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Wooli Beach / Village

Review of Coastal Hazards

301020-02273

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PROJECT 301020-02273 - WOOLI BEACH / VILLAGE

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D	Final	H.Nelson	D.Messiter	D.Messiter	4-Aug-10		

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1 INTRODUCTION

1.1 Background

The Clarence Valley Local Government Area (LGA) is located on the north coast of New South Wales (NSW). Wooli Beach is a large, open beach located within the LGA, approximately 40 km south-east of Grafton. Wooli has developed from a small fishing village in the early 1900s to the coastal township that it is today. In the 2006 Census, there were 502 persons usually resident in Wooli. Of the 418 private dwellings counted in the 2006 Census, 147 (35%) were unoccupied, which gives an indication of the number of holiday homes (accordingly, the population can increase significantly during peak school holiday periods). Unoccupied dwellings recorded during the Census also included those newly completed (such as those in the new subdivision to the north of the Wooli peninsula) but not yet occupied. From a review of data provided by Council, there are 422 rateable properties at Wooli, consequently there would be little change in the population since the 2006 Census. .

The majority of residential and commercial development at Wooli is located along a narrow sand spit which separates the Wooli River from the Pacific Ocean. The sand spit has been actively subdivided and developed over the years, with a significant number of dwellings erected close to the beachfront. Approximately 90 dwellings, the public school, voluntary rescue and storage facility, public hall, playground and RSL cenotaph are located on land fronting the beach.

Wooli Beach suffered severe storm damage in 1954 and 1974. Also, in the mid 1990's and during the last few years, the frontal dune along Wooli Beach has been severely eroded leaving a high, steep escarpment along much of the beachfront. The escarpment has continued to recede during this time with successive ocean storms, in particular a recent storm event during late May 2009.

The Coastline Hazard Study, Coastline Study and Coastline Management Plan were completed between 1996 and 1998. The former Ulmarra Shire Council (now incorporated in Clarence Valley Council) adopted the Coastline Management Plan in March 1998. The preferred option for managing the coastline hazard problem at Wooli was based on property relocation and buy-back. Beach scraping and vegetation regeneration was included as a management action in response to community comment.

With large exposure to coastal hazards at Wooli, concerns with practical implementation of currently adopted coastline management actions, as well as rapidly changing information relating to climate change related impacts (particularly sea level rise) Clarence Valley Council engaged WorleyParsons (WP) to review the appropriateness of its Coastal Management Plan.

1.2 Study Area

The Wooli Beach embayment comprises a sandy barrier about 7000m in length. Wooli Beach is situated between the rocky Wilsons Headland at the northern extent and by the entrance to Wooli

River in the south. The Wooli River has been trained with rock walls on either side of the entrance. The beach to the south of the entrance is known as Jones Beach.

After long periods of beach building conditions the beach berm and incipient dunes are typically 100m wide at the southern and northern ends, with a reduced typical width of 50m in the center of the beach. Dune height north of Wooli Village rises to approximately 12m relative to Australian Height Datum (AHD). Along the southern portion of the beach, dune height is limited to between 4m to 8m AHD. The majority of the sand spit behind the beach dune sits at an elevation of 4 to 6m AHD, with the portion containing Wooli Village rising above 8m AHD. Immediately north of Wooli Village, the dunes drop off to approximately 2 to 3m AHD and form part of the Wooli River floodplain.

The Study Area is shown in **Figure 1.1**.

1.3 Study Objectives

The objective of this portion of the study is to update previous coastal hazard planning lines for Wooli Beach and Wooli Village defined in the '*Wooli Beach Coastline Study – Stage 1 and 2 Coastline Hazard Definition'* (PBP 1997). Since the completion of the previous 1997 coastal hazards study, DECCW have produced three new years of photogrammetry profiles for Wooli Beach increasing the data set by 10 years.

This report aims to review the coastal hazards that impact the coastline at Wooli Beach and assess these hazards to update the immediate, 50 and 100 year hazard lines. The hazards examined in this report have been limited to beach erosion, shoreline recession, river entrance stability and considerations of the affects of climate change. For this investigation, coastline hazards have been estimated for the:

- immediate planning period;
- reduced foundation capacity associated with immediate hazard;
- 50 year planning period with a high-range sea level rise of 0.5 m; and
- 100 year panning period with a high-range sea level rise of 1.0 m.

A further report addressing the appropriateness of current management options in light of the coastline hazard review will complete the remaining portion of the study.

2 DATA ACQUISITION / ANALYSIS

2.1 Previous Studies

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

- Wooli Beach Coastline Study – Stage 1 and 2 Coastline Hazard Definition. (Patterson Britton 1997);
- Wooli Beach Coastline Management Plan (Patterson Britton 1997); and
- Wooli River Floodplain Management Study and Plan (Patterson Britton 1999).

2.1.1 Previous Coastal Hazard Definition

The previously defined coastal hazards and methodology as outlined in the 'Wooli Beach Coastline Study – Stage 1 and 2 Coastline Hazard Definition' (PBP 1997), of relevance to this study are outlined within this section.

Beach Erosion Hazard

The previous Beach Erosion Hazard was estimated through the comparison of two years of photogrammetry profiles, namely the April 1993 and June 1996 profiles. It was found that within this period three significant storms had occurred: March 1994 (approximately a 1 in 2 year event); March 1995 (approximately a 1 in 2 year event) and the May 1996 approximately a 1 in 10 year event). A lateral movement of the erosion escarpment of between 7.5 to 15m was observed from the photogrammetry profiles. This related to a storm demand of between 75 and 150 m^3/m from the beach.

Based on this assessment and considering existing beach erosion rates at that time elsewhere along the NSW coast, a 12m lateral movement in the erosion escarpment, with an addition 8m to account for slope readjustment and slumping, was adopted as the Beach Erosion Hazard for Wooli Beach.

Long term Recession

An analysis of beach escarpment position and active beach volume changes of Wooli Beach was undertaken using photogrammetry data supplied by the then Department of Land and Water Conservation (DLWC). The analysis, considering the beach profile for the period of 1942 to 1996, demonstrated an average long term recession rate of 0.3 to 0.5 m/yr for the length of Wooli Beach.

Based on this analysis, the previous study adopted a long term recession rate of 0.4 m/yr for the entire beach.

Climate Change

Additional long term landward recession due to climate change was examined in the previous report. Projected Sea Level Rise (SLR) was based on findings from the 1996 Intergovernmental Panel on Climate Change (IPCC) findings. In 1996, the IPCC's SLR projections for the 50 and 100 yr planning periods were 0.22m and 0.44m respectively. These values were adopted in the previous report.

Additional long term recession due to SLR of 11m for the 50 year planning period and 22m for the 100 year planning period were adopted in the previous study, based on application of the so-called Brunn Rule to an average nearshore active profile slope of 1 in 50.

2.1.2 Wooli River Flood Study

Flood inundation extents due to catchment flooding within Wooli River were obtained from the *Wooli River Floodplain Management Study and Plan* (PBP 1996). Inundation from the Wooli River in a 1% Annual Exceedance Probability (AEP) event would reach the alignment of Main Street at the northern end of Wooli Village. At this location, the approximate peak water level is estimated to exceed 2.6m AHD. **Figure 3.3** shows the 1% Annual Exceedance Probability (AEP) flood extent, and the PMF flood extent which reaches the Wooli Beach foredune. Note that the flood extents were based on the 1995 *Wooli River Flood Study* by the then Public Works Department and do not take into account sea level rise.

2.2 Photogrammetry

For the current study, a detailed photogrammetric analysis of historical vertical aerial photography (photogrammetry) was undertaken by the Department of Environment, Climate Change and Water (DECCW). Analysis of the photogrammetric profiles by WP enabled long term recession rates and storm erosion demand to be assessed. The photogrammetry profile data consisted of 140 shore-normal profiles in 9 blocks covering a total coastline length of approximately 7km from the northern edge of the Wooli River entrance to the northern extent of Wooli Beach. The data covers the period from 1942 to 2006, although not continuous through all 9 blocks. **Figure 2.1** shows the location of the photogrammetric profiles for Wooli Beach. **Table 2.1** outlines information on each of the photogrammetry blocks and the years of data used in this analysis.

Table 2.1: Photogrammetry Information

	Block								
	3	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
Number of Transects	8	24	24	10	16	28	12	14	4
Block Length (m)	400	1200	1200	500	800	1400	600	700	200
Year									
1942	X	X	X	X	X	X	X	X	X
1966	X	X	X	X	X	X	X	X	X
1978	X	X	X	X	X	X	X	X	X
1983	X	X	X	X	X	X	X	X	X
1984	X	X	X	X	X	X	X		
1988	X	X	X	X	X	X	X		X
1993	X	X	X	X	X	X	X	X	X
1996	X	X	X	X	X	X	X	X	X
2000	X	X	X	X	X	X	X		
2004	X	X	X	X	X	X	X		
2006		X	X	X					

X indicates data available within block for that year.

2.3 Hydrographic Survey

Offshore hydrographic survey acquired in 2007 by DECCW was utilized in the determination of the depth of closure for use in sea level rise considerations (see **Section 3.3**).

3 COASTLINE HAZARD ASSESSMENT

This study focuses on reviewing the following coastal hazards:

- short term beach erosion hazard;
- long term shoreline recession hazard;
- river entrance stability; and
- climate change considerations.

Each of these is discussed in turn in the following sections. The assessment of the hazards often draws upon the information set out in the preceding sections.

3.1 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) (approximately equivalent to Australian Height Datum (AHD)). The significant beach feature is usually taken to be the back beach erosion escarpment.

The amount of sand which can be removed from a beach during a storm event, and transported offshore, is referred to as the “storm demand”. 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.

At any location, at any point in time, the storm demand is dependent on a number of variables including the:

- wave height and period as well as the duration of the storm;
- state of the beach before the storm;
- direction of the storm relative to the orientation of the beach;
- magnitude of the storm surge accompanying the event;

- amount of wave setup and runup on the beach during and immediately following the storm;
- tidal range at the time of the storm; and
- state of the tide at the peak of the storm.

Chapman *et al.* (1982) considered that major erosion generally occurred during a phase of erosive conditions, with a final culminating storm.

Because the actual storm demand is a complex function of these variables, it is usual to express the storm demand in terms of an average recurrence interval (ARI), that is the storm demand for a 50 year ARI event, or 100 year ARI event, for example. In this study, the storm demand is estimated for a storm (or series of storms in close recession) producing an erosion event having an ARI of 100 years.

3.1.1 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 for open beaches to 220 m^3 / m at rip heads. In practice, in any one storm, more severe erosion would occur at discrete locations corresponding to the location of major rips.

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. Previous experience has shown this to be misrepresentative of actual volumes. Complex three dimensional processes (hydrodynamic flow and rip cells) and temporally varying conditions (e.g. a series of closely spaced storms) are not represented by simplistic modelling.

Estimation of storm bite volumes is sometimes possible based on comparison of two photogrammetric (or survey) profiles taken reasonably close in time, prior to, and following a design storm event. However, the lack of coincidental photogrammetry data and severe ocean storm dates at the site does not allow for direct estimation of a storm bite volume.

In light of these findings and given the uncertainties involved in estimating storm demand, a precautionary approach is deemed appropriate. It is therefore considered that a conservative 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 defining hazard lines.

3.2 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 from a beach compartment is greater than the incoming longshore transport;
- offshore transport processes move sand to offshore "sinks" from which it does not return to the beach; and
- there is a landward loss of sediment by windborne 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. At Wooli Beach, the second mechanism is 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 driven recession is discussed in more detail in **Section 3.3**.

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.

3.2.1 Interpretation of DECCW Photogrammetry

Based on the photogrammetric data provided by DECCW an assessment of the long-term trends in beach volumes and shoreline position has been completed. The aim of this assessment was to identify shoreline recession behaviour at Wooli Beach.

Trends in historical beach change can be estimated in two ways:

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

Both of these approaches have been used for Wooli Beach, the methods used for each techniques is detailed below.

Position Analysis

- the chainage of the most seaward downward crossing of the 4m AHD contour is identified in each beach profile; and
- regression analysis was used to identify trends in historical shoreline position based on the 4m contour.

The 4m AHD contour was used in this assessment as it was identified through the photogrammetry profiles as consistently describing the back beach erosion escarpment.

Volumetric Analysis

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

It should be noted that beach volumes calculated from the photogrammetry do not represent the entire volume of the active beach with volume contained in nearshore beach bars (below 0m AHD) neglected from the assessment.

Plots of long term trends in shoreline location change and volume change produced from the above assessment can be seen in **Figure 3.1** and **Figure 3.2**. A positive rate indicates accretion / progradation while a negative rate represents an erosion / recession.

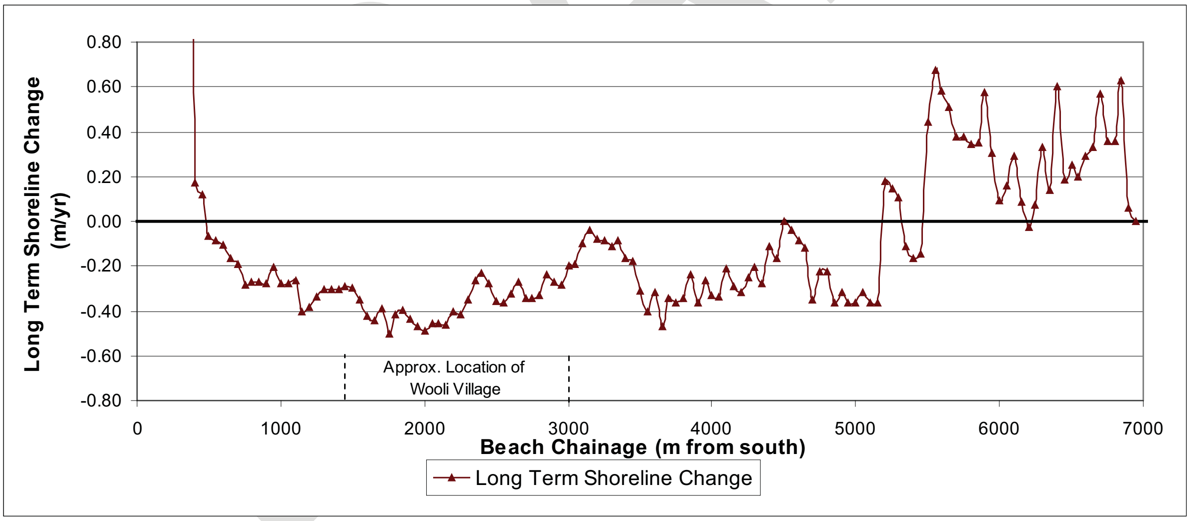

Figure 3.1. Long Term Shoreline Change along Wooli Beach

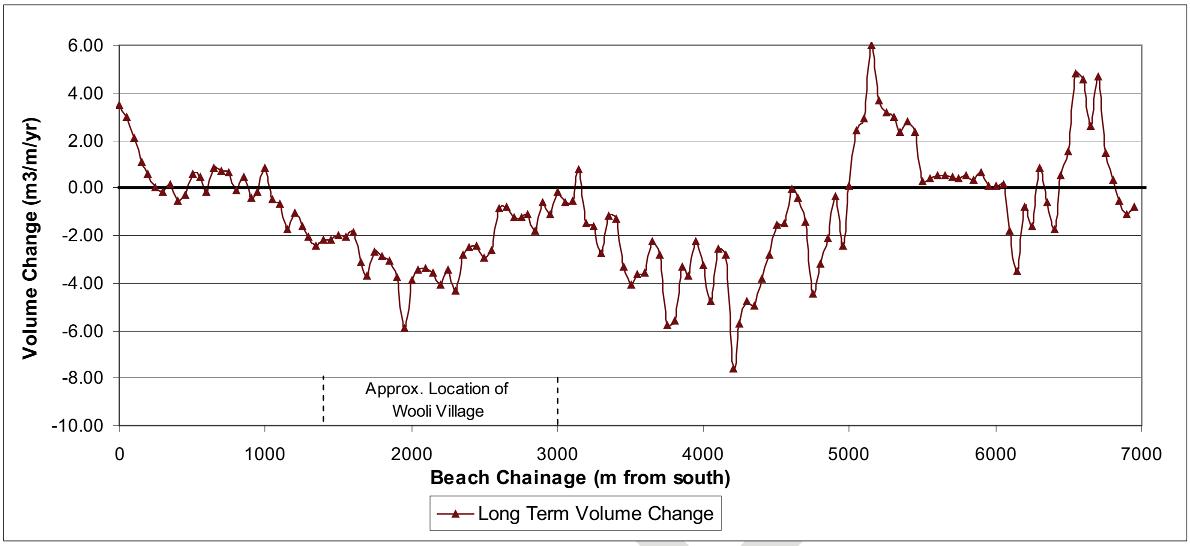

Figure 3.2. Long Term Active Beach Volume Change Analysis along Wooli Beach

Figure 3.1 and **Figure 3.2** indicate a similar trend, with the exception of between approximately 500m and 1000m chainage. The beach state of this particular area has been directly influenced by the construction of entrance training walls. The localised disparity at this location between the volumetric analysis and shoreline trend is attributed to the anthropogenic influence changing the beach profile shape over time such that the back beach escarpment position has receded but the volume in the beach berm above 0m AHD has remained relatively stable (i.e. the character of the beach has changed in response to a different environment).

As discussed above, volumetric analysis does not account for the whole volume in the active beach profile. Accordingly, for quantitative assessment of beach changes, the shoreline change analysis has been used.

The analysis of photogrammetry profiles shows a median recession rate of between 0.3 and 0.4 m/yr for the majority length of Wooli Beach. A higher rate of 0.5 m/yr recession is evident fronting the southern portion of Wooli Village, refer to **Figure 3.1**. Negligible net recession is shown at the southern and northern extents of the beach, with the analysis indicating a prograding trend.

The definition of the Hazard Lines resulting from the analysis of the photogrammetry profiles is outlined in **Section 4**.

3.3 Climate Change

Potential climate change impacts include sea-level rise, increased frequency and intensity of coastal storms and storm surges, and changes to local wave climate.

3.3.1 Sea Level Rise

The principle impact of climate change on coastline hazards will be associated with the predicted rise in mean sea-level. Relative to the 1990 level, global average mean sea-level is predicted to increase by 0.18 m to 0.59 m by 2090 to 2100, with potentially an additional increase due to a future rapid dynamic response to melting of the ice sheets (0.1 to 0.2 m) (IPCC 2007). Sea-level rise along the NSW coast will be slightly higher than the global average, with an estimated upper limit of 0.12 m by 2070 (McInnes et al. 2007). The recently released NSW Sea Level Rise Policy Statement (DECC 2009) adopts 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 is an increase above 1990 mean sea-levels of 0.40 m by 2050 and 0.90 m by 2100.

3.3.2 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. This profile is re-established by shifting it 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 (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 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.

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 below, 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.

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.

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:

$$d_c = 1.75 H_e$$

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 11 - 15 m depth (relative to AHD), while the boundary to Inner Shelf Sand (also known as Shelf Plain Relict or Palimpest Sand) is usually at 18 – 26 m depth. The boundary between Nearshore (Inner and Outer) Sands and Inner Shelf Sands correspond 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 approximately 10 m depth (relative to AHD) in the Byron Bay area. Other investigations by Patterson Britton and Partners (2004a) and others (Nielsen 1994, Stephens 2004) along the NSW mid-north and north coast indicated a depth of closure of 10 to 11 m relative to AHD.

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 limit the application of these techniques, particularly given postulated changes to wave climate due to climate change.

An analysis of detailed hydrographic survey along Wooli Beach was undertaken to estimate the depth of closure. Shore normal profiles from this survey indicated a change in bed slope (indicative of the limit of significant beach fluctuations), on average, at approximately -11m AHD. **Figure 3.4** provides a cross-section of the hydrographic survey, located in the middle of Wooli Beach, demonstrating this change in grade. This value of the depth of closure lies within the recommendations provided by Nielsen. Using the above depth of closure, the resulting average active beach slope was estimated to be approximately 1:40.

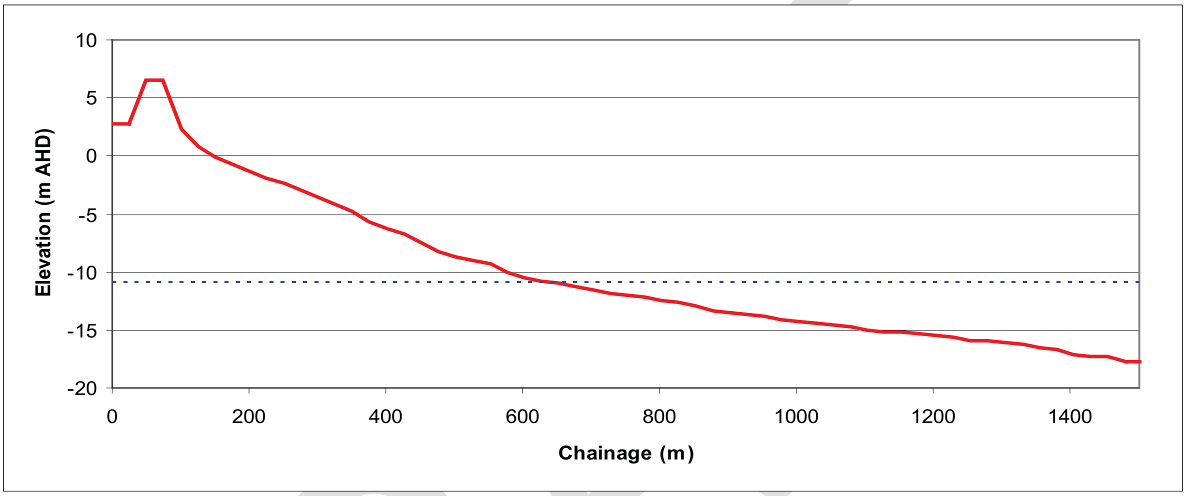

Figure 3.3. Shore Normal Cross-Section

For NSW open coasts (in the absence of measured data), the *Draft Coastal Risk Management Guidelines* (DECCW, 2009) indicates active beach profile slopes for use in the Bruun Rule should range between 1:50 to 1:100. As described above, the average active beach slope was estimated to be approximately 1:40 at Wooli from measured data, so this profile was adopted, and is consistent with the guidelines.

3.3.3 Other Climate Change Considerations

Another potential outcome of climate change is an increase in the frequency and intensity of storm events, and net wave direction changes with associated beach alignment changes.

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 changes in the angle of approach of the predominant wave climate (CSIRO 2007). For some beaches this may cause rotation of the shoreline, with resulting recession and accretion.

A recent study by Huxley (2009) involving various climate change scenarios indicated that climate change is likely to impact Wooli Beach. Further research is progressing to assess the likely impacts of climate change on Wooli Beach focusing on planning periods of 2030 and 2070. Outcomes from this study have not been completed to date.

There have been attempts (Ranasinghe et al, 2004) to explain beach rotation in terms of shifts in the Southern Oscillation Index (SOI)[1]. Specifically, Ranasinghe et al (2004) proposed that beaches rotate clockwise (with the northern end accreting and southern end receding) in El Niño phases (negative SOI). Conversely, it was proposed that beaches rotate anti-clockwise (with the northern end receding and southern end accreting) in La Niña phases (positive SOI)[2].

It has been postulated that, as a result of the greenhouse effect, El Niño conditions will be favoured in the future (Cai and Whetton, 2000; Boer et al, 2004), thus favouring clockwise beach rotation. In the study area, this would most likely have a negative effect on the southern end of Wooli Beach.

There is evidence that Wooli Beach rotates in response to shifts in the El Niño Southern Oscillation (ENSO) Index. **Figure 3.4** indicates the ENSO Index over the last 40 years and **Figure 3.5** illustrates the deviation of Wooli from the average beach alignment at discrete times when photogrammetry data is available. The envelope of rotated positions is indicated based on available data.

These discrete measurements, on beach significantly longer than that studied in Ranasinghe et al (2004), are not conclusive as to a definite correlation to quantify rotation in response to ENSO Index conditions. However, the plots indicate that following a sustained period of, on average, El Niño (eg. 1989 – 1996, and 2001 - 2006) clockwise rotation alignment changes appears to occur as proposed by Ranasinghe et al (2004).

It appears that the beach state responds more quickly to La Niña events due to the highly erosive nature of storm events associated with this period having the ability to move large volumes of sediment. Comparatively, El Niño are characterised by more benign conditions and as such the beach takes significantly longer to recover following a sustained La Niña period and then rotate. For this reason, beach alignment based on photogrammetry from 1978 and 1993, although taken in periods of El Niño, are still showing anticlockwise rotation due to preceding strong sustained La Niña periods.

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[1] The SOI is calculated from the monthly or seasonal fluctuations in the air pressure difference between Tahiti and Darwin. The method used by the Australian Bureau of Meteorology is the Troup SOI which is the standardised anomaly of the Mean Sea Level Pressure difference between Tahiti and Darwin (Bureau of Meteorology, 2005).

[2] It was also found that La Niña phases were associated with more energetic (erosive) conditions.

The following limitations should be noted in regard to this analysis:

- data is limited to available photogrammetry dates, containing snapshots of beach alignment at discrete times that may not cover the full extent of beach states;
- the average beach alignment was estimated based on the available photogrammetry data taken on discrete dates; and
- other factors that may influence beach alignment have not been considered (e.g. short fluctuations in beach alignment due to preceding storms events).

Given the limitations of the analysis, no quantitative description of future beach rotation was attempted.

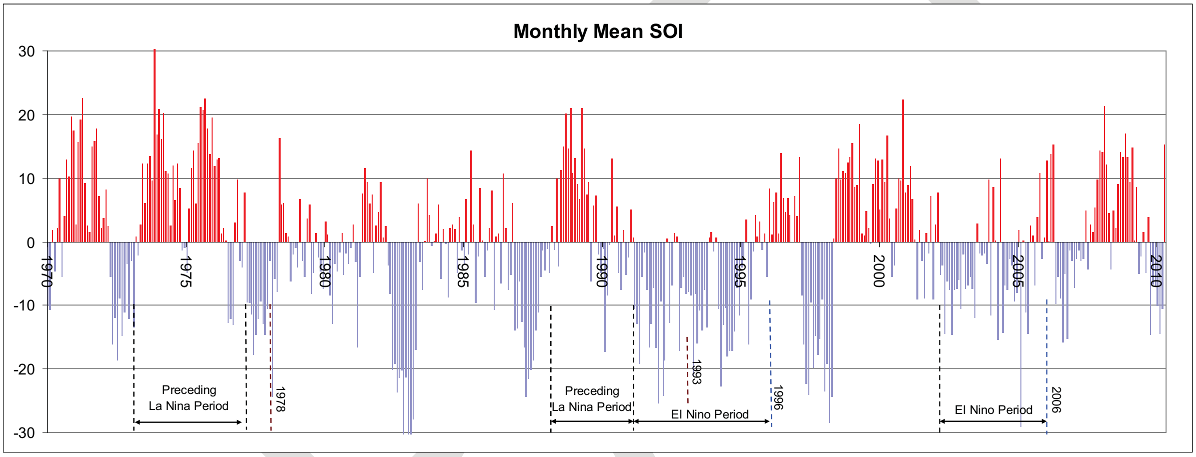

Figure 3.4. ENSO Index

Figure 3.5 shows that the beach alignment in 1996 and 2006 was in a state of clockwise rotation in response to a sustained El Niño phase, with 1996 the more rotated. The 1996 beach alignment was used in this Study as the baseline for hazard definition at Wooli for the 2050 and 2100 planning periods to account for the possibility that El Niño conditions will be favoured in the future.

Given the above uncertainty and difficulty in quantitative prediction, no specific account was taken of any potential changes in storm frequency and intensity, or changes in wave directions and possible beach rotation. However, this uncertainty should be taken into consideration when assessing the risk and consequences of recession occurring in the future. The potential for climate change related recession needs to be continually reviewed as more information develops in the scientific community.

Uncertainty in postulated climate changes and resultant shoreline response has been considered in this study through the application of conservative methods and values for the calculation of storm bite (see **Section 3.1.1**), sea level rise response (see **Section 3.3.2**) and average beach alignment (as described above).

3.4 River Entrance Stability

The stability of the Wooli River entrance was examined in the 1997 coastline hazard definition study. The previous study found, from drilling conducted along the sand spit in the 1980s that a historical entrance existed approximately 2 - 3 km north of its current location. The previous study found that current trained entrance is relatively stable. Although it noted that the sand spit that contains the Wooli Village should be regarded as vulnerable.

The main stability issue with regards the Wooli River entrance revolves around the interactions of the Wooli River floodplain adjoining the beach dune. **Figure 3.6** outlines the estimated 1% AEP Wooli River inundation extent from the 1999 flood study (PBP 1999) to the north of Wooli Village. The maximum 1% AEP inundation level in this region is approximately 2.65m AHD. Analysis of the photogrammetry and topographic information shows the elevation of the flood plain is limited to approximately 2m AHD (2006 transect) until it reaches the back of the beach dune. The beach dune in this region has a relatively small width of 40m (2006 transect), potential reduced during a 100yr storm event to a width less than 20m with a crest height of 10m AHD. It should be noted that from visual inspection during 2009 this width had been further reduced due to short term storm erosion in May, 2009. However, some recovery of the beach may have occurred since this short term erosion event. The 2010 hazard line, takes into account the long term recession in addition to the 2006 photogrammetry profile location.

Figure 3.7 provides a plot of photogrammetry data within this region (Block 6, Transect 3) demonstrating the low floodplain (left), thin beach dune and potential flood water level; erosion escarpment and dune crest height.

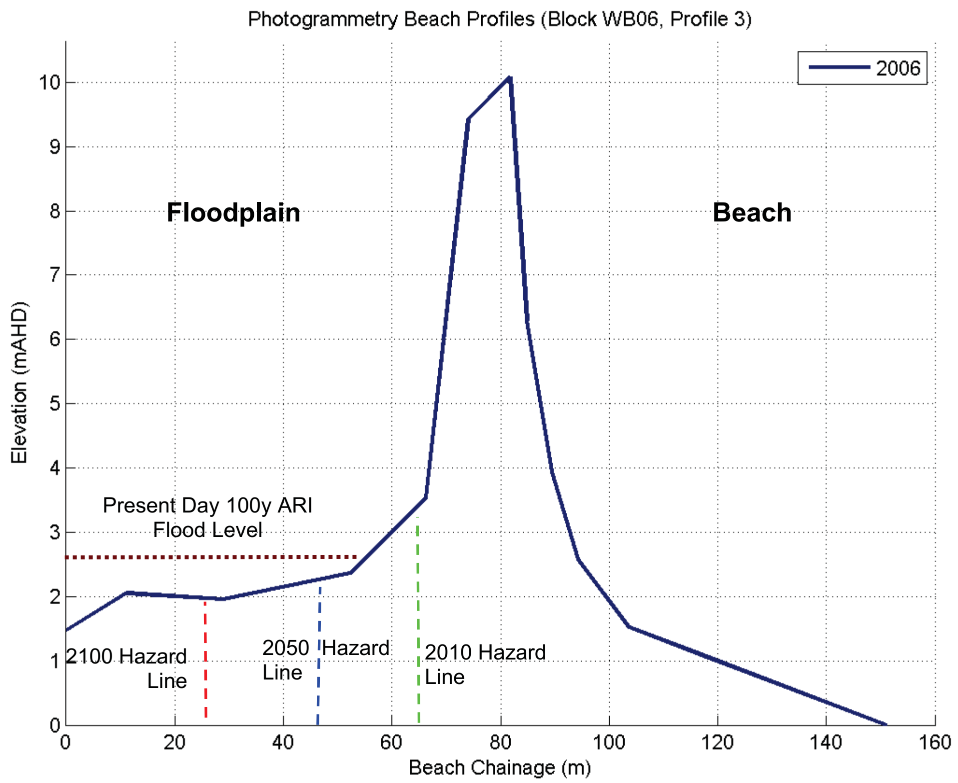

Figure 3.7. Photogrammetry Transect

With long term recession rates of approximately 0.4 m/yr (see **Section 4**) and recession due to SLR, this location would become increasingly vulnerable to the possibility of an entrance break out during major flood events if the beach dune was in a severely eroded or eroding state due to a concurrent ocean storm event. This would be further exacerbated by an increase in flood levels as a result of climate change impacts (e.g. increase in rainfall intensity, increase in tail water level due to sea level rise).

If the dune system was breached, catchment flow would follow the most hydraulically efficient path to the ocean and cut a new river channel north of the southern section of Wooli Village. This new entrance would be in a similar location to that indicated by previous studies as a historical entrance, and effectively isolate the southern portion of the village. Based on historical evidence, the new entrance (if untrained) would migrate slowly southward in response to catchment flow momentum and coastal process placing the village at risk.

It should be noted that this assessment is based on photogrammetry profiles and the application of reported flood levels and does not represent detailed flood modelling. As such, it indicates vulnerability only. More detailed investigations should be undertaken if temporal and spatial definition of a breakout event is required. The level of investigation required is outside of the scope of work for the study reported herein.

This risk is also relevant to emergency action planning for Wooli Village.

4 DERIVATION OF COASTAL HAZARDS

In this Section, coastline hazard zones are derived within the study area, based on the cumulative impacts of the coastline hazards outlined in **Section 3**, in relation to erosion and recession.

The position of the 2010 Hazard Line, 2050 Hazard Line and 2100 Hazard Line is the predicted position of the back beach erosion escarpment after a 100 year ARI coastal storm in 2010, 2050 and 2100 respectively, including subsequent slumping to a stable angle of repose. The 2010 Hazard Line was determined by removing the storm demand volume from the year 2006 / 2004 photogrammetric profile (where available) and making allowance for the long term recession between 2006 / 2004 and 2010 (present day). The 2006 / 2004 profiles were considered to be representative of; an average cross shore beach state for Wooli Beach (i.e. neither significantly eroded or accreted in the context of historical profile information).

The Zone of Reduced Foundation Capacity (ZRFC) for building foundations was 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 ZRFC would be considered to have an inadequate factor of safety.

The ZRFC was applied as per Nielsen *et al* (1992) using a profile by profile examination of dune height landward of the immediate hazard line along the beach frontage of Wooli Village and the new sub-division. On average, the ZRFC continues 15 m landward of the 2010 immediate hazard line and is up to 18m, depending on dune height.

Section 3.3.3 discusses the selection of the 1996 beach alignment as being representative of an El Niño phase rotation as the basis of hazard definition for future planning lines to accommodate uncertainty in climate change responses. This approach was based on literature which postulates El Niño conditions will be favoured due to climate change.

Table 4.1 outlines the components of the final Hazard Lines. The immediate and associated reduced foundation capacity, 2050 and 2100 Hazard Lines within the study area are shown in **Figures 4.1** and **4.2**. Although a prograding trend was evident at the southern end of the beach (as discussed in **Section 3.2.1**), the immediate hazard line reflects the volume of sand that would be eroded in the design storm. As the dune is lower in this location, the storm 'bite' would extend further inland.

Table 4.1: Components of 2010, 2050 and 2100 Hazard Lines

Beach Chainage (from south)	Adopted recession rate (m/yr)	Storm demand (m^3/m)	Long term recession due to sediment loss (m)		Long term recession due to sea level rise (m)	
			2050	2100	2050	2100
0m – 500m	0.0	220	0	0	17	42
500m – 1600m	0.4		16	36		
1600m – 2200m	0.5		20	45		
2200m – 5500m	0.4		16	36		
5500m – 7000m	0.0		0	0		

4.1 Coastal Hazard Comparison

Table 4.2 provides a comparison of the coastal hazards defined in the 'Wooli Beach Coastline Study – Stage 1 and 2 coastline hazard definition' (PBP 1997) and the updated coastal hazards from this study.

Table 4.2: Comparison of Coastal Hazards

	Previous Study	Updated Study
Beach Erosion		
Storm Demand	*Unspecified*	220m^3
Average Landward Retreat	20m (including slope readjustment)	20m to 25m
Long Term Recession		
Average Long Term Recession	0.4 m/yr	0.4 m/yr (0.0 to 0.5 m/yr)
Photogrammetry Data	1942 to 1996	1942 to 2006*
Climate Change		
SLR Projections (2050 / 2100)	0.22m / 0.44m	0.4m / 0.9m
Active Beach Slope	1 in 50	1 in 40
SLR Recession (2050 / 2100)	11m / 22m	17m / 42m

* see **Table 2.1** for list of years of available photogrammetry data for each block.

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FIGURES

▭ Study Area

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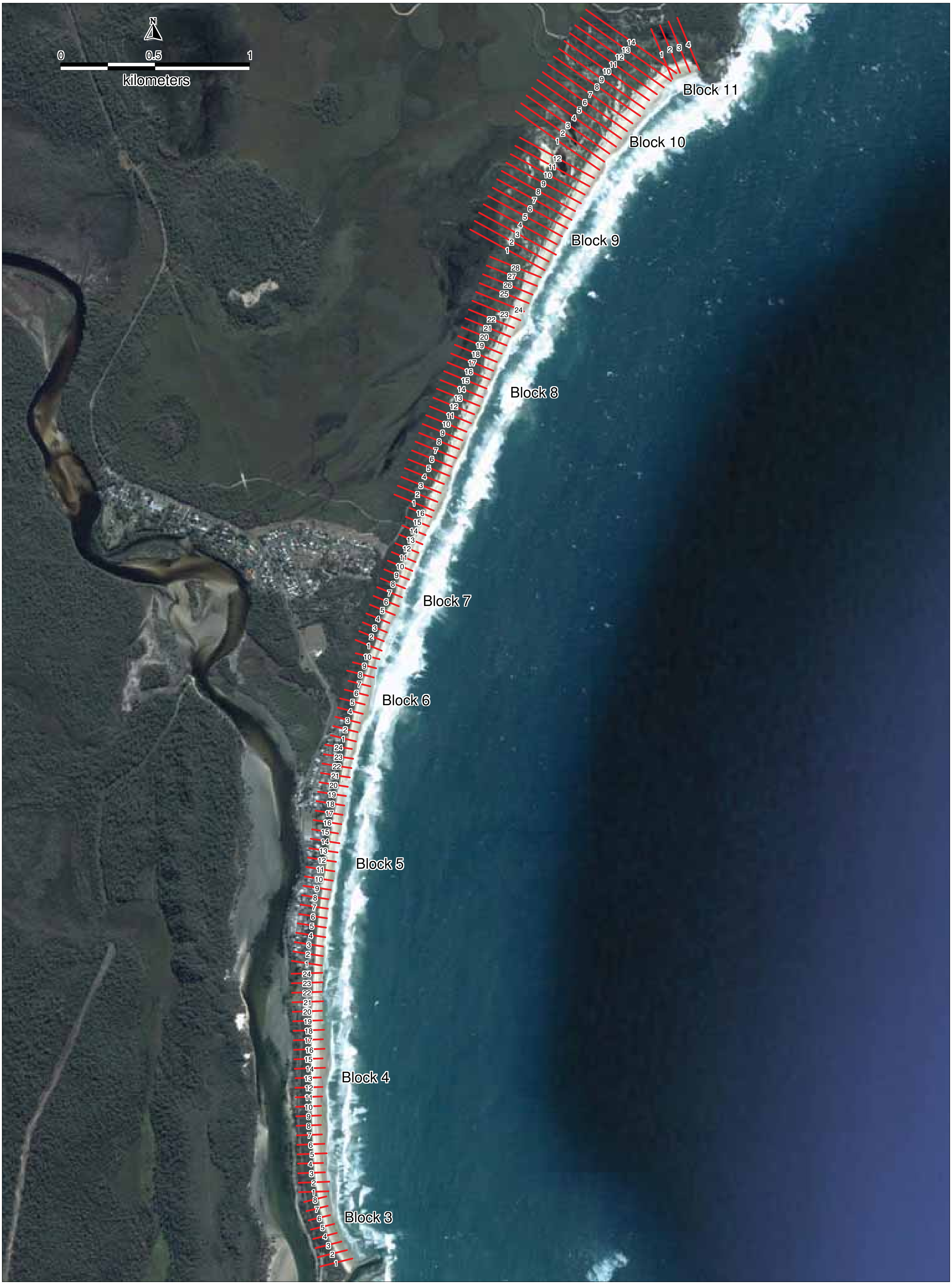
Locality Plan

June 2010

Figure 1.1



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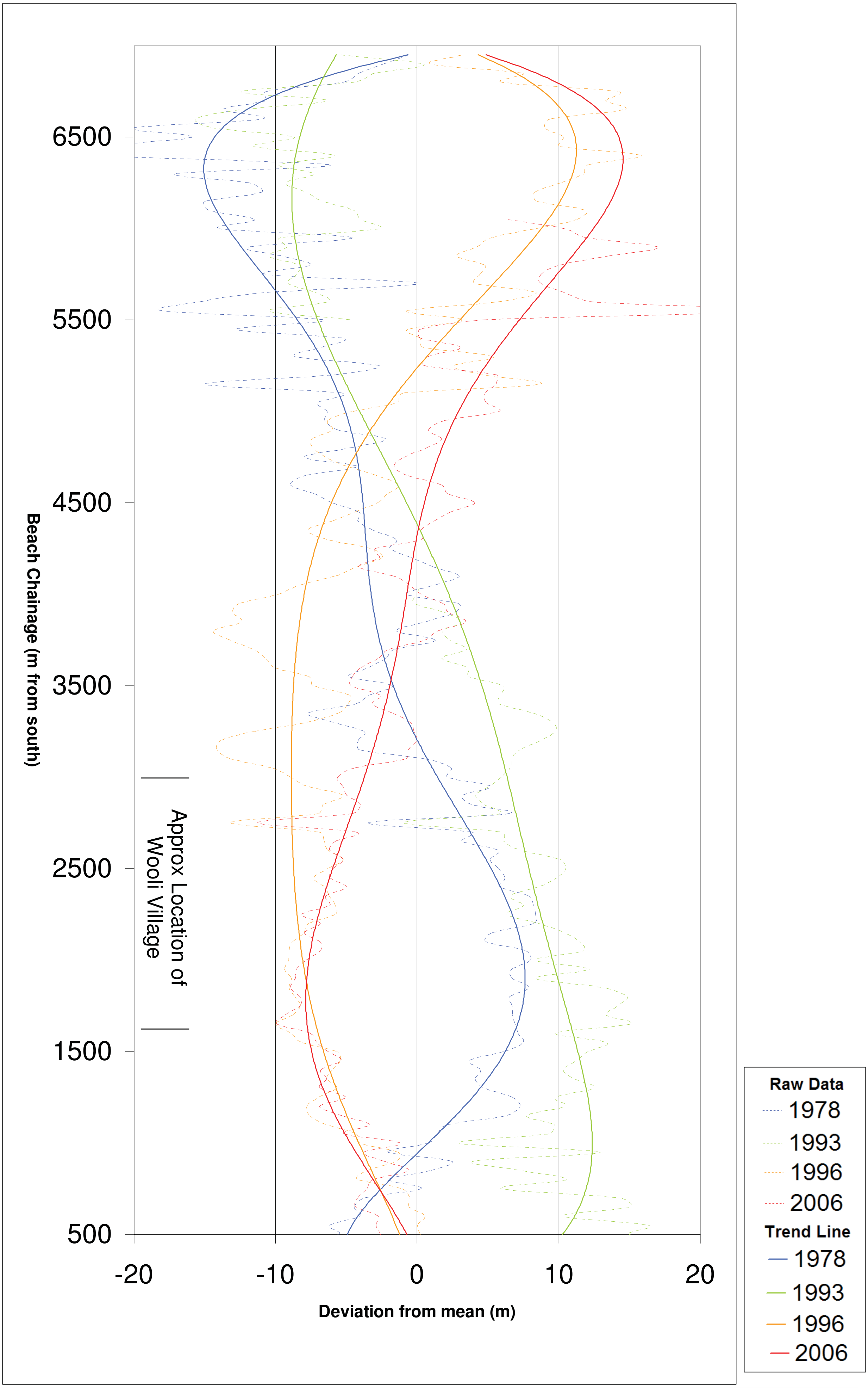
Photogrammetry Transects

DRAFT

June 2010

Figure 2.1



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Temporal Deviation From
Average Beach Alignment

May 2010

Figure 3.5

1% AEP Catchment Flooding Inundation Extent (Approx.)

PMF Catchment Flooding Inundation Extent

2010 Hazard

2050 Hazard including SLR

2100 Hazard including SLR

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Wooli River Entrance Stability \
Catchment Flooding

June 2010

Figure 3.6

— 2010 Hazard

— 2010 Reduced Foundation Capacity Hazard

— 2050 Hazard including SLR

— 2100 Hazard including SLR

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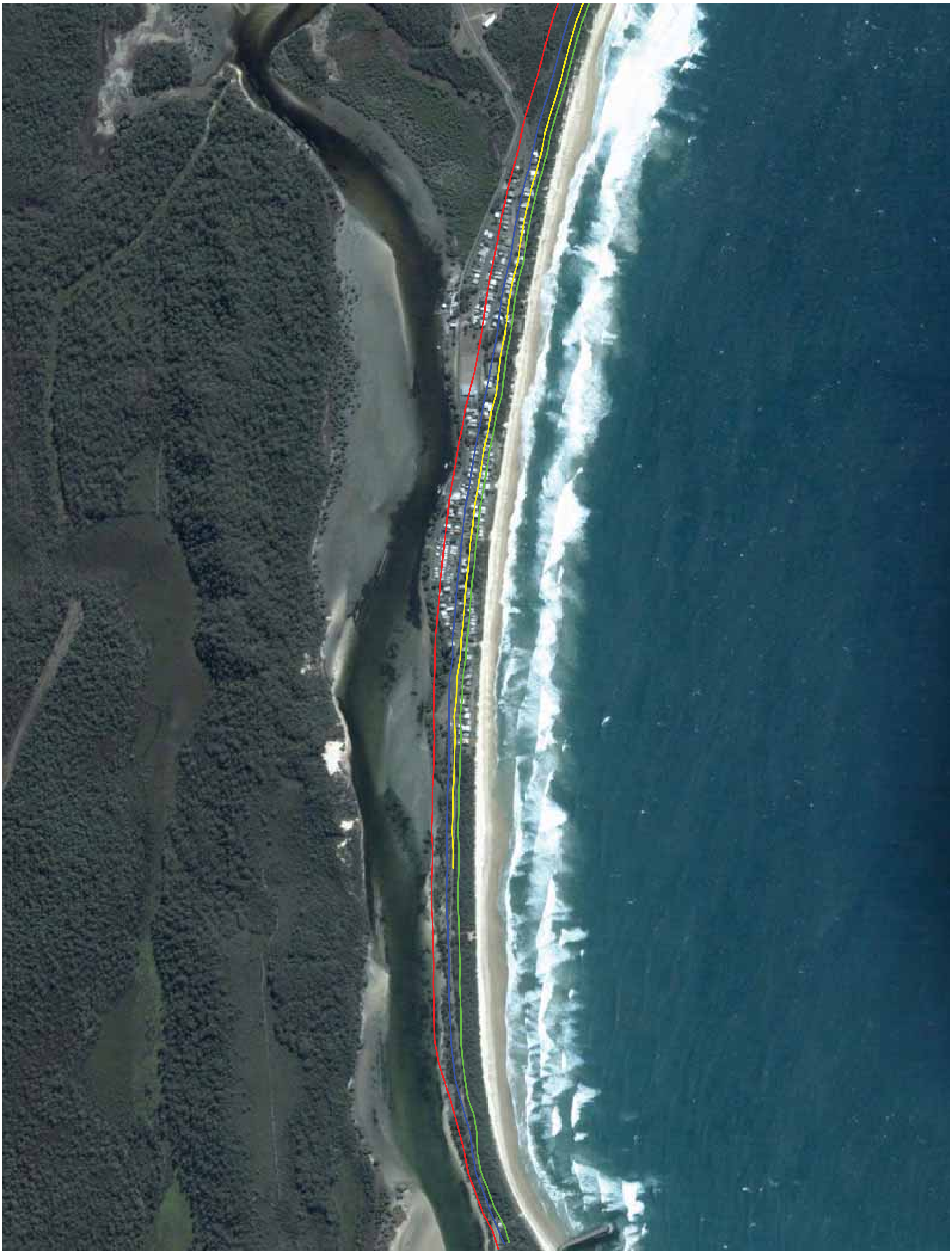
Coastal Hazard Lines - North

June 2010

Figure 4.1



🟩 2010 Hazard

🟨 2010 Reduced Foundation Capacity Hazard

🟦 2050 Hazard including SLR

🟥 2100 Hazard including SLR

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Coastal Hazard Lines - South

June 2010

Figure 4.2

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