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North Tuncurry

Coastal Processes, Hazards and Planning Study

301020-02358 – 002

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PROJECT 301020-02358 **- NORTH TUNCURRY**

REV	DESCRIPTION	ORIG	REVIEW	WORLEY-PARSONS APPROVAL	DATE	CLIENT APPROVAL	DATE
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C	Final Issue	T Hammond	D Messiter	D Messiter	30/9/2010		
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1 INTRODUCTION

1.1 Background

The Department of Industry, Crown Land and Water (DoI Lands) and Landcom have entered into a Project Delivery Agreement (PDA) for the development of land at North Tuncurry on the Mid North Coast of New South Wales (NSW). The agreement authorises the carrying out of site investigations for due diligence purposes to determine the feasibility of the site for residential development. Landcom will manage development of the site in consultation with DoI Lands.

The North Tuncurry site is nominated as a future urban release area in the *Mid North Coast Regional Strategy 2006-31* and the *Hunter Regional Plan 2036*. The site provides a unique opportunity for optimising the use of Crown land for the benefit of the community. DoI Lands allocates Crown land on a demonstrated needs basis, placing a strong emphasis on multiple use and the principles of sound asset and conservation management. In its development role, Landcom will undertake a community building project that promotes sustainable urban form, local economic development and the protection of natural and cultural resources.

Nine Mile Beach, located directly north of the Tuncurry township, fronts the Pacific Ocean at the eastern extremity of the subject site. Previous advice from PWD (1988) indicates that Nine Mile Beach has been the subject of progradation following the construction of training walls at the entrance to Wallis Lake. The potential developable area of the site, as identified in the Great Lakes Council Conservation and Development Strategy 2003, is about 430 hectares (ha) within Lot 331. This area is set back from the coastline, and as such, a buffer is provided to allow for coastal processes seaward of the potential development area. This Study investigation assesses whether progradation has occurred and to what extent it is expected to continue. It also assesses whether the buffer area is adequate to provide protection to any proposed development in the face of sea level rise and associated shoreline recession (long term erosion) in combination with short term erosion due to storm activity.

Previous studies undertaken by GHD (1995) and SKM (1988) indicate that the site has little natural surface drainage, with the majority of runoff infiltrating directly into the groundwater system. Other specialist studies undertaken as part of this engagement investigate stormwater management strategies and measures to minimise increased runoff as a result of development of the site.

1.2 Scope of this Report

This report summarises the current knowledge, to provide an understanding of the coastal processes that operate within the study area. The report examines the coastal hazards that impact the coastline and assesses these hazards to determine the immediate, 2060 and 2100 hazard lines.

The hazards examined in this report are generally those set out in section 4 (1) of the *Coastal Management Act 2016*, for the open coast areas *i.e.*:

- beach erosion
- shoreline recession
- coastal lake or watercourse entrance instability
- coastal inundation
- coastal cliff or slope instability
- tidal inundation
- impact of climate change.

2 STUDY AREA

2.1 Location

North Tuncurry is situated on the Mid North Coast of NSW, approximately 170 km north of Newcastle and 320 km north of the Sydney CBD (**Figure 2.1**). The study site is located in the Mid Coast Council area (LGA). The LGA is located between Port Stephens in the south, Diamond Head in the north and the foothills of the Great Dividing Range to the west. The Council area is over 10,000 km^2 in area, comprising both coastal and forested rural hinterland. It is approximately 100 km west to east at its widest point, 120 km north to south, and has a total coastline length of 190 km.

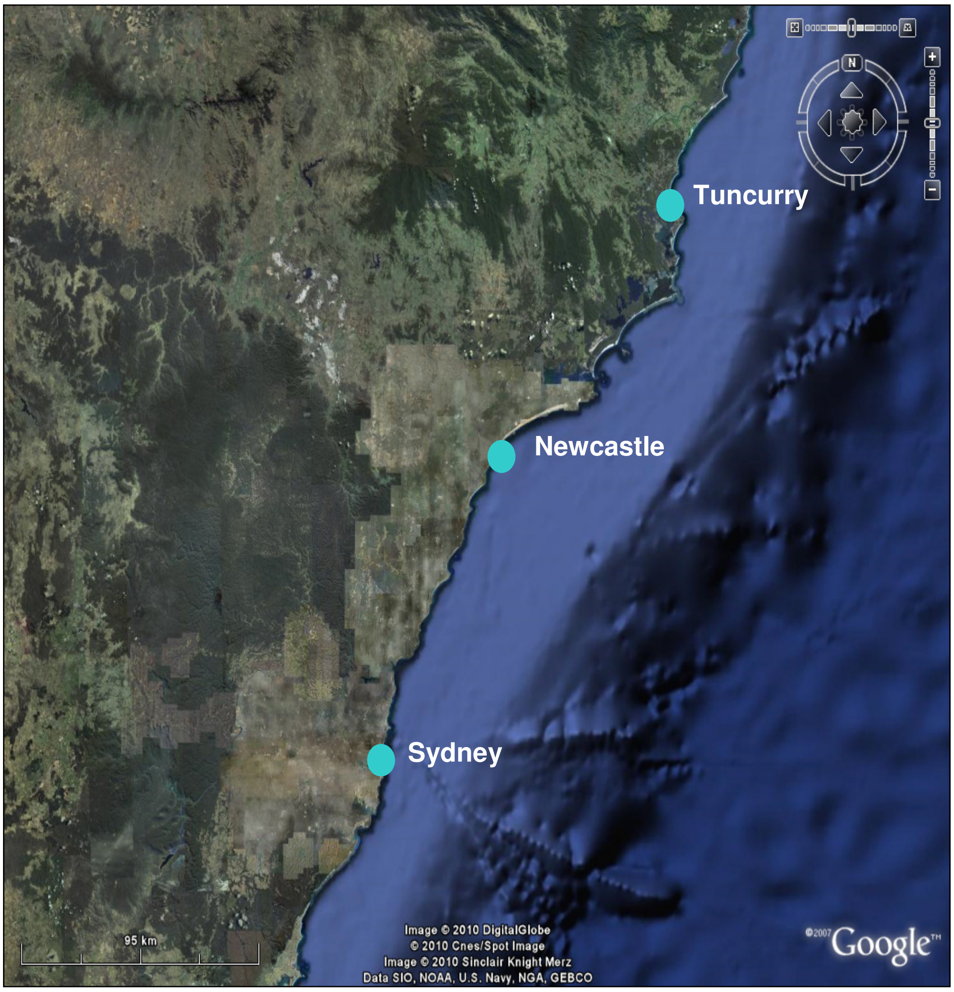


Figure 2.1 Location Map

2.2 Site Description

The proposed development site (shown in **Figure 2.2**) is comprehensively described in the Brief as follows:

- Study area of 555.2 ha in Lot 331, Deposited Plan 1104340 which lies east of the Lakes Way (the main road connecting to Taree) and extends north from the town of Tuncurry for approximately 4 km, and to the Mean High Water Mark (MHWM) along Nine Mile Beach in the east.
- The potential development area identified in the Great Lakes Council Conservation and Development Strategy 2003 is smaller, about 430 ha within Lot 331.
- Lot 331 and the potential development site surrounds, and includes the Forster Tuncurry Golf Course which is within Lots 294 & 295 DP 43110.
- The site is bordered to the south by the Great Lakes College campus, a combined High School and TAFE facility, and to the north adjoins the Tuncurry Waste Management Centre.
- The topography varies from remnant sand dunes in the west, through to more defined undulating dunes in the east.
- The potential development area does not include the area from the foredune to the MHWM (this area is part of Lot 331).
- The site is vegetated by coastal heathland (Banksia) regrowth with some areas of open Blackbutt Forest and plantation pine trees. For some 40 years, from 1916, the site was cultivated and worked for the production of pine trees in a prisons' afforestation programme.
- An airstrip operated in the south-western part of the site for a short time during the 1960s.
- The site is burdened in the south west by an easement for a transmission line and proposed easement for a sewage pipeline.
- A power transmission line, that traverses Lot 331 in the west, is not contained in an easement.

Figure 2.2 Potential Development Area

3 DATA ACQUISITION

3.1 Previous Studies/ Literature Review

As part of this study a comprehensive search and review of previous literature was undertaken. The reports most relevant to the current study are outlined below.

- *Draft Report on Planning and Development Investigations for North Tuncurry Urban Release Area* (Coastplan Consulting, 1995)
- *North Tuncurry Planning Study* (Croft and Associates, 1983)
- *Report of Geotechnical Investigation, North Tuncurry Plan Study* (Douglas and Partners, 1988)
- *North Tuncurry Planning Study, Drainage and Soil Investigations*, (Sinclair Knight and Partners, 1988)
- *Evaluation of trunk Drainage Strategies and Review of Precinct 1 & 2 Stormwater Disposal Strategy* (GHD, 1995)
- *PWD Coastal Engineering Advice* (1988)
- *Great Lakes Coastal Hazards Study* (SMEC 2013)
- *Great Lakes Coastal Zone Management Plan* (BMT WBM 2016)
- *Great Lakes Coastal Zone Management Plan – Options Study* (BMT WBM 2015).
- *NSW Coastal Management Act 2016*
- NSW Coastal Management Manual (OEH 2018).

3.2 Review of Historical Aerial Photographs

Aerial photography is available for the North Tuncurry coastline dating back to 1951. To assist in gaining an understanding of the coastal processes and to assist in photogrammetry analysis (identifying anthropogenic influences such as sand mining activities, beach reshaping and beach accessway construction) a review of the aerial photographs was undertaken. A compilation of aerials and a summary of some of the distinctive features of various dates of photography are provided in **Appendix A**.

3.3 Photogrammetry

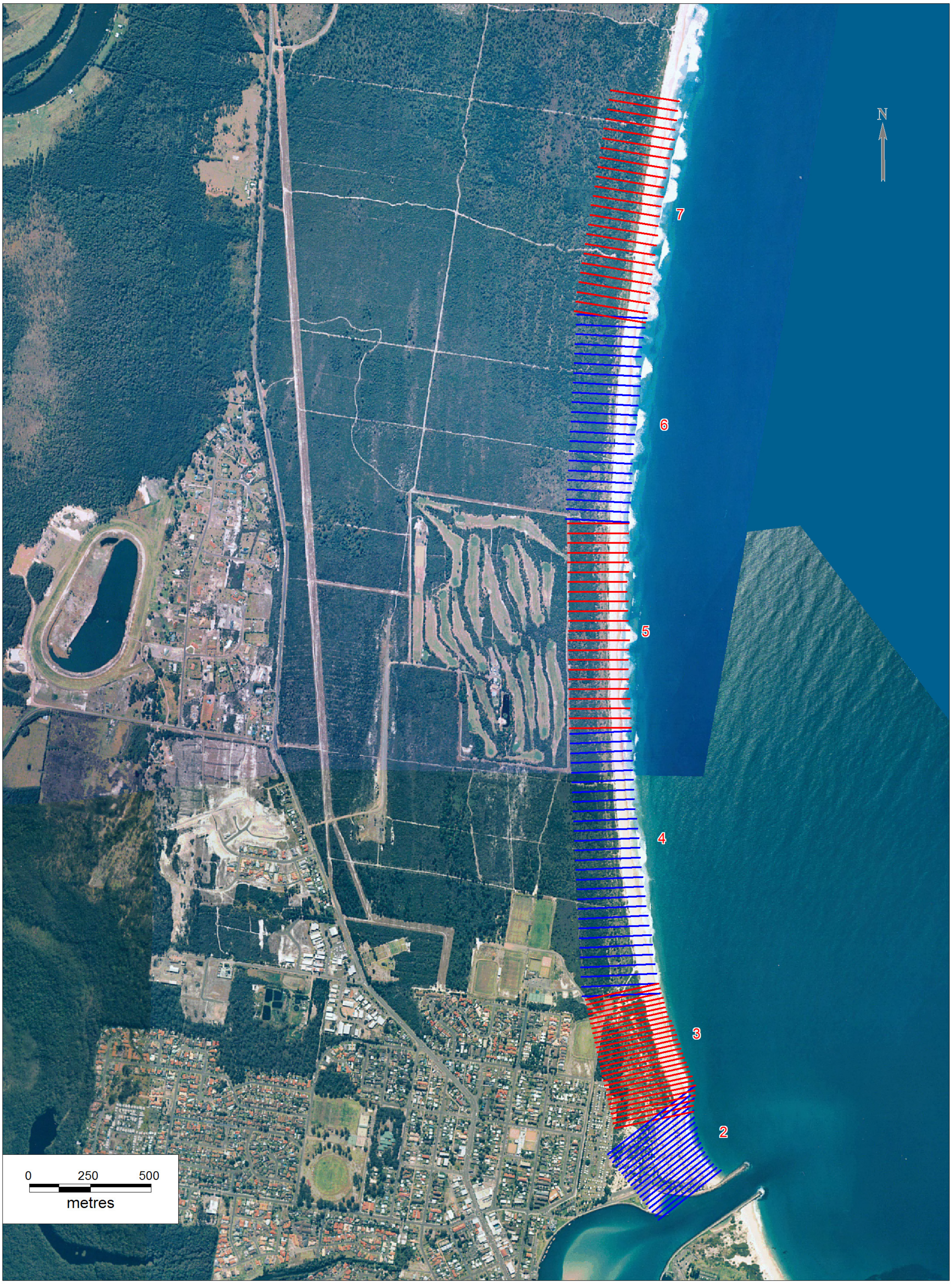
A detailed photogrammetric analysis of historical vertical aerial photography (photogrammetry) was undertaken by the Office of Environment and Heritage (OEH). This enabled long term recession rates and storm erosion demand to be assessed. The photogrammetric data consisted of 142 cross-shore profiles in 6 blocks covering approximately 4.6 km of the coastline from the northern Wallis Lake entrance training wall (see **Figure 3.1**). The data covered a period of 45 years and included eight different years, from 1963 to 2008. **Appendix B** provides further information regarding the photogrammetry including:

- details of the dates of photography and the locations of photogrammetric profiles;
- a description of the methodology used in the analysis of the photogrammetric data; and
- tables and plots of analysis results.

3.4 Survey Data

An Airborne Laser survey (ALS) of the site was conducted on behalf of the former Great Lakes Council. Council supplied the processed point data based on this survey information. The accuracy of this data is +/-0.2 m. Based on the supplied survey data, a Digital Terrain Model (DTM) of the study area was created using the 12D software package. This was used to assist in identifying low-lying areas subject to coastal inundation and in developing a Conceptual Coastal Processes Model (see **Section 4.13**).

Hydrographic survey data of the nearshore area of the study area is limited to Hydrographic Charts (Admiralty Chart - AUS 810).



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Photogrammetry Transect Locations

September 2010

Figure 3.1

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4 COASTAL PROCESSES

In this Section, the coastal processes prevalent along the study area coastline are outlined. In particular, details are provided on:

- wave climate (**Section 4.1**);
- elevated water levels (**Section 4.2**);
- wave runup (**Section 4.3**);
- coastal storms (**Section 4.4**);
- wave induced currents (**Section 4.5**);
- short term onshore/ offshore sediment transport (**Section 4.6**);
- longer term sand movement (**Section 4.7**);
- geological/ geotechnical conditions (**Section 4.8**);
- climate change (**Section 4.9**); and
- aeolian (wind) sand transport (**Section 4.10**).

4.1 Wave Climate

Manly Hydraulics Laboratory (MHL), part of the NSW Department of Finance, Services and Innovation, operates a network of Waverider buoys in deep water along the NSW coast. Waverider buoys are spherical floating accelerometers which determine sea level surface displacement based on the double integration of measured vertical accelerations. Analysis of the collected data allows (amongst other things) the significant wave height (H_s) and peak spectral wave period (T_p) to be determined. For the NSW network, records are collected for 2048 second bursts (about 34 minutes) every hour at 0.5 second intervals (Lord and Kulmar 2001). Waverider buoys can be non-directional or directional. Directional buoys allow the predominant wave direction to be determined.

In the vicinity of the study area a Waverider buoy is located offshore about 50 km north east of the site, at Crowdy Head. The Crowdy Head Waverider buoy is a non-directional buoy that has been operating since 10 October 1985. Hourly wave data from this wave buoy was sourced from MHL. The data covered the period from 10 October 1985 to 30 April 2008 with an 86% capture rate. The data consisted of H_s, H_{max}, T_z, and T_p for this period where H_{max} is the maximum wave height and T_z is the zero crossing wave period. Wave directions have been hindcast by MHL for the period 10 October 1985 to 31 December 1997 based on interpretation of historical synoptic chart information. Limitations in the accuracy of this hindcast method should be considered when using this data.

Based on analysis of the H_s data at Crowdy Head to 30 April 2008, the probability of exceedance of a particular offshore deepwater significant wave height (H_s) is as shown in **Figure 4.1**.

From the analysis it was calculated that:

- the average wave height is 1.6 m, the median or 50th percentile wave height is 1.5 m;
- H_s exceeds 3 m for about 5% of the time;
- H_s values exceeding 4 m occur less than 1% of the time;
- storm conditions with H_s exceeding 5 m occur on average once or twice a year;
- the one day per year (i.e. 1/365.25=0.274% Probability of Exceedance) wave height is 4.8 m, the 12 hour per year (i.e. 12/(365.25x24)=0.137% Probability of Exceedance) wave height is 5.0 m;
- the largest H_s was 7.35 m recorded on 4 March 1995 at 13:00 hrs with a T_p of 13.5 seconds, the corresponding H_{max} was 11 m;
- for a storm duration of 6 hours the 100- year Average Recurrence Interval (ARI) wave height is 7.8 m; and
- the average T_p at Crowdy Head is 9.7 s, with about 92% of records having a T_p between 6 and 14 s.

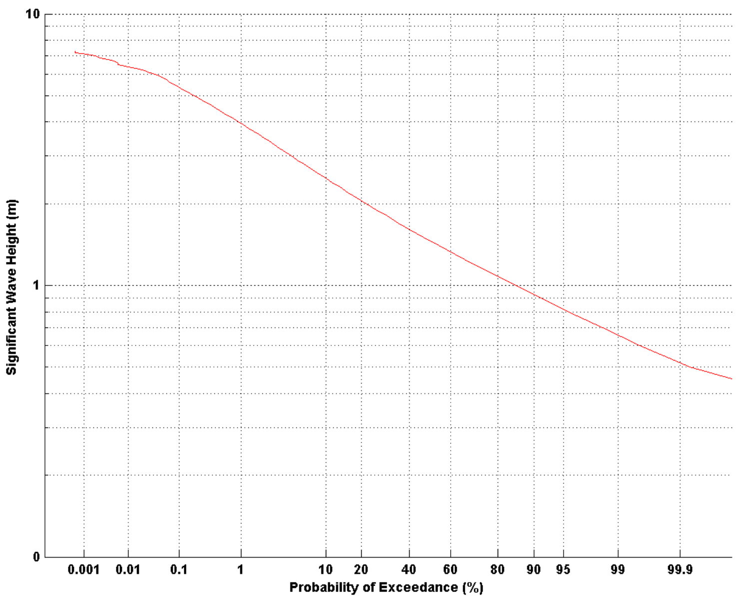


Figure 4.1 Significant wave height exceedance for Crowdy Head 1995 - 2008

Beach erosion is strongly linked to the occurrence of high wave conditions with elevated ocean water levels (the latter are discussed in **Section 4.2**). Therefore, inclusion of duration is likely to more accurately describe the severity of a storm in terms of beach erosion, rather than using average recurrence interval (ARI) alone (Lawson and Youll 1977). Erosion is more likely to be significant when the large waves coincide with a high tide. In general, storms with a duration in excess of 6 hours are likely to coincide with high tide on the NSW coast (Lord and Kulmar 2001) although the coincidence of high tide with wave height durations of less than 6 hours is still possible. It is considered that the 6 hour duration is the most appropriate to use for beach erosion and wave runup considerations, and as such has been adopted for use in this study.

Analysis of available wind data was used to hindcast directional wave data from October 1985 to December 1996 which is presented in the wave rose plot seen in **Figure 4.2**. In summary, this analysis indicates that deepwater waves approach the study area proportionally as follows:

- 6% from the NE;
- 11% from ENE;
- 17% from the E;
- 18% for ESE;
- 24% from SE;
- 13% from the SSE; and
- 11% from the S.

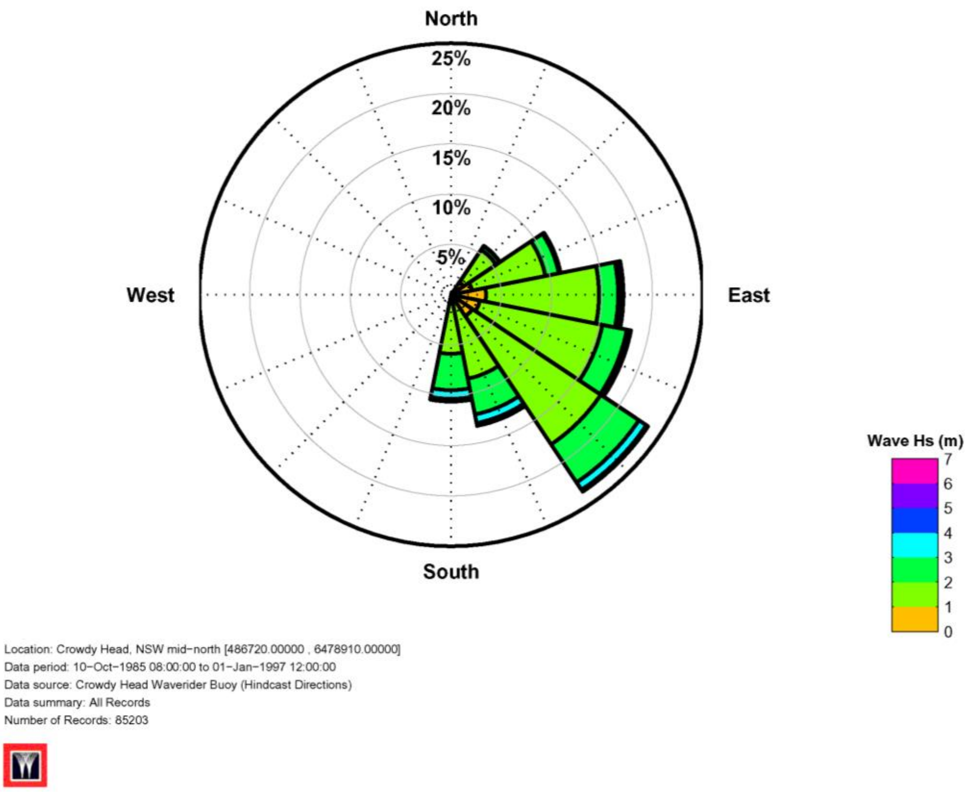


Figure 4.2 Hindcast Wave Rose for Crowdy Head 1985 -1996

Analysis of the hindcast directional wave data for Crowdy Head indicates the weighted (height and period) offshore directional average to be approximately from the SE at 134°N.

As previously discussed, the accuracy of this data is limited by the methodology employed to hindcast the wave direction. Nearshore coastal processes are highly sensitive to wave direction.

Analysis of the Sydney Waverider buoy directional data from 1992 to 1999 indicated that 34% of waves came from the south-southeast, with 17% of waves from the southeast and 14% of waves from the south. Furthermore, the south-southeast direction was dominant for larger waves (Lord and Kulmar, 2001). Installation of directional Waverider buoys (since 1992 in Sydney) has indicated that the predominant wave climate along the NSW coast is from the south-southeast.

While considering the limitations of the hindcast Crowdy Head directional data, the comparison with Sydney directional data suggests the possibility of a more easterly average offshore direction for the study region.

4.2 Elevated Water Levels

The potential factors contributing to elevated still water levels on the NSW coast comprise:

- astronomical tide;
- storm surge (barometric setup and wind setup); and
- wave setup (caused by breaking waves).

Individual waves also cause temporary water level increases above the still water level due to the process of wave runup or uprush (see **Section 4.3**). Note that sea level is also predicted to rise due to climate change. This is discussed further in **Section 4.9**.

In NSW, open coast still water levels (within the wave breaking zone) can increase by up to about 2.1 m above normal levels during storms due to storm surge and wave setup, with components approximately as large as follows:

- storm surge of 0.6 m (barometric setup of up to 0.3 m to 0.4 m and wind setup of up to 0.2 m to 0.3 m); and
- wave setup of up to 1.5 m (typically about 10-15% of the deepwater significant wave height).

This increase in water level is superimposed on the astronomical tide, which typically varies between about -1 m AHD (approximately equivalent to Lowest Astronomical Tide, LAT) and 1 m AHD (approximately equivalent to Highest Astronomical Tide, HAT) along the NSW coast, with 0 m AHD close to mean sea level. On the NSW coast, Mean High Water Springs is about 0.6 m AHD, Mean High Water is about 0.5 m AHD, and Mean High Water Neaps is about 0.4 m AHD. If a severe storm continued for a day, it would be expected that two high tides would occur during this time. Ignoring wave effects, the highest absolute water level that might be experienced in a storm would be when the maximum storm surge occurred at the same time as the HAT.

Water levels have been recorded at Fort Denison in Sydney Harbour for over 100 years, and are representative of NSW open coast water levels near Sydney (in the absence of waves). The data from 1914 onwards is considered to be reliable. Based on a joint probability analysis of tide and storm surge (assumed as independently occurring events), for the May 1914 to December 1991 data set, Manly Hydraulics Laboratory (MHL 1992) predicted that the 100 year, 50 year and 20 year ARI water levels at Fort Denison were 1.49 m, 1.46 m and 1.41 m AHD respectively. The highest recorded water level at Fort Denison was 1.48 m AHD in May 1974. These levels are representative of astronomical tide and storm surge, but exclude wave setup.

Assuming extreme water levels in Sydney were representative of conditions at North Tuncurry, the 100 year ARI water level (including astronomical tide and storm surge) adopted for this study was 1.5 m AHD. With a 100 year ARI offshore significant wave height of 7.8 m (**Section 4.1**), and assuming wave setup as 15% of this wave height, the 100 year ARI wave setup was determined as 1.2 m. Therefore, a 100 year ARI total design still water level (astronomical tide plus storm surge and wave setup) of 2.7 m AHD has been adopted for this study. This design level does not include climate change considerations which are further discussed in **Section 4.9**.

4.3 Wave Runup

Wave runup is site specific, but typically is about 3 m to 6 m above the elevated still water level (**Section 4.2**) on the NSW open coast. The height of wave runup on beaches depends on many factors including (NSW Government 1990):

- wave height and period;
- the slope, shape and permeability of the beach;
- the roughness of the foreshore area; and
- wave regularity.

Wave runup can be difficult to predict accurately due to the many factors involved. Anecdotal evidence and the surveying of debris lines following a storm event usually provide the best information on wave runup levels.

Hanslow and Nielsen (1995) provide guidance on calculating wave runup. They found that the runup above the still water level was given by:

$$R = 0.9H_s \left(\frac{L_s}{H_s} \right)^{0.5} \tan\beta$$

where R is the runup exceeded by 2% of waves, H_s is the significant wave height, L_s is the significant wave length, and $\tan\beta$ is the beach slope. The significant wave length is given by:

$$L_s = \frac{gT_s^{\,2}}{2\pi}$$

where g is the gravitational acceleration (9.8 ms^{-2}) and T_s is the significant wave period. Note: wave setup is implicitly included in this calculation of wave runup.

For Nine Mile Beach, the 100 year ARI H_s has been adopted as 7.8 m (**Section 4.1**) and T_s can be assumed to be 12 s, as is commonly used in coastal engineering design. Assuming that the beach face slope is equal to 1H:10V, as is common in an eroded profile, the predicted runup above the still water level is 3.8 m. With a still water level of 1.5 m AHD (**Section 4.2**), the predicted 100 year ARI wave runup level exceeded by 2% of waves is 5.3 m AHD. For planning purposes, it is considered that a runup level of 6.2 m AHD should be adopted for the study area, which includes the predicted sea level rise of 0.9 m over a planning period up to 2100. Refer to **Section 4.9** for discussion on sea level rise.

Runup levels in the order of 6 m AHD would only be realised if the foreshore was at this runup height or higher. This level would vary along the length of study area as the foredunes do not always extend above 6 m AHD. In these areas, wave runup would penetrate inland as sheet flow at shallow depth, spreading out and infiltrating over landward areas.

In the long term, as a beach receded, it could be postulated that the present dunal barrier would disappear, with the new shoreline taking on the existing topography landward of the present dune. This is considered to be unlikely from an understanding of the morphological response of beaches. The existing dune crest levels are a complex response to a variety of factors including beach sand characteristics, exposure to wind and wave action, and local topographic controls, all of which are likely to be relatively constant irrespective of the shoreline position in the long term; i.e. it is considered more likely the existing dune profile would 'roll back'.

4.4 Coastal Storms

4.4.1 General

The NSW coastline is subject to intense tropical and non-tropical storms at irregular intervals. The drop in atmospheric pressure and the winds and waves that accompany these storms can cause the ocean to rise above its normal level (see **Section 4.2**). If this occurs concurrently with high astronomical tides, there is the potential for:

- coastal erosion (in particular as the storm waves dissipate energy closer to the shoreline with the increased water levels); and/ or
- overwash into low-lying coastal areas (PWD 1985).

PWD (1985, 1986) categorised coastal storms to indicate the potential of a storm to generate abnormal water levels along the NSW coastline. The categories were discretised on the basis of offshore significant wave heights, as shown in **Table 4.1**.

Table 4.1 Categorisation of coastal storms in NSW by PWD

Category	Offshore significant wave height (H_s) m
X	$H_s \geq 6$
A	$5 \leq H_s < 6$
B	$3.5 \leq H_s < 5$
C	$2.5 \leq H_s < 3.5$

Category X and A storms were those expected to lead to coastal erosion and damage to coastal facilities. According to PWD (1985, 1986), Category X storms were characterised by damage to coastal installations, severe erosion, and serious disruption to shipping. Category A storms were characterised by erosion or other damage to coastal installations and disruption to shipping.

In PWD (1985), all Category X, A, B and C storms that were predicted to have occurred between 1880 and May 1980 were listed[1], along with a description of the storm generating mechanism and characteristics, and wave heights and periods (for selected storms). Estimates were given for each of four coastal sectors in NSW, namely North, Mid-North, Central and South. The Mid-North sector covered the NSW coastline north from Sugarloaf Point (near Seals Rocks) to Smoky Cape (near South West Rocks), placing the study area within this sector.

Similarly, in PWD (1986), all Category X, A, B and C storms that were predicted to have occurred between May 1980 and December 1985 were listed.

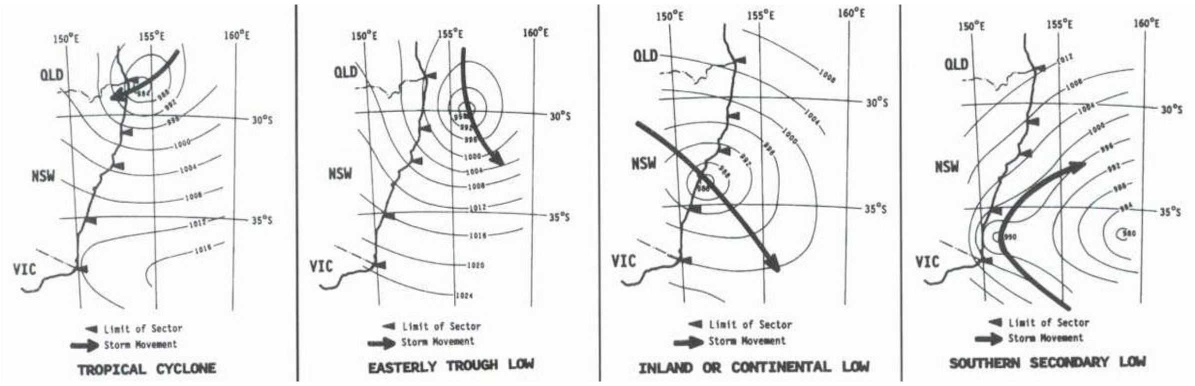
4.4.2 Storm Types

PWD (1985) recognised six different major storm types which impact on the NSW coast, namely:

- tropical cyclones;
- easterly trough lows;
- inland trough lows;
- continental lows;
- southern secondary lows; and
- anti-cyclonic intensification.

Typical synoptic patterns for tropical cyclones, easterly trough lows, inland trough/ continental lows and southern secondary lows are shown in **Figure 4.3**.

[1] However, the only reliable data for statistical analysis was from 1920 to 1944 and 1957 to 1980.



Source: NSW Government 1990

Figure 4.3 Typical Synoptic Patterns associated with NSW Coastal Storms

Based on PWD (1985, 1986) it is evident that on average:

- the Mid-North Coast sector receives a relatively high rate of coastal storm incidents with only the Central Coast sector receiving significantly greater coastal storm incidents. This is due to these sectors being influenced by storms originating in both the tropical and southern area, as well as those developing locally;
- easterly trough lows and tropical cyclones are the dominant storm types[2] on the Mid-North Coast, however southern secondary lows can also affect the area; and
- most storms on the Mid-North Coast occur in Summer, Autumn and Winter, with June and March being the most prevalent months for storms (tropical cyclones generally only occur between January and April, with easterly trough lows dominating between April and July).

4.4.3 Storm History

As noted in **Section 4.4.1**, PWD (1985, 1986) listed all Category X, A, B and C storms that were predicted to have occurred between 1880 and 1985. Storm history information, derived from the offshore Crowdy Head Waverider buoy was also obtained from Manly Hydraulics Laboratory, NSW Department of Finance, Services and Innovation (MHL, 2008). OEH is acknowledged as the owner of this data. The information was for events where the significant wave height exceeded 3 m since the commissioning of the Waverider buoy in 1985, up until the end of 2007. Further information on this data is given in **Section 4.1**.

A listing of the predicted Category X storms from 1940 to 1985 is given in **Table 4.2** including the storm type. The Category X storms measured at the Crowdy Head Waverider buoy from October 1985 to January 2008 are listed in **Table 4.3**, with the recorded H_s (at the peak of the storm) and T_s values also shown.

[2] These storm types are predominantly weather systems that come from the north.

A total of 12 Category X events were recorded at the Crowdy Head Waverider buoy from October 1985 to January 2008. This represents an average of one Category X event every 1.9 years, in the 22 years of record. However, the time period between storms was not uniform. For example, there were no Category X storms from 1991 to 1994, and 3 Category X storms in 1990.

Table 4.2 Mid-North Coast Category X Storms from 1940 to 1985

Date	Storm Type
12-15 October 1942	Easterly Trough Low
10-13 June 1945	Easterly Trough Low
18-19 January 1950	Inland Tough
8 June 1951	Easterly Trough Low
14-15 June 1952	Continental Low
19-22 February 1954	Tropical Cyclone
18-23 February 1957	Tropical Cyclone
20-24 January 1959	Tropical Cyclone
29-31 January 1967	Tropical Cyclone
23-24 July 1968	Southern Secondary Low
24-25 August 1969	Easterly Trough Low
22-25 July 1971	Continental Low
18-20 March 1978	Easterly Trough Low

Source: PWD 1985 and 1986

Table 4.3 Category X Storms measured at Crowdy Head from 1985 to 2008

Date	Peak H_s (m)	Mean T_s (s)
8-11 February 1988	6.5	10.6
7-10 March 1990	6.3	10.4
28-30 May 1990	6.7	9.2
12-15 October 1990	6.4	11.1
2-5 March 1995	7.4	9.9
6-8 March 1995	6.3	10.4

Date	Peak H_s (m)	Mean T_s (s)
9-12 May 1997	6.3	10.1
22-25 April 1999	6.5	11.2
13-17 July 1999	6.8	10.5
28 -29 July 2001	6.3	11.9
29 June - 2 July 2002	6.3	11.7
13 -17 May 2005	6	9.2

Based on the available Crowdy Head Wave Rider data, as documented in MHL (2008), a total of 24 Category A events were recorded from October 1985 to January 2008. This represents an average of approximately 1.1 Category A events per year, in the 22 years of record. However, the time period between storms was not uniform. For example, there were no Category A storms in 1993, 1997-1998, 2000-2003 and 2006, and three Category A storms in 1989 and 2004.

4.5 Wave Induced Currents

The most common forms of wave induced currents are longshore currents and rip currents. Longshore currents occur within the breaker zone and move essentially parallel to the shoreline, they are usually generated by waves breaking at an angle to the shoreline. These currents cause movement of sediment along the shoreline, commonly referred to as littoral drift. Due to the variability in wave approach direction at beaches, there may be times when the littoral drift is in one direction and at other times when it is in the opposite direction.

There is a net south to north longshore movement of littoral sand within the surf zone of most NSW beaches. As such, Mid-North Coast beaches are generally supplied by sand from the south and are the source of sand for beaches to the north. This net northward movement of sand is caused by the dominant SSE wave climate (**Section 4.1**) in relation to the general NSW coast orientation of NNE to SSW, and is particularly pronounced in northern NSW as headlands are less prominent. Storm waves can also carry sand around headlands.

Where there is a longshore variation in the rate of longshore sand transport, there will be a net gain or loss of sand from the beach compartment. That is, where more sand is transported out of a beach area than is being brought in over an extended period of time, the beach will erode with the shoreline gradually realigning. The erosion will occur initially in the surf zone where sand transport is greatest, and manifest as beach retreat (recession) following onshore / offshore readjustment of the nearshore profile.

On a dominant northwards longshore transport coastline, based on Stephens *et al.* (1981), shoreline evolution was predicted to occur as recession, commencing at the southern end of the compartment forming an embayment between controlling headlands/ features. Within each embayment, recession was also expected to be highest in the southern hook, reducing northwards to negligible rates immediately south of each headland/ feature. The evolution of zeta form embayments[3] between controlling headlands was considered to be the result of this longshore transport process.

As the shoreline realigned within each compartment, the longshore transport rate was expected by Stephens *et al.* (1981) to reduce, with an ultimate reduction in the supply of sand to the next compartment. This would induce a greater transport differential in the next compartment, and cause progressive recession from south to north. The increasing sediment transport rates moving north along the NSW Mid-North Coast are consistent with the compartmentalisation and zeta form model of Stephens *et al.* (1981).

Rip currents are strong currents which flow seaward from the shore. They comprise the return movement of water which is "piled up" on the shore by incoming waves and wind. The rip consists of three parts: the feeder currents flowing parallel to shore inside the breakers; the neck, where the feeder currents converge and flow through the breakers in a narrow band or "rip"; and the head where the current widens and slackens outside the breaker line.

As the "rip" is a locally deeper channel through the sand bars, larger waves can reach the shoreline opposite rip heads. Accordingly, it is common to distinguish the higher storm erosion demand which can occur at rip heads and the lower storm erosion demand which prevails away from rip locations.

Nine Mile Beach generally consists of a single nearshore bar. Rips dominate the entire length of the beach cutting the bar every 200 – 300m, often in combination with a deep trough running along much of the beach. There is no evidence to suggest that the rip locations are "fixed" along the beaches. Rather rip locations are likely to be dependent on a number of factors including wave direction and preceding bar shape. Consequently, for purposes of assessing the possibility of increased storm erosion demand at rip heads, it is necessary to assume that a rip could form at any location along the beach.

4.6 Short Term Onshore/ Offshore Sediment Transport

Onshore/ offshore (also known as cross-shore) sand movement is caused by natural variations in wave climate and water level. The offshore movement of sand is usually referred to as storm erosion. This onshore/ offshore movement of sand results in short term fluctuations in the width of the beach profile.

[3] Many sections of coastline which are situated in the lee of a headland, feature a curved shoreline geometry. Where sections of coastline are situated between two headlands, and particularly when there is a single, dominant wave direction, the shoreline may likewise assume a curved or "scalloped" shape. In both cases, the curved portion of the shoreline related to the headland(s) is termed a crenulate or "spiral bay". Because of their geometries, these shorelines are also sometimes termed "parabolic," or "zeta-bay" shorelines. The shape results from longshore transport processes which move sediment in the downdrift direction along the down-wave section of the shoreline, and from processes associated with wave diffraction which move sediment in the opposite direction in the immediate lee of the up-wave headland (Rosati *et al*, 2002).

During storms, the beach is cut by storm waves with beach sand moving offshore to form bars in the surf zone. This process typically occurs over a period of hours to days. When extended periods of calmer waves occur, the material held in these bars migrates onshore to re-build the beach berm. Depending on the magnitude of the preceding storm, this beach building process can occur over a time scale of days to years.

Onshore/ offshore sand movement can also be caused by wind, particularly manifested as landward sand drift into dune areas (see **Section 4.10**) for further discussion on aeolian sand movement).

4.6.1 Storm Demand

The amount of sand which can be removed from a beach during a storm event, and transported offshore, is referred to as the storm erosion demand or simply 'storm demand'. This quantity is generally measured above 0 m AHD (approximately mean sea level), and is usually expressed as a volume per m length of beach (m^3/m). Knowledge of the storm demand for a beach allows estimation of the amount of material required to be held in reserve for a storm in order to protect a given asset. It also allows estimation of the degree to which a beach would be eroded, or cut back, in a storm for a given pre-storm beach profile.

The reason that the storm demand is generally measured above 0 m AHD is a reflection of the manner in which the data to describe storm demand has been obtained. Storm demand estimates are typically derived from survey or photogrammetric techniques, where only that portion of the beach above mean sea level is either considered or is visible. The storm demand or the extent of erosion along the beach in any given event is based on a broad range of factors that include, but are not limited to:

- wave height, period and direction of storm waves;
- tidal conditions (i.e. spring or neap tidal range and the phase of the tide at the peak of the storm);
- co-incidence with elevated ocean water levels (storm surge and wave setup);
- duration of the event;
- exposure and orientation of the beach;
- state of the beach and surf zone bars before the storm;
- presence of rip cells;
- topographic features (e.g. adjoining headlands), reefs and coastal structure that affect surf zone dynamics; and
- climatic influences such as El Niño and La Nina episodes.

Due to the lack of measured data on historical storm bite[4] volumes it is difficult to assign a statistical design ARI value for storm demand. Several of the aforementioned factors have statistical ARI design values and have been used (e.g. waves and elevated water levels) as surrogates for estimating design storm demand. For example the 100 year wave heights and water levels have been used with numerical models as a surrogate to derive the 100 year ARI storm demand. In fact these approaches are unlikely to provide a 100 year ARI storm demand due to physical processes that are neglected in these models. As such it is typical to consider the largest measured storm bites at similar exposed locations and apply these as upper bound allowances for planning purposes, in accordance with the precautionary principle.

Chapman *et al.* (1982) considered that major erosion generally occurred during a phase of erosive conditions, with a final culminating storm. For most beaches the storm demand is likely to vary along the length of beach for any given storm event.

4.6.2 Estimate of Storm Demand

Gordon (1987) estimated that for the exposed NSW beaches the storm demand above 0 m AHD for a 100 year ARI event ranged from 140 m^3/m to 220 m^3/m, for open beaches and rip heads, respectively. In practice, in any one storm, more severe erosion would occur at discrete locations corresponding to the location of major rips.

As mentioned above, numerical modelling techniques are limited in the estimation of storm demand. Typically, one dimensional cross-shore modelling is employed to estimate a storm bite during a synthesised simulation based on design forcing inputs such as 100 year ARI wave heights and water levels. Previous experience has shown this to be misrepresentative of actual volumes. Complex three dimensional processes (particularly rip cells and hydrodynamic flows) and temporally varying conditions (e.g. a series of closely spaced storms) are not represented by this simplistic modelling.

No known measurements of storm bite are available for Nine Mile Beach and given the uncertainties involved in estimating storm demand, a precautionary approach is deemed appropriate. It is therefore recommended that a storm demand of 220 m^3/m (consistent with the storm demand for an exposed NSW beach at a rip head (Gordon 1987) generally be adopted for the entire length of the beach.

4.7 Longer Term Sand Movement

4.7.1 General

Longer term sand movement on Nine Mile Beach has been examined using photogrammetric data supplied by OEH. By considering the trends in historical beach changes, such as the volume of sand within the active beach system, the dominant long term mode of shoreline change (i.e. accretion, recession or stability) can be estimated.

[4] Storm bite refers to the volume of sand eroded from the beach during a historical event

Caution needs to be exercised in the interpretation of the information due to a number of factors, for example:

- the relatively short period of historical data (it is implicitly assumed that coastal processes over this period are representative of the longer term situation);
- the frequency and severity of storms over the time span for which the volume changes were measured;
- the typically large fluctuations in sand volumes due to storms which can often mask longer term trends;
- the influence of sea level rise which causes a reduction in the volume of sand above AHD and which has been operative over the period of the photographic record; and
- the effects of local coastal engineering structures, e.g. Wallis Lake breakwaters.

The longer term trends in sand movement are discussed below.

4.7.2 Interpretation of OEH Photogrammetry

Based on the photogrammetric data provided by OEH an assessment of the long-term trends in beach volumes and shoreline position has been completed. The aim of this assessment was to identify potential shoreline recession behaviour at Nine Mile Beach. Trends in shoreline recession were estimated in two ways:

- by assessment of changes over time in the volume of sand contained within the beach and dune system above 0 m AHD (sediment budget approach); and
- by measurements over time of the position in plan of a certain "cut" level, taken in this study as 3m AHD, through the foredune.

Details of the photogrammetry data, the analysis methodology and the results are presented in **Appendix B**.

An assessment of changes in the volume of sand contained within the active beach and dune system at Nine Mile Beach revealed that there was a gain of sand within the beach compartment between 1963 and 2008 of approximately 275 m^3/m. It should be noted that the majority of this volume increase occurred early in the data set between 1963 and 1974 in response to the training of the Wallis Lake entrance (see **Section 4.12**). Based on linear regression analysis of beach volume in all years between 1963 and 2008 the rate of accretion is 5.8 m^3/m/year. Based on a profile by profile consideration of the average profile height this equates to a progradation of the shoreline at an average rate of 1 m/year. **Figure B.1** (**Appendix B**) shows a plot of the average beach volume at each year of profiles.

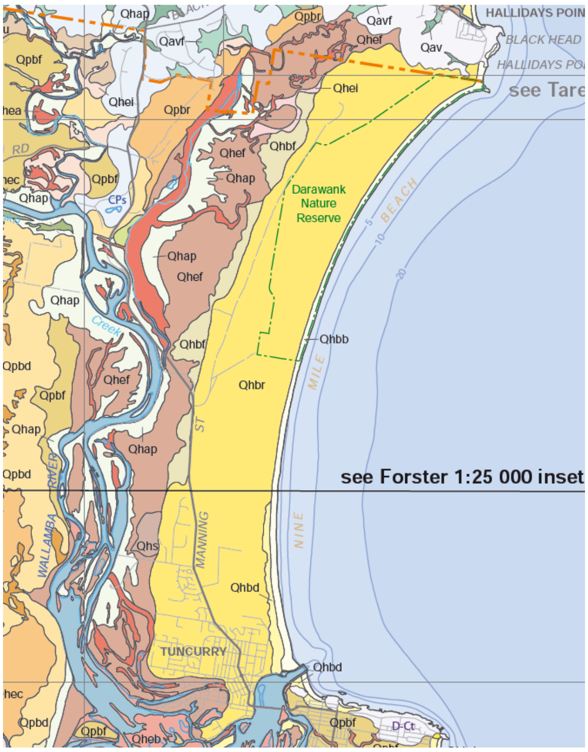
Similarly, assessment of the position of the 3 m AHD contour shows that over the long term (1962 to 2008) the rate of progradation of the Tuncurry Beach shoreface has been over 1 m/year. However, in recent years, as the sediment supply from Wallis Lake has diminished, this progradation has not been evident. The last 14 years of photogrammetric analysis (1994 – 2008) indicates recession of up to 2.0 m/year at some locations (see **Figure B.2**).

SMEC (2013) undertook a detailed photogrammetric analysis for the beaches of the then Great Lakes LGA, including Nine Mile Beach. The findings of that assessment, which has been adopted by MidCoast Council, were similar to those reported herein, with a measured beach progradation rate of 1 m/year but with a noticeable slowing in the rate of progradation evident in the most recent photogrammetry data.

Typically, when undertaking photogrammetric analysis, the longest time period is considered to minimise the influence of short term fluctuations (due to individual storm events) on long term trends. In the case of Tuncurry Beach with the obvious anthropogenic influence of the extension of the breakwaters at the Wallis Lake entrance in the 1960s, analysis of the longest time period may be misleading. Significant net accretion/ progradation has occurred over the period 1963 to 2008 which is reflected in the volume and shoreline position change rates for this period. However, progradation has occurred at a steadily decreasing rate to the point where analysis of the period 1986 to 2008 indicates the reversal of the trend, such that a net recession of the shoreline is occurring. The processes influencing this phenomenon are discussed further in **Section 4.12**.

4.8 Geotechnical Conditions

Figure 4.4 provides a brief outline of the main coastal geological features within the study area. The site and surrounding area is predominately made up off quartz marine sands with the deposits being laid during the Holocene period.



Reference

Qhap - Holocene floodplain;

Qhbb - Holocene sandy beach;

Qhbd - Holocene dune, marine sand;

Qhbf - Holocene backbarrier flat;

Qhbr - Holocene beach ridge;

Qhef - Holocene tidal-delta flat;

Qpbd - Pleistocene dune, marine sandy indurated sand;

Qpbf - Back barrier flat;

Qpbr - Pleistocene beach ridge;

Qpbdr - Bedrock mantling dune.

D-Ct - Devonian to Carboniferous sedimentary rocks (Tamworth Belt);

Figure 4.4 Coastal Quaternary Geology of Study Area (NSW DPI 2004)

No offshore rocky features exist in the proximity of Nine Mile Beach, with the entire beach made up of exposed marine sands.

A geological investigation was undertaken as part of the WorleyParsons' *North Tuncurry (NSW) Residential Land Development Soil Contamination Investigation* (2010a). The study concluded, based on boreholes undertaken, that the site is made up of quartz-rich marine and aeolian sediments. Similarly, the *Douglas Partners Geotechnical Investigation* (1988) also indicated that the site is predominantly sand.

4.9 Climate Change

Potential climate change impacts include sea level rise, increased rainfall frequency and intensity, increased coastal storms and storm surge and changes to local wave climate. Examples of climate change considerations are discussed below and are mentioned separately within each technical component.

Sea Level Rise - The principal impact of climate change on the North Tuncurry site will be associated with the predicted rise in mean sea level. Relative to the level over the period 1986 - 2005, global average mean sea level is predicted to increase by 0.28 to 0.82 m by to the period between 20812100, depending on the scenario assumed for greenhouse gas emissions (IPCC, 2014). A recent study (McInnes et al, 2007) predicted that the future sea level rise along the NSW coast will be slightly higher than the global averages, with an estimated upper limit contribution of 12 cm by 2070. The former NSW Department of Environment, Climate Change and Water (*DECCW, now OEH*) adopted a *Sea Level Rise Policy Statement* (DECCW, 2009) which adopted a sea level rise planning benchmark for the NSW coastline based on the upper limits of the most credible national and international projections. The NSW sea level rise planning benchmark was for an increase above 1990 mean sea levels of 0.40m by 2050 and 0.90m by 2100. While the benchmark is no longer NSW Government policy, Mid Coast Council in the Great Lakes Coastal Hazards Study (SMEC 2013) have adopted these sea level rise benchmarks for planning purposes as part of their overall Great Lakes Coastal Zone Management Plan.

***Storms* –** Recent research has pointed to a potential increase in the frequency and intensity of storms along the NSW coast as a result of climate change. Changes to the storm patterns will impact on extreme rainfall events and coastal storm surge events. DECC (2007) indicate that increases in design rainfall intensities of between 10% and 30% should be considered when assessing long-term flooding. An increase in storm surge may impact on the design tailwater conditions for flood modelling and was considered in accordance with DECC (2007). Increased frequency and intensity of coastal storms will impact on coastal erosion, this was considered in assessing long term coastal hazard lines.

***Wave Climate* –** The local wave climate at Nine Mile Beach may alter as a result of climate change. The local wave climate is the dominant morphological forcing for most ocean beaches along the NSW coastline. The potential for shoreline rotation and changes to the beach alignment is discussed in **Section 4.12**.

4.9.1 Sea Level Rise

The principal impact of climate change on coastal processes at Nine Mile Beach site will be associated with the predicted rise in mean sea level. The latest research on the evidence of sea level rise indicates that we are currently tracking at the upper end of the Intergovernmental Panel on Climate Change's (IPCC) predictions. Ocean thermal expansion and melting of non-polar glaciers and ice caps are the largest contributors to recent sea level rise.

Sea level projections are reported in the IPCC Fifth Assessment Report (AR5) of 2014 for a range of future emissions scenarios. The range of AR5 model projections (with a 90% confidence range) are for a mean sea level rise of 28-96 cm by 2100. The AR5 notes that sea level rise will not be uniform across regions. By the end of the 21st century, it is very likely that sea level will rise in more than about 95% of the ocean area.

Increases in sea level will not occur uniformly across ocean basins, with some regions experiencing higher levels of sea level rise and others lower. Variations in the mean sea level anomaly are the result of spatial variations in the thermal expansion of the ocean due to large scale atmospheric and oceanographic circulation patterns. A recent study found the future sea level rise along the NSW coast will be slightly higher than the global averages, with an upper estimate of 12 cm by 2070.

The NSW Sea Level Rise Policy Statement 2009 was repealed in September 2012 and prescribed state-wide sea level rise benchmarks no longer apply to coastal hazard assessments. The NSW Government indicated that local councils should adopt sea level rise values that are “widely accepted by competent scientific opinion” (OEH, 2013). MidCoast Council in the Great Lakes Coastal Hazards Study (SMEC 2013) adopted an increase above 1990 mean sea levels of 0.40 m by 2050 and 0.90 m by 2100. This level accords with the benchmarks in the former NSW Government Sea Level Rise Policy.

4.9.2 Other Climate Change Considerations

Another potential outcome of climate change is an increase in the frequency and intensity of storm events. Modest to moderate increases in average and maximum cyclone intensities are expected in the Australian region in a warmer world. However, cyclone frequency and intensity are strongly associated with the El Niño/ Southern Oscillation (ENSO) phenomenon. How this phenomenon will vary in a warmer world is currently unknown (CSIRO, 2001; CSIRO Marine Research, 2001).

Mid latitude storms have been predicted to increase in intensity but decrease in frequency with global warming (CSIRO, 2002), due to a reduction in equator to pole temperature gradients. However as with tropical cyclones, climate modelling at present lacks the resolution to accurately predict changes associated with global warming.

If overall weather patterns change as a result of global warming, there is potential for change in the angle of approach of the predominant wave climate (Moratti and Lord, 2000). For some beaches this may cause realignment of the shoreline, with resulting recession and accretion.

Given the above uncertainty and difficulty in quantitative prediction, no specific account was taken of any potential changes to storm frequency and intensity, or changes in wave directions. However, the potential for these effects to occur needs to be continually reviewed as more information develops in the scientific community.

4.10 Aeolian (Wind) Sand Movement

Aeolian sand transport can occur at beaches when dry sand is entrained by surface winds, particularly if the dunes are not densely covered by vegetation. Sand drift is the result of aeolian movement of beach sediment, and as such can be controlled to a large extent by the presence of a well vegetated foredune. Sand drift leads to a number of hazards depending on the volume of sand involved. For low sand volumes, sand drift is only of nuisance value. However, for high sand volumes it can represent a permanent loss of sand from the active beach system, thereby causing shoreline recession (if the sand moves landward beyond the foredune[5] into the hinddune), and can result in abrasion, burial, blockage and damage to coastal developments (NSW Government, 1990).

[5] The foredune is the larger and more mature dune lying between the incipient dune (generally characterised by grasses) and hinddune area (generally characterised by trees and understorey species). Foredune vegetation is characterised by grasses

It is important to recognise that dune vegetation is necessary to stabilise dune systems and protect them from wind erosion. Should impact from human activities on the dunes at Nine Mile Beach increase in the future, there is the potential for landward sand drift to occur, with resulting shoreline recession. As noted by the NSW Government (1990), the likely direction of sand drift (where it occurs) on the NSW North Coast is to the north-west.

Analysis of historical aerial photography has indicated that vegetation coverage over the entire study site including the frontal dune has becoming increasingly dense since approximately 1980. Specific inspection of the length of foreshore adjacent to the site undertaken in December 2009 generally indicated dense dune vegetation containing a variety of native dune species stabilising the dune area along the majority of the site. If this vegetation is preserved, it is unlikely that a large amount of sand drift would occur at the site. However, vegetation along the northern portion of the site foreshore, approximately 1 km east of Council waste transfer station, is less dense and is patchy in places. In addition, relatively high 4WD activity is evident as informal "access tracks" along the beach in the fore and hinddune areas.

There are a number of "access tracks" visible in aerial photographs which run perpendicular to the beach alignment terminating at the beach (or linking to beach parallel tracks) after cutting through the dune vegetation.

4.11 River Entrances

The southern end of Nine Mile Beach terminates at the training wall of the Wallis Lake entrance/ Cape Hawke Harbour entrance. The position of this entrance is considered relatively stable due to the engineering works and does not pose a potential hazard to the study area.

The training of the Wallis Lake Entrance has resulted in an increase in the volume of sediment available for Nine Mile Beach, the effects of this are discussed in **Section 4.12**.

4.12 Regional Processes

4.12.1 General

The coastline from Cape Hawke in the south to Black Head in the north (refer **Figure 4.5**) represents a coastal processes compartment containing the study area. This regional compartment is complicated by the presence of the dynamic Wallis Lake estuary entrance and the anthropogenic influence of training works undertaken to stabilise the entrance for navigational purposes.

Sediment transport in this coastal compartment can be characterised by a net northerly littoral drift of relatively small magnitude. Others have quantified the regional sediment transport rate in the order of

and shrubs. Foredunes provide an essential reserve of sand to meet erosion demand during storm conditions. During storm events, the foredune can be eroded back to produce a pronounced dune scarp (NSW Government 1990).

30,000 m^3/yr. In the absence of the required data to further quantify sediment transport rates this estimate has been adopted for the purposes of this study.

A conceptual model of the regional processes occurring between Cape Hawke and Black Head is presented in **Figure 4.5**. Potential relative sediment transport rates are indicated by the relative magnitude of arrow lengths. Further explanation of these processes is provided below (from south to north).

It is important to note that the conceptual model attempts to summarise the long term average condition. Event based conditions may occur which would appear to contradict this model, especially where complex local coastal features exist, e.g. Wallis Lake estuary entrance. Additionally, climate change impacts have not been considered in the conceptual model.

The planform of a sandy coastline is shaped by the *actual* alongshore sediment transport processes. The magnitude of the *potential* alongshore transport at any place depends on the incident wave conditions, the offshore topography, and the coastal alignment. However, the *actual* rate of transport depends on the volume of sand available to be transported by this *potential*. Where the supply of sand exceeds the amount the waves can potentially transport, sand is deposited and the foreshore progrades. Conversely, where the supply is less than the amount waves can potentially transport, sand is eroded from the beach and the foreshore recedes.

In an equilibrium system, sediment supply is relatively unchanged and coastal planform is related to the driving forces (or potential transport) along the beach. **Section 4.5** included a discussion on the evolution of zeta form embayments, in which recession occurs progressively from south to north. However, for this particular stretch of coastline the anthropogenic influence of the construction of the training walls and breakwaters at the entrance to Wallis Lake (and ongoing modifications) has created a system that is not in equilibrium.

The construction has caused a significant perturbation in the supply of sediment to the adjacent downdrift foreshore (Nine Mile Beach) such that coastal planform is currently driven by this supply mechanism. Significant volumes of sand once held in the entrance compartment, in equilibrium with the coastal and estuarine processes (periodic flooding), have been mobilised by the increased hydraulic efficiency of the trained entrance. Initially sand deposited on the offshore entrance bar was moved onto the downdrift foreshore by wave processes, at a much greater rate than could be moved further north. This reducing rate of transport in the northerly direction resulted in a prograding shoreline (see **Section 4.7.2**) in contradiction to the classic zeta from embayment evolution.

As is discussed in **Sections 4.7.2** and **4.12.2**, there is some evidence to suggest that the excess supply of sediment from the entrance compartment in recent times has slowed and may no longer be controlling the rate of transport. Without the excess sediment supply, the planform of the coastline that has resulted is out of balance with the driving forces and may lead to readjustment until a new equilibrium is reached. The supply of sediment from the entrance compartment may continue to reduce until the actual sediment supply is less than the amount which potentially could be moved further north by the processes that exist in the southern portion of the beach. The resultant increasing rate of transport in the northerly direction would cause a return to the evolution of a zeta form embayment (recession progressively from south to north).

Cape Hawke to the south of the study area is a significant coastal feature marking the northern extremity of the next significant beach compartment to the south. Sand by-passing of this feature by littoral drift is considered to be limited. To the north of Cape Hawke, the foreshore is predominantly rocky with a few intermittent pocket beach compartments until the Wallis Lake Entrance area/ Forster Main Beach and Nine Mile Beach. Sand by-passing of this rocky foreshore area by littoral drift is also considered to be limited. As such the net supply of sediment to the Nine Mile Beach compartment (including Forster Beach and the entrance area) from the south is considered to be limited.

4.12.2 Wallis Lake Entrance

The southern (Forster) breakwater was constructed in 1898. While improving the tidal conveyance somewhat, entrance navigability was often compromised and, in 1966, the southern breakwater was extended some 90 m and the 460 m northern (Tuncurry) breakwater was constructed.

Training of the entrance increased the hydraulic efficiency, while also increasing scour within the harbour. More sediment from the harbour was transported to the north onto Nine Mile Beach. The effects of the increased sediment load is evident in the photogrammetry profiles with the beach in close proximity to the break walls, prograding 200 m.

According to Nielsen (2006), the tidal range within the Wallis Lake estuary has increased due to the breakwall construction, reflecting the increased hydraulic efficiency of the entrance. Nielsen and Gordon (2008) undertook a hydraulic stability analysis of Wallis Lake and found that the tidal range within the Lake has continued to increase, with little sign of abating. They found that the increase in spring tidal range was linear between 1987 and 2004, and that at that rate, the inlet flow area would increase to 5000 m^2 and would take approximately 375 years to reach equilibrium. Thus, the entrance will continue to supply sediment to the adjacent beach compartments for the foreseeable future, though the rate of this sediment supply may reduce over time as the channel flow area approaches equilibrium.

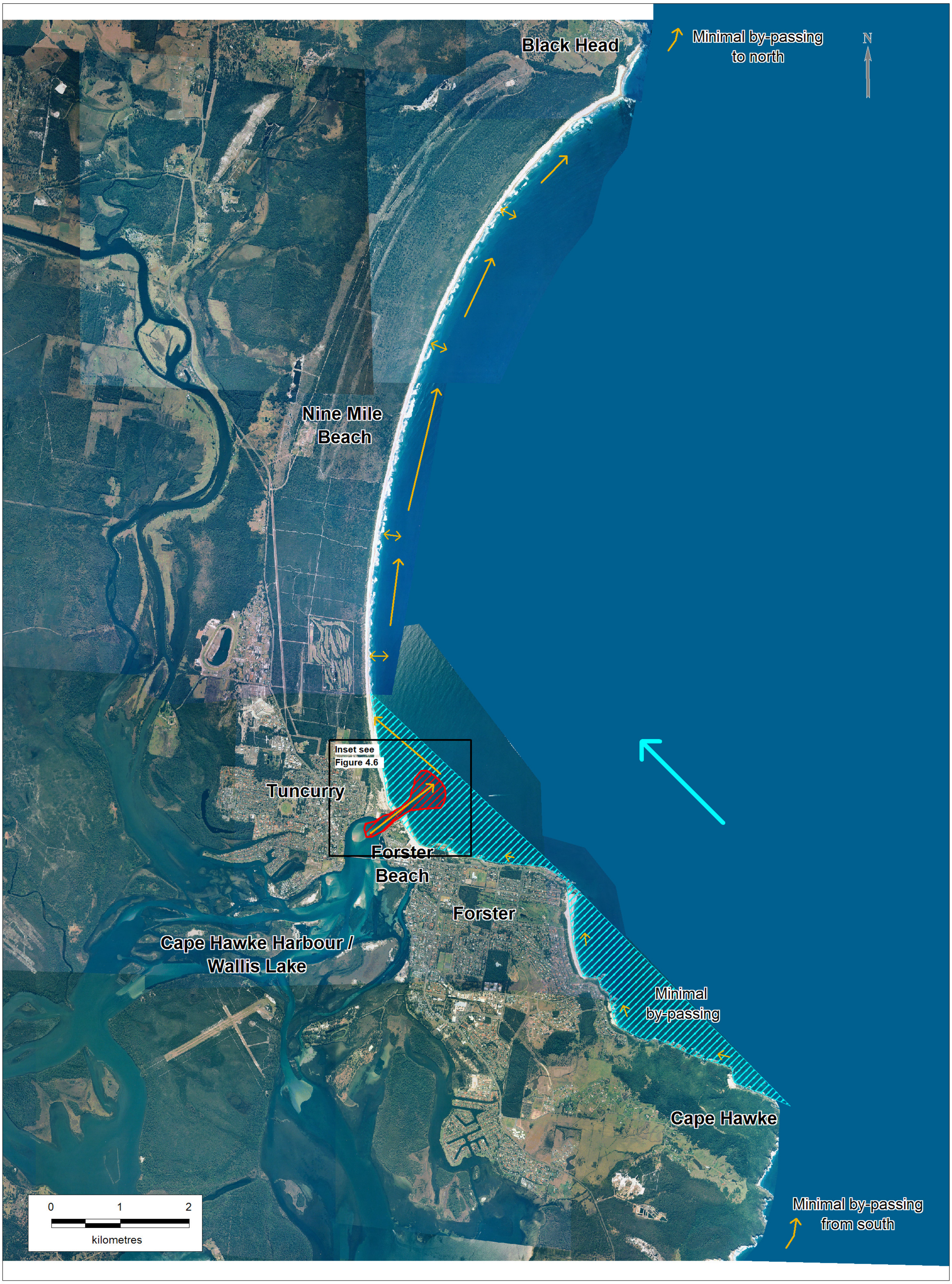
A conceptual model of the local complexities in coastal processes occurring in the immediate vicinity of the harbour entrance is presented in **Figure 4.6.**

A significant planform feature is the occurrence of a sediment transport node point evident approximately 500 m north of the northern entrance breakwater where sediment is moving onshore from the offshore entrance bar under the influence of local breaking wave processes. Either side of this point the direction of net sediment transport reverses. Southward movement occurs south of the node point due to lateral expansion currents (caused by a differential in wave heights as a result of the diffraction/ refraction wave shadow in the lee of the entrance bar) and northward movement north of the node point due to the net weighted average wave direction being at an angle to the beach alignment.

Analysis of photogrammetric data indicates that this node point prograded in absolute terms until about 1986 indicating a net supply of sediment from offshore. However, since 1986 its absolute location has remained static, with the adjacent areas (both north and south) receding relative to this point. This suggests that sediment supply to this location has reduced such that there is a zero net sediment budget at this location (see **Figure B.1**). This observation supports the theory that the entrance compartment is reaching an equilibrium state and that sediment supply to the adjacent beach compartment is diminishing.

4.12.3 Conceptual Coastal Processes Model

Figures 4.5 and **4.6** summarise the conceptual coastal process model for the coastal compartment between Cape Hawke and Black Head.



Weighted average wave direction

Net sediment transport (length is indicative of relative magnitude of transport potential)

Wave diffraction / refraction "shadow"

Net sediment supply from Wallis Lake

LANDCOM

WorleyParsons resources & energy

Landcom
North Tuncurry Coastal Hazard Study
Conceptual Model
Regional Processes

September 2010

Figure 4.5

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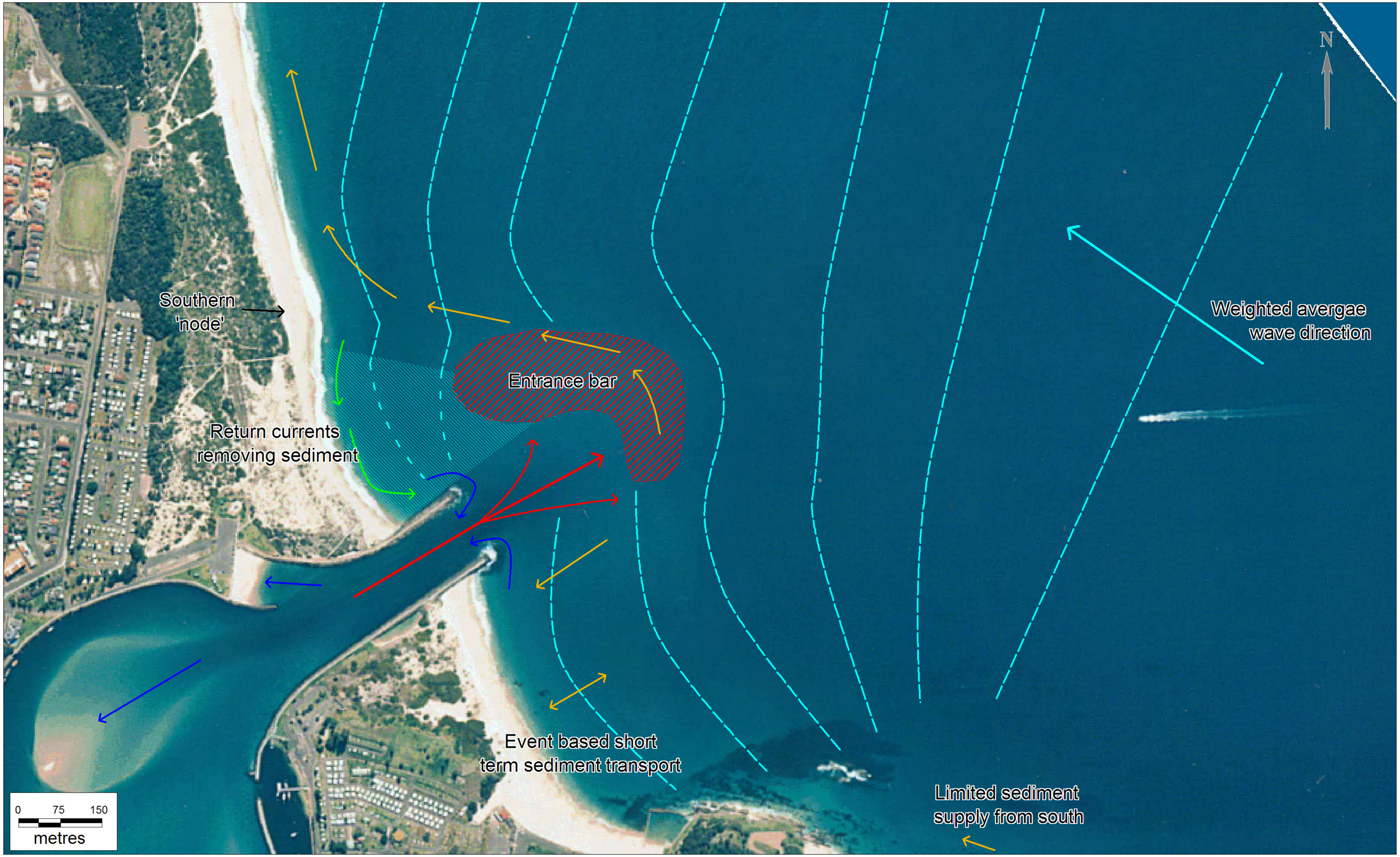

Net sediment transport
Ebb tide sediment jet supply
Flood tide sediment return
Wave return currents
Net sediment supply from Wallis Lake
Average wave defraction / refraction
Reduced wave height

LANDCOM
WorleyParsons
resources & energy

Landcom
North Tuncurry Coastal Hazard Study
Conceptual Model
Wallis Lake Entrance

September 2010

Figure 4.6

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5 COASTLINE HAZARD ASSESSMENT

5.1 Overview

The NSW *Coastal Management Act 2016* identifies the following coastal hazards for open coast areas:

- beach erosion
- shoreline recession
- coastal lake or watercourse entrance instability
- coastal inundation
- coastal cliff or slope instability
- tidal inundation
-

The NSW Coastal Management Manual (OEH 2018) also notes that climate change should be taken into account in the consideration of management options. Climate Change impacts and hazards relevant to the site are discussed in turn in the following sections (the stability of Wallis Lake entrance was addressed in **Section 4.12.2**). The assessment of the hazards often draws upon the information set out in the preceding sections.

5.2 Beach Erosion Hazard

During storms, large waves, elevated water levels and strong winds can cause severe erosion to sandy beaches (NSW Government 1990). The hazard of beach erosion relates to the limit of erosion that could be expected due to a severe storm, or from the effects of a series of closely spaced storms.

The erosion can be measured in terms of the volume of sand transported offshore or in terms of the landward movement of a significant beach feature. The volume is usually expressed in terms of cubic metres per metre run of beach (m^3/m), as measured above Mean Sea Level (MSL) or Australian Height Datum (AHD). The significant beach feature is usually taken to be the back beach erosion escarpment.

The beach erosion hazard is analogous to the "storm demand" discussed in **Section 4.6.2**. It has previously been established, based on work by other researchers and experience, that the storm demand or beach erosion hazard for exposed beaches, such as Nine Mile Beach, can be as high as 220 m^3/m (see **Section 4.6.2**). Based on the precautionary principle, the conservative value of 220 m^3/m has been adopted for planning purposes for this site.

The adopted value is consistent with the design storm erosion demand volume of 230 – 240 m^3/m assessed by SMEC (2013) and adopted by MidCoast Council in the Great Lakes CZMP (2016).

5.3 Shoreline Recession Hazard

The hazard of shoreline recession is the progressive landward shift in the average long term position of the coastline. The two causes of shoreline recession are sediment loss and an increase in sea level.

Sediment Loss - Recession of a sandy beach is the result of a long term and continuing net loss of sand from the beach system. Recession tends to occur when:

- the outgoing longshore transport of sediment from a beach compartment is greater than the incoming longshore transport of sediment;
- offshore transport processes move sand to offshore “sinks” (beyond the active beach system) from which it does not return to the beach; and
- there is a landward loss of sediment by wind (aeolian) transport.

Sea Level Rise - A progressive rise in sea level will result in shoreline recession through two mechanisms: first, by drowning low-lying coastal land, and second, by shoreline readjustment to the new coastal water levels. The second mechanism is probably the more important: deeper offshore waters expose the coast to attack by larger waves; the nearshore refraction and diffraction behaviour of waves will change; a significant volume of sediment will move offshore as the beach adjusts to a new equilibrium profile. Sea level rise is discussed in more detail under The Hazards of Climate Change in **Section 5.7**.

Shoreline recession is typically a long term process which, in some cases, is imperceptible. Its effect on a beach is often masked by the more rapid and dramatic erosion and accretion that accompanies storm events. Consequently, it can be difficult to identify recession from historical data, even if it extends over many years.

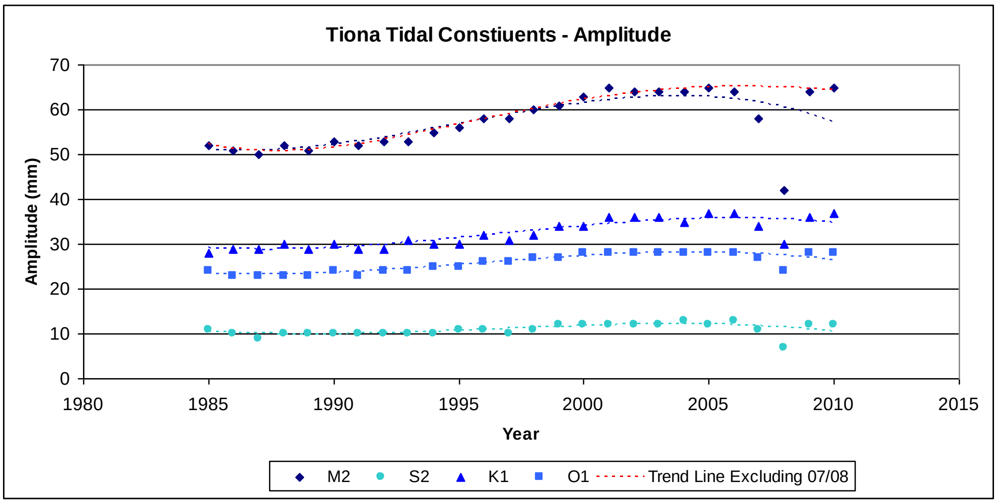
The hazard of shoreline recession is the progressive landward shift in the average long term position of the coastline (NSW Government 1990). The two potential causes of shoreline recession identified above are discussed in **Sections 5.3.1** and **5.3.2** respectively. It is also appropriate to discount the historical recession due to net sediment loss by taking into account the actual sea level rise that occurred during the measurement period, as discussed in **Section 5.3.3**.

5.3.1 Long Term Recession Due to Net Sediment Loss

The analysis of photogrammetric data at Nine Mile Beach showed that there is no net sediment loss from the beach. Rather, the shoreline has been observed to be prograding at a rate of over 1m/year over the long term. It is not considered appropriate to adopt a prograding trend for planning purposes. Changes to the wave climate due to climate change or sediment supply, a severe storm event or simply the Wallis Lake entrance channel reaching an equilibrium condition could see the current prograding trend cease or be reversed in the future. There is some evidence in this particular case that this is already occurring due to the reduction in sediment supply from Wallis Lake, as the entrance compartment reaches an equilibrium state following training by breakwaters (see **Section 4.7.2** and **Section 4.12**).

While the long term trend has been of progradation, there have been periods within the approximate 50 years of record when recession of the beach has been observed. The analysis of photogrammetry indicates that this is not simply a short-term fluctuation but a trend of reducing progradation and reversal to a receding beach state. This is neglecting the impact of sea level rise which is discussed below.

Analysis of the tidal range within Wallis Lake indicates that the trained entrance compartment is approaching an equilibrium state, as per the findings of Nielsen (2006). **Figure 5.1** provides four tidal constituents for the Tiona water level gauge (Tiona is located to the south of Forster-Tuncurry). A trend line, excluding the anomalous values from 2007 and 2008, has been provided. Based on this data it is estimated that equilibrium of the entrance system may be reached soon. However, further ongoing analysis of tide data at Wallis Lake by Nielsen & Gordon (2016) showed that the tidal range has continued to increase since 2008, indicating that the equilibrium state has not yet been reached. When equilibrium is eventually reached, the net supply of sediment to Nine Mile Beach would only be that which bypasses the entrance, or is scoured out of the entrance during extreme flood events. At Nine Mile Beach, the severity of the future response to a potentially reduced sediment supply from Wallis Lake entrance is unknown. However it is anticipated that there would be a return to a zeta shaped embayment, with progressive recession from south to north (see **Section 4.12**). Accordingly, a conservative recession rate of 1 m/yr was considered appropriate for the study area (based on an average of the recession trend in the most recent years). The adopted long term recession rate is consistent with that assessed in SMEC (2013) and accepted by MidCoast Council.



M_2 = main lunar semidiurnal constituent, S_2 = main solar constituent, K_1 = soli-lunar constituent, O_1 = main lunar diurnal constituent

Figure 5.1 Tidal Constituents for Tiona Water Level (after Nielsen, 2006)

5.3.2 Long Term Recession Due to Sea Level Rise

Bruun (1962) proposed a methodology to estimate shoreline recession due to sea level rise, the so-called Bruun Rule. The Bruun Rule is based on the concept that sea level rise will lead to erosion of the upper shoreface and deposition of this sediment offshore, followed by re-establishment of the original equilibrium profile. The beach profile is re-established by a shift landward and upward. The concept is shown graphically in Bruun (1983), and can be described by the equation (Morang and Parson 2002):

$$R = \frac{S \times B}{h + d_c}$$

where R is the recession in metres (m), S is the long term sea level rise (m), h is the dune height above the initial mean sea level (m), d_c is the depth of closure[6] of the profile relative to the initial mean sea level (m), and B is the cross-shore width of the active beach profile, that is the cross-shore distance from the initial dune height to the depth of closure (m). This means that the recession due to sea level rise is equal to the sea level rise, multiplied by the average inverse slope of the active beach profile.

Nielsen (1994) found that, based on a synthesis of field and laboratory data and analytical studies (particularly offshore of SE Australia), there were consistent limits of sub-aqueous beach fluctuations, namely water depths (relative to AHD) of:

- 12 m ± 4 m being the limit of significant wave breaking and beach fluctuations;
- 22 m ± 4 m being the absolute limit of sand transport under cyclonic or extreme storm events; and
- 30 m ± 5 m being the limit of reworking and onshore transport of beach sized sand under wave action.

The 12 m ± 4 m depth can be considered to be analogous to the depth of closure for use in the Bruun Rule, given that it is the limit of significant beach fluctuations, and consistent with formulae for its prediction[7].

[6] The depth of closure is the water depth beyond which repetitive profile surveys (collected over several years) do not detect vertical sea bed changes, generally considered to be the seaward limit of littoral transport. The depth can be determined from repeated cross-shore profile surveys or estimated using formulas based on wave statistics. Note that this does not imply the lack of sediment motion beyond this depth (Szuwalski and Morang 2001).

[7] The 12 m ± 4 m depth has been used in almost all known investigations that have utilised the Bruun Rule to determine recession due to sea level rise in eastern Australia, where the depth of closure has been related to the limit of significant long term profile changes, and where rock reef has not been present. A rare exception would be Gordon (1991), who estimated a depth of closure of 37 m relative to AHD for the coastline in the vicinity of Belmont Ocean Outfall near Newcastle.

Rijkswaterstaat (1987), approximating the work of Hallermeier (1978, 1981 and 1983), found the following simplified equation for the effective depth of closure, d_c, namely:

$$d_c = 1.75H_e$$

where H_e is the effective significant wave height exceeded for 12 hours per year (that is, the significant wave height with a probability of exceedance of 0.137%).

Bruun (1988) suggested a depth of closure of $2H_b$, where H_b is actual breaker height of the highest waves within a certain time period, namely 50 to 100 years according to Dubois (1992).

Sedimentological data consistently shows distinct changes in the characteristics of sediments with water depth. These changes include variations in grain size, sorting, carbonate content and colour. The boundary between Inner and Outer Nearshore Sand is typically found at about the 11 - 15 m depth contour (relative to AHD), while the boundary to Inner Shelf Sand (also known as Shelf Plain Relict or Palimpsest Sand) is usually at a depth of 18 – 26 m. The boundary between Nearshore (Inner and Outer) Sands and Inner Shelf Sands corresponds to those parts of the seabed considered to be active and relict (Nielsen 1994).

Nielsen (1994) reported that three studies had identified the boundary between Inner and Outer Nearshore Sand at a depth of approximately 10 m (relative to AHD) in the Byron Bay area. Other investigations by Patterson Britton and Partners (2004) and others (Nielsen 1994, Stephens 2004) along the NSW mid-north and north coast indicated a depth of closure of 10 – 11 m relative to AHD.

However, it should be noted that there are a number of limitations to the accuracy of the Bruun Rule, based on the accuracy of the estimate of the depth of closure.

As described above, there are a broad range of techniques available for estimating the closure depth and several (Hallermeier, Birkmeier, Rijkswaterstaat, USACE, Bruun etc.) idealised formulae for estimating closure depth, based on offshore wave statistics. All formulae provide differing results.

The various techniques used for estimating the closure depth for application of the Bruun rule are generally dependent on wave data. Limited availability of complete local wave data sets and variations in wave statistics from year to year therefore also limit the accuracy of the Bruun rule results. The use of historical information to assume future wave statistics also limits the application of these techniques, particularly given postulated changes to wave climate due to climate change.

It is therefore appropriate to consider a sensitivity analysis for this element of the Bruun Rule. It is common for the active beach profile slope to fall in the order of 1:50 to 1:100 for the east coast of NSW. The range of recession due to sea level rise then becomes R = 50r to 100r. It is therefore possible for the recession due to sea level rise to be up to double the amount determined using the adopted active beach slope of 1:50.

Measurements of the active beach and nearshore slopes (to depths of 40 m) for Nine Mile Beach indicate an approximate slope of 1:60. This falls within the range of that recommended for NSW open coasts, as reported in DECCW (2010a) which indicates active beach profile slopes for use in the Bruun Rule should range between 1:50 to 1:100. It is noted that MidCoast Council have adopted an active beach slope of 1:50 for Nine Mile Beach in the Great Lakes Coastal Hazards Study (SMEC 2013), which is consistent with the value determined herein.

5.3.3 Discounting of Historical Recession Rates

Shoreline recession rates determined from historical data may be influenced by any sea level rise which occurred in the period of the historical record. If this contribution is significant, the historical recession rates should be adjusted (discounted) to represent recession due to sediment loss only. This is because, in predicting the future position of the coastline, shoreline recession due to net sediment loss and shoreline recession due to sea level rise are calculated separately.

Based on analysis of average annual water levels at Fort Denison in Sydney Harbour from 1887 to 1987, the NSW Government (1990) estimated that the mean sea level rise over the 101 years of record was 0.5 mm/year. More recent estimates by Church *et al.* (2001) indicated that, for the two water level recording stations with the longest records in Australia (Sydney and Fremantle, both in excess of 80 years), the observed rates of relative sea level rise were 0.86 ± 0.12 mm/year (from 1915 to 1998) and 1.38 ± 0.18 mm/year (from 1897 to 1998) respectively[8]. The Department of Defence (1999), cited in Nielsen *et al.* (2001), estimated that the rate of relative sea level rise at Newcastle (on the NSW Central Coast), from 1967 to 1999, was 1.18 mm/year. Averaged around Australia, the relative sea level rise from 1920 to 2000 was about 1.2 mm/year (CSIRO Marine Research 2004).

Adopting a rate of relative sea level rise of 0.86 mm/year from 1965 to 2006, represented a sea level rise of 35 mm over this period. Using the adopted inverse slope of the active beach profile of 60 (**Section 5.3.2**), this was equivalent to a total shoreline recession of about 2.1 m during this time (to be subtracted from the calculated total recession, or added to the calculated total progradation). This is equivalent to an average recession of 0.04 m/year. Given the predicted low rate of recession due to historical sea level rise (together with the uncertainties in the Bruun analysis) it was not considered warranted to increase the measured progradation to account for this.

5.4 Sand Drift Hazard

As noted in **Section 4.10,** sand drift is a result of sediment loss due to aeolian (wind) movement of beach sediment, and as such can be controlled to a large extent by the presence of a well vegetated foredune. Sand drift leads to a number of hazards depending on the volume of sand involved. For low sand volumes, sand drift is only of nuisance value. However, for high sand volumes it can

[8] Corrected for land movement, the absolute rates of sea level rise at Sydney and Fremantle were about 1.2 and 1.6 mm/year respectively.

represent a permanent loss of sand from the active beach system, thereby causing shoreline recession (if the sand moves landward beyond the foredune[9] into the hinddune), and can result in abrasion, burial, blockage and damage to coastal infrastructure/ developments (NSW Government 1990). The likely direction of sand drift (where it occurs) on the NSW North Coast is to the north west.

The dune vegetation along the foreshore adjacent to the site is generally well established, mitigating this hazard. The exception is the northern most portion of the site's foreshore. Vegetation has not established as well as the remainder of the site and is subject to damage from 4WD vehicles.

Although there is no evidence of dune major blowouts having occurred, continued uncontrolled vehicular access in the dune area may further degrade the vegetation and increase the risk of sand ingress to the site.

5.5 Coastal Inundation Hazard

Coastal inundation is the flooding of coastal lands by ocean waters, which generally results from large waves and elevated water levels associated with severe storms. Severe inundation is an infrequent event and is normally of short duration, but it can result in significant damage to both public and private property (NSW Government 1990).

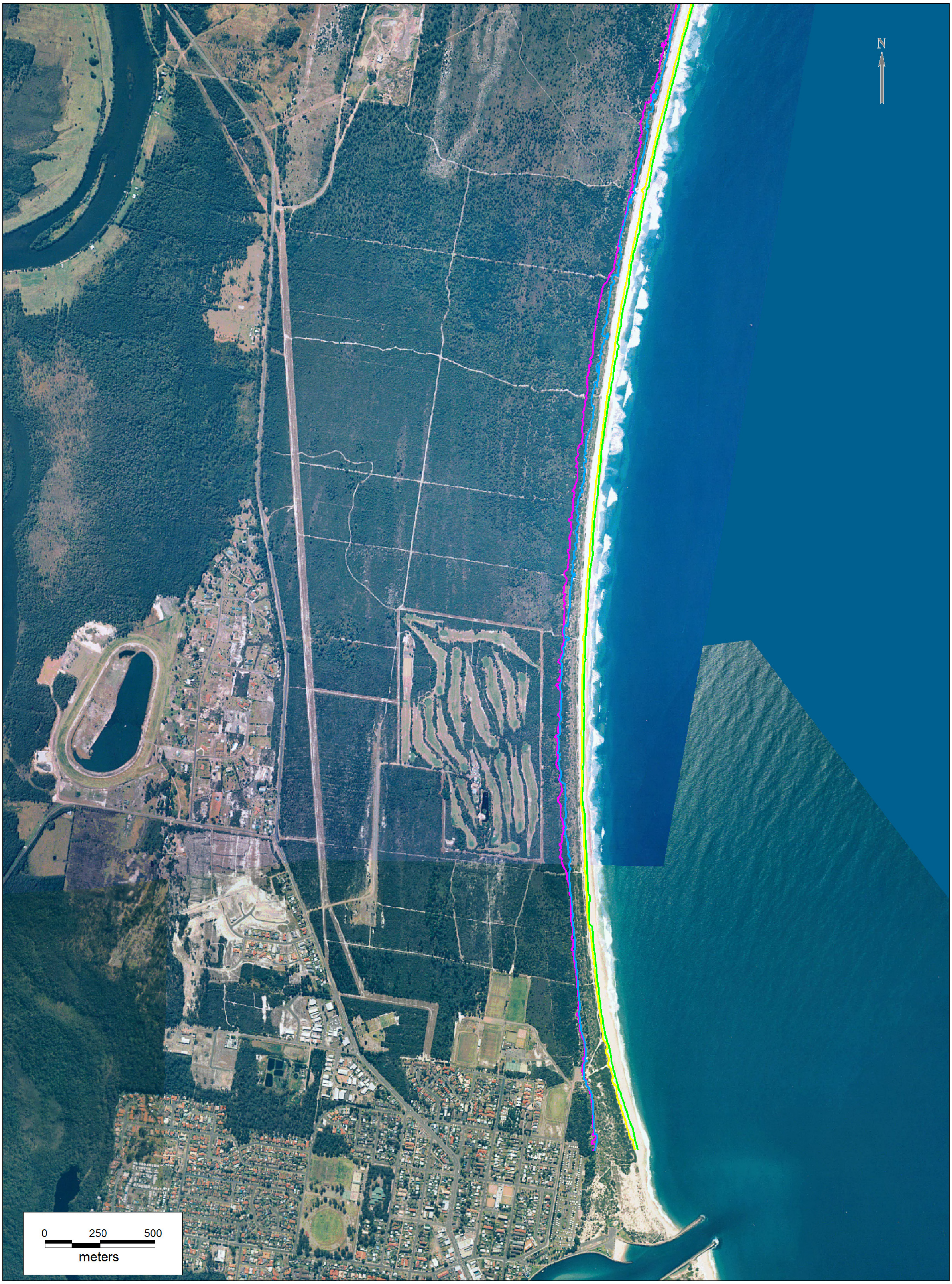
The components which give rise to elevated mean water levels at times of storms were referred to in **Section 4.2**, namely storm surge (wind setup and the barometric setup) and wave setup. This increase in water level may persist for several hours to days and can inundate low-lying beach areas and coastal creeks. A 100 year ARI total design elevated water level of 2.7 m AHD has been adopted for this study. For long term planning purposes, sea level rise (as outlined in **Section 4.9**) was added to bring the total elevated water level in the year 2100 to 3.6 m.

During storm events, individual waves cause further temporary water level increases above the still water level due to the process of wave setup and runup or uprush (**Section 4.3**). The wave runup values adopted were given in **Section 4.3**, namely 6.2 m AHD (for the 100 year ARI storm event including sea level rise). Note that MidCoast Council have adopted a 2% wave runup level of 5.6 m AHD for Nine Mile Beach (SMEC 2013), which equates to 6.5 m AHD by 2100 when a sea level rise of 0.9 m is taken into account. That value is similar to that adopted for this assessment.

The areas potentially affected by coastal inundation have been illustrated in **Figure 5.2**. From this figure it is evident that the dune system is generally sufficiently high to prevent inundation of the site due to elevated water levels and wave runup.

As discussed in **Section 4.3** runup levels in the order of 6 m AHD would only be realised if the foreshore was at this runup height or higher. In the case of low-lying areas, waves that overtopped

[9] The foredune is the larger and more mature dune lying between the incipient dune (generally characterised by grass vegetation coverage) and hinddune area (generally covered by trees and shrubs). Foredune vegetation is characterised by grasses and shrubs. Foredunes provide an essential reserve of sand to meet erosion demand during storm conditions. During storm events, the foredune can be eroded back to produce a pronounced dune scarp (NSW Government 1990).



Indicative Current and 2100 Planning Period Design Ocean Water Levels and Wave Runup Levels

- Design Elevated Water Level (2.7m AHD)
- 100-yr Design Elevated Water Level Including SLR (3.6m AHD)
- 100-yr Design Wave Runup Level (5.3m AHD)
- 100-yr Design Wave Runup Level Including SLR (6.2m AHD)

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Potential Coastal Inundation

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Figure 5.2

the dunes would fold over the crest and travel as a sheet flow at shallow depth, spreading out and infiltrating over landward areas. A significant reduction in the velocity and depth of runup would be expected within 10 m of the dune crest. In addition, wave runup and overtopping is generally episodic, occurring around the peak of the high tide. As such the duration of inundation would expected to be less than 2 hours. The affected areas would, however, become more vulnerable to inundation in the longer term as sea level rises.

5.6 Stormwater Erosion Hazard

There are no apparent coastal hazards due to stormwater for the undeveloped site, as stormwater infiltrates into the ground. There are no surface flow paths crossing the foredune and beach to the ocean. The *North Tuncurry Stormwater Constraints and Opportunities Assessment* (WorleyParsons, 2010b) outlines stormwater management options for development of the site with infiltration of all stormwater runoff within the site. As such, there would be no future coastal hazards attributed to stormwater within the site. If alternative management options were to be implemented, e.g. directing overland flow paths onto the beach, further assessment of these hazards would need to be undertaken.

5.7 Climate Change

A discussion on sea level rise associated with climate change was provided in **Section 4.9.1**. A discussion on the possibility of other effects resulting from climate change was provided in **Section 4.9.2**. Under current sea level rise projections, it is expected that shoreline recession will occur. This issue was discussed in **Section 5.3.2**, as part of the discussion on shoreline recession hazards.

5.8 Slope and Cliff Instability Hazard

Beach slope and cliff instability hazards relate to the possible structural incompetence of these features, and associated potential problems with the foundations of buildings, seawalls and other coastal works (NSW Government 1990). The study area is composed largely of sandy beach and dune areas within the active coastal zone. For such areas, based on Nielsen *et al.* (1992), a number of coastline hazard zones can be delineated as shown in **Figure 5.3**.

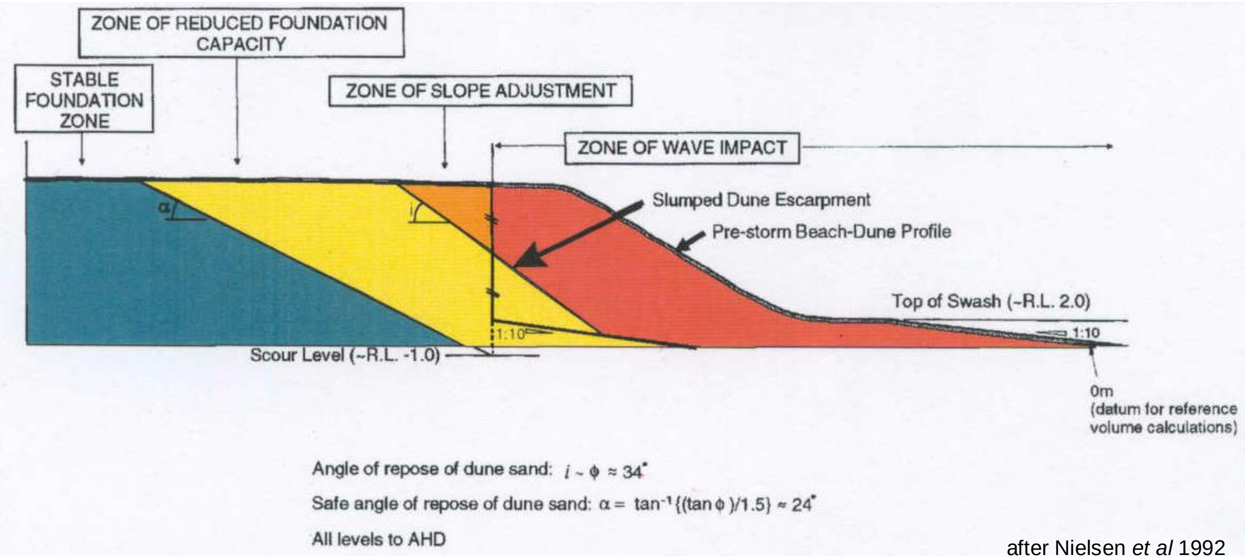

Figure 5.3 Schematic representation of coastline hazard zones

The *Zone of Wave Impact* delineates an area where any structure or its foundations would suffer direct wave attack during a severe coastal storm. It is that part of the beach which is seaward of the beach erosion escarpment.

A *Zone of Slope Adjustment* is delineated to encompass that portion of the seaward face of the beach that would slump to a natural angle of repose following removal by wave erosion of the design storm demand. It represents the steepest stable beach profile under the conditions specified (as defined by the beach erosion hazard, see **Section 5.2**).

A *Zone of Reduced Foundation Capacity* for building foundations is delineated to take account of the reduced bearing capacity of the sand adjacent to the storm erosion escarpment. Nielsen *et al.* (1992) recommended that structural loads should only be transmitted to soil foundations outside of this zone (i.e. landward or below), as the Factor of Safety within the zone is less than 1.5 during extreme scour conditions at the face of the escarpment. In general (without the protection of a terminal structure such as a seawall), dwellings/ structures not piled and located with the Zone of Reduced Foundation Capacity would be considered to have an inadequate Factor of Safety.

The coastline hazard zones for the study area are determined in **Section 6**, with the position of the Zone of Slope Adjustment and Zone of Reduced Foundation Capacity defined for the immediate, 2060 and 2100 planning periods.

6 DEFINITION OF COASTLINE HAZARD ZONES

In this Section, coastline hazard zones are defined within the study area, based on the cumulative impacts of the coastline hazards outlined in **Section 5**, in relation to erosion and recession.

Hazard zones associated with coastal storms include the wave impact zone and the Zone of Slope Adjustment and the Zone of Reduced Foundation Capacity (see **Section 5.8**)[10]. For simplicity, the landward limit of the Zone of Slope Adjustment for each of the planning timeframes has been denoted as the "Hazard Line". The position of the 2010, 2060 and 2100 hazard lines are thus the predicted position of the back beach erosion escarpment after an extreme coastal storm in 2010, 2060 and 2100 respectively, including subsequent slumping to a stable angle of repose[11].

The location of the immediate (2010) hazard line was determined by removing the storm demand volume (220 m^3/m) from an equilibrium profile. The photogrammetry year used to represent the equilibrium year was based on assessing the set of photogrammetric profiles which best fit the mean profile volumes along the beach using a least square fitting technique. This was found to be the 2008 profile for Nine Mile Beach. The volumes were applied as per Nielsen *et al* (1992); see **Figure 5.3**, on a profile by profile basis. Thus, at each profile, a position in relation to the 2010 hazard line was determined.

The Zone of Reduced Foundation Capacity was also derived for each profile. As noted in **Section 5.8**, the Zone of Reduced Foundation Capacity (ZRFC) takes account of the reduced bearing capacity of the sand adjacent to the storm erosion escarpment. In general, structures not piled and located within the ZRFC would be considered to have an inadequate factor of safety.

Note that the ZRFC was derived assuming a beach profile composed entirely of sand. If there were layers of less erodible or inerodible material, such as stiff clays and/ or rock within the ZRFC, then the extent of the Zone could potentially be reduced. However, as discussed in **Section 4.8** it is highly unlikely that less erodible material exists within the ZRFC.

The immediate, 2060 and 2100 Hazard Lines and ZRFC Lines within the study area are shown in **Figure 6.1**. It is recommended that if any development is planned seaward of the ZRFC, consideration be given to placement of structures on piers (spread footings or piles) extending into the Stable Foundation Zone as defined by Nielsen *et al* (1992), unless geotechnical conditions enable reduced foundation depths.

A comparison of the coastal hazard mapping provided in this report was made against the mapping included as part of the Great Lakes Coastal Hazards Study (SMEC 2013), which has been adopted by Council. The comparison indicated that the extents of the coastal hazards determined for this

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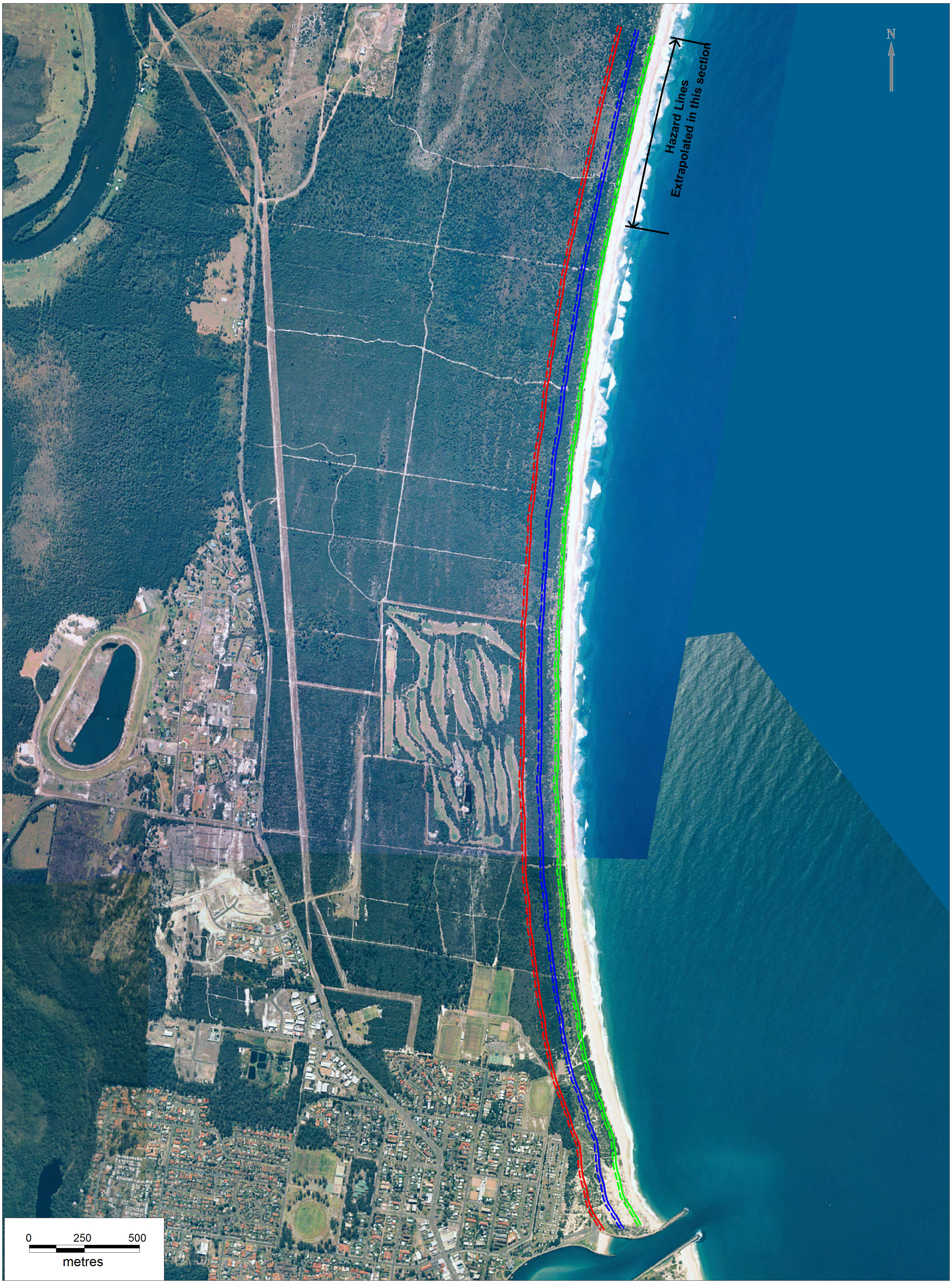
[10] The Zone of Wave Impact was also defined as part of the calculations, but is not depicted in **Figure 5.3**.

[11] That is, the Hazard Lines do not represent future predicted shorelines, but future predicted erosion escarpments after a 100 year ARI coastal storm erosion event.

investigation are very similar to those provided in SMEC (2013), and thus can be relied upon for planning purposes.



Hazard Lines

Immediate Hazard Line	2010 Zone of Reduced Foundation Capacity
2060 hazard line	2060 Zone of Reduced Foundation Capacity (indicative)
2100 hazard line	2100 Zone of Reduced Foundation Capacity (indicative)

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Immediate, 2060 and 2100 Hazard Lines
Figure 6.1

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7 SITE PLANNING RECOMMEDATIONS

7.1 Land Use

It is noted that there is no existing development at Tuncurry located within the 2100 hazard line and that current foreshore land uses west of the hazard line comprise open space (playing fields, golf course) and tourist uses comprising moveable structures. Development of the greenfield site provides the opportunity to continue this type of land use on a similar alignment and therefore provide a vegetated dune buffer zone to accommodate coastal processes.

Based on our experience in other developed areas of the coast, the most complicated risk management problems involve areas where individual residential subdivisions have occurred on an alignment that is inconsistent with the planform of the coastal embayment, i.e. where some subdivisions have been developed proud of others. Feasible physical management options for these areas are inevitably at the expense of beach amenity and may be associated with exacerbating the risk to adjacent properties. The legislative, economic and social constraints in applying management options, such as planned retreat, to private property are extremely complex and emotive.

For these reasons it is recommended that land seaward of the 2100 hazard line be retained in public ownership. This does not sterilise economic opportunities associated with the land but provides flexibility to restrict appropriate uses and building forms to a specified timeframe, through a lease or licence system. Options for lease or licence renewal also provide flexibility to continue and/ or reduce the area associated with the land use in response to the actual future impacts of sea level rise and coastline recession.

The types of land use/ building forms that could be considered in the three identified hazard zones are outlined below. The life cycle of assets (where fixed) should be consistent with the coastal planning period.

7.1.1 Immediate to 2060 hazard line

It is recommended that this area be maintained as a vegetated buffer, with controlled beach access points (possible incorporating light weight viewing platforms), surf life saving facilities (e.g. observation tower and rescue equipment storage) and dune restoration where necessary. Any structures in this zone should be able to be dismantled and moved.

It is noted that existing dune vegetation has been damaged by 4WD vehicles and this issue, together with the future location(s) of 4WD access points to the beach and along the beach, would need to be addressed to maintain dune vegetation and the safety of beach goers. It is also noted that measures to control the introduced Bitou Bush are underway and would need to continue into the future.

The maintenance of a viable dune system defence and coastal buffer has added benefits, physically, ecologically and aesthetically which can increase the perceived value of adjacent land developments.

Commercial activities, such as learn to surf schools and fitness training and beach hire (surf boards, beach chairs) and kiosks associated with SLSC facilities can provide an economic return in this zone.

7.1.2 2060 to 2100 hazard line

It is recommended that only moveable and demountable structures or structures/ buildings/ facilities with a life cycle consistent with the coastline risk (i.e. 50 years) be permitted in this zone. This could comprise public assets such as surf life saving club facilities/ public amenities, passive recreation areas and sporting fields and other uses which could be subject to a lease/ licence arrangement including private recreation (e.g. golf courses, bowling greens), cafes and kiosks, tourist/ ecotourism uses (tent platforms, moveable cabins, camping grounds).

7.1.3 Immediately landward of the 2100 hazard

As properties closest to the coast may become at risk post 2100, it is recommended that roads be orientated at right angles to the shoreline so that access could be maintained to remaining properties. It is also recommended that public infrastructure (e.g. reticulated water and sewerage mains and other buried services) be located landward of the 2100 hazard line and designed such that they could be maintained under shoreline recession post 2100. Orientating roads at right angles would assist in maintaining and modifying these services as required.

‘Planned retreat’ development controls (i.e. lapse of development consent once a trigger distance to the shoreline is reached) may need to be introduced in the future, depending on the shoreline response to climate change. Development controls should encourage light weight construction (as per DoP Coastal Design Guidelines) in consideration of climate change impacts beyond the 100 year planning period.

7.2 Coastline Planning Strategy

In considering appropriate land uses and development types in each of the above zones, it is recommended that these do not preclude the ‘rolling back’ of foreshore uses as sea level rise and coastline recession are realised.

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Appendix A Review of Historical Aerials

Historical aerials of the site, Nine Mile Beach and Cape Hawke Harbour / Wallis Lake were examined as part of the coastal assessment. The aerials date from 1951, prior to the construction of the northern training wall, to 2009.

The following distinctive features are present in the historical aerials:

1951

- Large amounts of visible sediment within the harbour.
- The southern end of Nine Mile Beach is located to the west of the present day location.
- An offshore bar is visible to the north of the entrance.

1961

- The entrance channel shows visible closing off.
- Large amounts of visible sediment in the harbour, although slightly less than the 1951 aerial.

1971

- Post construction of the northern training wall.
- The south end of Nine Mile Beach has prograded significantly.
- Reduction in visible sediment within the harbour.

1977

- Formation of southern 'node'

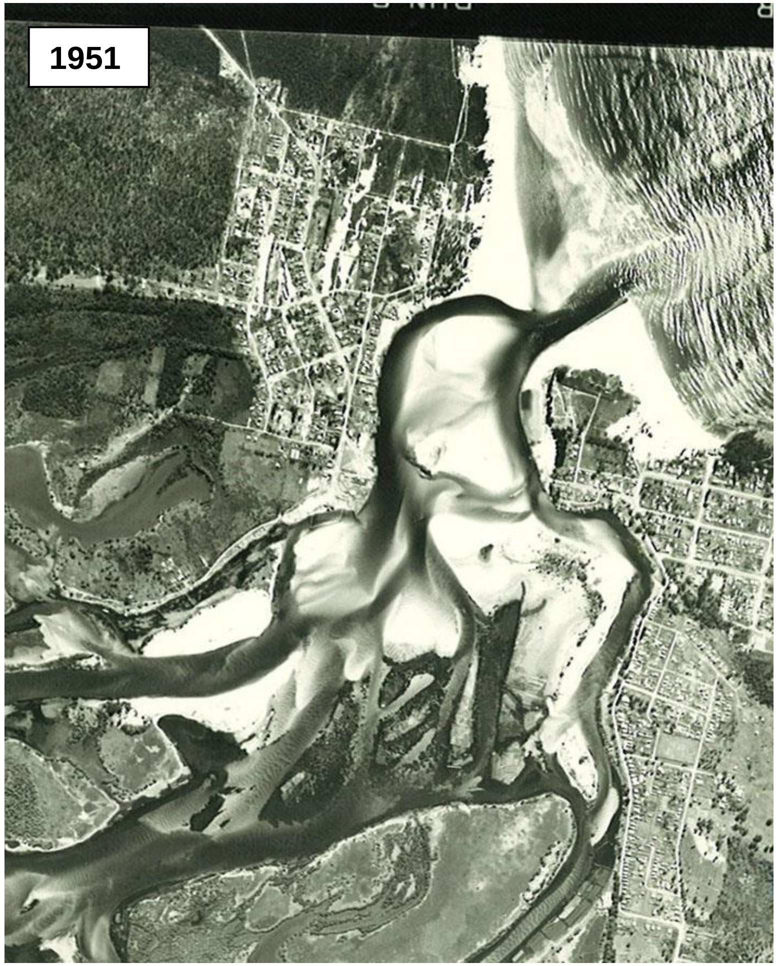
1986

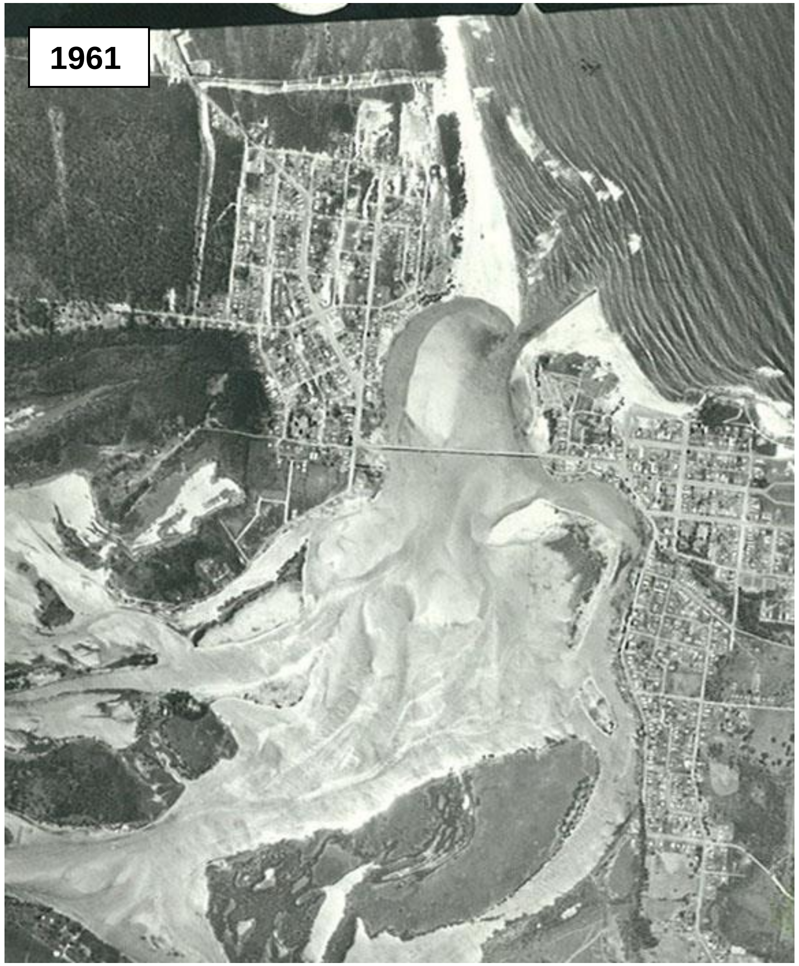
- Initial vegetation starting to take hold on new southern beach sections.

2003

- Vegetation covering new southern beach section created by the northern training wall.
- Visible lengthening between the southern 'node' and the training wall from 1980 through to the 2003 aerial.

A compilation of notable historical aerials for the area follows.

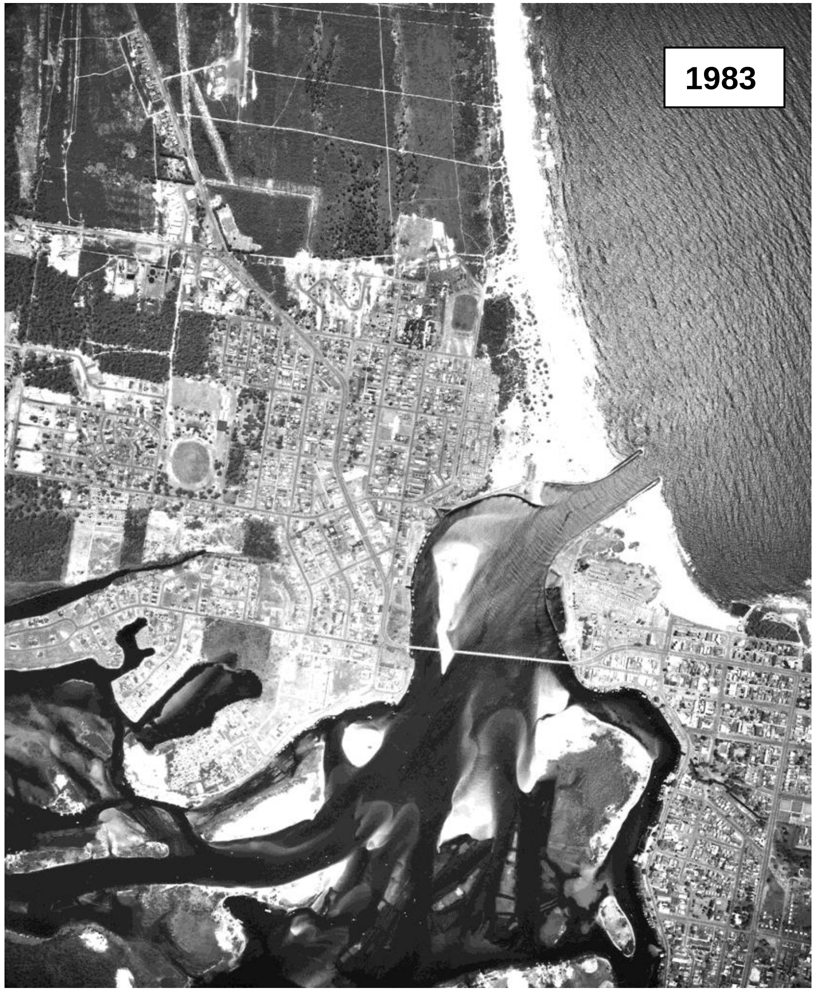

1951


1961

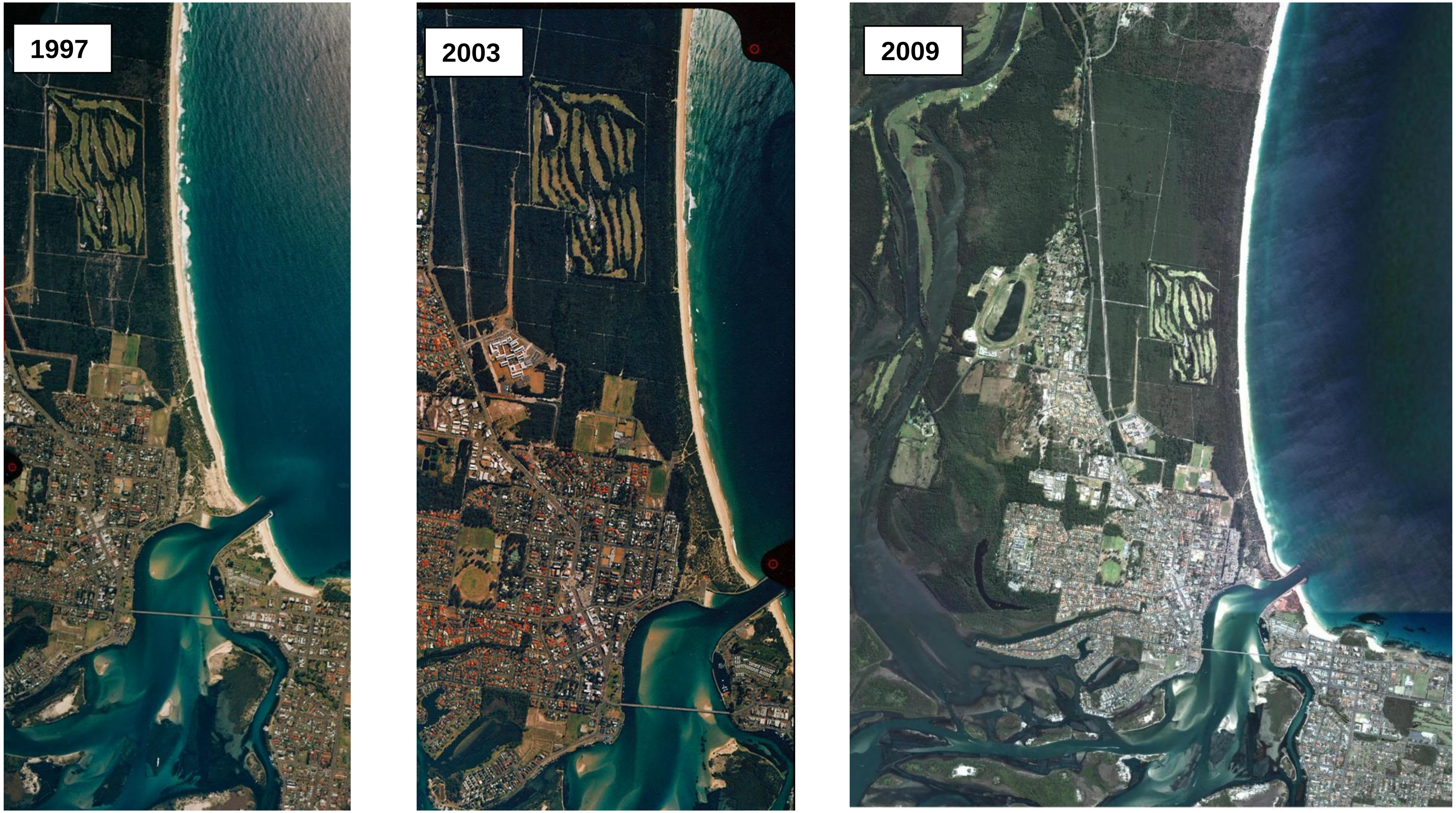

1971


1977


1980


1983


1986


1997
2003
2009

Appendix B Photogrammetric Data Assessment

B1 Introduction

The aim of the photogrammetric data assessment was to detect and measure historical changes occurring at Nine Mile Beach. OEH archives of aerial photographs, taken at regular intervals since the 1940s form the basis for this quantitative assessment.

B2 Photogrammetry

Photogrammetry is the science of measurement and data acquisition from photographic and other remotely sensed images. This appendix describes the methodology used in the analysis of the photogrammetric data as well as providing the results. Interpretation of results is discussed in **Section 5** of the main report.

The photogrammetric data used in this study was supplied by OEH. Using their AC3 stereo plotter, OEH are able to deduce an elevation model from appropriately selected vertical aerials. The supplied photogrammetry data consisted of 142 cross-shore profiles in six blocks covering the southern 4.6 km of Nine Mile Beach. The data covered the period from 1963 to 2008.

Figure B1 shows the locations of each cross-shore profile within each of the blocks. A summary of each block is provided in **Table B.1.**

Table B.1 Summary of Photogrammetry Cross-shore Profile Blocks

Block Number	Length of Coastline (m)	Number of Profiles	Profile Spacing (m)
2	360	18	20
3	560	28	20
4	1,120	28	40
5	880	22	40
6	880	22	40
7	960	24	40

B3 Analysis Methodology

The data obtained from aerial photography primarily consists of cross-sections (or profiles) of the beach and dune at the locations shown on **Figure 3.1**. Trends in historical beach change can be estimated in two ways:

- by assessment of the volume of sand contained within the beach and dune system above 0m AHD; and

- by measurements of the position of various beach features, such as the position of the back beach erosion escarpment or the position in plan of a certain “cut” level through the foredune.

Both of these approaches have been used for Nine Mile Beach. The methods used are detailed below.

Volumetric Analysis

Volumetric analysis was conducted in the following manner:

- a portion of the back beach area was removed from the profile, such that only that portion considered to be the active beach was included;
- the area under the truncated profile was determined, this is expressed as a volume of material (assumed to be sand) per metre of shoreline (i.e. m^3/m); and
- regression analysis was used to identify trends in historical beach volumes and net beach volume changes were quantified.

A plot showing the average beach volume for the years of photogrammetry data is shown in **Figure B.1**.

Figure B.1 demonstrates a prograding trend for Nine Mile Beach during the early years of the data set, while an equilibrium / recession in beach volume is evident in later years.

Position Analysis

No evidence of a consistent erosion scarp feature is present in the photogrammetric profiles. As such the position of the 3 m AHD contour has been used. Position analysis was conducted in the following manner:

- the chainage of the most seaward downward crossing of the 3 m AHD contour is identified in each beach profile; and
- regression analysis is used to identify trends in historical shoreline position based on the 3m contour.

A plot showing the results of the regression analysis for beach position change over the entire photogrammetry data set are shown in **Figure B.2**.

Negative values indicate a recessive / erosion trend while positive values indicate a prograding trend.

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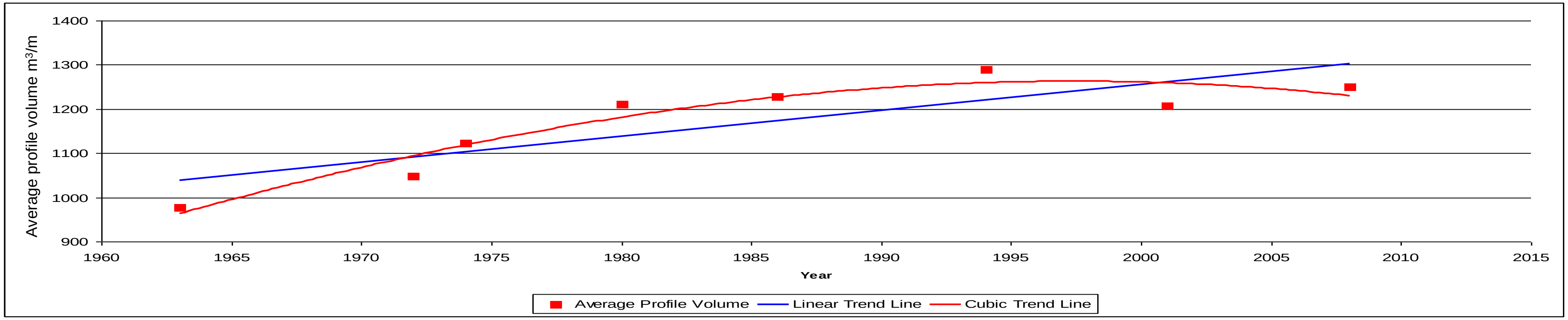

Figure B.1 Average beach volumes

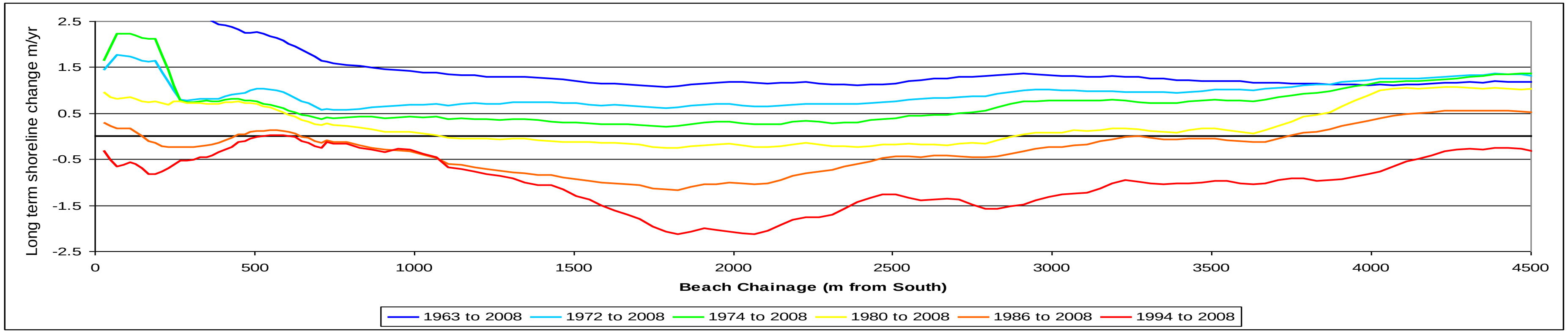

Figure B.2 Annual rate of shoreline position change

GLOSSARY

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

Flood tide	A non-technical term used for rising tide or flood current. In technical language, flood refers to current. The portion of the tidal cycle between low water and the following high water.
Geomorphology	That branch of physical geography that deals with the form of the Earth, the general configuration of its surface, the distribution of the land, water, etc.
High water (HW)	Maximum height reached by a rising tide. The height may be solely due to the periodic tidal forces or it may have superimposed upon it the effects of prevailing meteorological conditions. Nontechnically, also called the high tide.
Inshore	(1) The region where waves are transformed by interaction with the sea bed. (2) In beach terminology, the zone of variable width extending from the low water line through the breaker zone.
Inshore current	Any current inside the surf zone.
Inter-tidal	The zone between the high and low water marks.
Littoral	(1) Of, or pertaining to, a shore, especially a seashore. (2) Living on, or occurring on, the shore.
Littoral currents	A current running parallel to the beach, generally caused by waves striking the shore at an angle.
Littoral drift	The material moved parallel to the shoreline in the nearshore zone by waves and currents.
Littoral transport	The movement of littoral drift in the littoral zone by waves and currents. Includes movement both parallel (long shore drift) and perpendicular (cross-shore transport) to the shore.
Longshore	Parallel and close to the coastline.
Longshore drift	Movement of sediments approximately parallel to the coastline.
Low water (LW)	The minimum height reached by each falling tide. Non-technically, also called low tide.
Mean high water (MHW)	The average elevation of all high waters recorded at a particular point or station over a considerable period of time, usually 19 years. For shorter periods of observation, corrections are applied to eliminate known variations and reduce the result to the equivalent of a mean 19-year value. All high water heights are included in the average where the type of tide is either semidiurnal or mixed. Only the higher high water heights are included in the average where the type of tide is diurnal. So determined, mean high water in the latter case is the same as mean higher high water.
Mean high water springs (MHWS)	The average height of the high water occurring at the time of spring tides.
Mean low water (MLW)	The average height of the low waters over a 19-year period. For shorter periods of observation, corrections are applied to eliminate known variations and reduce the result to the equivalent of a mean 19-year value.
Mean low water springs (MLWS)	The average height of the low waters occurring at the time of the spring tides.
Mean sea level	The average height of the surface of the sea for all stages of the tide over a 19-year period, usually determined from hourly height readings.
Morphology	The form of a river/estuary/lake/seabed and its change with time.
Nearshore	In beach terminology, an indefinite zone extending seaward from the shoreline well beyond the breaker zone.
Nearshore circulation	The ocean circulation pattern composed of the nearshore currents and the coastal currents.

Nearshore current	The current system caused by wave action in and near the breaker zone, and which consists of four parts: the shoreward mass transport of water; longshore currents; rip currents; and the longshore movement of the expanding heads of rip currents.
Refraction	The process by which the direction of a wave moving in shallow water at an angle to the bottom contours is changed. The part of the wave moving shoreward in shallower water travels more slowly than that portion in deeper water, causing the wave to turn or bend to become parallel to the contours.
Rip current	A strong current flowing seaward from the shore. It is the return of water piled up against the shore as a result of incoming waves. A rip current consists of three parts: the feeder current flowing parallel to the shore inside the breakers; the neck, where the feeder currents converge and flow through the breakers in a narrow band or "rip"; and the head, where the current widens and slackens outside the breaker line.
Runup	The rush of water up a structure or beach on the breaking of a wave. The amount of run-up is the vertical height above still water level that the rush of water reaches. It includes wave setup.
SBEACH	A computer program, developed by the US Army Corps of Engineers, that is used to determine, among other things, wave transformation across the surf zone, beach and dune erosion and levels of wave runup on natural beaches.
Setup	Wave setup is the elevation of the nearshore still water level resulting from breaking waves and may be perceived as the conversion of the wave's kinetic energy to potential energy.
Shoal	(1) (noun) A detached area of any material except rock or coral. The depths over it are a danger to surface navigation. (2) (verb) To become shallow gradually.
Shore	That strip of ground bordering any body of water which is alternately exposed or covered by tides and/or waves. A shore of unconsolidated material is usually called a beach.
Shoreface	The narrow zone seaward from the low tide shoreline permanently covered by water, over which the beach sands and GRAVELS actively oscillate with changing wave conditions.
Shoreline	The intersection of a specified plane of water with the shore.
***Significant* wave**	A statistical term relating to the one-third highest waves of a given wave group and defined by the average of their heights and periods.
***Significant* wave height**	Average height of the highest one-third of the waves for a stated interval of time.
Spring tide	A tide that occurs at or near the time of new or full moon, and which rises highest and falls lowest from the mean sea level (MSL).
Storm surge	A rise or piling-up of water against shore, produced by strong winds blowing onshore. A storm surge is most severe when it occurs in conjunction with a high tide.
Sub-aerial beach	That part of the beach which is uncovered by water (e.g. at low tide sometimes referred to as drying beach).
Surf zone	The nearshore zone along which the waves become breakers as they approach the shore.
Swell	Waves that have traveled a long distance from their generating area and have been sorted out by travel into long waves of the same approximate period.

Tide The periodic rising and falling of the water that results from gravitational attraction of the moon and sun acting upon the rotating earth. Although the accompanying horizontal movement of the water resulting from the same cause is also sometimes called the tide, it is preferable to designate the latter as tidal current, reserving the name tide for the vertical movement.