980												
1981	26/10/1981	16000	0.3	26/10/1981	16000	0.3						
1983	31/08/1983	10000	0.3									
1985							21/10/1985	16000	0.3	21/10/1985	16000	0.3
1986												
1988	9/05/1988	10000	0.3									
1989												
1993	17/06/1993	10000	0.3							17/06/1993	10000	0.3
1994												
1996	28/06/1996	10000	0.3	28/06/1996	10000	0.3	28/06/1996	10000	0.3			
2000	17/05/2000	10000	0.3							17/05/2000	10000	0.3
2004	28/07/2004	10000	0.3									
2006	26/11/2006	10000	0.3	26/11/2006	10000	0.3						
2007							11/01/2007	10000	0.3	11/01/2007	10000	0.3
Data Quality / Issues	1956 not complete - Block 2 missing. Last four profiles of Block 2 (Pr 11 to 14) overlap with the first four profiles of Block 3. Due to this missing data for these profiles in Block 2, only profiles 1 to 10 in Block 2 have been used in analysis. The following data issues are being pursued again with DECC (C.G.): Block 5 Profile 9 & 10 for 2000 is incorrect. Block 5 Profile 14 is incorrect for 2004 (straight line). Block 5 Profile 14 is missing in 1996. Block 4 Profiles 17 & 18 missing in 1996, 2000, 2004.											

Table B-2 Photogrammetry Dates and Storm Data

[1] Mean yearly storm severity value is 3.6, St Dev 0.6. Hence, Low < 3.6-0.3 (blue), moderate / average= 3.6-0.3 to 3.6+0.3 (no colour), high = 3.6+0.3 to 3.6+0.6, very high > 3.6+0.6

[2] Monthly storm severity value, mean is 2.97, St Dev 2.51. Hence, Low < Mean-0.5*St Dev (1.72,no colour), moderate / average= Mean-0.5*St Dev to Mean+0.5*St Dev (1.72 to 4.23, yellow), high = Mean+0.5*St Dev to Mean+1St Dev (4.23 to 5.48, orange), very high > Mean+1St Dev (5.48, red)

Photogrammetry dates	No. storms in year	Storm Severity[1]	Description of storms immediately prior	Storminess in 3 mths prior	Likely profile state in photogrammetry data	Storm data reference	Month	Storm Severity[2]	Month	Storm Severity[2]	# storms	Month	Storm Severity[2]	# storms	Month	Storm Severity[2]	# storms
23/04/1942	5		2 in feb, 1 in march		Moderately eroded to average	Blain, Bremner & Williams (1985)											
9/03/1943	5		Very large storm in Oct 42, and Dec 42		Average, or signs of erosion still evident	Blain, Bremner & Williams (1985)											
11/03/1943	5		Very large storm in Oct 42, and Dec 42		Average, or signs of erosion still evident	Blain, Bremner & Williams (1985)											
4/05/1954	4		Very large storm in Feb 54		Average, or signs of erosion still evident	Blain, Bremner & Williams (1985)											
1/04/1956	o records				Unknown	Blain, Bremner & Williams (1985)											
1/05/1956	o records				Unknown	Blain, Bremner & Williams (1985)											
1/08/1964	5		2 storms in Jan, 2 in Mar and 1 in Apr		Average profile	Blain, Bremner & Williams (1986)											
12/08/1964	5		2 storms in Jan, 2 in Mar and 1 in Apr		Average profile	Blain, Bremner & Williams (1986)											
7/02/1966	1				Average to accreted - insufficient data	Blain, Bremner & Williams (1986)											
23/08/1966	1		Storm early June		Average to accreted - insufficient data	Blain, Bremner & Williams (1986)											
12/12/1967	12		Storm during the 3 days prior; large storms particularly Jan and June. Very stormy year		Very eroded	Blain, Bremner & Williams (1986)											
6/04/1969	3		Storm in Feb		Average	Blain, Bremner & Williams (1986)											
1/08/1969	3		Storm in May		Average	Blain, Bremner & Williams (1986)											
14/04/1973	5		Storm in Oct 72, and 2 in Feb		Moderately eroded to average	Blain, Bremner & Williams (1986)											
15/04/1973	5		Storm in Oct 72, and 2 in Feb		Moderately eroded to average	Blain, Bremner & Williams (1986)											
3/05/1973	5		Storm in Oct 72, and 2 in Feb		Moderately eroded to average	Blain, Bremner & Williams (1986)											
9/05/1973	5		Storm in Oct 72, and 2 in Feb		Moderately eroded to average	Blain, Bremner & Williams (1986)											
21/05/1974	6		Storm in Jan, Feb and 2 in Mar		Moderately eroded to average	Blain, Bremner & Williams (1986)											
23/06/1974	6		2 storms at beginning of June	Storms in Jan, Feb and 2 in Mar	Moderately eroded	Blain, Bremner & Williams (1986)											
18/08/1974	6			2 storms in June	Eroded to average	Blain, Bremner & Williams (1986)											
2/12/1976	11			2 smaller storms at beginning of Sept [majority of storms in first half of year]		Blain, Bremner & Williams (1986)											

Photogram-metry dates	No. storms in year	Storm Sev-erity^1	Description of storms immediately prior	Storminess in 3 mths prior	Likely profile state in photogrammetry data	Storm data reference	Month	Storm Severity^2	Month	Storm Severity^2	# storms	Month	Storm Severity^2	# storms	Month	Storm Severity^2	# storms
1/06/1977	19	3.61	Storm on 1/05/1977 (Max Hsig 3.5 m, 24hrs), 3/05/1977 (Max Hsig 2.9 m, 48 hrs); very large storm on 16/05/1977 (Max Hsig 5.5 m, 90 hrs)	Very high	Very eroded	Based upon Waverider Buoy data (Coffs, Byron)			May-77	9.34	3	Apr-77	2.97	2	Mar-77	3.92	2
12/10/1977	19	3.61	Small storm 5 days prior (Max Hsig 2.6 m, 6 hrs).	Low to moderate	Very eroded	Based upon Waverider Buoy data (Coffs, Byron)	Oct-77	1.09	Sep-77	1.47	1	Aug-77	1.09	1	Jul-77	2.27	2
29/10/1977	19	3.61	Small storm at beginning of October (Max Hsig 2.6 m, 6 hrs).	Low to moderate	Eroded	Based upon Waverider Buoy data (Coffs, Byron)	Oct-77	1.09	Sep-77	1.47	1	Aug-77	1.09	1	Jul-77	2.27	2
4/04/1978	21	3.43	2 storms in Jan, 1 in Feb and 2 in Mar	Moderate to high	Eroded to average, depending on recovery from storminess of 1977	Based upon Waverider Buoy data (Coffs, Byron)			Mar-78	4.53	2	Feb-78	1.66	1	Jan-78	2.84	2
30/08/1978	21	3.43	4 storms prior: 07/08/1978 (Max Hsig 2.8 m, 6 hrs); 20/08/1978 (Max Hsig 3.2 m, 18 hrs); 23/08/1978 (Max Hsig 3.9 m, 48 hrs); 27/08/1978 (Max Hsig 2.8 m, 6 hrs)	High	Very eroded	Based upon Waverider Buoy data (Coffs, Byron)	Aug-78	5.01	Jul-78	2.79	2	Jun-78	6.24	5	May-78	3.44	1
4/04/1980	22	3.16	1979 was moderate to low storminess (3.19)	Low to moderate (in Feb)	Accreted	Based upon Waverider Buoy data (Coffs, Byron)			Mar-80	3.13	1	Feb-80	4.66	1	Jan-80	2.42	3
4/11/1980	22	3.16	Storm prior on 3/11/80 with max Hsig 3.1 m for 12 hrs	Low	Profile may be eroded due to recent storm activity, but 1980 overall would have been accreted	Based upon Waverider Buoy data (Coffs, Byron)			Oct-80	-	0	Sep-80	1.37	2	Aug-80	1.35	2
26/10/1981	26	2.85	Storm prior on 23/10/81 with max Hsig 3.18 m for 12 hrs	Low	Profile may be eroded due to recent storm activity, but 1981 overall would have been accreted	Based upon Waverider Buoy data (Coffs, Byron)	Oct-81	1.9	Sep-81	2.06	3	Aug-81	2.46	2	Jul-81	2.92	2
27/11/1981	26	2.85	1 storms, on 17/11/1981 (Max Hsig 2.5 m, 6 hrs)	Low	Average	Based upon Waverider Buoy data (Coffs, Byron)	Nov-81	1.09	Oct-81	2.16	2	Sep-81	2.35	3	Aug-81	2.8	2
31/08/1983	20	3.65	No storms during Aug 83	Very high during Jul and Jun	Average to eroded depending on impact of Jun & Jul storms	Based upon Waverider Buoy data (Coffs, Byron)	Aug-83	-	Jul-83	5.26	3	Jun-83	6.62	2	May-83	-	0

Photogrammetry dates	No. storms in year	Storm Severity^1	Description of storms immediately prior	Storminess in 3 mths prior	Likely profile state in photogrammetry data	Storm data reference	Month	Storm Severity^2	Month	Storm Severity^2	# storms	Month	Storm Severity^2	# storms	Month	Storm Severity^2	# storms
21/10/1985	21	3.79	No storms prior (1 storm after photo on 26/10)	Low to moderate	Accreted	Based upon Waverider Buoy data (Coffs, Byron)			Sep-85	2.41	1	Aug-85	-	0	Jul-85	4.35	1
23/04/1986	12	3.9	One storm in Apr, on 6/4/86 with max Hsig 3.32 m for 5 hrs	Low	Accreted to average depending on impact of recent storm	Based upon Waverider Buoy data (Coffs, Byron)	Apr-86	1.16	Mar-86	0	0	Feb-86	0	0	Jan-86	4.04	1
22/06/1986	12	3.9	No storms prior (1 storm after photo on 30/6)	Low to moderate	Accreted	Based upon Waverider Buoy data (Coffs, Byron)	Jun-86	2.12	May-86	4.36	1	Apr-86	1.16	1	Mar-86	0	0
9/05/1988	35	4.9	No storms prior (2 large storms after photo, on 11/5 & 25/5)	Extremely high in 3 months prior	Eroded	Based upon Waverider Buoy data (Coffs, Byron)			Apr-88	7.22	5	Mar-88	4.29	1	Feb-88	7.87	2
26/09/1988	35	4.9	2 storms prior, on 14/9/86 with max Hsig 4.88 m for 51 hrs, and 16/9/86 with max Hsig 3.48 m for 4 hrs	Consistently high in 4 mths prior	Very eroded	Based upon Waverider Buoy data (Coffs, Byron)	Sep-88	4.91	Aug-88	3.75	2	Jul-88	3.24	3	Jun-88	5.29	3
1/01/1989	26	4.6	4 storms prior, on 14/12/88 with max Hsig 3.84 m for 28hrs, 18/12/88 with max Hsig 4.07 m for 34hrs, 27/12/88 with max Hsig 4.2 m for 21hrs, and 30/12/88 with max Hsig 3.49 m for 6hrs.	Very high during month prior, moderate in Nov	Very eroded	Based upon Waverider Buoy data (Coffs, Byron)			Dec-88	5.35	8	Nov-88	2.73	4	Oct-88	0.71	1
20/08/1989	26	4.6	No storms prior	High	Likely to still be eroded, following high storm activity in June and July	Based upon Waverider Buoy data (Coffs, Byron)	Aug-89	0	Jul-89	4.53	3	Jun-89	10.38	7	May-89	1.92	1
28/08/1989	26	4.6	No storms prior	High	Likely to still be eroded, following high storm activity in June and July	Based upon Waverider Buoy data (Coffs, Byron)	Aug-89	0	Jul-89	4.53	3	Jun-89	10.38	7	May-89	1.92	1
17/06/1993	15	2.53	3 storms prior, on 5/6/93 with max Hsig 3.04 m for 2 hrs, on 13/6/93 with max Hsig 4.2 m for 34 hrs and 15/6/93 with max Hsig 3.39 m for 2 hrs (based on Byron Data)	Moderate to low in months prior	Profile may be eroded due to recent storm activity, but 1993 overall would have been accreted	Based upon Waverider Buoy data (Coffs, Byron)	Jun-93	3.44	May-93	1.85	1	Apr-93	-	0	Mar-93	4.81	3
7/05/1994	23	3.44	No storms prior	Moderate to high in 3mths prior	Average	Based upon Waverider Buoy data (Coffs, Byron)			Apr-94	3.43	1	Mar-94	5.4	5	Feb-94	3.64	1

Photogram-metry dates	No. storms in year	Storm Sev-erity[1]	Description of storms immediately prior	Storminess in 3 mths prior	Likely profile state in photogrammetry data	Storm data reference	Month	Storm Severity[2]	Month	Storm Severity[2]	# storms	Month	Storm Severity[2]	# storms	Month	Storm Severity[2]	# storms
18/05/1994	23	3.44	1 storm on 9/5/1994 (Max Hsig 3.2 m, 6hrs)	Moderate	Average	Based upon Waverider Buoy data (Coffs, Byron)	May-94	1.39	Apr-94	3.43	1	Mar-94	5.4	5	Feb-94	3.64	1
28/06/1996	20	3.14	No storms during Jun 96	Extremely high in month prior (May)	Profile may be eroded due to recent storm activity, but 1996 overall would have been accreted	Based upon Waverider Buoy data (Coffs, Byron)	Jun-96	0	May-96	7.13	4	Apr-96	1.33	1	Mar-96	0	0
16/05/2000	22	3.71	4 storms prior, on 1/5/00 with max Hsig 3.40 m for 2hrs, 2/5/00 with max Hsig 3.63 m for 16hrs, 3/5/00 with max Hsig 3.23 m for 5hrs, and 7/5/00 with max Hsig 3.54 m for 20hrs.	Moderate to low in months prior	Profile may be eroded due to recent storm activity, but 2000 overall would have been average	Based upon Waverider Buoy data (Coffs, Byron)	May-00	3.74	Apr-00	2.22	1	Mar-00	0	0	Feb-00	2.35	2
17/05/2000	22	3.71	4 storms prior, on 1/5/00 with max Hsig 3.40 m for 2hrs, 2/5/00 with max Hsig 3.63 m for 16hrs, 3/5/00 with max Hsig 3.23 m for 5hrs, and 7/5/00 with max Hsig 3.54 m for 20hrs.	Moderate to low in months prior	Profile may be eroded due to recent storm activity, but 2000 overall would have been average	Based upon Waverider Buoy data (Coffs, Byron)	May-00	3.74	Apr-00	2.22	1	Mar-00	0	0	Feb-00	2.35	2
28/07/2004	19	3.25	3 storms prior on 10/7 with max Hsig 3.12 m for 5hrs, 11/7 with max Hsig 3.06 m for 2hrs, and 19/7 with max Hsig 4.04 m for 30hrs	Relatively low	Profile may be eroded due to recent storm activity, but 2004 overall would have been average to accreted	Based upon Waverider Buoy data (Coffs, Byron)	Jul-04	3.27	Jun-04	0	0	May-04	0	0	Apr-04	1.96	2
7/08/2004	19	3.25	No storms immediately prior this photogramm in Aug	Low	Average to accreted depending on recovery from July	Based upon Waverider Buoy data (Coffs, Byron)			Jul-04	3.27	3	Jun-04	0	0	May-04	0	0
26/11/2006	28	4.03	3 storms prior, on 4/6 with max Hsig 3.22 m for 3 hrs, 12/6 with max Hsig 4.84 m for 33 hrs, and 17/6 with max Hsig 3.36 m for 11hrs (last 2 storms from Byron Data)	High in months prior	Moderately eroded	Based upon Waverider Buoy data (Coffs, Byron)	Nov-06	4.06	Oct-06	1.4	1	Sep-06	3.83	3	Aug-06	6.79	3
11/01/2007	23	3.27	No storms immediately prior	Very Low	Accreted	Based upon Waverider Buoy data (Coffs, Byron)			Dec-06	2.13	1	Nov-06	4.06	4	Oct-06	1.4	1

BMT WBM Brisbane
Level 11, 490 Upper Edward Street Brisbane 4000
PO Box 203 Spring Hill QLD 4004
Tel +61 7 3831 6744 Fax +61 7 3832 3627
Email wbm@wbmpl.com.au
Web www.wbmpl.com.au

BMT WBM Denver
14 Inverness Drive East, #B132
Englewood Denver Colorado 80112 USA
Tel +1 303 792 9814 Fax +1 303 792 9742
Email wbmdenver@wbmpl.com.au
Web www.wbmpl.com.au

BMT WBM Melbourne
Level 5, 99 King Street Melbourne 3000
PO Box 604 Collins Street West VIC 8007
Tel +61 3 9614 6400 Fax +61 3 9614 6966
Email wbmmelbourne@wbmpl.com.au
Web www.wbmpl.com.au

BMT WBM Mackay
Suite 1, 138 Wood Street Mackay 4740
PO Box 4447 Mackay QLD 4740
Tel +61 7 4953 5144 Fax +61 7 4953 5132
Email wbmmackay@wbmpl.com.au
Web www.wbmpl.com.au

BMT WBM Newcastle
126 Belford Street Broadmeadow 2292
PO Box 266 Broadmeadow NSW 2292
Tel +61 2 4940 8882 Fax +61 2 4940 8887
Email wbmnewcastle@wbmpl.com.au
Web www.wbmpl.com.au

BMT WBM Perth
1 Brodie Hall Drive Technology Park Bentley 6102
Tel +61 8 9328 2029 Fax +61 8 9486 7588
Email wbmperth@wbmpl.com.au
Web www.wbmpl.com.au

BMT WBM Sydney
Level 1, 256-258 Norton Street Leichhardt 2040
PO Box 194 Leichhardt NSW 2040
Tel +61 2 9713 4836 Fax +61 2 9713 4890
Email wbmsydney@wbmpl.com.au
Web www.wbmpl.com.au

BMT WBM Vancouver
1190 Melville Street #700 Vancouver
British Columbia V6E 3W1 Canada
Tel +1 604 683 5777 Fax +1 604 608 3232
Email wbmvancouver@wbmpl.com.au
Web www.wbmpl.com.au