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Review of the Wyong Coastal Zone Hazard Study

Final Report

November 2018

Central Coast Council

Review of the Wyong Coastal Zone Hazard Study

Prepared for:	Central Coast Council
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Synopsis: **This report presents a review and update of the hazard lines for the Wyong coastline, and in particular, incorporates a reassessment of the beach 'erosion' and cliff/bluff 'geohazard' elements. The study also reflects resolutions by former Wyong Shire Council (now Central Coast Council) relating to how coastal hazards are presented.**

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Executive Summary

This study comprises a review of the coastal erosion and geotechnical hazard studies undertaken for the former Wyong Shire Local Government Area (LGA). It also presents the coastal inundation hazard levels resulting from extreme wave runup processes, determined by SMEC (2010). Wyong Shire now forms part of the Central Coastal Council (CCC, or Council). This study remains specific to the coastline of the former Wyong LGA only. Herein, references to “Wyong’s coast”, “the Wyong coastline”, “Wyong’s beaches” and so on are a reference to the coastline of the former Wyong Shire LGA.

Study Area

Located on the Central Coast of NSW, the Wyong coastline study area stretches from the Yumbool Point to Lake Munmorah State Conservation Area located on Budgewoi Beach in the north (see Figure 1-1). The Wyong coastline is geologically diverse and comprises wide open coast beaches, semi exposed coastal embayment’s, a major coastal inlet, complex sand dune systems, rocky cliffs and bluffs and numerous offshore rocky reefs. The coastline has formed within the parent bedrock geology composed of interbedded sandstones, siltstones, claystones and conglomerates. The beaches, cliffs and bluffs of the Wyong coastline are exposed to high energy wave climate typical of the NSW Central Coast.

Background

A number of inconsistencies and information gaps were identified in the Wyong Shire coastal hazard and geotechnical hazard studies completed in 2010. Specific issues were identified when the coastal erosion and geotechnical hazard mapping datasets were combined for inclusion within the draft Wyong Shire Coastal Zone Management Plan by Umwelt (2011a) (WCZMP 2011). Mapping issues were specifically in relation to mapping coverage, misalignment between sandy and rocky specific hazard lines, and a general a lack of consideration for the interrelated nature of beach erosion and cliff recession processes. In response to these issues, Council required some elements of the existing hazard studies to be reviewed and revised. In addition to the above, recent state legislative reforms and adoption of new Council polices relating to the coastal zone were an additional driver for this re-assessment of coastal and geotechnical hazards.

BMT WBM partnered with JK Geotechnics to undertake this re-assessment of coastal and geotechnical hazards, which was completed in parallel with a review of the CZMP by BMT WBM. This current study provides an update to the *Wyong Coastal Hazard Study* (SMEC, 2010) and *Report on the Geotechnical Issues Associated with the Coastline Hazard Management Study for the Wyong Shire Council* (SCE, 2010) in relation to the following:

- Coastal hazard elements including: beach erosion, dune stability, historical recession and climate change impacts;
- Geotechnical hazard elements, in relation to cliff recession and non-coastal geotechnical hazards occurring within the coastal zone;
- Assessment of future hazard impacts in accordance with Council’s interim sea level rise, which assumes no further sea level rise will take place;
- New and updated data on coastal processes and new analytical techniques for assessing coastal hazards;

- Revised methodology for assessing cliff recession hazards; and
- Newly developed approach for mapping hazards across the transitional areas between sandy and rocky substrates.

A number aspects of the SMEC and Shirley Consulting Engineers (SCE) studies (SMEC, 2010; SCE, 2010) did not require revision, as listed in Table 1-1 (e.g. coastal inundation assessment, geological mapping). The coastal inundation assessment of wave runup levels by SMEC (2010) has been summarised within the current study.

Study Objectives

The aim of this study is to revise the coastal and geotechnical hazard elements of the SMEC (2010) and SCE (2010) studies for the Wyong coastline, such as the influence of bedrock geology on beach erosion, or the interaction between coastal and geotechnical processes and hazards. A secondary aim of this assessment was to assess future coastal hazard assessment for an additional scenario that assumes no sea level rise, consistent with the former Wyong Council's interim sea level rise policy.

Coastal and Geotechnical Hazards

Coastal hazards arise where coastal processes interact with our use and development of coastal land and assets, or where human development has impeded natural coastal processes. The major coastal hazards of note defined in this report include:

- *Beach Erosion*, relating to periods of intense storminess over seasons to years, and associated dune instability;
- *Long Term Recession* of sandy shorelines, relating to a long term sediment deficit and due to both prevailing sediment deficits and sea level rise in the future; and
- *Cliff/Bluff Geohazards*, relating to a range cliff recession and other hillslope processes, and incorporating the effects of climate change induced sea level rise;
- *Coastal Inundation from Wave Runup* that can cause temporary flooding low lying land adjacent the ocean, when high tides are combined with storms. Wave runup can also overtop coastal barriers and foreshore structures, causing the backing land to become inundated.

Assessment Approach

A range of methods were applied to assess coastal processes, coastal hazard and geotechnical hazards for this study, including:

- Review of available information and data sources
- Field inspection of geological conditions and mapping of transitional boundaries
- Photogrammetric assessment of historical beach change
- Interrogation and interpretation of remotely sensed data (historical and modern aerial photographs, terrestrial LiDAR topography and marine LiDAR bathymetry).

Future coastal erosion and geotechnical hazard were assessed for two climate scenarios:

- No sea level rise, in accordance with Council current interim sea level policy; and
- Sea level rise of 0.4 metres by 2050 and 0.9 metres by 2100 above 1990 levels.

Coastal inundation from wave runup processes defined by SMEC (2010), and presented in this report, was assessed for the immediate timeframe only.

Coastal hazards were assessed for geomorphologically common segments of beach. Coastal hazard parameters were defined though application of standard coastal engineering methods in most instances. **Beach erosion** demand volumes were defined based on the available photogrammetry data. Beach profile data were processed to interrogate the envelope of volumetric variability recorded for each beach segment. The most eroded beach state relative to current condition was then adopted to define the erosion hazard relative to current conditions. **Historical shoreline recession** rates were extracted from long term trend identified in the beach/dune volumes and dune scarp positon. **Future recession impacts without sea level rise** were assessed through projection historical recession trends (if present), and **future climate change impacts** were estimated through application of the Bruun Rule. The Nielsen *et al* (1992) schema was applied to map beach erosion and dune instability extents, relative to the erosion demand volumes defined for each beach segment. Future climate change impacts were mapped to include any underlying historical trends. Coastal erosion and recession hazard extents were constrained in some locations by mapping of geological controls undertaken for this study.

Geotechnical hazards were assessed with consideration to field observations, aerial photograph interpretation, relevant published information and site specific information provided in SCE (2010). **Cliff recession** hazard mapping methods developed by SCE (2010) were refined as part of this study. Recession distances were calculated based on local geotechnical and topographic conditions, as per the cliff recession scheme refined for this study. Areas susceptible to landslip and soil creep **geotechnical hazards** within the coastal zone were identified in addition to cliff recession hazards, based on local knowledge and topographic evidence of slope instability.

Transitional mapping between sandy foreshore areas exposed to coastal erosion hazard and rocky foreshore areas exposed to cliff recession hazards was undertaken. Interpretation of buried cliff line locations and estimation of future exposure timeframes were required to undertake geologically sensible transitional mapping.

Coastal inundation levels at the shoreline resulting from the action of breaking waves (**wave runup**) during extreme storm conditions were modelled for a number of beach locations by SMEC (2010). That wave runup assessment produced wave runup levels and mapping which is reproduced in this study.

Key Findings – Coastal Hazards

The assessment of coastal processes and hazards found that beach erosion hazards varied across the Wyong coastline depending on beach orientation and exposure. Beaches fronted by shallowly submerged rocky reefs were found to be significantly protected from stormy activity, with erosion demand volumes of 75 and 115 m^3/m determined for Blue Lagoon and Toowoon Bay respectively. Southeast to east facing beaches that experience some protection from protruding headlands and reefs, such as Bateau Bay, Soldiers Beach, Hargraves Beach and Lakes Beach were found to have a moderate erosion hazard, with erosion demand volumes between 150 and 180 m^3/m. The wide open coast lengths of shoreline at Shelly Beach and between

Magenta Shores to Pelican Beach were found to have the greatest exposure to erosion from this region, with erosion demands reaching volumes in excess of 300 m^3/m. Both those beaches are fully exposed to dominant southeast wave climate.

Analysis of available photogrammetry data shows that the majority of Wyong's beaches are predominately stable. However, superimposed on the short to medium term fluctuations that occur at all beaches, some sandy shorelines appear to be actively accreting while others are subject to progressive shoreline recession. For example, analysis undertaken for this study found North Entrance Beach to be receding at approximately 0.2 m/year. While the cause of this trend is not definitively understood, it may be in response to a number of processes identified in this report. Lakes Beach, located in the far southern end of the Budgewoi Beach embayment, is also found to be receding with a recession rate measured at 0.1 m/year. Similar historical trends and coastal morphologies between Tuggerah and Budgewoi Beach compartment may suggest a net longshore sediment transport in a northerly direction. Cabbage Tree Harbour is another receding beach, which also has a long and complex history of landslide activity.

Key Findings – Geotechnical Hazards

Recession of the rocky cliff faces along Wyong's coast is considered to occur primarily due to preferential weathering of sedimentary layers occurring at the cliff toe slopes, which subsequently causes the overlying sandstone blocks to topple. Taller cliffs comprised of Tuggerah Formation or Munmorah Conglomerate Rocks overlain by thick sandy soil profiles, such as across Norah Head, were estimated to most exposed to recession impacts.

Key Findings – Coastal Inundation from Wave Runup

Analysis of wave runup hazard for a design storm event under present sea level conditions by SMEC (2010) indicates that determined that the runup levels may generally reach between 6 – 7 m AHD, with the highest value of 8.1 m AHD modelled for North Entrance. A number of built assets are at risk from wave runup inundation, and overtopping may occur at where low lying coastal barriers and foreshore structures occur (SMEC, 2010).

Conclusion

The revision of hazards has considered the complex geological conditions occurring along Wyong's coastline. Central to this was the mapping of geological controls on coastal hazards including buried cliff lines beneath beach and dune sands for example. Transitional mapping between sand foreshores and rock lengths of coastline was complete in a geologically sensible manner that considered the likely exposure of mapped geological controls to coastal processes. This study builds on understanding of coastal processes, hazards and geotechnical conditions for Wyong's coastline, and provides new hazard maps for coastal planning purposes consistent with Councils current planning scheme. Council plans to review the new hazard maps on a 5 year basis, to incorporate updated coastal and geotechnical information.

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1 Introduction

1.1 Background to this Study

This study comprises a review of the coastal erosion and geotechnical hazard studies undertaken for the former Wyong Shire Local Government Area (LGA), and presents a summary of coastal inundation hazards assessed by SMEC (2011) that did not require review and therefore remain current. Wyong Shire now forms part of the Central Coastal Council (CCC, or Council). This study remains specific to the coastline of the former Wyong LGA only. Herein, references to “Wyong’s coast”, “the Wyong coastline”, “Wyong’s beaches” and so on are a reference to the coastline of the former Wyong Shire LGA.

Located on the Central Coast of NSW, the Wyong coastline study area stretches from the Yumbool Point to Lake Munmorah State Conservation Area located on Budgewoi Beach in the north (see Figure 1-1). The Wyong coastline is located some 70 km north of Sydney and 50 km south of Newcastle. This coastline comprises a range of sandy beach and dune systems located between rocky headlands and nearshore reefs. A major coastal estuary system entrance is positioned along the Wyong coastline at The Entrance. While large sections of coastal zone remain undeveloped, there are significant lengths of urbanised foreshore with a history of erosion threatening residential development, particularly at The Entrance North, Cabbage Tree Harbour and Hargraves Beach (Noraville).

Coastal hazards occurring at Wyong’s beaches and rocky coasts were assessed for the former Wyong Shire Council in 2010, whereby the *Wyong Coastal Hazard Study* by SMEC (2010) detailed the assessment of beach related hazards and SCE (2010) assessed coastal cliff and slope instability (geo) hazards within the *Report on the Geotechnical Issues Associated with the Coastline Hazard Management Study for the Wyong Shire Council*. Hazard mapping independently produced from those two studies were combined for inclusion within the Wyong Shire Coastal Zone Management Plan by Umwelt (2011a) (WCZMP 2011). As part of that process, a number of inconsistencies and knowledge gaps were revealed in the combined coastal hazard maps (see Section 3.14). Consequently, the beach ‘erosion’ and cliff/bluff ‘geohazard’ elements of those earlier studies have been re-assessed and mapped for this current project to ensure a complete and sensible set of hazard maps is available to Council for planning purposes.

BMT WBM partnered with JK Geotechnics to review and re-assess erosion hazards and geohazards along the Wyong coastline. An important consideration for this BMT WBM / JK Geotechnics study was to ensure that the erosion and geohazard mapping transition between the beach and cliff areas in geologically sensible and consistent manner. In addition to addressing the 2010 mapping inconsistencies, this current study has also incorporated two recent Council resolutions:

- Adoption of an interim sea level rise policy (in response to Stage 1 NSW Coastal Reforms), which essentially assumes no future sea level rise (as per Council resolution in October 2012); and

Title:

Locality Map of the Wyong Coastline NSW Central Coast

Figure: 1-1

Rev: A

N 0 2.5 5km

Approx. Scale

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- Adoption of new *Coastal Hazard Planning Scheme* that re-classifies the immediate, 2050 and 2100 coastal hazards extents, as "immediate", "high" and "low coastal hazard zone(s)", consecutively (as per Council resolution in May 2013).

Table 1-1 summarises the beach erosion and coastal geohazards re-assessed for this study. A number of beach hazard and coastal geohazard aspects of the SMEC (2010) and SCE (2010) studies did not require revision. Those hazard elements, as listed in Table 1-1 are therefore still current. A summary of the SMEC (2010) assessment of coastal inundation due to wave runup is presented within this study.

Table 1-1 Currency of Coastal Hazard and Geohazard Elements within this Hazard Re-Assessment and the Hazard Studies by SMEC (2010) and SCE (2010)

Coastal Hazards	Geohazards
Current Hazard Study (BMT WBM / JK Geotechnics)	
• Review of Photogrammetry • Assessment of Coastal Processes and Geomorphology • Beach Erosion and Dune Instability Hazards • Assessment of Historical Recession Trends • Future Recession Hazard Definition due to Sea Level Rise • Mapping of 'Bedrock Control' on Erosion • Erosion Hazard Mapping	• Assessment of Site Characteristics • Define Slope and Cliff Instability Mechanics • Evaluation of Cliff Recession Rate • Slope and Cliff Instability Recession Hazard Definition • Mapping of Geohazards • Mapping Hazard Transition between Sandy (Beach) and Rocky (Cliff/Slope) Substrates
SMEC (2010)	**SCE (2010)**
• Review of Historical Information (Storms)* • Description of Coastal Hazard Processes (including Erosion, Dune Instability, Recession, Wave Run-up and Overtopping)* • Coastal Inundation Hazard Definition**	• Review of Historical Information Regarding Cliff Retreat and Slope Instability) (Photographs, Survey Plans)* • Coastal Geological Mapping for Coastal Slope and Cliff Areas* • Geological / Geotechnical Notes on Wyong Coastal Geological Substrates*

* Current coastal hazard and geotechnical hazard elements that are not further addressed within this study.

** SMEC's (2010) coastal inundation assessment methods and results are presented within this report.

1.2 Study Area Coastline

The Wyong coastline is approximately 35 km long, stretching between south of Yumbool Point, near Crackneck Point and Bongon Head, north of Frazer Beach. For the purpose of this hazard re-assessment, the study area extends north from Yumbool Point to the southern boundary of Munmorah State Conservation Area at Budgewoi Beach (see Figure 1-1). The coastal environment included within this study area encompasses a diverse landscape including:

- Wide open coast beaches (Tuggerah Beach and Budgewoi Beach);
- Semi exposed coastal embayment's (e.g. Bateau Bay, Toowoon and Blue Bays);

- Coastal entrance (The Entrance) to a major Intermittently Closed and Opened Lakes and Lagoons (ICOLL) estuary system (Tuggerah Lakes);
- Complex sand dune systems, including modern Holocene-age sand dunes (e.g. Shelly Beach and Pelican Beach) and old Pleistocene-age dunes (e.g. Bateau Bay, Cabbage Tree Bay);
- Rocky cliffs and bluffs (e.g. Crackneck Point, Norah Head); and
- Numerous offshore rocky reefs (e.g. Toowoon and Blue Bays, The Entrance Channel, Hargraves Beach).

The various shoreline segments covered in this re-assessment of coastal hazards are listed in Table 1-2 and mapped on Figure 2-1.

1.3 Aims and Objectives

The aim of the study is to revise the coastal and geotechnical hazard elements of the SMEC (2010) and SCE (2010) studies that were found to contain inconsistencies and knowledge gaps, such as the influence of bedrock geology on beach erosion, or the interaction between coastal and geotechnical processes and hazards. A secondary aim of this assessment was to assess future coastal hazard assessment for an additional scenario that assumes no sea level rise, consistent with the former Council’s interim sea level rise policy (adopted October 2012).

In achieving the above study aims, the following objectives were identified:

- Re-assess beach related coastal hazards including erosion, dune stability, historical recession, and climate change impacts for all lengths of sandy shoreline located within the study area. The re-assessment of coastal hazards should draw upon available data sources and consider the influence of local geological conditions;
- Re-assess geotechnical hazards occurring along all lengths of rocky coastline, as well as for all lengths of indurated sand bluff. This assessment should give consideration to the interaction of coastal and geotechnical hazards where sand dunes abut bedrock cliffs, for example;
- Assess the above described hazards for the current and future (2050, 2100) planning timeframes. Estimation of future hazard should consider the impacts of climate change, as well as assess the unlikely scenario that sea level rise does not continue; and
- Produce a series of hazard maps for the study area that delineates the coastal and geotechnical hazards and also transitions between sandy beach areas and rocky cliff areas in a geologically sensible manner.

1.4 About this Report

This report presents the methodology and findings relating to the re-assessment of coastal hazards and geotechnical hazards for the Wyong coastline. Particular attention has been given to re-assessing hazards in a geologically sensible manner, which gives consideration to the interaction of hazards specific to the sandy beach and dune substrates with geohazards occurring on the bedrock cliff and slopes substrates.

Table 1-2 Study Site Coastal Locations (South to North) and Shoreline Type Summary

Location	Shoreline Description	Coastal Substrates		
		Clean Sand	Indurated Sand	Bedrock
Crackneck Point and surrounds	Bedrock cliffs			✓
Bateau Bay	Embayed sandy beach, backed by indurated sand bluff	✓	✓	
Unnamed Headland, north of Bateau Bay	Bedrock cliffs			✓
Blue Lagoon, Shelly Beach and Little Bay	Sandy beaches	✓		✓
Toowoon Bay and Blue Bay	Embayed sandy beach	✓		✓
Unnamed Headland, north of Blue Bay	Bedrock cliffs			✓
South Entrance Beach	Sandy beach, bedrock backed	✓		✓
The Entrance Channel	Estuary entrance	✓		
North Entrance Beach, Tuggerah Beach and Pelican Beach	Sandy beaches	✓		
Soldiers Beach	Sandy beach	✓		✓
Soldiers Point	Bedrock cliffs			✓
Pebbly Beach	Sandy beach, bedrock backed	✓		✓
Norah Head, including Lighthouse Beach	Bedrock cliffs, with perched sandy beach	✓		✓
Cabbage Tree Harbour	Embayed sandy beach, backed by indurated sand bluff	✓	✓	✓
Unnamed Headland, north of Cabbage Tree Harbour	Bedrock cliffs			✓
Jenny Dixon Beach	Bedrock cliffs, with perched sandy beach	✓		✓
Hargraves Beach	Embayed sandy beach	✓		✓
Lakes Beach and Budgewoi Beach	Sandy beaches	✓		

The document is set out as follows:

This Chapter Provides study area context and relevant background information.

Chapter 2 Describes the methodology and assessment approach adopted for this study.

Chapter 3 Presents coastal and geotechnical results on a location by location basis. Specific attention is given to the beach related hazards, however key results relating to the geotechnical hazards are also presented. A comparative assessment of the SMEC (2010) hazard study and SCE (2010) geotechnical study, with the current study is also provided at the end of this chapter.

Chapter 4 Presents a summary of results, which includes a general overview of the coastline morphology and processes, as well as details specific to the coastal and geotechnical hazards present within the study area.

Chapter 5 Presents the coastal hazard mapping for Wyong

Chapter 6 Contains a list of references used for this study

Appendix A Includes the geotechnical study of coastal cliff and slope instability geohazards for the Wyong coastline, completed by JK Geotechnics. Key findings of the JK report are documented throughout the main body of this report.

2 Coastal Hazard Assessment Methodology

2.1 Coastal Hazard Components

Coastal hazards for the Wyong coastline were most recently assessed in 2010 (SMEC, 2010 and SCE, 2010) and provide the basis for the existing erosion hazards and management plan provisions. As previously described in Chapter 1, elements of these two hazard assessments were in need of revision. The coastal hazards being re-assessed in this study relate to:

- **Beach erosion**, relating to periods of intense storminess over seasons to years, and associated dune instability;
- **Long term recession** of sandy shorelines, relating to a long term sediment deficit and due to both prevailing sediment deficits and sea level rise in the future; and
- **Cliff/Bluff geohazards**, relating to a range coastal and hillslope processes, and incorporating the effects of climate change induced sea level rise.

Updated knowledge of the extent of the above hazards is based on newly obtained coastal and geotechnical information and improved methodology that accounts for the interaction between the sandy (beach) and rocky (cliff/bluff) sections of coastline.

Existing information regarding **coastal inundation** hazards occurring from wave runup processes during extreme storm conditions under present sea level conditions are also presented in this study.

2.2 Sea Level Rise

This study has assessed future hazards for the following two separate sea level rise scenarios:

- **No sea level rise**, in accordance with Council current interim sea level policy; and
- **Sea level rise of 0.4 metres by 2050 and 0.9 metres by 2100** above 1990 levels, as per Council's previously adopted a sea level rise policy that was consistent with the repealed NSW Governments' Sea Level Rise Policy Statement (DECCW 2009a).

The Office of Environment and Heritage (OEH) advised that an estimated sea level rise of 0.06 m between 1990 and present should be considered in coastal assessments incorporating the impact of projected sea level rise, as was done for the SMEC (2010) and SCE (2010) studies. The sea level rise provisions adopted for this assessment are 0.34 m by 2050 and 0.84 m by 2100.

2.3 Beach Erosion

2.3.1 Erosion Processes

During severe storms or a series of storms in succession, increased wave heights and elevated ocean levels results in wave attack of the beach berm and foredune region. Storm events generate high transport rates of sand both:

- Offshore, with sand eroded from the beach face and transported to the nearshore seabed to form a sand bar roughly parallel to the shoreline; and

- Alongshore, either upcoast or downcoast depending on wave direction, with gradients in the transport rates leading to erosion or accretion.

The result is erosion on the beach face and dune that may pose a hazard to back beach land and assets. The short term storm related cross shore sand transport and longshore drift occur simultaneously, the latter commonly leading to a significant shoreline erosion component immediately downdrift of headlands in cases where the sand supply into the beach compartment is less than the transport away to the north. Their effects are additive, although the beach itself (above mean sea level) will be observed to erode predominantly during storm events.

The extent of storm erosion that will occur under the same set of water level and wave conditions may vary. This is because the volume of erosion relates also to:

- The occurrence, location and strength of rip current cells, which promote seaward transport of sediment and may allow larger waves access to the beach face, resulting in further localised beach erosion;
- The state of the beach (eroded / accreted both on land and underwater) immediately prior to the storm; and
- Adjacent headlands, nearby rocky reefs or other coastal structures that can modify local wave conditions and the supply of sand during the storm event.

Immediately following storm erosion events on sand beaches, a near vertical erosion scarp of substantial height can be left in the dune or beach ridge. A zone of reduced foundation capacity can exist on the landward side of sand escarpments. This can impact on structures founded on sand within this zone and the sand escarpments pose a hazard associated with sudden collapse. Over time the near vertical erosion scarp will slump through a zone of slope adjustment to the natural angle of repose of the sand. Nielsen *et al.* (1992) outlined the zones within and behind the erosion escarpment on a dune face that is expected to slump or become unstable following a storm erosion event (see Figure 2-1), namely:

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

Amongst other factors, the width of the ZRFC behind the top of an erosion escarpment is dependent upon the angle of repose of the dune sand and the height of the dune above mean sea level.

On average, stable beaches exhibit a form of dynamic equilibrium. Following periods of large-scale short term erosion, the beach will tend to restore itself over time to an average or accreted state during favourable wave conditions. This recovery involves the shoreward return of sand from nearshore and/or, where the erosion resulted from alongshore losses, a sand supply from updrift that exceeds the transport away, commonly associated with headland bypassing processes.

On beaches that are in long term 'dynamic equilibrium', the amount of sand that returns to the beach is equal to the amount eroded during the storm. However, at beaches experiencing long term recession, not all the sand eroded may be returned and the eroded dune escarpment will move landward on average over time.

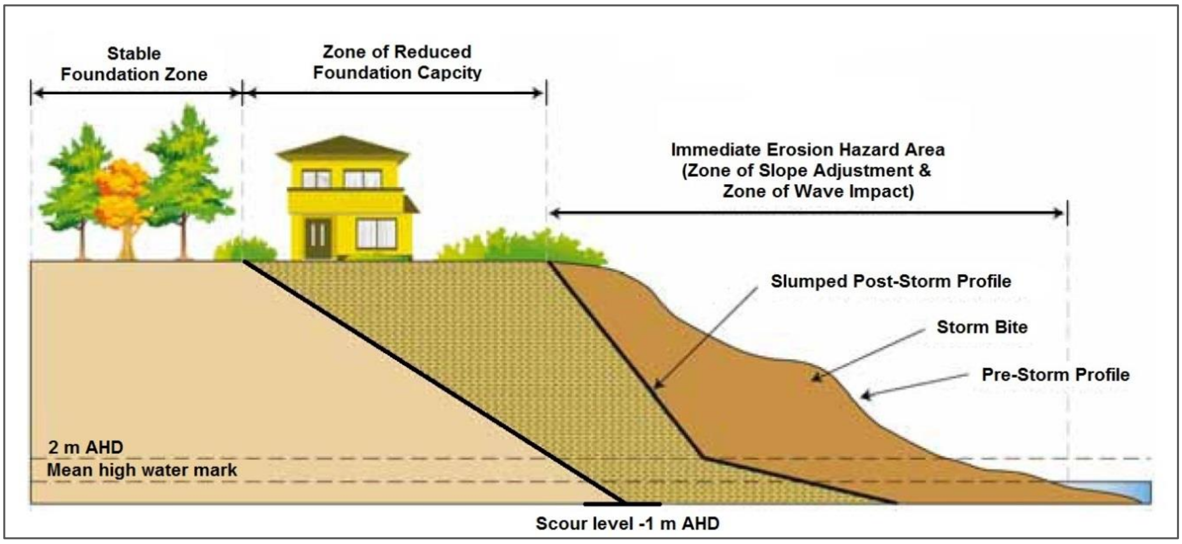


Figure 2-1 Schematic Beach/Dune Cross Section Showing Pre and Post Erosion Dune Face and Dune Stability Profiles (from DECCW, 2010; after Nielsen *et al.,* 1992)

2.3.2 Erosion Demand Assessment

Photogrammetric data provides information on changes to sub-aerial beach volume and the position of dunes over time. As these data provide insight into changes occurring above mean sea level, consideration of longer term trends is based primarily on movements of the upper beach/dune system. However, the photographs present individual ‘snapshots’ that describe beach state at one particular time. Knowledge of the timing and intensity of major historical storm erosion events is taken into account when interpreting the available data.

The photogrammetric data available for beaches across the Wyong coastline was processed to calculate beach/dune volumes for each profile cross-section and average volumes along representative sections of shoreline analysed. The envelope of volumetric variability in the photogrammetric data over a period of several years or decades provides a measure of the potential erosion demand volume even where the data does not relate to any particular storm event, provided any long term trends are accounted for. This takes account of both storm erosion and short term (months to years) variability due to alongshore fluctuations (see Figure 2-2 for example). As well, the horizontal distances of specified contour level positions have been determined to indicate historical movements of the dune face. This information provides insight into coastal processes, beach response to storms and long term shoreline behaviour. This information was used as a sensibility check against the erosion demand volumes determined for each beach.

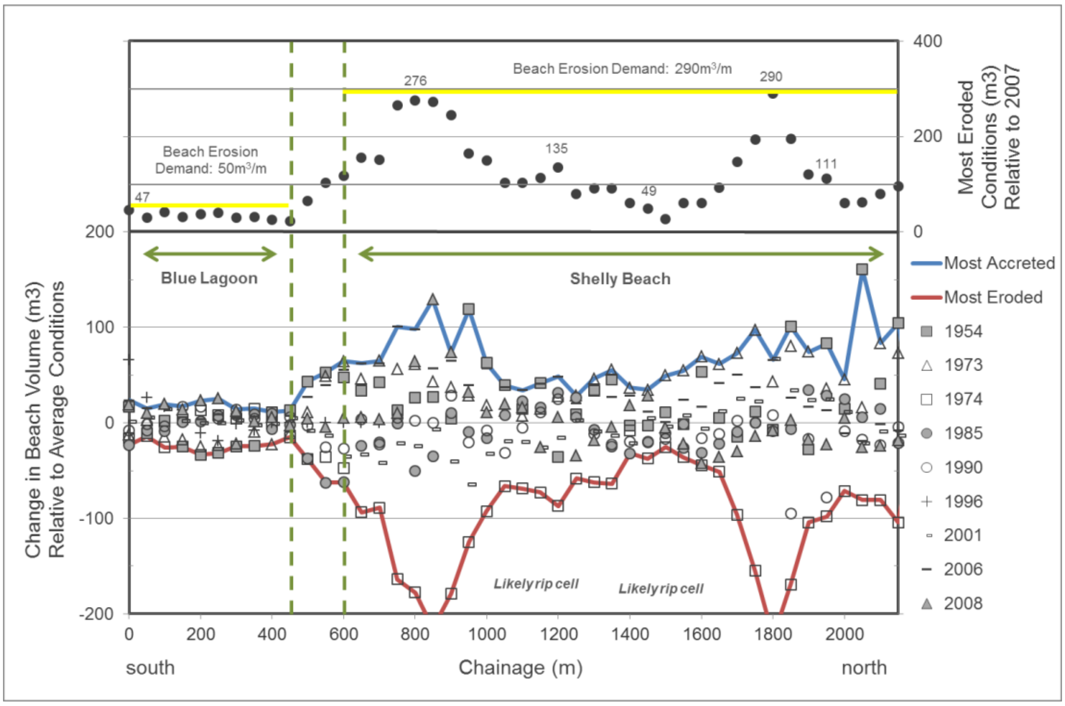


Figure 2-2 Envelope of Beach Profile Volume Change for Blue Lagoon and Shelly Beach, with Erosion Demand Volumes Measured Relative to circa 2007 Conditions to Allow Accurate Hazard Line Mapping from the Available LiDAR Topography from that Year

Review of photogrammetric processing methods by Hanslow (2007) concluded that both the horizontal movement of a selected dune contour position and the sub-aerial beach volume calculation have statistical significance to be appropriate for use in hazard assessments. Both of these methods have advantages and disadvantages. The sub-aerial beach volume data (average volumes, individual profile volumes) has been used to assess beach erosion potentials, relative to the most eroded conditions experienced within the recorded envelope of beach volume change (see Figure 2-2).

Beach erosion demand volumes were determined for geomorphological related sections of beach, as the beach behaviour was found to vary within beach compartments at a number of locations (e.g. Blue Lagoon to Shelly Beach compartment, as shown on Figure 2-2). Locations found to be undergoing significant historical (net) losses in beach volume were processed to remove those long term trends from the data, prior to determining beach erosion demand volumes (e.g. North Entrance Beach; see Section 3.6). Beach erosion demand volumes were adopted for the areas without any photogrammetry data from geomorphologically related beaches within the Wyong coastline (e.g. open coast beaches).

Erosion distances depend on a combination of storm demand volume, the height of the dune affected, and the presence of rocky substrate. Typically, where the average dune height is about 5 metres, a storm demand volume of 200 m^3/m will correspond to about a 40 m recession of sandy shoreline. Higher dunes will erode less distance, and calculated erosion distances can be limited where rising bedrock slopes are located within the immediate back beach area. Erosion demand volumes have been established relative to the beach condition in 2006/2007. This timeframe was chosen due to the availability of good photogrammetric coverage of the study area in 2006, and this photogrammetric profile data was found to compare well to the high resolution topographic data (LiDAR digital elevation model) available for the following year.

The immediate erosion hazard lines were mapped for the beach sections by subtracting the determined erosion demand volumes from the 2007 LiDAR beach/dune topography, using the approach outlined by Nielsen *et al* (1992) which described the zone of wave impact (ZWI, i.e. the erosion escarpment) and the zone of slope adjustment (ZSA, i.e. the area landward of the vertical erosion escarpment crest that may be expected to collapse after the storm event). The revised beach erosion hazard lines produced from this study map the ZSA for the immediate scenario, assuming an angle of repose of 35 degrees as commonly adopted for NSW hazard studies. This scheme is described in more detail by SMEC (2010).

2.3.3 Zone of Reduced Foundation Capacity

The zone of reduced foundation capacity (ZRFC) is the area adjacent to the (slumped) dune erosion slope, which is considered to be of reduced bearing capacity for buildings (see Figure 2-1). The ZRFC was mapped for the immediate timeframe (only) for this study. Nielsen *et al* (1992) describes the now commonly adopted scheme for defining the zone of dune instability that sits landward of the ZSA, which is based on the dune heights and a factor of safety. Again, this method is further described by SMEC (2010). This zone adopts a factor of safety (1.5) which can theoretically propagate landward for large distances where the dune topography is elevated above 7 m AHD, for example. The ZRFC scheme assumes a scour level of -1 m AHD to determine the zone width. It has been suggested that the scheme is overly conservative in some situations, such as where tall dune topography is present, or erosion resistant strata may underlie the beach and dunes above -1m AHD. Unlike the SMEC (2010) study, the ZRFC has not been assessed for future timeframes in the present study, as there is too much uncertainty surrounding the future dune topography, backing substrate and future shoreline configuration. Therefore, it is considered that the future ZRFC cannot be credibly defined.

The coastal morphologies of Wyong's Beaches are complex at many locations. Tall dune systems are at times positioned close to the shoreline, while other dunes are comprised of older (Pleistocene-aged) indurated and cemented sands. These 'relic' dunes can have varying geotechnical properties in comparison to modern (Holocene-age) dunes which are formed of clean-unconsolidated sands only. Further, rocky reefs and shore platforms siting higher than -1 m AHD extend beneath a number of beaches in the study area. Such variations to the 'typical' NSW beach morphology described in the Nielsen *et al* (1992) scheme are likely to influence the ZRFC widths estimated at some locations.

A slight variation on the Nielsen *et al* (1992) ZRFC scheme was adopted for this study to better represent the local geological conditions experienced across the Wyong coastline, noting that dunes at some locations are underlain by a rocky substrate. At these locations, the scour depth was modified to elevations that better represent the local conditions. The presence and depths of rocky substrate were measured in the field and from the LiDAR topography (based on presence of outcropping rocky platforms), or inferred from the aerial photography. Table 2-1 demonstrates how the ZRFC widths are reduced where rocky substrate underlies the beach and dunes.

Table 2-1 Width of Zone of Reduced Foundation Capacity, for Varying Dune Heights and Geological Profiles

RL of Dune System (m AHD) [1]	Indicative ZRFC width (m) for dunes comprised of sand only [2]	Indicative ZRFC width (m) for dunes underlain by 1 m AHD rocky substrate [2,3]
4	9.3	5.0
5	10.7	6.4
6	12.2	7.9
7	13.6	9.3
8	15.0	10.7
9	16.4	12.1
10	17.9	13.6

[1] *Assumed that the dune system is approximately level (see Figure 2-1).*

[2] *Distance measured landward from the top of the erosion escarpment following slope readjustment (see Figure 2-1).*

[3] *Dune systems underlain by buried rocky substrate occur locally throughout Wyong's beaches, typically at the ends of beach compartments and where the beach is fronted by shallowly submerged rocky reef. Scour depths included for the ZRFC calculations where rocky substrate was present ranged from 0 m to 2.5 m AHD.*

2.4 Long Term (Beach) Recession

Shoreline recession is defined as the long term trend of a shoreline moving permanently landward over time. This may occur in some settings due to the persistent loss of beach and dune sediments, or in response to sea level rise. A historical trend of shoreline recession may be apparent at some NSW beaches from the persistent and progressive loss of sand to onshore (dunes), offshore (shoreface), alongshore or estuarine sediment 'sinks'. Any such net loss in sediment supply over time can be caused by natural processes or artificial modification to a natural sediment compartment such as groyne construction or sand dredging.

Sea level rise is another driver of potential future long term recession. An increase in mean sea level is generally expected to drive a future trend of shoreline recession, as waves, tides and wind processes progressively act on higher positions of the beach face. In principle, the equilibrium shape of the beach will be maintained relative to mean sea level, as demonstrated by the Bruun Rule, resulting in the upward and landward shift of the beach in response to rising water levels (Bruun, 1962; see Section 2.4.2 for details).

The assessment of future (2050 and 2100) shoreline recession impacts on Council's beaches have been carried out for two scenarios, including:

- Future beach recession with no sea level rise, in response to a long term net loss of sediment budget over time, as per the adopted recession rate determined from the assessment of historical recession (see Section 2.4.1); and
- Future beach recession due to sea level rise impacts, as per the Bruun Rule assessment in addition to any long term net loss of sediment budget determined for each beach (see Section 2.4.2).

The approaches taken for both scenarios are detailed below. BMT WBM notes the scenario incorporating *no* future sea level rise accords with Council's current sea level rise policy, which is in contrast to measured sea level rise over the past 100 years and widely accepted future sea level rise projections (IPCC 2014). These projections state that "Global mean sea level rise will continue during the 21st century, very likely at a faster rate than observed from 1971 to 2010" (IPCC 2014).

2.4.1 Analysis of Historical Shoreline Recession

Beaches experiencing long term recession are characterised by a persistent trend of reduction in the average sand volume and, often, a prominent back beach escarpment which moves landward over time. The long term shoreline behaviour of Wyong's beaches were assessed based on the available photogrammetric data, together with an appraisal of the geomorphology and coastal processes within the study area. Historical shoreline recession trends were identified from the photogrammetry data in terms of:

- Persistent progressive changes in the (sub-aerial) volume of sand contained in the beach/dune system (e.g. Figure 2-3); and/or
- Persistent and progressive changes in the position of the dune scarp (e.g. Figure 2-4).

Changes in dune scarp positions were measured from the +3 m contour for partly exposed beaches (e.g. Bateau Bay, Toowoon Bay) and +4 m contour for open coast beaches (e.g. Shelly Beach, North Entrance Beach). Yearly net recession and accretion rates were determined from the measured beach volume and dune scarp trends. Volumetric trends were converted to horizontal shoreline movement based on representative dune heights.

For the purpose of defining future erosion hazards, long term recession relates to the persistent and progressive existing trends of shoreline change that may be projected with reasonable confidence into the future. Forward projections of recession trends were incorporated into all future erosion hazard mapping. Beaches with a measured long term trend of accretion were considered to be stable for the purpose of future erosion hazard mapping. That is, the precautionary principle was adopted for these beaches, as sufficient evidence was not available to indicate the measured accretion trend would prevail over the coming 50 to 100 year planning timeframe.

For the 'no sea level rise' scenario, future erosion hazards were mapped landward of the immediate (ZSA) erosion hazard line where a long term recession trend was determined. As the vast majority of Wyong beaches were found to be stable, the future erosion hazard lines remained unchanged from the immediate erosion hazard lines under this scenario. As a result, the future risk profile remains unchanged from present condition for most beaches assuming no future sea level rise (see Figure 12 for example).

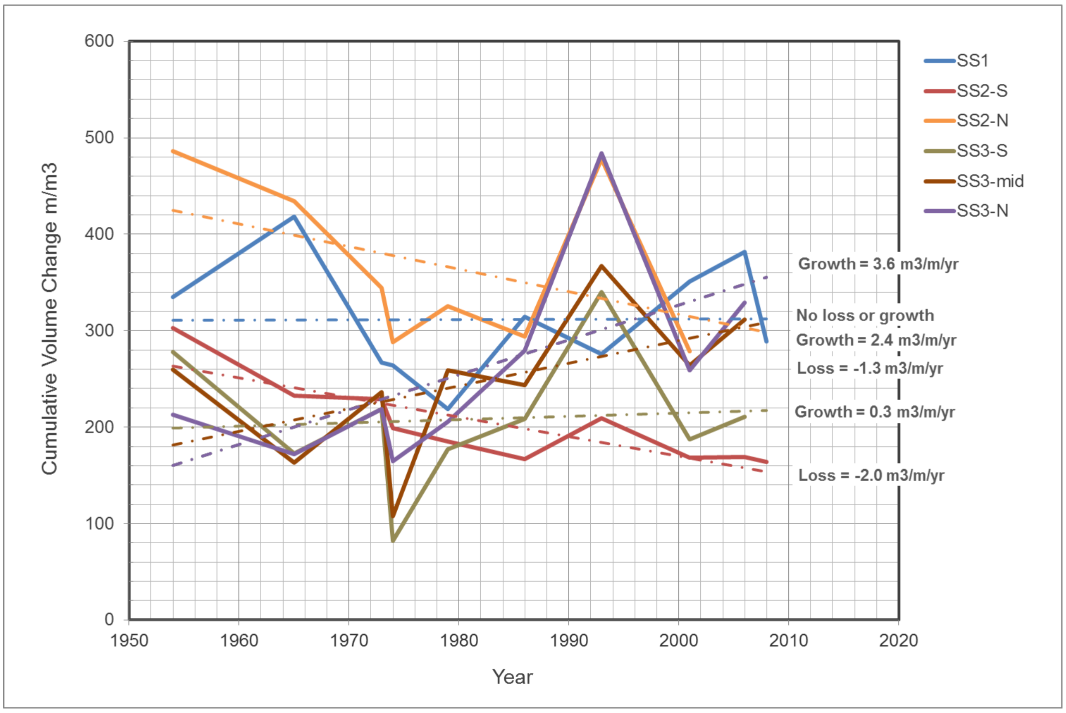


Figure 2-3 Average Change in Beach Volume for Tuggerah Beach Compartment (note: SS1 is The Spit, SS2 is North Entrance Beach and SS3 is Magenta Shores to Pelican Beach)

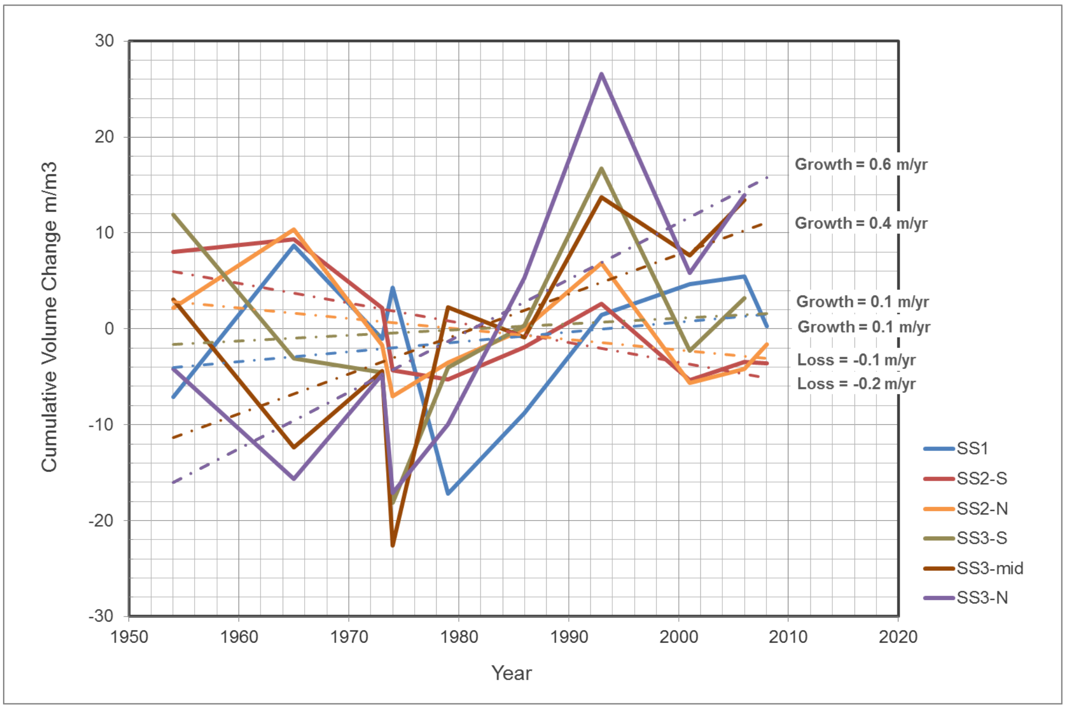


Figure 2-4 Average Change in Dune Face Position for Tuggerah Beach Compartment (note: SS1 is The Spit, SS2 is North Entrance Beach and SS3 is Magenta Shores to Pelican Beach)

2.4.2 Sea Level Rise Impacts

Modern Sandy Beach and Dune Systems

The impacts of sea level rise on Wyong's beaches were approximated for future planning timeframes through application of the Bruun Rule method, with the addition of forward projections of historical recession. This analysis used the 2050 and 2100 sea level rise benchmarks of 0.4 and 0.9 m from 1990 respectively, as per Council's previous sea level rise policy that was consistent with the repealed NSW Governments' Sea Level Rise Policy Statement (DECCW 2009a).

In general, all beaches have evolved with mean sea level relatively constant at or near present level over about 6,000 years to a condition of cross-shore dynamic 'equilibrium'. That is, the profile shape across the beach/dune and nearshore areas to the lower shore-face has an equilibrium form about which cross-shore storm erosion and accretion seabed changes fluctuate. In principle, that equilibrium shape tends to be maintained relative to sea level as the sea level changes. This two dimensional concept is demonstrated by the Bruun Rule on Figure 2-5.

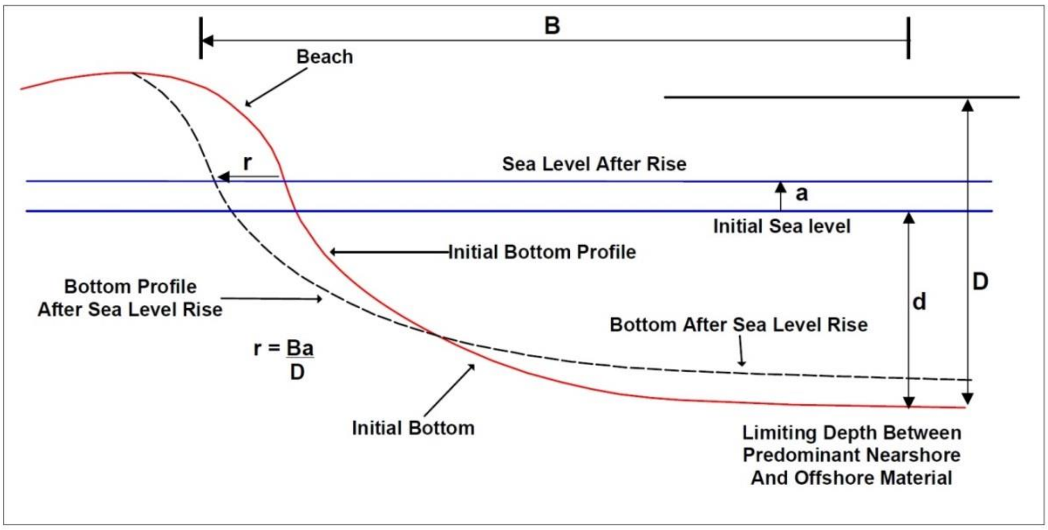


Figure 2-5 Bruun (1962) Concept of Recession due to Sea Level Rise

Application of this 'standard' Bruun Rule has been contested within the coastal science community (e.g. Ranasinghe *et al*., 2007), often relating to the depth of closure to which the equilibrium shape is maintained. For this re-assessment of coastal hazards, the slope factor was determined from a series of cross shore profiles extracted for each beach from the available marine and terrestrial high resolution LiDAR bathymetry/topography. An example of the cross shore (dune/beach/shoreface) profiles used to determine the slope factors for Tuggerah Beach compartment is provided on Figure 2-6.

Submerged rocky reef is a common feature of the shoreface across Wyong's coast, as demonstrated by the cross shore profiles below. The presence of rocky substrate near to the shore typically resulted in Bruun rule slope factors being estimated within a range of 1:35 to 1:50 for Wyong's beaches.

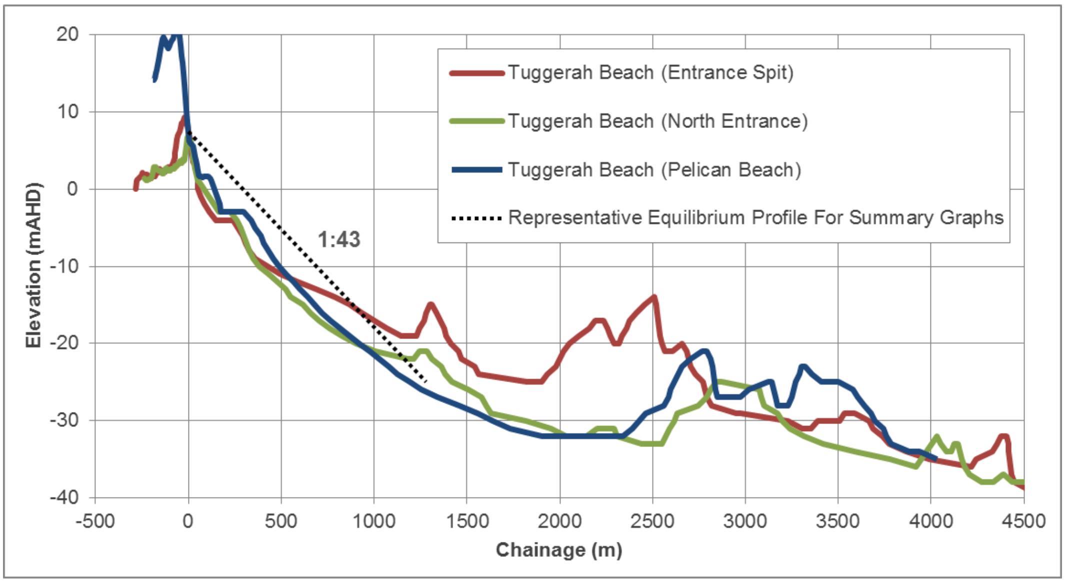


Figure 2-6 Cross Shore Profiles from the Tuggerah Beach Compartment

Sandy Beaches backed by Relic Indurated Sand Bluffs

The tall indurated sand bluffs located at the back of Bateau Bay and Cabbage Tree Harbour beaches are susceptible to wave erosion and shoreline recession over the coming century. These sandy landforms are expected to respond much like modern beach and dune sands with respect to coastal hazards (see **Appendix A**: Coastal Geotechnical Study by JK Geotechnics). The particularly tall and steep topography of the indurated sand bluff features is however considered to influence how these bluff shorelines respond to erosion and recession through time, specifically in relation to:

- Erosion escarpment slumping and corresponding ZSA distances; and
- Active cross shore profile shapes and corresponding Bruun Rule slope factors.

Erosion escarpment slumping of the tall indurated sand bluffs will result in hazard extents (relative to the erosion escarpment) retreating more landward than it would for the much lower profile modern foredunes that front these sand bluffs. That is, higher dune faces will experience a greater degree of slumping in comparison to lower dune faces, as demonstrated in Table 2-2. Conversely, Bruun Rule sea level rise recession calculations that incorporate the tall sand bluff topography into estimates of the equilibrium profile slope factors will result in smaller recession distances, relative to profiles slopes estimated from the lower foredune topography of the modern dunes. That is, relative to low lying topography of modern dunes, the Bruun Rule slope factors that encompass the tall sand bluffs at the back of Bateau Bay and Cabbage Tree Harbour will be comparatively steeper (see Figure 2-7, for example).

Table 2-2 Width of Zone of Slope Adjustment for Varying Dune Heights

RL of Dune System (m AHD) [1]	Indicative ZSA width (m) [2]
5	2.1
10	5.7
15	9.3
20	12.9
25	16.4

[1] *Assumed that the dune system is approximately level (see Figure 2-1).*

[2] *Distance measured landward from the top of the erosion escarpment (see Figure 2-1).*

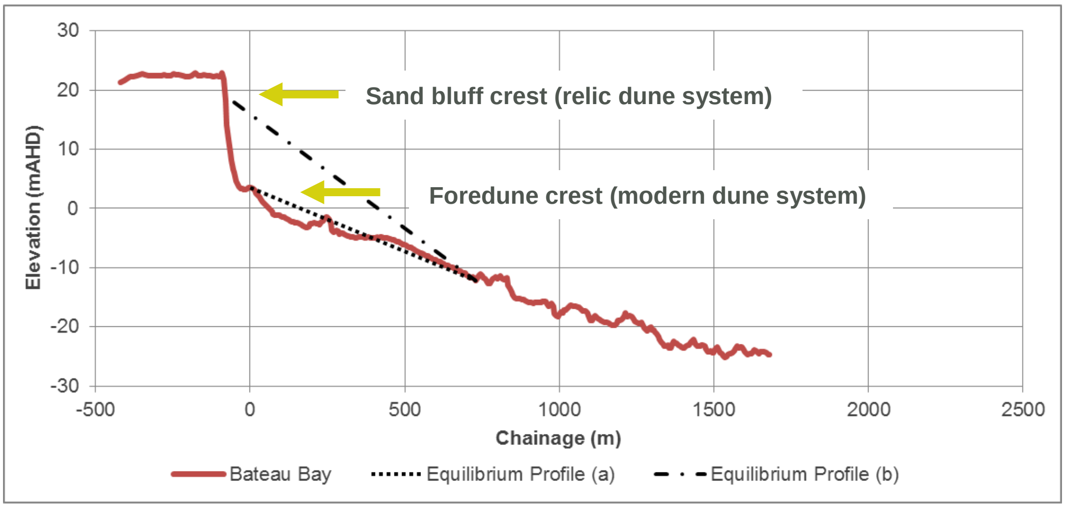


Figure 2-7 Cross Shore Profile from Bateau Bay, showing two Bruun Slope factors adopted, with the shallower Profile A specific to the modern beach and dune system, and the steeper Profile B incorporating the tall indurated sand bluff

Estimations of Future Sand Bluff Slumping

To adequately assess the risk of future bluff slumping in response to sea level rise recession, the ZSA has been calculated for each timeframe that the bluff is impacted by erosion and recession. Where the bluff is impacted under the immediate timeframe, the erosion hazard is calculated on a volumetric basis as per the Nielsen *et al.* (1992) approach outlined in Section 2.3.2. For future timeframes, the hazard extents have been mapped by recalculating the ZSA relative to the dune topography that occurs landward of the estimated 2050 and 2100 escarpment locations. The future escarpment locations were estimated by adding the 2050 and 2100 recession distances onto the scarp location determined for the immediate timeframe (i.e. the zone of wave impact, as calculated for the erosion hazard). This approach ensures that the changing dune slumping hazard that may occur through time in response to bluff recession is adequately incorporated into the sea level rise recession assessment.

Sand Bluff Estimations of Future Sea Level Rise Recession

When exposed to sea level rise impacts, erosion of the tall indurated sand bluffs will liberate substantial volumes of sand into the active beach system. This ongoing source of sediment is expected to help to slow the shoreline recession response to sea level rise impacts. The Bruun Rule approach estimates future sea level rise impacts relative to the equilibrium profile of the active coastal slope, typically taken from the dune crest height down to the ‘depth of closure’ on the shoreface, as previously discussed. Considering the tall height of the indurated sand bluffs at Bateau Bay and Cabbage Tree Bay, the Bruun Rule slope factors will be much steeper (and recession distances relatively lower) when the dune height is taken from the bluff crest (15 -20 m AHD) as opposed to the foredune crest (approximately 4 m AHD; see Figure 2-7). Once exposed to erosion, the tall sand bluff will supply a new source of sediment to the beach system. As such, it is considered appropriate to initially apply the shallower slope factors (resulting in larger recession estimations) where the tall indurated sand bluff is protected by the modern foredune (as the case for much of Bateau Bay in the immediate timeframe). Once the tall bluff forms part of the active beach system, it is then considered appropriate to adopt the steeper active slopes for the sea level rise recession estimates.

The future recession estimations were therefore calculated for each timeframe using the appropriate slope factor as described above. That is, the shallower slope factors were used to estimate recession for any given timeframe where the preceding hazard line intersected the modern beach and dune substrates. However, once the erosion hazard estimates progressed landward into the indurated sand bluff substrates, the subsequent sea level rise recession estimates were determined using the steeper slope factor. This in effect results in progressively smaller sea level rise recession distances being estimated once the tall indurated sand bluff becomes more exposed.

2.5 Bedrock Limits to Beach Erosion

The interaction of sandy related erosion hazards (such as beach erosion, dune instability and shoreline recession) and geohazards specific to rocky substrates (including rock falls, land slips and cliff line retreat) will be apparent on some lengths of Council’s shoreline over the coming planning timeframes (e.g. where sandy beaches are backed by rising bedrock slopes, like that at Pebbly Beach). The points at which coastal hazards transition into geotechnical hazards are controlled by the geological boundary between sandy and rocky substrate (see Figure 2-8 for example). This bedrock control on coastal hazards was mapped by BMT WBM and JK Geotechnics, based on detailed field investigations and geomorphic interpretation of remote sensing information (aerial photography and high resolution topographic data). At the ends of beach compartments, the location of buried bedrock cliffs were mapped by projecting joint planes measured in the observed rocky reefs and platforms in a landward direction from the exposed cliff. Schematic examples demonstrating how this geological boundary will control occurrence of the coastal hazard and geohazard mechanics through time is provided on Figure 2-8 and Figure 2-9. A discussion of how the rocky geohazard lines are constructed, relative to the bedrock control boundary is presented in Section 2.6.1.

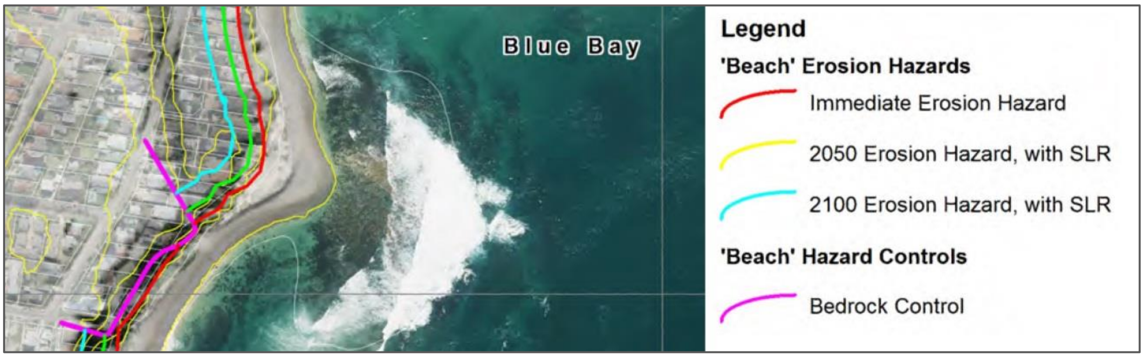


Figure 2-8 Bedrock Control Mapping (Pink) marking the Transitional Interface between Sandy Coastal 'Sandy' Hazards (mapped) and Geotechnical 'Rocky' Hazards (not mapped here)

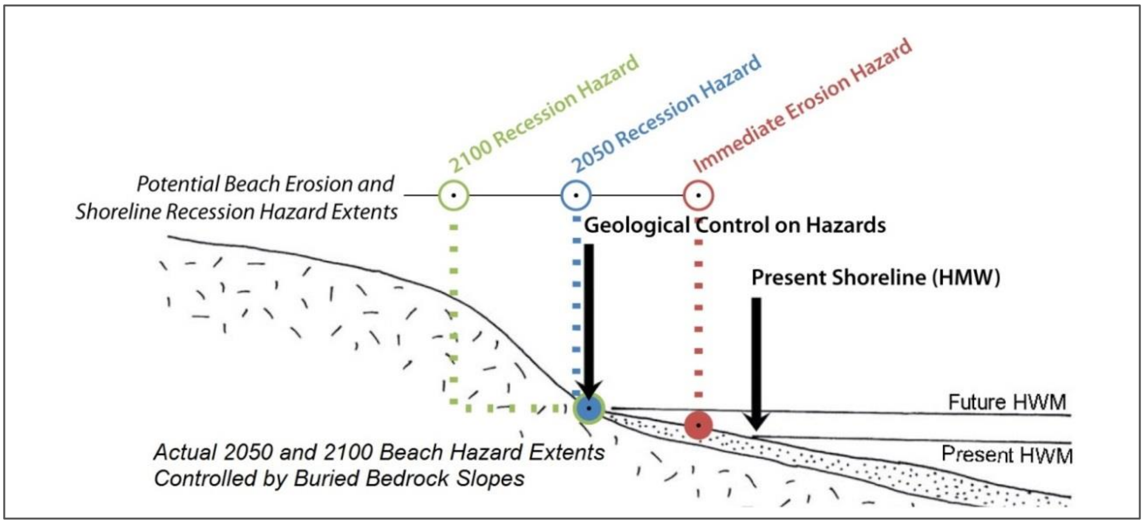


Figure 2-9 Schematic Representation of Geological 'Transitional' Boundary Between Sandy Beach/Dune and Rocky Cliff/Bluff Substrates, noting (a) Coastal Hazards are estimated seaward of the 'Geological Control on Hazards'; and (b) Geotechnical Hazards are estimated landwards of this boundary

2.6 Geotechnical Hazards

A detailed re-assessment of coastal geotechnical slope and instability hazards present along the Wyong shoreline are assessed in the Coastal Geotechnical Study by JK Geotechnics (see Appendix A of this report). A summary of key elements relating to the assessment and mapping of coastal geohazards are presented below.

2.6.1 Bedrock Cliffs and Slopes

Cliff Recession and Bedrock Types

Bedrock cliffs and slopes occurring along the Wyong coastline experience cliff line recession to varying degrees. A major controlling factor influencing recession of bedrock shorelines is the underlying geology/lithology (rock types). The major geological units present along the Wyong coastline include:

- Patonga Claystone;
- Tuggerah Formation; and
- Munmorah Conglomerate.

Cliff recession was found to be controlled by the underlying geological structure of the rock types (see Table 2-3 for details). Preferential weathering of weaker claystone of shale beds ultimately lead to toppling failure from the overlying sandstone strata in isolated blocks. The orientation and size of these blocks are determined by the jointing and bedding planes. Localised and episodic block toppling is considered to be the primary driver of cliff recession, as opposed to uniform and progressive cliff line recession over larger areas.

Table 2-3 Coastal Bedrock Types Occurring Along Wyong's Coastline

Bedrock Unit	Lithology Types Present	Joint Spacing (and Joint Dip Angle)	Typical Joint Plane	Typical Location (in the Cliff Face)	Other Comments
Patonga Claystone *(Rnp)*	Interbedded lithic sandstone, siltstone and claystone. Typically thinly and very thinly bedded.	2 m (70°)	Three sets of joint planes common. Jointing orientated between: 020°& 040°; 290° & 305°; and 325° & 330°.	Crackneck to Entrance	Triassic age. Overlies Rnu. Greater proportion of sandstone occurs north of Bateau Bay.
Tuggerah Formation *(Rnu)*	Lithic sandstone with siltstone, claystone and conglomerate beds	4 m (70°)		Norah Head to Jenny Dixon and Hargraves Beaches	Triassic age. Overlies Rnm. Intruded by Igneous Dykes.
Munmorah Conglomerate *(Rnm)*	Conglomerate and lithic sandstone with sandstone, siltstone and claystone bands.	4 m (70°)		Soldier Beach Pebbly Beach Norah Head?	Triassic age. Intruded by Igneous Dykes.
Igneous Dyke	Igneous rock, commonly highly weathered	N/A	N/A	Soldiers Beach? to Hargraves Beach?	Sub-vertical intrusion occurring along joint plains.

Cliff and headland profiles typically form a convex profile. At these locations, bedrock substrate typically forms the lower sub-vertical toe slopes while the upper more shallow slopes comprise an overlying ‘soil’ profile, which are formed of either: dune sands, residual bedrock soils or colluvium.

Where convex profiles occur, such as at localised areas at Crackneck and Jenny Dixon Beach, the foreshore slopes are considered to possibly form relic landslip material that sits seaward of the underlying bedrock substrate, which is likely located at some distance behind the toe location.

Cliff Retreat and Recession Rates

As previously summarised, the cliff recession hazard for bedrock cliff/slope shorelines is controlled by the jointing structure of the underlying rock type. For the immediate timeframe, it is considered the current cliff face will retreat by 1 joint spacing. Therefore, the bedrock coastal slopes may retreat 2 m at any location where the cliff face is formed of Patonga Claystone (i.e. Crackneck to the Entrance) while bedrock coastal slopes may retreat 4 m along where the cliff face is formed of Tuggerah Formation of Munmorah Conglomerate rocks (i.e. Soldiers Point to Jenny Dixon/Hargraves Beach).

Future cliff face recession based on estimated historical recession rates presented in SCE (2010) were considered to be overly conservative and inconsistent with field observations. Historical recession rates adopted to estimate future bedrock cliff geohazards for this study are:

- 4 m/100 years for Patonga Claystone (sandstone dominant) based on an average of ten minimum and maximum recession rates and with a platform recession rate of 1 m/100 years.
- 3 m/100 years for Tuggerah Formation based on the Norah Head data with a platform recession rate of 1 m/100 years.
- 3 m/100 years for Munmorah Conglomerate based on generally similar rock types to the Tuggerah Formation (i.e. sandstone and conglomerate, although conglomerates are more prevalent in the Munmorah Conglomerate) and the Norah Head data with a platform recession rate of 1 m/100 years. The platform comprises Munmorah Conglomerate at Norah head.

The above listed cliff face recession rates are based on a combination of other published data considered to be representative of, and comparable to, the geological conditions of the study site, as well as rocky shore platform width. Unlike that reported in SCE (2010), no readily discernible increase in cliff erosion rates are considered to occur where igneous dykes were present and therefore cliff areas intruded by dykes are treated no differently than the adjoining areas formed of the same parent sedimentary bedrock material.

Future cliff face recession distances assuming no sea level rise are estimated in Table 2-5. These rates are based on the estimated recession rates listed above, and the geological structure of the underlying bedrock substrate type.

Table 2-4 Adopted Bedrock Cliff Recession Rates for the No Sea Level Rise Scenario

Bedrock Unit	Historical Recession Rate	Joint Spacing / Block Width	2050 Recession No SLR Scenario (Joint Controlled & Rounded)[1]	2100 Recession No SLR Scenario (Joint Controlled & Rounded)[1, 2]
Patonga Claystone *(Rnp)*	4 m/100 years *or* 0.04 m/yr	2 m	2 m	4 m
Tuggerah Formation *(Rnu)*	3 m/100 years *or* 0.03 m/yr	4 m	4 m	8 m
Munmorah Conglomerate *(Rnm)*	3 m/100 years *or* 0.03 m/yr	4 m	4 m	8 m

1 For Rnp, extrapolation of the recession rate implies about 1.4 m of cliff recession by 2050, relative to the 2015 hazard toe slope position. Recession for this 35 year period is therefore rounded up to 2 m, based on typical joint spacing for this rock type;
For Rnu and Rnm, extrapolation of the recession rate implies about 1.1 m of cliff recession by 2050, relative to the 2015 hazard toe slope position. Recession for this 35 year period is therefore conservatively rounded up to 4 m based on typical joint spacing for these rock types.

2 For Rnp, extrapolation of the recession rate implies about 2.0 m of cliff recession between 2050 and 2100. Recession for this 50 year period is rounded up to 2 m based on typical joint spacing for this rock type. Recession by 2100 is therefore estimated at 4 m for Rnp, relative to the 2015 hazard cliff face slope position;
For Rnu and Rnm, extrapolation of the recession rate implies about 1.5 m of cliff recession between 2050 and 2100. Recession for this 50 year period is conservatively rounded up to 4 m based on typical joint spacing for these rock types. Recession by 2100 is therefore estimated at 8 m for Rnu and Rnm, relative to the 2015 hazard cliff face slope position.

To consider the impacts of climate change on the rocky lengths of coastline, SCE (2010) postulated that sea level rise would increase the underlying recession rate as per follows:

- By 2050, 110% of current base value; and
- By 2100, 120% of current base value.

It is considered the above sea level rise factors are reasonable and this current study has therefore adopted the same approach (albeit the underlying recession rates adopted for this assessment are different to those adopted by SCE, 2010). Based on the estimated recession rates, measured geological structures and adopted sea level rise factors, future cliff face recession distances due to sea level rise are presented in Table 2-5. These results show that climate change is not estimated to increase recession distances, which are ultimately controlled by joint spacing. That is, the estimated increases in cliff face recession resulting from sea level rise are not large enough to cause additional block failures for the 2050 and 2100 timeframes.

Table 2-5 Adopted Bedrock Cliff Recession Rates for the Sea Level Rise Scenario (0.4m and 0.9m by 2050 and 2100, relative to 1990

Bedrock Unit	Historical Recession Rate *2050 Recession Rate (x1.1)* *2100 Recession Rate (x1.2)*	Joint Spacing / Block Width	2050 Recession SLR Scenario (Joint Controlled & Rounded)[1]	2100 Recession SLR Scenario (Joint Controlled & Rounded) [1, 2]
Patonga Claystone *(Rnp)*	4 m/100 years *4.4 m/100 years* *4.8 m/100 years*	2 m	2 m	4 m
Tuggerah Formation *(Rnu)*	3 m/100 years *4.4 m/100 years* *4.8 m/100 years*	4 m	4 m	8 m
Munmorah Conglomerate *(Rnm)*	3 m/100 years *3.3 m/100 years* *3.6 m/100 years*	4 m	4 m	8 m

[1] For Rnp, extrapolation of the 2050 recession rate implies about 1.5 m of cliff recession by 2050, relative to the 2015 hazard toe slope position. Recession for this 35 year period is therefore rounded up to 2 m, based on typical joint spacing for this rock type;
For Rnu and Rnm, extrapolation of the 2050 recession rate implies about 1.2 m of cliff recession by 2050, relative to the 2015 hazard cliff face position. Recession for this 35 year period is therefore conservatively rounded up to 4 m based on typical joint spacing for these rock types.

[2] For Rnp, extrapolation of the 2100 recession rate implies about 2.4 m of cliff recession between 2050 and 2100. Recession for this 50 year period is rounded to 2 m based on typical joint spacing for this rock type. Recession by 2100 is therefore estimated at 4 m for Rnp, relative to the 2015 hazard cliff face position;
For Rnu and Rnm, extrapolation of the 2100 recession rate implies about 1.8 m of cliff recession between 2050 and 2100. Recession for this 50 year period is conservatively rounded up to 4 m based on typical joint spacing for these rock types. Recession by 2100 is therefore estimated at 8 m for Rnu and Rnm, relative to the 2015 hazard cliff face position.

Cliff Profile Adjustment and Hazard Line Construction

Bedrock cliff geohazards are considered to occur landward of the existing cliff face location (baseline). This location was mapped using a GIS based on field observation and interpretation of remote sensing data (aerial photographs, LiDAR topography). For most locations where the rocky coast was formed of active cliff faces, the baseline was easily mapped where the cliff toe adjoined the rocky shore platform. In some areas however, the baseline position had to be interpreted where cliff toe was buried by surficial deposits (e.g. colluvial material or beach and dune sands; see also Section 2.5).

Cliff recession hazards were mapped for this study to include not only cliff face recession, but also the soil slope adjustments that may occur upslope of the cliff face position. The following methodology was applied for this purpose:

- For the immediate timeframe, the cliff face was established at a landward set-back distance equivalent to the joint spacing and a new cliff face projected up at 70° from the rocky shore platform to the estimated bedrock surface level occurring on the cliff face.

- From the estimated bedrock surface level, a more shallow 'soil' adjustment profile was then projected as follows:
    - For sandy soil profiles considered to primarily comprise dune sand for example, the 'soil' profile was projected upward and landward at an angle of 30° to intersect with the ground surface (see Figure 2-11); and
    - For thin clayey residual soil profiles, which typically include weathered bedrock faces exposed in places, the 'soil' profile was adjusted at an angle of 45° for an adopted residual soil thickness of 2 m (see Figure 2-10).
- For future timeframes, the above process was repeated relative to the immediate hazard cliff face position (i.e. one joint spacing landward of the existing cliff toe baseline positon), and with reference to the recession distances outlined in Table 2-4 and Table 2-5.

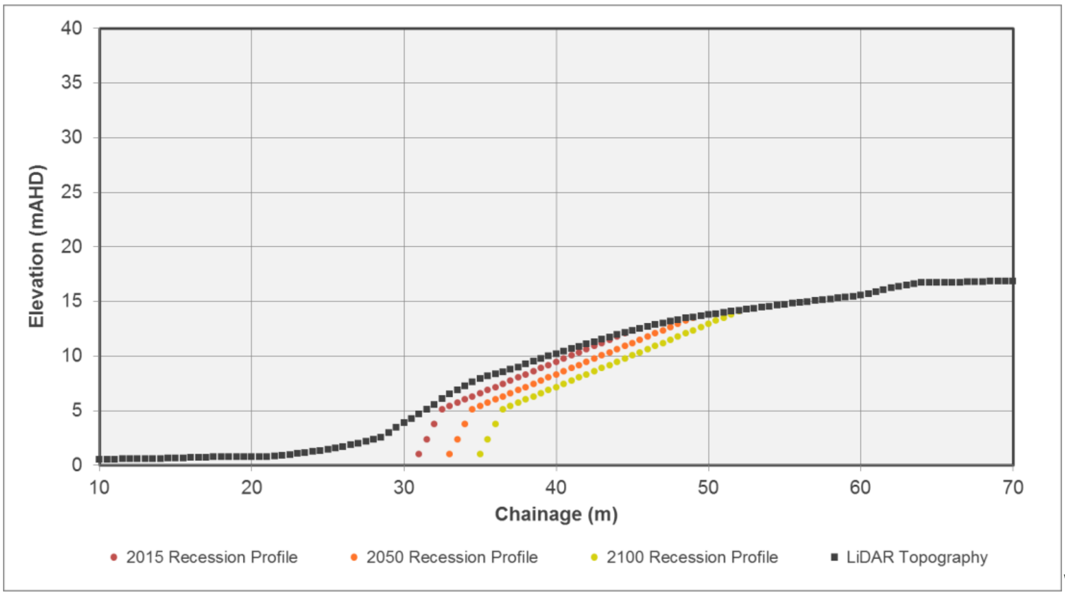


Figure 2-10 Cliff Recession Geohazard Lines Projected at Little Beach, with an estimated bedrock survey at 5 mAHD and a 30° soil adjustment angle applied

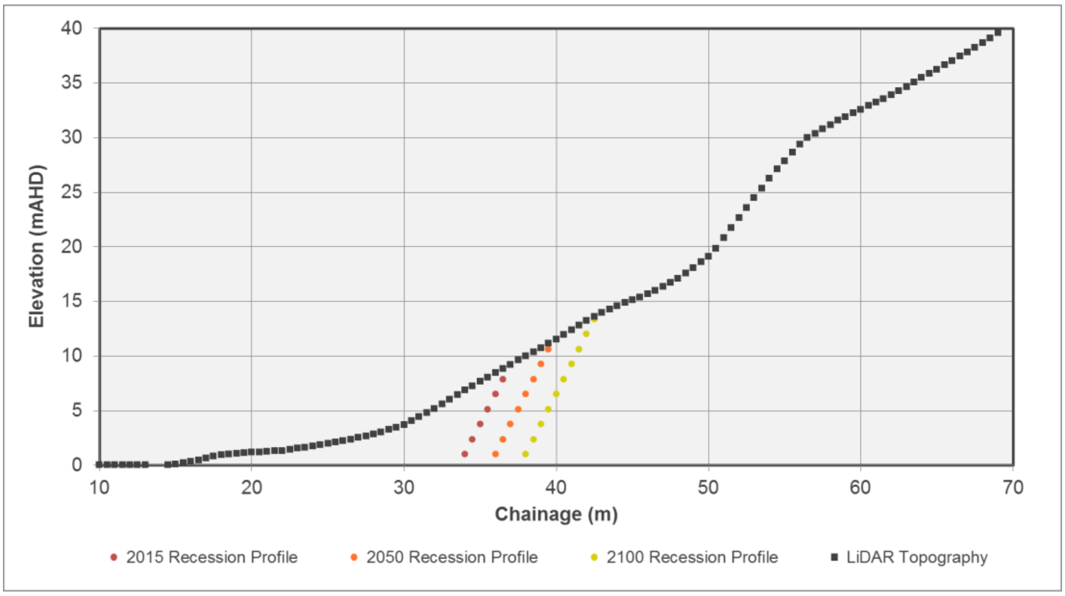


Figure 2-11 Cliff Recession Geohazard Lines Projected at Crackneck, noting a thin residual soil adjustment factor is added to these projected cliff faces lines

2.6.2 Non-Coastal Geotechnical Hazards within the Coastal Zone

During the re-assessment of hazards, it became apparent that some areas within coastal zone are susceptible to geotechnical instability which is not directly related to cliff recession processes. SCE (2010) originally identified a number of such areas, which they labelled 'Geotechnical Hazard Zones'. The current study considers the designation of geotechnical hazard zones are a valid addition to the cliff recession hazard lines, as they identify to Council areas susceptible to landslide and soil erosion. These areas have been identified and mapped at the following locations:

- Crackneck Point;
- Bateau Bay;
- Blue Lagoon;
- Toowoon Bay and Blue Bay;
- Pebbly Beach;
- Cabbage Tree Harbour; and
- Jenny Dixon Beach.

Where the above geotechnical hazard zones occur immediately adjacent to the shoreline, the hazard zones have been mapped down to the immediate cliff recession hazard line (e.g. Figure 2-12).

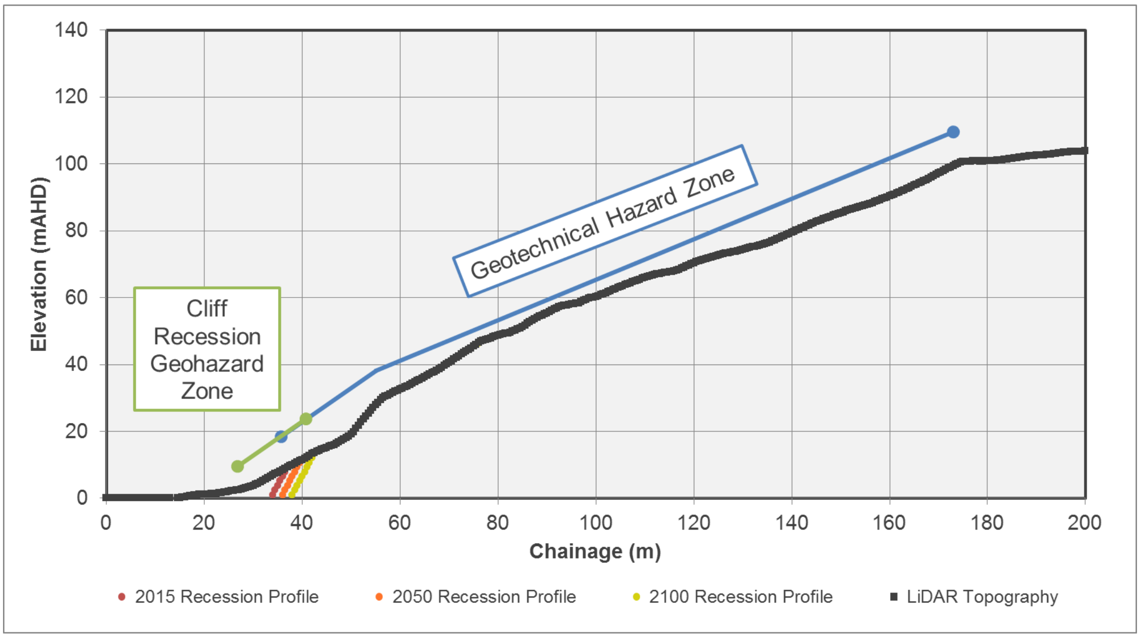


Figure 2-12 Cross Shore Headland Profile from Crackneck, showing relationship between 'coastal' geohazards and 'non-coastal' (landslip/soil creep) geotechnical hazards

2.6.3 Indurated/Cemented Sand Bluffs

The tall indurated sand bluffs are located within the active coastal zone at Bateau Bay and Cabbage Tree Harbour, as well as within the back beach area at Blue Lagoon. Key geotechnical aspects specific to this substrate type include:

- The cementation of the indurated and cemented sands increases their shear strength parameters, however when exposed to water (e.g. wave action) the cementation minerals dissolve and the shear strength parameters reduce to values typical for marine sand.
- The indurated bands typically form discrete bands within past dune sand deposits and are not laterally or vertically continuous due to the complex range of processes that have led to their formation.
- Based on the above, it is considered that coastal indurated/cemented sand bluffs should be assessed in a similar manner to other modern beach and dune areas (see Section 2.4.2 for details).

As an acknowledgement of the complex issues specifically affecting this Cabbage Tree Harbour, it is considered that the following hazard parameters should also be applied:

- Reduced angle of repose of 30° for dune slumping and foundation stability calculations; and
- Historical recession rate of about 0.3 m per year.

2.7 Wyong's Coastal Hazard Planning Scheme

Council has adopted a Coastal Hazards Planning Scheme suitable for land use planning purposes across the Wyong coastline. This planning scheme applies to coastal erosion, shoreline recession and geotechnical instability hazards and simplifies the coastal hazard type and timeframe information down to one of three (3) risk ratings, including an Immediate Coastal Hazard Zone, a High Coastal Hazard Zone and a Low Coastal Hazard Zone as demonstrated in Table 2-6.

Table 2-6 Coastal Hazards Types and Timeframes and Wyong Shire Council's Planning Scheme

Hazard Types	Wyong Council's Planning Scheme
- Immediate Beach Erosion Hazard - Immediate Cliff Recession Hazard	Immediate Coastal Hazard Zone
- Immediate Dune Instability Hazard *- Geotechnical Hazard Zone*	*Not mapped under Councils current planning scheme*
- 2050 Beach Recession - 2050 Cliff Recession Hazard	High Coastal Hazard Zone
- 2100 Beach Recession - 2100 Cliff Recession Hazard	Low Coastal Hazard Zone

2.8 Coastal Inundation

Ocean water levels become elevated during storms and can lead to inundation of low lying land adjacent to the coastal waters. In an open coastal situation like that experienced along the Wyong coastline, the components which contribute to elevated ocean water levels during storms include:

- astronomical tide;
- inverted barometric setup;
- wind setup;
- wave setup; and
- wave runup.

Sea level rise will also contribute to elevated ocean water levels in the future.

Where the crest height of a cliff, shoreline structure or dune is less than the wave run-up level, waves will overtop the shoreline and may cause inundation of the land behind. Consequently, this may present a hazard if the rate of overtopping can cause a significant impact to people or assets behind it.

An assessment of coastal inundation was completed for Wyong by SMEC (2010). That assessment did not require revision as part of this hazard study review and therefore the outputs from that study continue to be current. A summary of the SMEC (2010) coastal inundation assessment approach is provided in Section 2.8.1 below, and the results are reproduced in Chapter 4.

2.8.1 Coastal Inundation Assessment Methods

Wave runup levels were modelled for a number of locations at Wyong by SMEC (2010). That wave runup assessment was completed using the Automated Coastal Engineering Software (ACES). Wave runup calculations with ACES applied a combined 1% Annual Exceedance Probability (AEP) design offshore wave height condition and 1% AEP water level conditions determined for the Sydney region. Nearshore significant wave height was calculated SBEACH software (SMEC, 2010).

Wave runup levels were calculated by adding the runup level outputs from ACES modelling to the modelled elevated nearshore water levels and the maximum recorded ocean water level of 1.48 m AHD for Sydney, presented by Kulmar and Nalty (1997) (SMEC, 2010).

3 Coastal Hazard Re-assessment by Location

The following Chapter presents the location specific results of the coastal erosion and geotechnical hazard re-assessment, moving south to north along the study coastline. A brief description of the physical environment for each coastal location is presented. Additional site specific details and photographs relating to geotechnical conditions can be found in Coastal Geotechnical Study by JK Geotechnics (see Appendix A). Site specific coastal inundation assessment outputs by SMEC (2010) are also summarised within this Chapter..

A comparison between this current study (BMT WBM and JK Geotechnics) and the preceding studies (SMEC, 2010; SCE, 2010) is provided at the end of this chapter (see Section 3.14).

3.1 Crackneck Point and Surrounding Rocky Headlands

Crackneck Point and surrounding rocky headland areas, extending northwards from Yumbool Point to Bateau Bay beach, are contained within the southern section of Wyrrabalong National Park. This rocky coastline comprises a prominent headland feature that rises to elevations of up to 100 m and protrudes seaward from the surrounding coastline. This headland feature is predominantly formed of Patonga Claystone with an upper capping of Terrigal Formation, while the rocky shore platform is comprised of the Tuggerah Formation (SCE, 2010). The rocky shore platform situated northward of Crackneck Point is notably wide (see Figure 3-1), whereas the rocky platform southward of here is much narrower. Coastal cliffs dominate the east facing coastline, while coastal slopes are common along the north facing shoreline.

Figure 3-1 Coastal Cliffs and Slopes of Crackneck Point, fringed by a well formed Rocky Shore Platform. Photo looking southeast from Bateau Bay Bluff

3.1.1 Slope and Cliff Instability

Lengths of rocky coast at Crackneck Point are susceptible to cliff recession. Recession setback distances have been estimated based the local geological characteristics summarised in Table 3-1.

In addition to coastal cliff recession, large areas of Crackneck headland and surrounding slopes are also susceptible to non-coastal related landslide and soil erosion geotechnical hazards driven by hillslope processes and groundwater flows, for example. The extent of this geotechnical hazard zone extends from the crest of the headland and extends seaward to the immediate cliff recession hazard zone.

Further details regarding geotechnical hazards are found in Appendix A: Coastal Geotechnical Study by JK Geotechnics.

Table 3-1 Geotechnical Characteristics for Crackneck Point and Surrounds

Coastal Morphology	Geology	Cliff Recession Mechanism	Recession Rate	Adopted Recession Angle	Slope Instability Hazards
Bedrock cliffs and slopes rocky shore platform of variable width	Terrigal Formation, **Patonga Claystone,** Tuggerah Formation (2m joint spacing; 70° jointing angle)	Block collapse and soil slope adjustment	1 joint spacing (2 m) per planning horizon timeframe	70° for bedrock 45° for surficial soil profile	Upper slopes also susceptible to non-coastal geotechnical hazards (landslip/soil creep)

3.2 Bateau Bay and Adjoining Unnamed Headland to the South

Bateau Bay is a small 400 m curving sandy beach that faces southeast, and is partly protected by two protruding bedrock headlands with wide rocky shore platforms (see Figure 3-2). Submerged rocky reef also fronts the middle section of the bay. The beach is backed by low-lying foredunes (some 100 m wide, and below 4 m AHD), which adjoin a steeply rising, well vegetated, embankment that plateaus at around 20 – 25 m AHD. This embankment feature forms a relic coastal cliff/slope (i.e. coastal bluff) that has become stranded by the development of the modern beach and dune system. The backing bluff is comprised mostly of indurated and cemented sands that likely form a relic (Pleistocene-age) dune system. The modern (Holocene-age) dunes have been disturbed in historical times through the early construction (circa 1890) and more recent demolition and rehabilitation (1987) of the Bateau Bay Lodge that was located at the north end of the beach.

Crackneck Point to the south extends some 1 km southeast of the embayment to shelter the beach from swell out of the southerly sector (see Figure 3-1). The unnamed headland adjoining the northern end the bay is less prominent, sitting around 15 m tall and fringed by a wide rocky shore platform. This headland is formed predominantly of Patonga Claystone with a base of Tuggerah Formation.

Figure 3-2 Bateau Bay looking east, showing the Steep and Vegetated Indurated Sand Bluff (foreground) that backs the Small Curving Beach and Low Dune Field (midground)

3.2.1 Beach Profile Data

Beach profiles from the years listed in Table 3-2 were analysed for Bateau Bay.

Table 3-2 Summary of Beach Profile Data for Bateau Bay

Beach Profile Years	Comments
• 1965 • 1976 • 1984 • 2001 • 2007* • 2011*	• Beach profile information for 2007 and 2011 was extracted from existing LiDAR datasets, to improve the historical coverage of this beach • Only two photogrammetric profiles exist for this beach, each located near the northern and southern ends of the embayments • Bateau Bay Beach has a history of human intervention, with the construction (circa 1890) and subsequent removal (1987) of Bateau Bay Lodge that was located at the north end of the beach. It is not known if these works have had a significant influence on the sediment budget for this beach, or otherwise.

3.2.2 Erosion

Bateau Bay beach appears to have been relatively stable between 1965 and 1984, which was then followed by a period of accretion that has persisted to current times. Field observations by the authors found the beach to be in an accreted state in June 2015, with a well formed incipient dune present. The total recorded envelope of beach volume fluctuations reaches between 170 to 180 m^3 (see Figure 3-3). Changes to the dune face position (3 m AHD contour) were consistent with the beach volumes trends described above, and with the dune position mostly stable up to 1984 before moving seaward by 45 m by 2007. It has undergone some erosion since then (see Figure 3-4).

The erosion demand volume determined for Bateau Bay, based on the historical beach profile data and relative to the 2007 conditions, was estimated to be 160 m^3/m (see Figure 3-5). Under this event, the backing indurated sand bluff and rocky slopes would become exposed at some locations near the northern and southern ends of the beach.

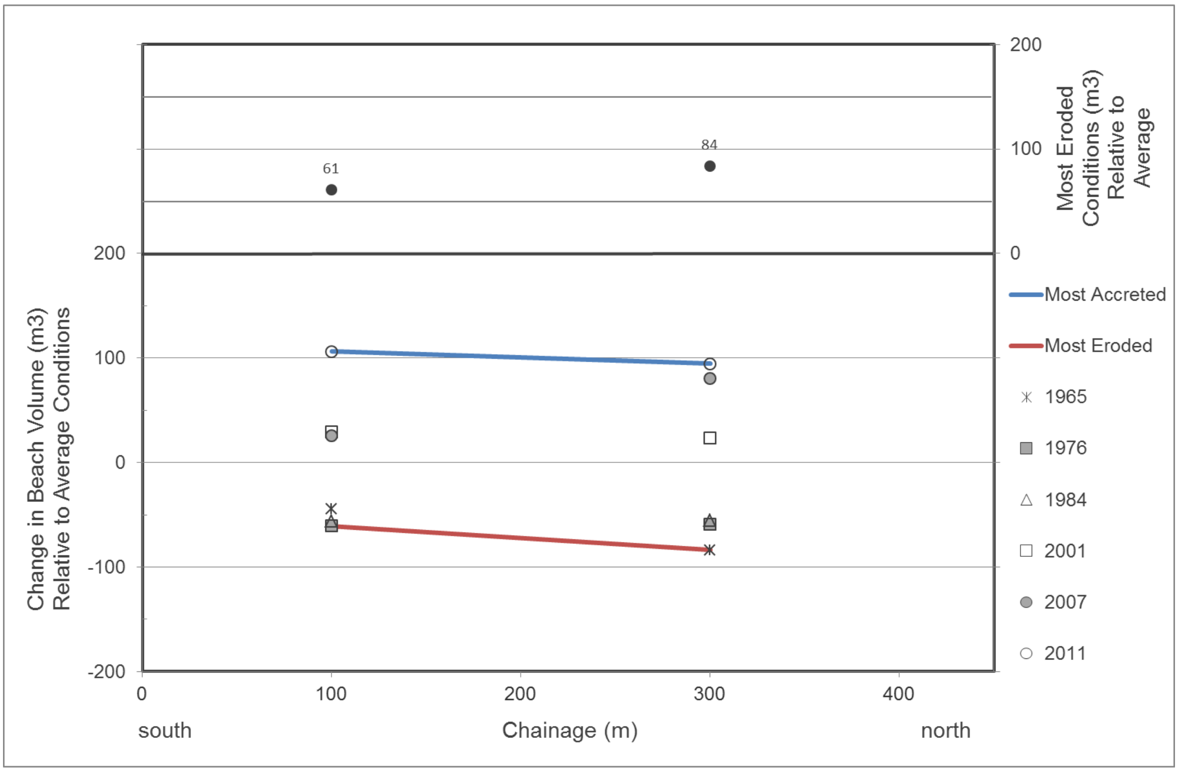


Figure 3-3 Changes in Beach Profile Volume for Bateau Bay

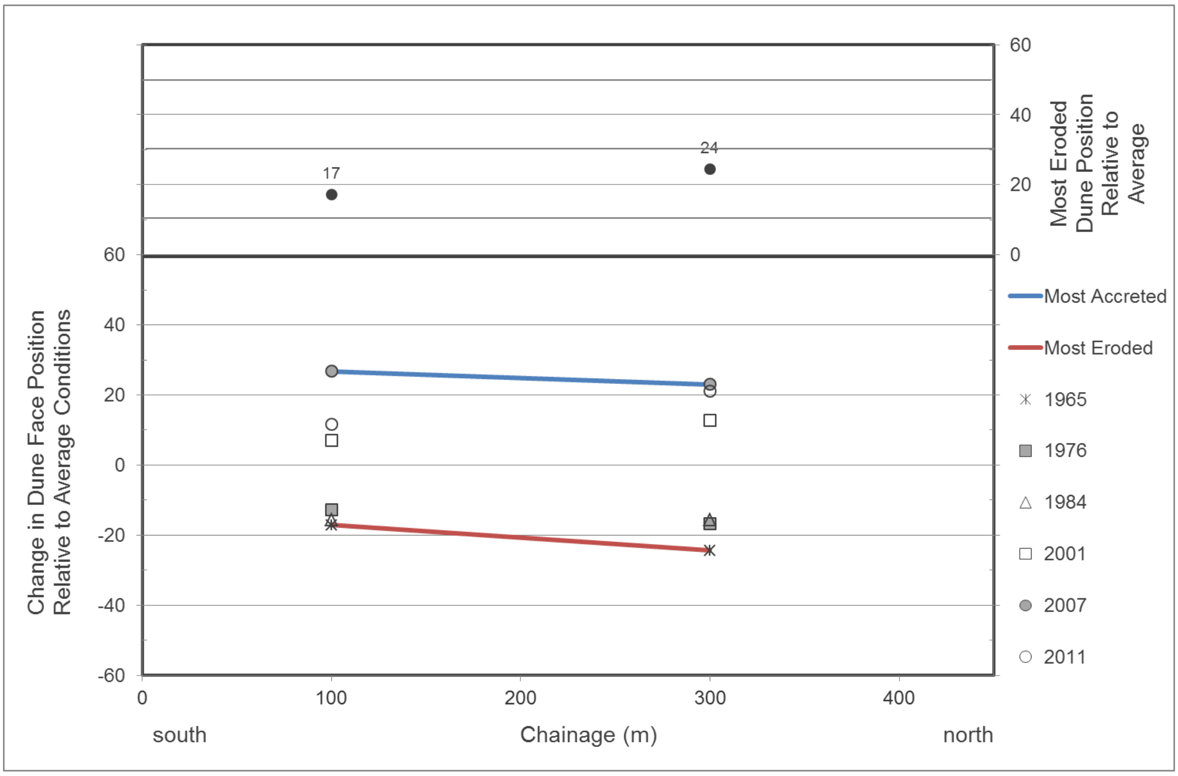


Figure 3-4 Changes in Dune Position for Bateau Bay

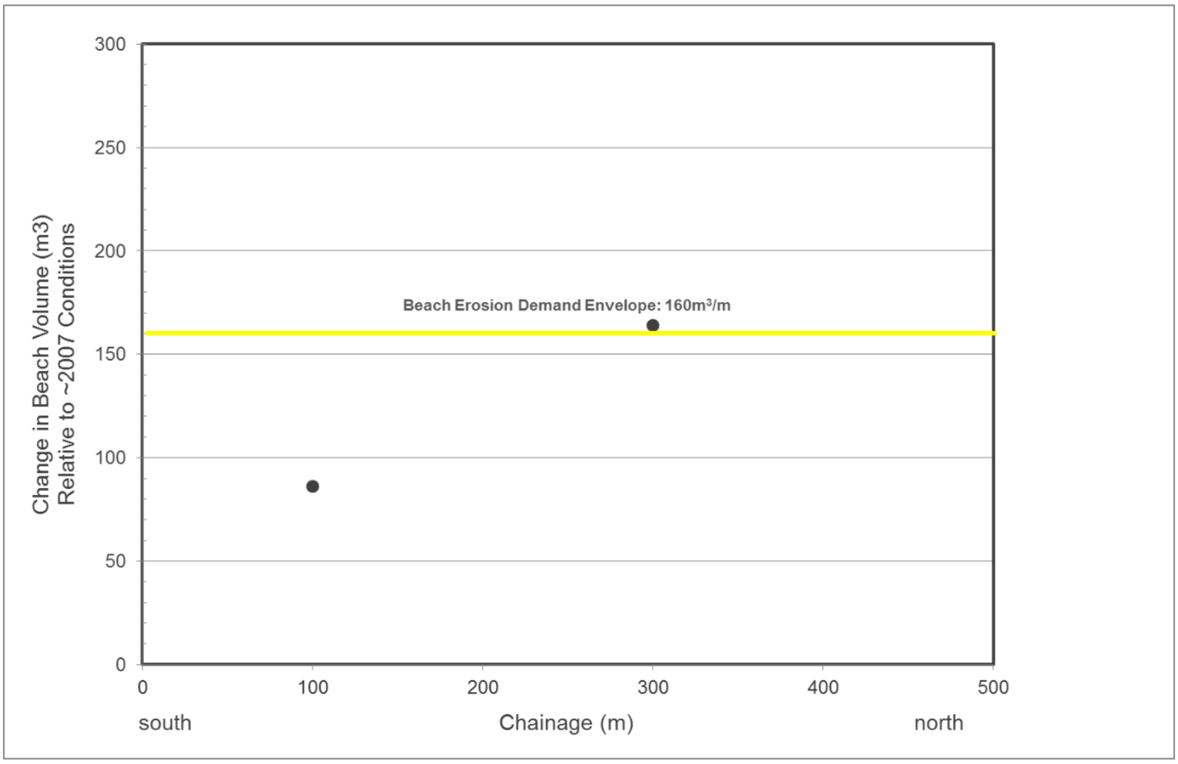


Figure 3-5 Beach Erosion Demand Volumes Relative to 2007 for Bateau Bay

3.2.3 Recession

Historical Recession

Analysis of long term trends in beach volume change for Bateau Bay, found that the subaerial beach has experienced a net volume increase of 3.6 m^3/m/yr (see Figure 3-6), which equates to an accretion rate of 1.0 m/yr based on a dune height considered to be representative of entire embayment shoreline (see Table 3-3). Analysis of dune face position based on the 3 m AHD contour position, also found the beach to be accreting at a rate of 1.0 m/yr (see Figure 3-6 and Table 3-4).

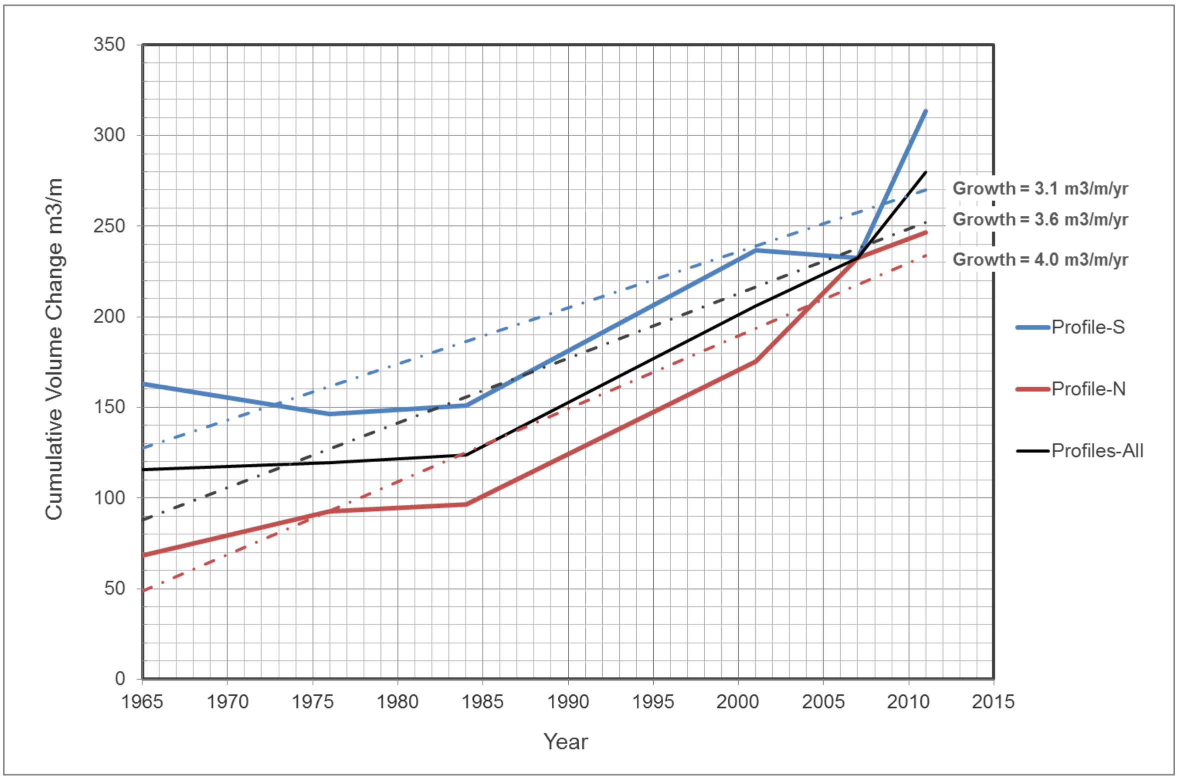


Figure 3-6 Cumulative Change in Beach Volume per metre length of Beach for Bateau Bay

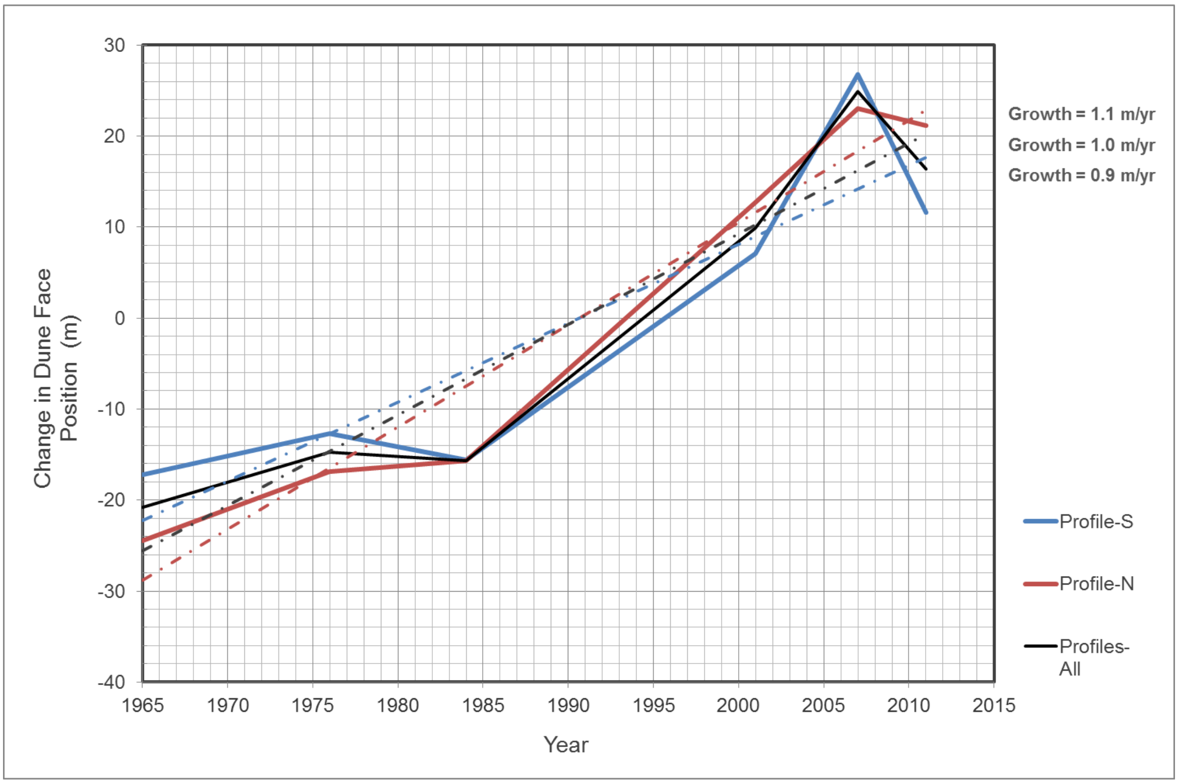


Figure 3-7 Cumulative Change in Dune Face Position for Bateau Bay

Table 3-3 Long Term Shoreline Change for Bateau Bay from Beach Volume Change

Net Volume Changes Recorded from the Active Beach System (m^3/m/yr)
Bateau Bay (Profiles-All)
3.6
Adopted Dune Heights (m)
Bateau Bay (Profiles-All)
3.5
Historical Recession and/or Accretion Rates (m/yr)
Bateau Bay (Profiles-All)
1.0

Table 3-4 Long Term Shoreline Change for Bateau Bay from Dune Movement

Historical Recession and/or Accretion Rates (m/yr)
Bateau Bay (Profiles-All)
1.0

Table 3-5 Adopted Historical Recession Rates for Hazard Definition Purposes

Historical Recession Rates (m/yr)
Bateau Bay (Profiles-All)
0.0

There are no obvious reasons that could account for the continued long term supply of sand to this beach, considering no significant net longshore sediment transport is occurring in the region, nor is there a significant storage of sediment located immediately offshore (as indicted by the common rocky reefs observed in the high resolution marine LiDAR bathymetry). As such, the accretion measured over the past decades may be in response to a favourable medium term wave climate that promoted the onshore transport of the isolated sediment body that extends offshore. In addition, any shoreward supply of sediment occurring at present will likely be reduced with continued and accelerating sea level rise that is projected to occur over the coming century. Considering the above assumptions, a historical recession rate of 0 m/year has been adopted for this hazard assessment.

Sea Level Rise Impacts

The impact of future sea level rise on Bateau Bay beach is summarised in Table 3-6. The slope factors used for the Bruun Rule estimates are provided in the table below and plotted against a cross shore profile on Figure 3-8, which show submerged rocky reef to widespread across the shoreface.

Table 3-6 Bruun Rule and Sea Level Rise Impacts for Bateau Bay

Beach Location	Photogram. Available? / No. Years / No. Dates	Adopted Long Term Recession			Estimated Recession from SLR		
		Adopted Rate (m/yr)	2050 Recession (m)	2100 Recession (m)	Active Slope (1:X)	2050 SLR Recession (m) [1]	2100 SLR Recession (m) [2]
Bateau Bay	Yes / 46 yrs / 6 dates	Nil	Nil	Nil	46 / 29	15	29

[1] **2050 SLR Recession** distances are estimated with the active slope of 1:46 that incorporate the topography of the low lying modern dune only.

[2] **2100 SLR Recession** distances are calculated assuming the future shoreline recedes landwards into the tall indurated sand buff by 2050; therefore the immediate to 2050 sea level rise recession impacts are estimated with the active slope of 1: 46 and the 2050 to 2100 sea level rise recession impacts are estimated with the active slope of 1:25 which incorporate the topography of tall indurated sand bluff.

* **Note** all recession distances are rounded to the nearest metre.

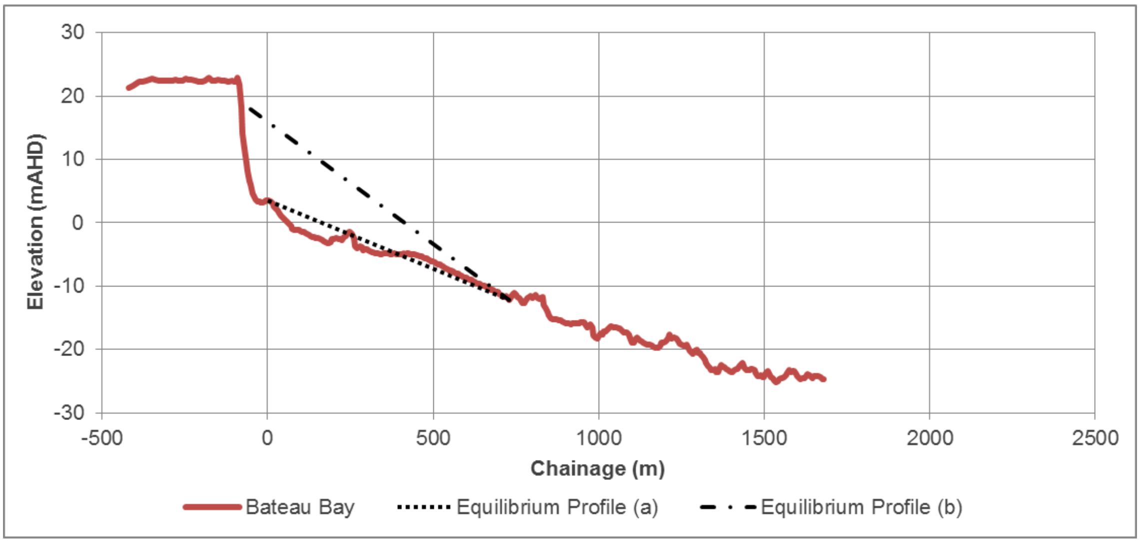


Figure 3-8 Cross Shore Profile from Bateau Bay, showing the Active Profile Slope

Bateau Bay beach, like Cabbage Tree Harbour, varies from other beaches in that the active beach and dunes are backed by a tall indurated sand bluff. While the sand bluff is expected to respond to sea level rise much like that of modern beach and dunes, the significantly increased topography of this feature is expected to influence the sea level recession behaviour, as discussed in Section 2.4.2. As such, the sea level rise recession impacts for Bateau Bay beach have been estimated to encompass the changing shoreline response expected once the tall indurated sand bluff becomes exposed to erosion and recession. Note the mapped recession distances across the sand bluff for areas will be greater than that provided in Table 3-6, as the dune bluff slumping under future timeframe scenarios has also incorporated into the future sea level rise hazard mapping (see Section 2.4.2. for details).

3.2.4 Slope and Cliff Instability

The tall sand bluff backing Bateau Bay beach is formed of indurated/cemented sand. In addition to the coastal erosion and recession hazards, this sand bluff is also susceptible to non-coastal related landslide and soil erosion geotechnical hazards, driven by hillslope processes and groundwater flows (for example, see Table 3-7). The extent of this geotechnical hazard zone extends from behind the crest of the bluff in a seaward direction down to the bluff toe slopes.

Lengths of rocky coast that form the unnamed rocky headland at the northern end of Bateau Bay are susceptible to cliff recession. Recession setback distances have been estimated based the local geological characteristics for this headland, as summarised in Table 3-7.

Further details regarding geotechnical hazards are found in Appendix A: Coastal Geotechnical Study by JK Geotechnics.

Table 3-7 Geotechnical Characteristics for Bateau Bay and Surrounds

Coastal Morphology	Geology	Cliff Recession Mechanism	Recession Rate	Adopted Recession Angle	Slope Instability Hazards
Bateau Bay Bluff					
Tall indurated sand bluff (relic coastal cliff) fronted by modern beach and dune sands	**Indurated / Cemented Sands**	Slope adjustment in response to wave attack of toe slopes, when exposed	As per Bruun Rule estimates of recession due to SLR	35° for indurated sands; Sand slump as per Nielsen *et al* (1992) Zone of Slope Adjustment Schema	Slopes also susceptible to non-coastal geotechnical (landslip/soil creep) hazards
Unnamed Headland, separating Bateau Bay and Blue Lagoon					
Bedrock headland with steep cliffs and fringed by a wide rocky platform	**Patonga Claystone**, Tuggerah Formation *(2 m joint spacing; 70° jointing angle)*	Block failure and slope adjustment	1 joint spacing (2 m) per planning horizon timeframe	70° for bedrock 30° for soil profile	None

3.3 Blue Lagoon, Shelly Beach and Little Beach

The 2.5 km long Shelly Beach coastal compartment is comprised of three separate shoreline segments including Blue Lagoon, Shelly Beach and Little Bay. **Blue Lagoon** is the southernmost section of foreshore that comprises a 500 m long sheltered beach protected by continuous rocky reefs that extend offshore. This shoreline segment is backed by a moderately tall (5-6 m AHD) dune systems that has been flattened by the development of a foreshore caravan park / tourist resort. **Shelly Beach** is an exposed sandy beach that is backed by a high foredune which adjoins a mostly vegetated transgressive dune field which extends inland for a considerable distance. **Little Bay** is a 200 m long curving beach that stretches northward from the northern end of Shelly Beach to adjoin with the Toowoon Bay tombolo. The narrow, perched, and semi protected beach is fronted by a continuous rocky reef and backed by a steeply rising rocky embankment, formed of Patonga Claystone.

Figure 3-9 Shelly Beach Compartment looking north, showing the Semi Protected Blue Lagoon Foreshore with Fronting Rocky Reefs and Developed Low Dunes (foreground), the Exposed Shelly Beach with a Large Dune System (midground); and the Little Bay Beach that is Backed by Rocky Slopes (background – top right)

3.3.1 Beach Profile Data

Photogrammetry derived beach profiles from the years listed in Table 3-8 were analysed for Blue Lagoon and Shelly Beach (only).

Table 3-8 Summary of Beach Profile Data for Bateau Bay

Beach Profile Years	Comments
• 1941 • 1954 • 1973 • 1974 • 1985 • 1990 • 1996 • 2001 • 2006 • 2008	• Beach compartment split into three photogrammetry Blocks 1 – 3 spanning from the southern end of Blue Lagoon to the northern end of Shelly Beach; Block 1 includes Blue Lagoon entirely. • The photogrammetry data has been analysed in two geomorphologically related sections of beach, including the: **Blue Lagoon** (0 – 450 m chainage), which comprises low dunes fronted by rocky reef; and **Shelly Beach** (600 – 2150 m chainage), which is an exposed shoreline backed by tall and wide transgressive dunes. Distinct patterns in beach behaviour are noted between these two shoreline sections, as detailed below. • 1941 photogrammetry data was excluded from hazards analysis, due to coarse nature of profile data and likely topographic errors.

3.3.2 Erosion

Analysis of the historical beach volume data shows that Blue Lagoon is a relatively stable beach, in comparison to Shelly Beach which has experienced significant fluctuations in sediment volume through time. On average, Blue Lagoon beach volume has fluctuated some 40 m^3/m on average (SD± 10 m^3/m), with a maximum envelope of volume change measured at nearly 60 m^3/m. These low volumes are indicative of the protection provided by the rocky reefs located immediately offshore. Conversely, the more exposed Shelly Beach has a fluctuated some 170 m^3/m on average (SD± 75 m^3/m), with a maximum envelope of beach volume change measured at 340 m^3/m. Measured changes in beach volume and dune face position, shows that Blue Lagoon was most eroded in the 1973 data, whereas Shelly Beach experienced significantly accreted conditions in that same year. Shelly Beach was most eroded in 1974, with the occurrence of two significant rip cells (and/or dune blowouts) occurring at the northern and southern ends of the beach.

The erosion demand volume determined for Blue Lagoon and Shelly Beach, based on the historical beach profile data and relative to the 2007 conditions, was determined to be 50 m^3/m and 290 m^3/m, respectively (see Figure 3-12). The small volume of sediment contained within Little Bay beach is considered to be easily eroded by an extreme storm event, and therefore this section of coast is assessed for geohazards only (see Section 3.3.4).

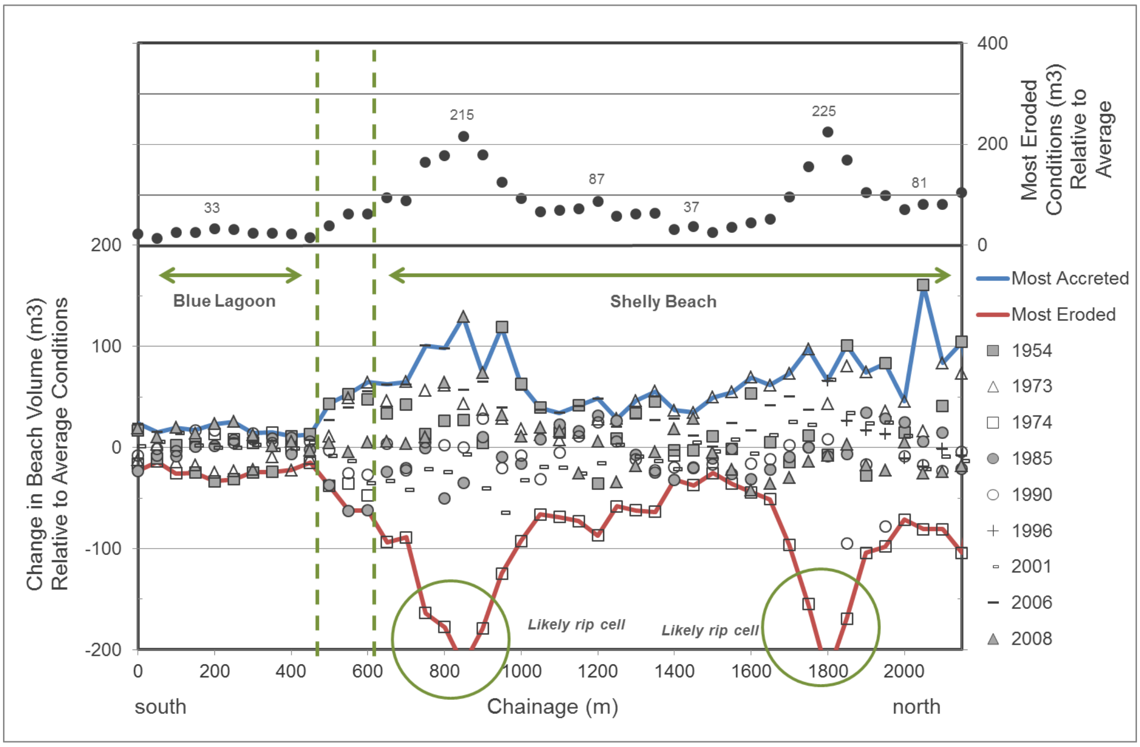


Figure 3-10 Changes in Beach Profile Volume for Blue Lagoon and Shelly Beach

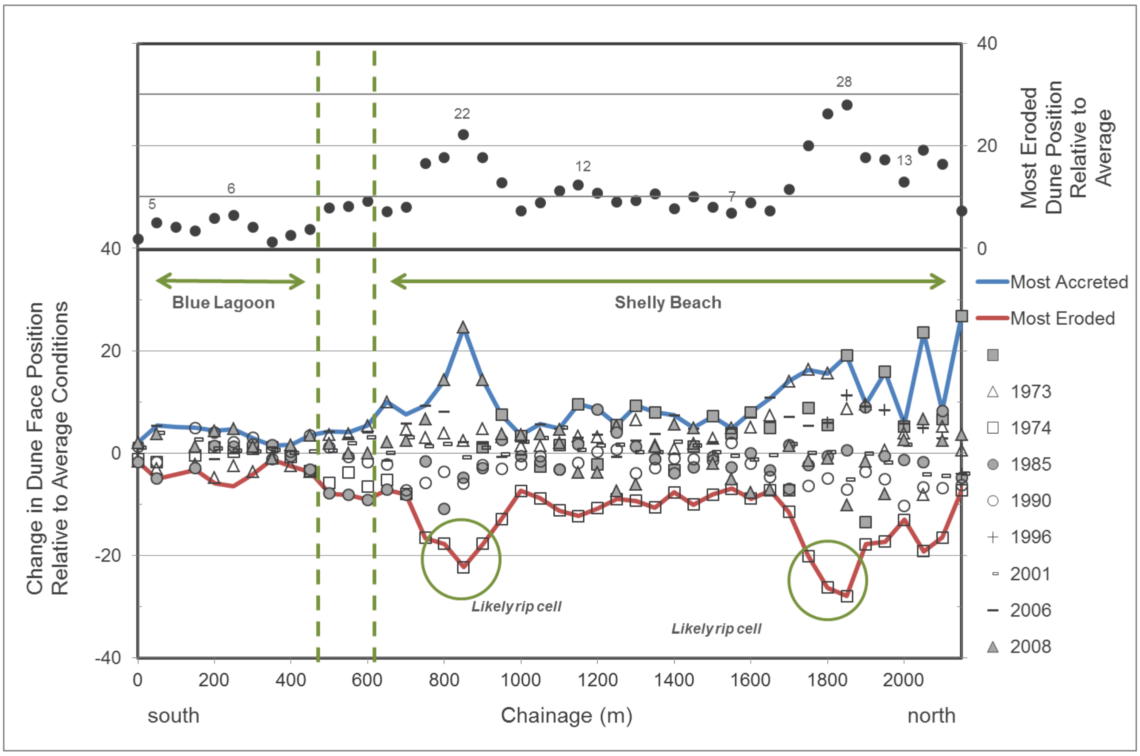


Figure 3-11 Changes in Dune Position for Blue Lagoon and Shelly Beach

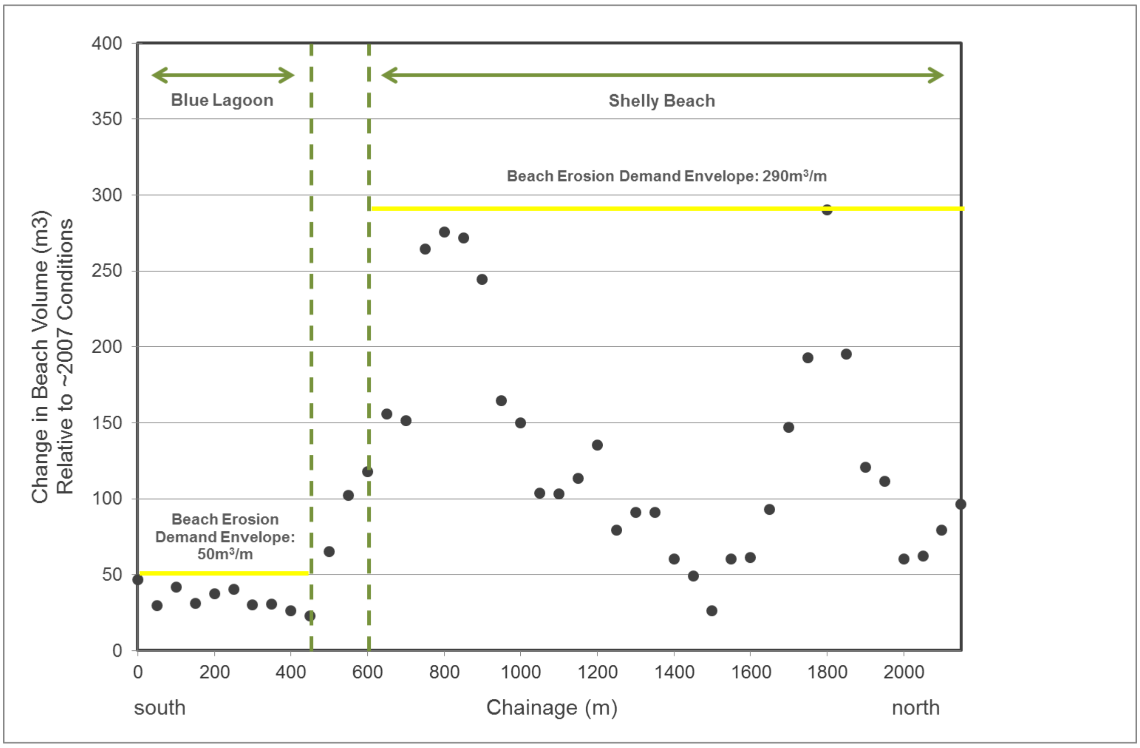


Figure 3-12 Beach Erosion Demand Volumes Relative to 2007 for Blue Lagoon and Shelly Beach

3.3.3 Recession

Historical Recession

Long term trends in beach volume were analysed for Blue Lagoon (SS1) and Shelly Beach (SS2), with the southern (SS2-S), central (SS2-mid) and northern (SS2-N) lengths of Shelly Beach analysed separately and together (SS2-All).

Figure 3-13 shows that the active beach at Blue Lagoon has experienced a net volume increase of about 0.4 m^3/m/year whereas Shelly Beach has experienced no long term gains or losses of sediment volume over this same period. The measured trend in volumetric change has been converted into rates of shoreline movement in Table 3-9, based on dune heights considered to be representative of the corresponding shoreline segments. This conversion found that Blue Lagoon is experiencing minor shoreline accretion of 0.1 m/yr, while Shelly Beach is stable on average. Analysis of dune face position, based on the 3 m AHD contour position for Blue Lagoon and 4 m AHD contour position for Shelly Beach found comparable shoreline trends (see Figure 3-14 and Table 3-10).

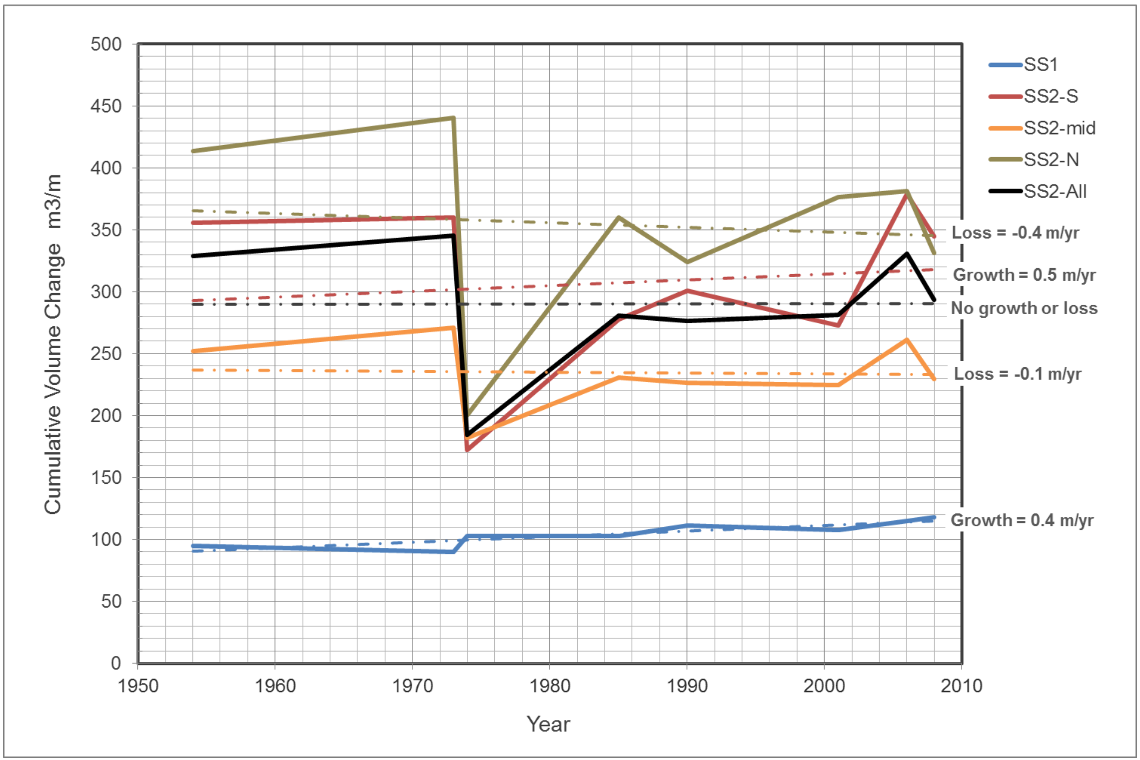


Figure 3-13 Cumulative Change in Beach Volume per metre length of Beach for Blue Lagoon (SS1) and Shelly Beach (SS2)

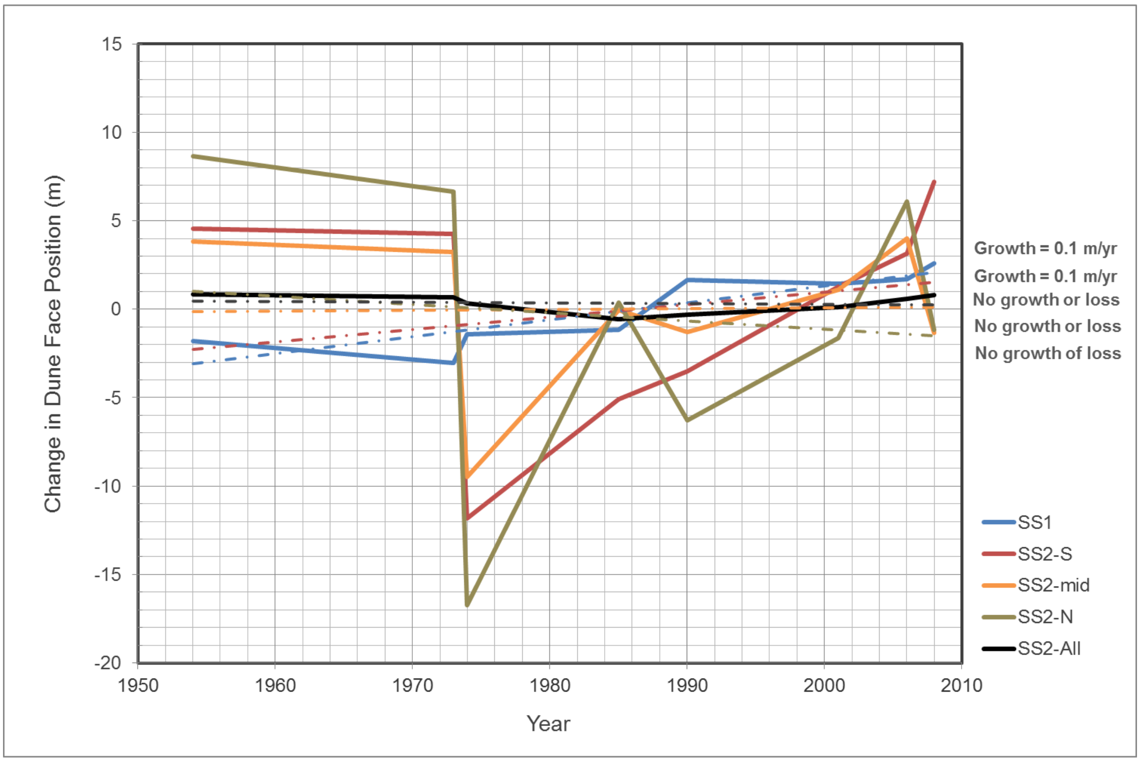


Figure 3-14 Cumulative Change in Dune Face Positon for Blue Lagoon (SS1) and Shelly Beach (SS2)

Table 3-9 Long Term Shoreline Change for Blue Lagoon and Shelly Beach from Beach Volume Change

Net Volume Changes Recorded from the Active Beach System ($m^3/m/yr$)				
Blue Lagoon	**Shelly Beach**			
SS1	**SS2-South**	**SS2-middle**	**SS2-North**	**SS2 (All)**
0.4	0.5	-0.1	-0.4	0.0
Adopted Dune Heights (m)				
Blue Lagoon	**Shelly Beach**			
SS1	**SS2-South**	**SS2-middle**	**SS2-North**	**SS2 (All)**
5.5	7.0	6.0	6.0	6.3
Historical Recession and/or Accretion Rates (m/yr)				
Blue Lagoon	**Shelly Beach**			
SS1	**SS2-South**	**SS2-middle**	**SS2-North**	**SS2 (All)**
0.1	0.1	0.0	-0.1	0.0

Note: Blue Lagoon (SS1) comprised Block (B) 1, Profiles (P) 1-10; southern Shelly Beach (SS2-S) comprised B1 P13-16 and B2 P-P5; middle Shelly Beach (SS2-mid) comprised B2 P6-17; and northern Shelly Beach (SS2-N) comprised B2 P18-20 and B3 P1-5.

Table 3-10 Long Term Shoreline Change for Blue Lagoon and Shelly Beach from Dune Movement

Historical Recession and/or Accretion Rates (m/yr)				
Blue Lagoon	Shelly Beach			
SS1	SS2-South	SS2-middle	SS2-North	SS2 (All)
0.1	0.1	0.0	0.0	0.0

Note: Blue Lagoon (SS1) comprised Block (B) 1, Profiles (P) 1-10; southern Shelly Beach (SS2-S) comprised B1 P13-16 and B2 P-P5; middle Shelly Beach (SS2-mid) comprised B2 P6-17; and northern Shelly Beach (SS2-N) comprised B2 P18-20 and B3 P1-5.

Sea Level Rise Impacts

The estimated impact of future sea level rise on Blue Lagoon and Shelly Beach is summarised in Table 3-11. The slope factors used for the Bruun Rule estimates are provided in the below table also and average equilibrium slope factor plotted against a cross shore profiles on Figure 3-15. Note: the extensive occurrence of submerged rocky reefs fronting Blue Lagoon, relative to the predominately sandy shoreface that fronts Shelly Beach.

Table 3-11 Bruun Rule and Sea Level Rise Impacts for Shelly Beach Compartment

Beach Location	Photogram. Available? / No. Years / No. Dates	Adopted Long Term Recession			Estimated Recession from SLR		
		Adopted Rate (m/yr)	2050 Reces-sion (m)	2100 Reces sion (m)	Active Slope (1:X)	2050 SLR Reces-sion (m) [1]	2100 SLR Reces-sion (m) [2]
Blue Lagoon	Yes / 54 yrs / 8 dates	Nil	Nil	Nil	34	11	28
Shelly Beach	Yes / 54 yrs / 8 dates	Nil	Nil	Nil	39	13	32

*** Note** all recession distances are rounded to the nearest metre; and future beach recession hazard lines for the 2050 and 2100 sea level rise scenarios are mapped from a combining historical recession and Bruun Rule sea level rise recession estimations.

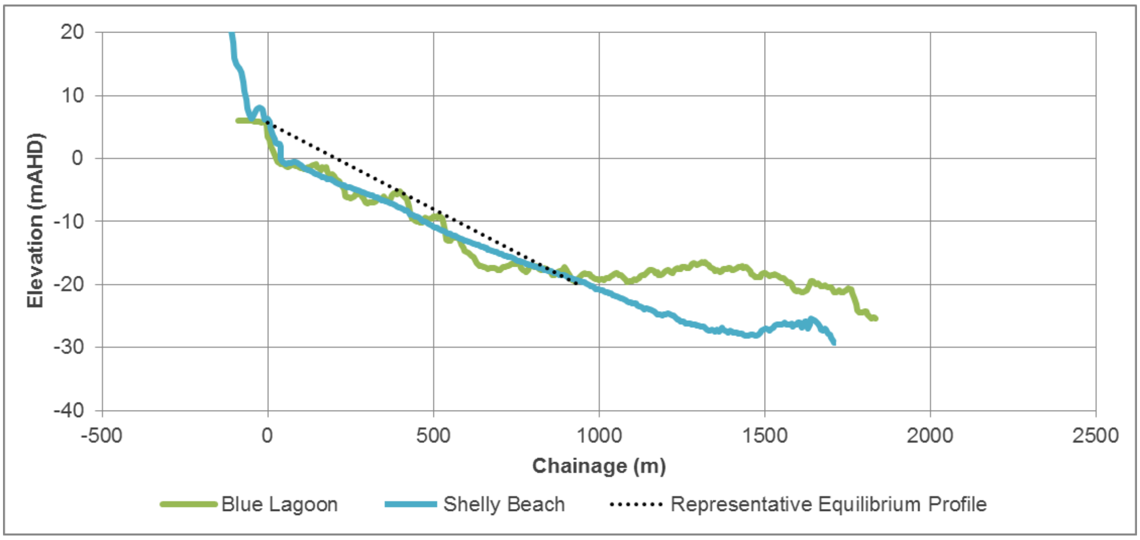


Figure 3-15 Cross Shore Profile from the Shelly Beach Compartment, showing the Active Profile Slope

3.3.4 Slope and Cliff Instability

A tall sand bluff escarpment located landward of the foreshore caravan park / tourist resort is formed of indurated/cemented sand. This sandy feature sits outside of the active coastal zone and is therefore not exposed to coastal erosion and recession hazards. The topography and substrate characteristics of this feature indicate that it is susceptible to non-coastal related landslide and soil erosion geotechnical hazards, driven by hillslope processes and groundwater flows, for example (see Table 3-12). The extent of this geotechnical hazard zone extends from behind the crest of the bluff seaward and toward the bluff toe slopes.

Further details regarding geotechnical hazards at are found in Appendix A: Coastal Geotechnical Study by JK Geotechnics.

Table 3-12 Geotechnical Characteristics for Blue Lagoon and Little Bay

Coastal Morphology	Geology	Cliff Recession Mechanism	Recession Rate	Adopted Recession Angle	Slope Instability Hazards
Blue Lagoon Bluff					
Indurated sand bluff (relic coastal cliff) protected by modern beach and dune sands	**Indurated / Cemented Sands**	*Coastal erosion unlikely in 100 year planning timeframe*			Slopes susceptible to non-coastal geotechnical (landslip/soil creep) hazards

Coastal Morphology	Geology	Cliff Recession Mechanism	Recession Rate	Adopted Recession Angle	Slope Instability Hazards
Little Bay Cliffs and Slopes					
Bedrock cliffs and rocky platform with a perched sandy beach	**Patonga Claystone**, Tuggerah Formation *(2 m joint spacing; 70° jointing angle)*	Block failure and slope adjustment	1 joint spacing (2 m) per planning horizon timeframe	70° for bedrock 30° for soil profile	None

3.3.5 Coastal Inundation

Coastal inundation of land adjacent to the ocean from wave action during an extreme storm event was assessed along the Shelly Beach compartment by SMEC (2010). Under present sea level conditions, two locations at Blue Lagoon were assessed and three at Shelly Beach. Extreme water levels from wave runup processes was found to be around 7 m AHD across the compartment, with the highest level modelled for the south end of Blue Lagoon (see Table 3-13). These modelled levels indicate that some overtopping may occur at Blue Lagoon.

Table 3-13 Extreme Wave Runup Levels for Shelly Beach Compartment (1% AEP water levels combined with 1% AEP wave height) calculated by SMEC (2010)

Location	Water Level (m)	Maximum Wave Runup (m)	2% Wave Runup (m)	Significant Wave Runup (m)	1% AEP Offshore WL (mAHD)	Max Runup Height (mAHD)
Blue Lagoon Resort - south end	1.21	4.62	4.18	3.17	1.48	**7.31**
Blue Lagoon Resort - north end	0.99	4.35	3.96	3.00	1.48	**6.82**
Shelly Beach SLSC	1.01	4.44	3.96	3.00	1.48	**6.93**
North carpark beach access	1.05	4.27	3.89	2.95	1.48	**6.80**
Far northern corner of beach	1.05	4.19	3.82	2.90	1.48	**6.72**

3.4 Toowoon and Blue Bay

Toowoon Bay and Blue Bay are two adjacent semicircular shaped bays, bounded by a sandy tombolo in the south and a rocky headland in the north (see Table 3-27). Both bays are strongly controlled by the presence of rocky reefs and shore platforms. Residential development is located very close to the active shoreline at both bay locations.

Toowoon Bay is the southernmost bay that curves for some 700 m northward of the Toowoon Bay tombolo to adjoin a sandy foreland at its northern end. Both the tombolo and foreland are major depositional features connected to offshore rocky reefs. As such, Toowoon Bay is relatively protected with a low lying and poorly developed dune system. The bay is backed by moderately rising slopes comprised of Patonga Claystone. **Blue Bay** forms the smaller of the two bays, curving for some 250 m from the southern sandy foreland to a wide rocky shore platform in the north. Again the beach is relatively protected, but receives marginally higher waves than Toowoon Bay. Blue Bay beach is backed by a poorly developed and low lying dune system. A locally incised creek drains the hinterland to the northern end of the beach.

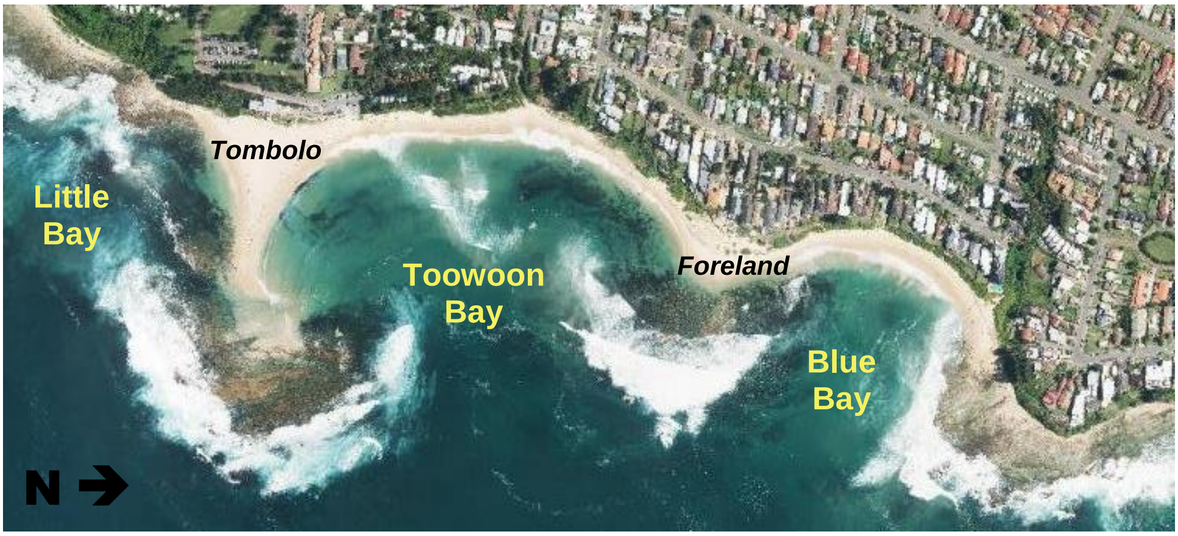


Figure 3-16 Aerial Image of Toowoon Bay and Blue Bays, showing the Toowoon Bay Tombolo (left) separating the Toowoon and Little Bays, and the Sandy Foreland Feature (middle) separating the Toowoon and Blue Bays (Image source: NSW Land and Property Information)

3.4.1 Beach Profile Data

Photogrammetry derived beach profiles from the years listed in Table 3-14 were analysed for Toowoon Bay and Blue Bay.

Table 3-14 Summary of Beach Profile Data for Toowoon and Blue Bays

Beach Profile Years	Comments
• 1941 • 1973 • 1974 • 1990 • 1993 • 1996 • 1998 • 2001 • 2006 • 2008	• Adjoining bays spilt into seven photogrammetry blocks, Block P – V; Toowoon Bay included in Block P – T and Blue Bay included in Blocks T – V. • 1941 photogrammetry data excluded from hazards analysis, due to coarse nature of profile data and likely topographic errors. • SMEC (2010) suggested that datum shift exists between 1973 and 1974 photogrammetry data. They applied a profile by profile correction, based on the relative height difference measured at the back of the beach. The vertical corrections mostly ranged between 0.4 m for Toowoon Bay and 1.0 m for Blue Bay. • Some anomalous profiles were also observed by the authors, however the approach adopted by SMEC was not applied as it is considered that the highly urbanised back beach environment may lead to errors, where development occurred between consecutive photogrammetry years. Furthermore, any datum error should have produced a regional scale offset in the data (Bob Clout *pers. comm.*), which was not produced by the SMEC corrections (see Figure B.28 from SMEC, 2010). • Considering the above, we have not applied any correction to the data, but instead considered the possible scale of error that may exist with our analysis. For example, a vertical offset of 0.4 m would cause an error of 20 m^3/m for a 50 m wide section of beach (i.e. dune face to RL 0 m), while a vertical offset of 1.0 m would cause an error of 50 m^3/m for a comparable section of beach.

3.4.2 Erosion

Analysis of the beach volume data shows that the sandy depositional features have experienced significantly greater volumetric changes through time in comparison with the central lengths of each embayment. The Toowoon Bay tombolo beach fluctuates within a maximum envelope of volume change measured at 290 m^3/m immediately south of the surf club, while a maximum volumetric envelope of change for the sandy foreland separating Toowoon and Blue Bays was estimated to be 180 m^3/m. Both features were most eroded in the 1974 data, while their most accreted conditions were apparent in 1990 and 2006 datasets for the tombolo, and the 1973 dataset for the sandy foreland feature (see Figure 3-17).

Excluding the large depositional features discussed above, the central lengths of Toowoon and Blue Bay's shorelines fluctuate within much narrower beach change volume envelopes. On average, the middle lengths of Toowoon Bay fluctuated some 60 m^3/m (SD± 10 m^3/m), with a maximum envelope of volume change measured just over 80 m^3/m. Similarly, the middle lengths of Blue Bay have fluctuated nearly 35 m^3/m on average (SD± 15 m^3/m), with a maximum envelope of beach volume change measured at just over 60 m^3/m. It is noted again however some errors were observed in the photogrammetry data, and therefore the above volumes should be treated with caution. Changes in dune face position (3 m AHD contour), found that Toowoon Bay fluctuated mostly between 10 to 20 m, while the Blue Bay dune position was more stable, fluctuating no more than 10 m along most of its middle shoreline.

Estimation of the erosion demand volumes for Toowoon and Blue Bay were made with consideration to the elevation errors observed in the data. For this assessment, an erosion demand volume of 70 m^3/m for Toowoon Bay and 115 m^3/m for Blue Bays have been estimated relative to 2007 conditions (see Figure 3-18). These volumes are specific to the middle lengths of each embayment beach and are based on beach profile data not influenced by the stormwater and creek outlets, nor the tombolo and foreland features. The potential datum errors contained within the photogrammetry data for the two sites have been accounted for the above erosion demand volumes, approximated at 20 m^3/m for Toowoon Bay and 50 m^3/m for Blue Bay (refer to Table 3-14 for details).

Difficulties can be experienced when mapping volume based erosion hazards on highly dynamic and variable depositional features, such as the tombolo and foreland occurring at Toowoon and Blue Bays. This is exemplified in the SMEC (2010) volume based erosion hazard assessment for Toowoon Bay, which resulted in hazard lines being mapped on bare sand across the tombolo. For this reason, the beach erosion hazards were mapped based on the most landward dune face position recorded in the photogrammetry data for the sandy tombolo and foreland features.

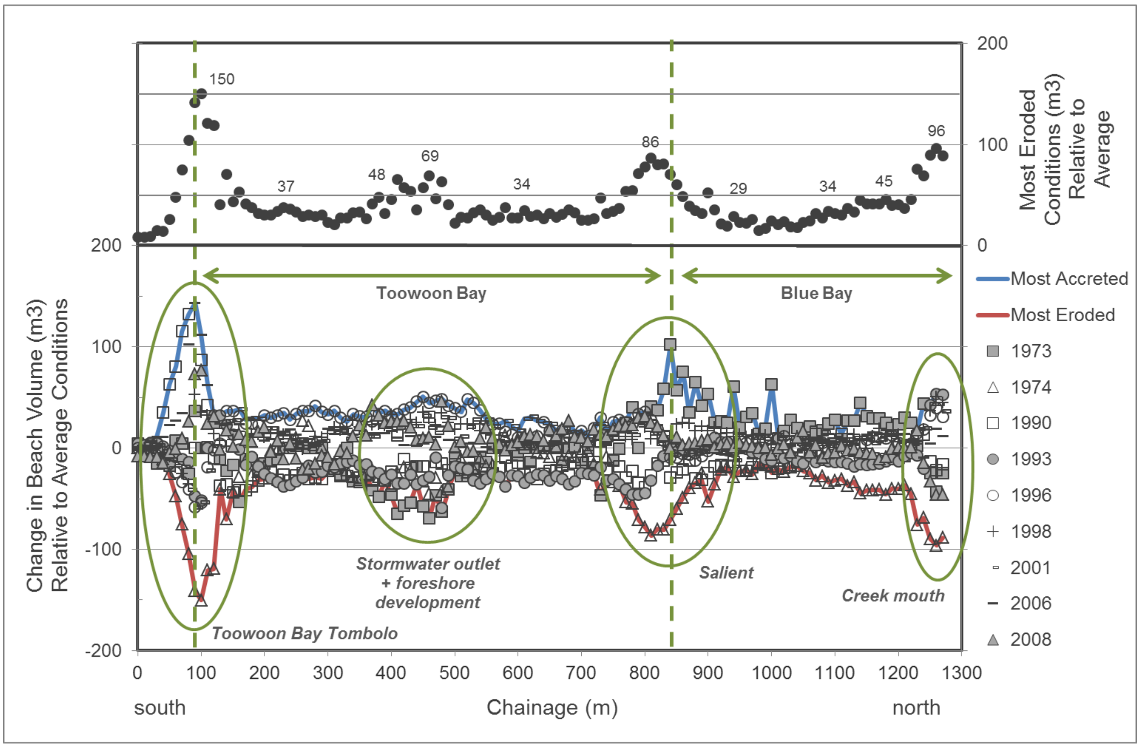


Figure 3-17 Changes in Beach Profile Volume for Toowoon and Blue Bays

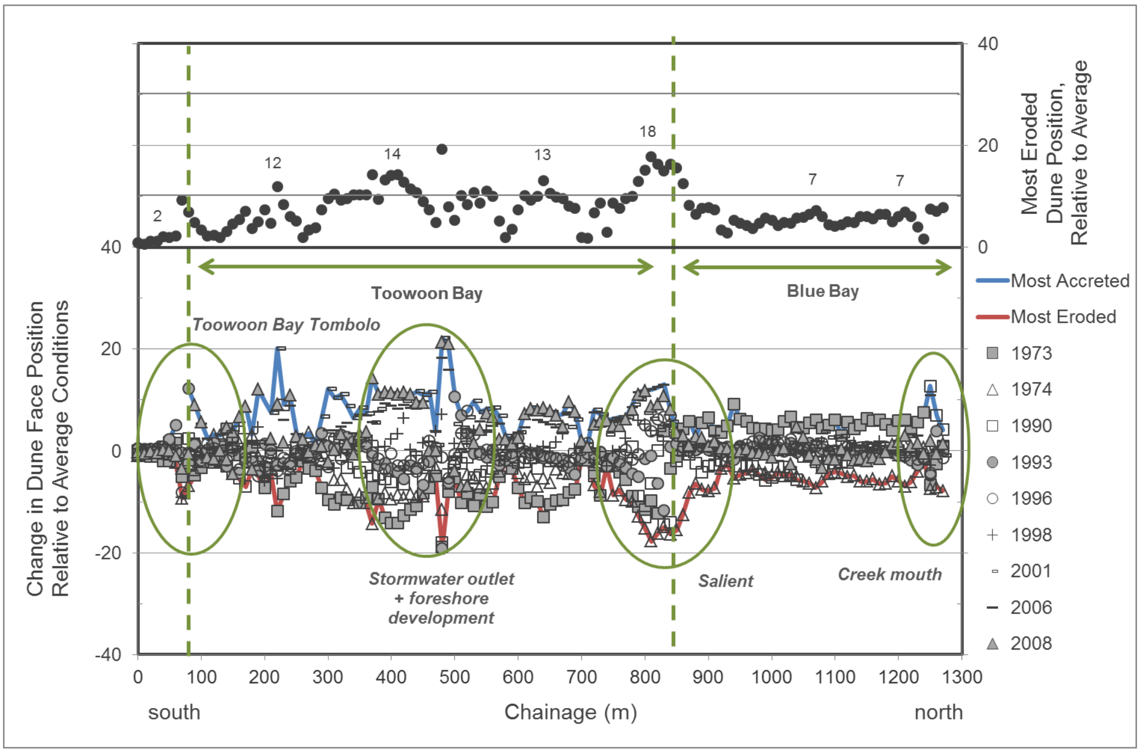


Figure 3-18 Changes in Dune Position for Toowoon and Blue Bays

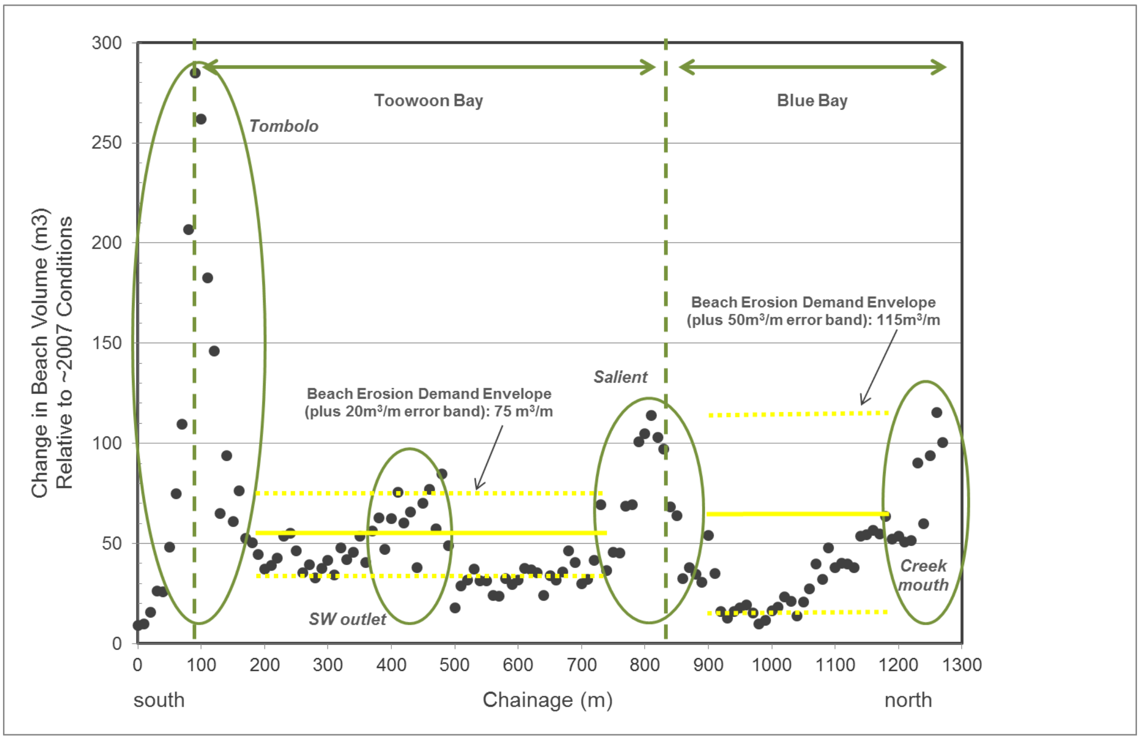


Figure 3-19 Beach Erosion Demand Volumes Relative to 2007 for Toowoon and Blue Bays

3.4.3 Recession

Historical Recession

Due to the vertical errors occurring in the photogrammetry data, it is not possible to reliably determine historical recession / accretion trends from the beach volume data. Measuring changes in the dune positon could theoretically provide an alternate empirical approach to investigate historical recession. However, both beaches are highly developed and have been exposed to widespread human modification of the foredune areas. For example, lengths of rock wall, rock rubble and timber retaining walls have been constructed at the back beach in some sections, coupled with widespread dune flattening for development (PWD, 1992). Considering these issues, a qualitative assessment of the historical beach behaviour of Toowoon and Blue Bays has been undertaken for this study.

The extensive offshore reef system and the bounding rock platforms occurring at both embayment beaches would significantly limit the potential for large volumes of sediment to be lost from the beach system in an alongshore or offshore direction. Also, no active blow out dunes are present, nor are any human activities that would result in significant loss of sediment in a landward direction. As such we consider that Toowoon and Blue Bays are not likely to be experiencing historical recession at present.

This assumption is further backed up by geomorphic evidence. For example, the profiles of the low dunes at Toowoon Bay display broadly convex forms, as opposed to concave profiles which are typical of receding beaches. Also the current dune face/scarp position at Blue Bay and the adjoining foreland feature is located further seaward than the 1974 scarp position that can be clearly identified in the LiDAR (Digital Elevation Model) DEM. Figure 3-20 demonstrates this observation, with the photographed dune face located some 10 to 35 m seaward of the relict scarp identified on the foreland feature. The *Toowoon and Blue Bays Historical Beach Behaviour* study by PWD (1992) also noted that no significant changes could be observed in the shoreline location at Blue Bay, based on a comparison between two photographs from 1910 and 1990.

While it is considered likely that both embayment beaches are stable, this study has taken a precautionary approach and has adopted a recession rate of 0.1 m/yr in the absence of reliable beach volume and dune position data (see Table 3-15).

Figure 3-20 Foreland Feature Separating Toowoon and Blue Bay, showing the current dune scarp (black arrow) and historic dune scarp (yellow line)

Table 3-15 Adopted Long Term Shoreline Change for Toowoon and Blue Bays

Adopted Recession and/or Accretion Rates (m/yr)
Toowoon and Blue Bays
-0.1

Sea Level Rise Impacts

The estimated impact of future sea level rise on Toowoon and Blue Bays is summarised in Table 3-16. The slope factors used for the Bruun Rule estimates are provided in the below table and an average equilibrium slope factor plotted against a cross shore profiles on Figure 3-21. These profiles demonstrate the presence of extensive submerged rocky reefs that front both beach embayments.

Table 3-16 Bruun Rule and Sea Level Rise Impacts for Toowoon and Blue Bays

Beach Location	Photogram. Available? / No. Years / No. Dates	Adopted Long Term Recession			Estimated Recession from SLR		
		Adopted Rate (m/yr)	2050 Recession (m)	2100 Reces sion (m)	Active Slope (1:X)	2050 SLR Recession (m) [1]	2100 SLR Recession (m) [2]
Toowoon Bay	Yes / 35 yrs / 9 dates	0.1	4	9	35	11	28
Blue Bay	Yes / 35 yrs / 9 dates	0.1	4	9	34	11	28

* **Note** all recession distances are rounded to the nearest metre; and future beach recession hazard lines for the 2050 and 2100 sea level rise scenarios are mapped from a combining historical recession and Bruun Rule sea level rise recession estimations.

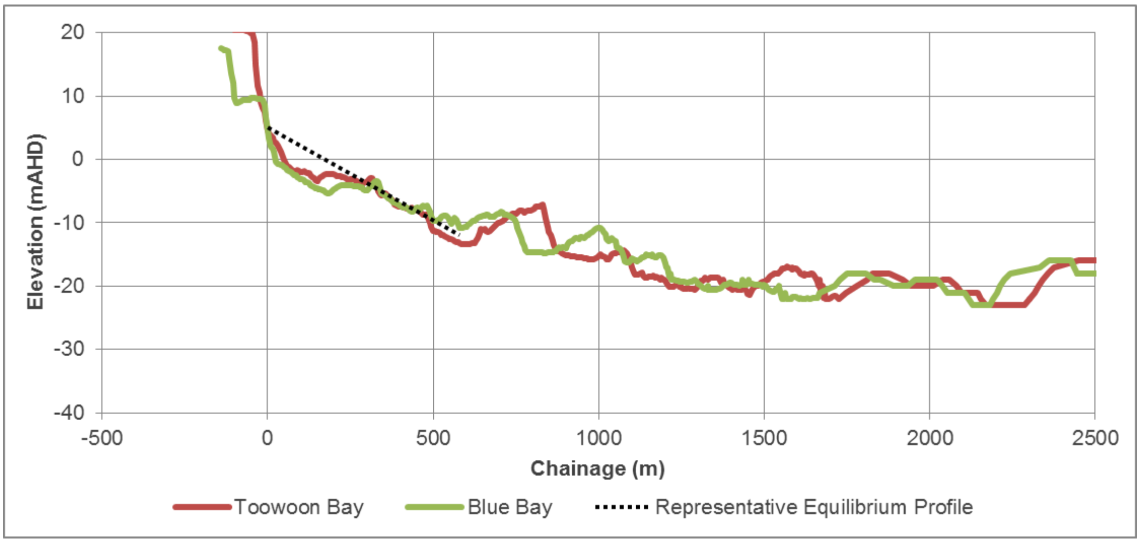


Figure 3-21 Cross Shore Profiles from Toowoon and Blue Bays, showing the Active Profile Slopes

3.4.4 Slope and Cliff Instability

Landward of the modern beach dune system are two landscape features considered to be susceptible to non-coastal related landslide and soil erosion geotechnical hazards. These features include a relic coastal escarpment located behind the active coastal zone of both embayment beaches, and a steep erosion gully located adjacent the northern extent to Blue Bay. The mapped geotechnical hazard zone for Toowoon and Blue Bay cover the full extent of these topographic features. Further details regarding geotechnical hazards are provided in Appendix A: Coastal Geotechnical Study by JK Geotechnics.

Table 3-17 Geotechnical Characteristics for Toowoon and Blue Bay Region

Coastal Morphology	Geology	Cliff Recession Mechanism	Recession Rate	Adopted Recession Angle	Slope Instability Hazards
Bedrock cliffs and slopes rocky shore platform of variable width	Terrigal Formation, **Patonga Claystone,** Tuggerah Formation (2m joint spacing; 70° jointing angle)	Block collapse and soil slope adjustment	1 joint spacing (2 m) per planning horizon timeframe	70° for bedrock 45° for surficial soil profile	Upper slopes also susceptible to non-coastal geotechnical hazards (landslip/soil creep)

3.4.5 Coastal Inundation

Coastal inundation of land adjacent to the ocean from wave action during an extreme storm event was assessed at Toowoon Bay and Blue Bays by SMEC (2010). Under present sea level conditions, four locations at Toowoon Bay were assessed and one at Blue Bay. Extreme water levels from wave runup processes was found to range between approximately 5.5 and 6.5 m AHD, with the highest level modelled for Blue Bay (see Table 3-18). These modelled water levels indicate that some overtopping may occur at south end of Blue Bay.

Table 3-18 Extreme Wave Runup Levels for Toowoon and Blue Bays (1% AEP water levels combined with 1% AEP wave height) calculated by SMEC (2010)

Location	Water Level (m)	Maximum Wave Runup (m)	2% Wave Runup (m)	Significant Wave Runup (m)	1% AEP Offshore WL (mAHD)	Max Runup Height (mAHD)
Toowoon Bay SLSC car park	1.11	2.96	2.77	2.11	1.48	**5.55**
Central Toowoon Bay (~Kims Beachside Retreat)	1.20	2.92	2.74	2.09	1.48	**5.60**
Northern Toowoon Bay (between Toowoon Bay Rd and Beenbah Ave)	1.18	3.03	2.84	2.16	1.48	**5.69**
Far northern end of Toowoon Bay	1.14	3.07	2.87	2.18	1.48	**5.69**
Southern Blue Bay	1.19	3.84	3.53	2.68	1.48	**6.51**

3.5 South Entrance Beach (The Entrance)

South Entrance Beach is a small beach located at the base of a rocky bluff and adjacent the southern side to the Tuggerah Lakes entrance channel. The beach is mostly east facing and exposed to all swell directions, but experiences some protection from submerged rocky reefs located immediately offshore in places. The beach widens to the north to adjoin a near shore rocky reef located off the mouth of the estuary, before curving westward and narrowing into the Entrance Channel. Much of the beach is underlain by a rocky platform and backed by a rocky bluff that is now buried by landscaping works which may include a revetment in places. The historic Entrance Surf Club and Entrance Ocean Pools are located at southern end of the beach (see Figure 3-22). Southward from here, the shoreline is rocky, comprising east facing cliffs and bluffs formed of Patonga Claystone that extend for some 900 m to adjoin with Blue Bay. A sandstone rock wall fronts the historic surf club and extends northward beneath a wide incipient dune for an unknown distance. This sandstone wall appears overly steep and may not have been constructed to coastal engineering standards.

Figure 3-22 South Entrance Beach, looking south

3.5.1 Beach Profile Data

Photogrammetry derived beach profiles from the years listed in Table 3-19 were analysed for South Entrance Beach.

Table 3-19 Summary of Beach Profile Data for South Entrance Beach

Beach Profile Years	Comments
• 1941 • 1954 • 1965 • 1973 • 1974 • 1985 • 1996 • 2001 • 2006 • 2008	• Beach compartment split into two photogrammetry blocks, Blocks 1 and 2 (south to north); Block 1 includes the wave dominated section of beach that faces east; Block 2 includes the northeast facing section of beach located within the Entrance Channel that is influenced by both tidal currents and waves. • 1941 photogrammetry data was excluded from hazards analysis, due to coarse nature of profile data and likely topographic errors. • The wide tombolo like feature occurs at around 140 m chainage. • Some sand nourishment (approx. 30,000 m^3) occurred in 2004 (Cardno, 2013). • Rock revetment is located along the back of the beach, for most of its length (Cardno, 2013).

3.5.2 Erosion

South Entrance Beach is controlled by an extensive offshore rocky reefs and the Entrance Channel to the immediate north. A large tombolo feature centred on chainage 140 m on Figure 3-23 and Figure 3-24 adjoins with a section of rocky reef that is extends part way into the channel mouth. This tombolo feature remains in all of the photogrammetry dates in various accreted and eroded states. Analysis of the photogrammetry data shows that the subaerial sand volume fluctuates considerably on this beach, with the historical ranges of beach volume increasing from 160 m^3/m adjacent the Surf Life Saving Club to a maximum of 340 m^3/m at the tombolo feature. Upstream of the tombolo, the Entrance Channel section of shoreline has fluctuated around 100 m^3/m. Similarly, the dune position (3 m AHD contour) varies significantly throughout the historical data and most notably at the position of the sandy tombolo.

South Entrance Beach experienced the most eroded condition in 1974, when much of the beach was eroded back to the rocky bluff at the back of the beach (see Figure 3-25). Profiles from 1974 show that the tombolo features became completely eroded from the east facing beach section, with some of this sediment being moved upstream into the channel as a sandy shoal. This likely occurred from wave overtopping of the tombolo feature during the large storm events of 1974 when the water levels were elevated (Cardno, 2013).

In 2004, an episode of sand nourishment occurred resulting in the placement some 30,000 m^3 of dredged sand on the east facing section of beach. These works are reflected in the 2006 beach profile data, which recorded the east facing section of beach and tombolo feature in their most accreted conditions.

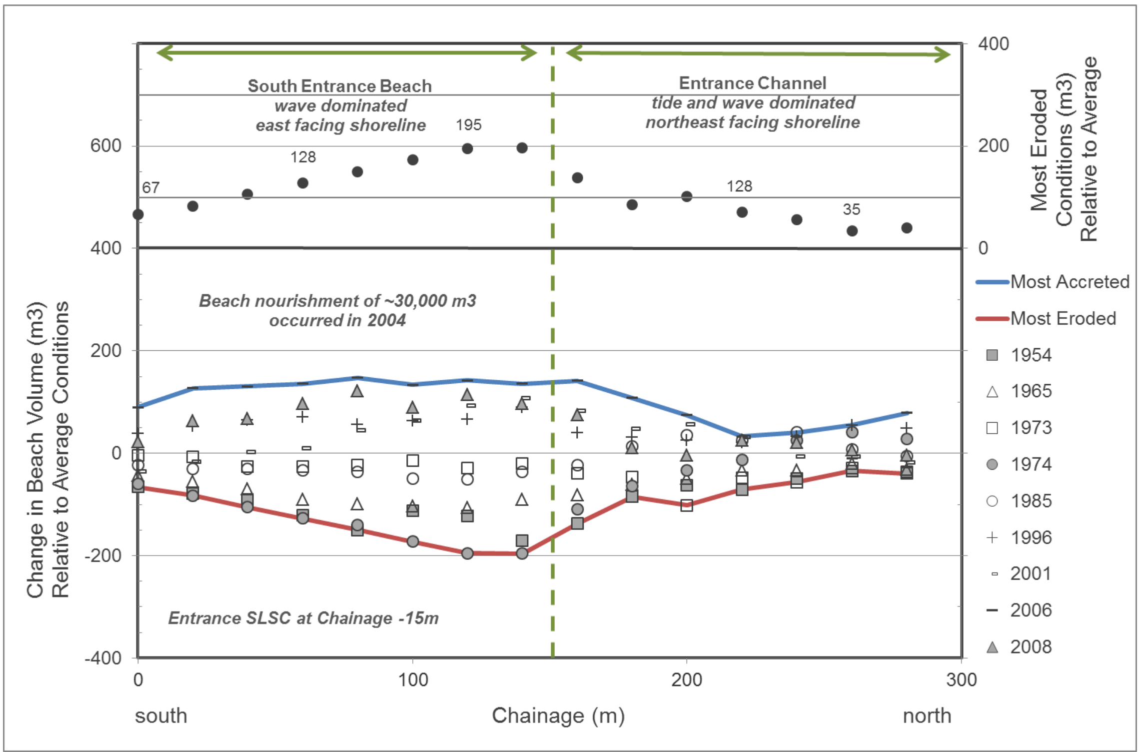


Figure 3-23 Changes in Beach Profile Volume for South Entrance Beach

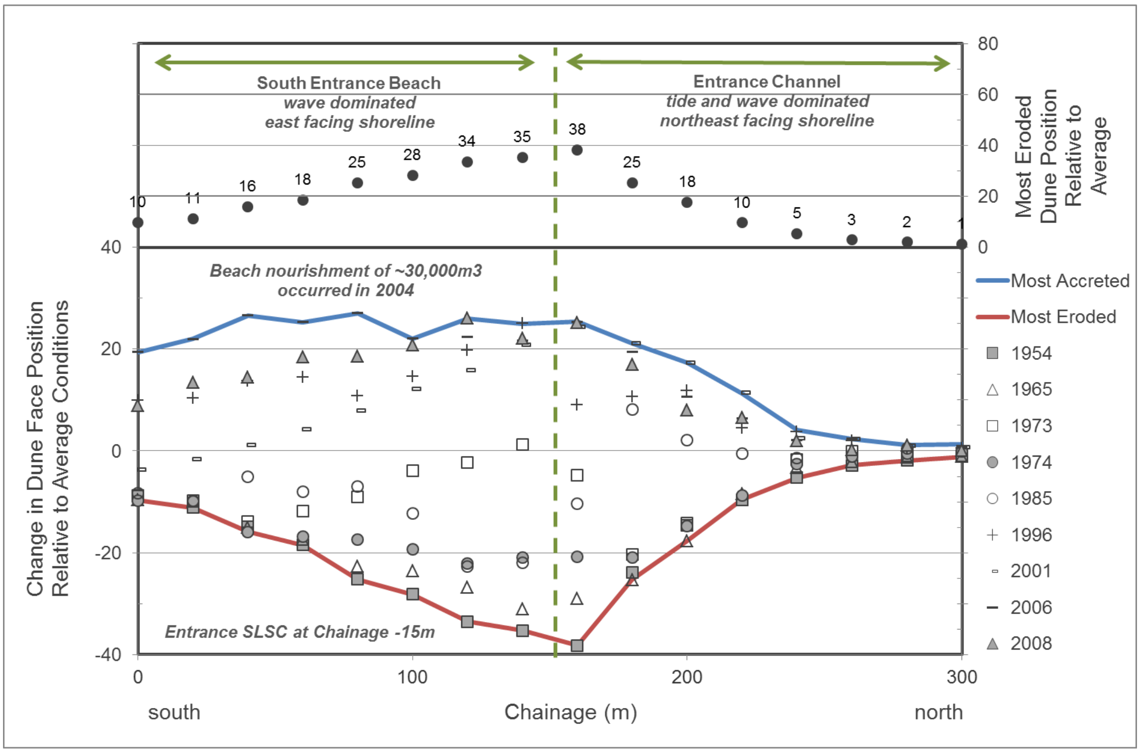


Figure 3-24 Changes in Dune Position for South Entrance Beach

Figure 3-25 South Entrance Beach in 1974 showing the Beach Completely Eroded Away after Extreme Erosion Event(s) (image sourced from Umwelt, 2011a)

Considering the dynamic nature of South Entrance Beach, which is influenced by both wave and tide action, and has a history of becoming completed eroded away by extreme storm activity; this section of coastline will be assessed for geohazards only (see below)

3.5.3 Slope and Cliff Instability

Lengths of rocky coast at the Entrance are susceptible to cliff recession. Recession setback distances have been estimated based the local geological characteristics summarised in Table 3-1. Further details regarding geotechnical hazards are found in Appendix A: Coastal Geotechnical Study by JK Geotechnics.

Table 3-20 Geotechnical Characteristics for The Entrance

Coastal Morphology	Geology	Cliff Recession Mechanism	Recession Rate	Adopted Recession Angle	Slope Instability Hazards
Bedrock headland with cliffs and slopes, and fringed by rocky platform with a perched sandy beach at South Entrance	**Patonga Claystone**, Tuggerah Formation *(2 m joint spacing; 70° jointing angle)*	Block failure and slope adjustment	1 joint spacing (2 m) per planning horizon timeframe	70° for bedrock 30° for soil profile	None

3.5.4 Coastal Inundation

Coastal inundation of land adjacent to the ocean from wave action during an extreme storm event was assessed for two locations at South Entrance by SMEC (2010). Under present sea level conditions extreme water levels from wave runup processes were found to be around 6.4 m AHD (see Table 3-21). These modelled levels indicate that some overtopping may occur at Entrance Ocean Baths.

Table 3-21 Extreme Wave Runup Levels for South Entrance Beach (1% AEP water levels combined with 1% AEP wave height) calculated by SMEC (2010)

Location	Water Level (m)	Maximum Wave Runup (m)	2% Wave Runup (m)	Significant Wave Runup (m)	1% AEP Offshore WL (mAHD)	Max Runup Height (mAHD)
South Entrance SLSC	1.32	3.56	3.29	2.50	1.48	**6.36**
Boatshed	1.17	3.78	3.48	2.64	1.48	**6.43**

3.6 Tuggerah Beach Compartment (The Entrance, North Entrance, Tuggerah and Pelican Beaches)

The Tuggerah Beach compartment is a long (8.2 km) exposed east-southeast facing embayment that stretches northward from the Entrance Channel Spit to Pelican Point, and includes North Entrance Beach, Tuggerah Beach (Magenta Shores) and Pelican Beach (see). The embayment beach impounds Tuggerah Lakes Estuary, which opens to the ocean in the far south of adjacent to a low rocky bluff at The Entrance. The southern third of the embayment which includes Entrance Spit and North Entrance Beach is backed by a sand spit which comprises a narrow dune barrier backed by sand flats. Residential development is located close to the beach at some locations, most notably Curtis Parade at North Entrance. The northern two thirds of the embayment which includes Magenta Shores and Pelican Beach, is backed by a large and complex barrier dune system that includes a transgressive dune field that widens in a northward direction. This dune system has been historically disturbed and reshaped through mining for heavy minerals. The Tuggerah Beach embayment is exposed to all swell directions, with the exception of the estuary entrance and surrounds which receives some protection from southerly swells by offshore reefs. The Entrance Channel can become intermittently closed through progressive shoaling under natural conditions; however regular maintenance dredging currently keeps the channel entrance open to the ocean.

For the purpose of analysing the photogrammetry records, this extensive stretch of sandy coastline has been partitioned into three geomorphological common segments of shoreline, namely: the Entrance Spit (0 – 620 m chainage); North Entrance Beach (620 – 3400 m chainage; see) and Magenta Shores to Pelican Beach (3400 – 8250 m chainage). Each of the three shoreline segments has varying morphologies, historical beach behaviour, and land use/disturbance history of the foredune and backbeach areas.

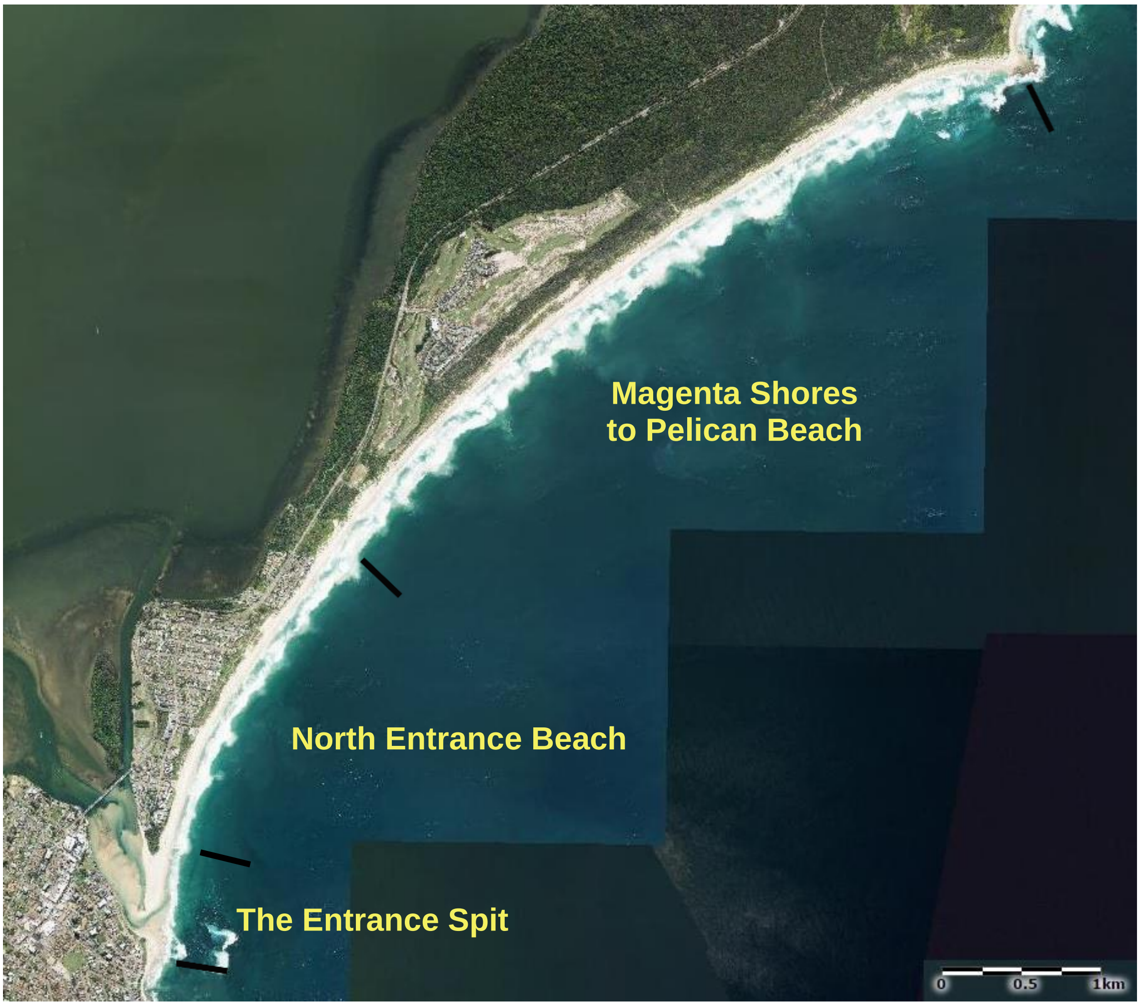


Figure 3-26 Tuggerah Beach Embayment Shoreline Segments (image source: SIX Maps)

Figure 3-27 Tuggerah Beach Compartment, looking north from North Entrance Beach (Curtis Parade); note the Sand Drift and Proximity of the Houses to the Foreshore

3.6.1 Beach Profile Data

Photogrammetry derived beach profiles from the years listed in Table 3-22 were analysed for Tuggerah Beach compartment, which spans from North Entrance in the south to Pelican Beach in the north.

Table 3-22 Summary of Beach Profile Data for Tuggerah Beach Compartment

Beach Profile Years	Comments
• 1941 • 1954 • 1965 • 1973 • 1974 • 1979 • 1986 • 1993 • 2001 • 2006 • 2008	• Block A includes the narrow sand spit at the entrance to Tuggerah Lakes; Block B includes the foreshore residential area near Hutton Road; Block C covers the beach and dunes around the surf club; Block D includes more foreshore development including Curtis Parade; Block E stretches across Magenta Shores development; Block F, G and H cover the northern end of the compartment including Pelican Beach. • The dune systems in Blocks E to J have been subject to sand mining in the 1960's and 1970's, which have generally resulted in the backbeach dunes being significantly reshaped. In many instances, the new barrier dune profile that immediately backs the beach and foredunes is taller than its original form. • The photogrammetry data has been analysed in three geomorphologically related segments of beach, including: **The Entrance Spit** (0 – 620 m chainage), which separates Tuggerah Lakes from the ocean and forms a typically a mobile and dynamic feature; **North Entrance Beach** (620 – 3400 m chainage), which includes mostly developed dunes and is backed by the relatively narrow sand barrier; and the section of coast spanning **Magenta Shores to Pelican Beach** (3400 – 8200 m chainage)**,** which is backed by a progressively widening barrier with widespread transgressive dunes that have undergone significant modification adjacent the shoreline from sand mining operations. Distinct patterns in beach behaviour are noted between these three sections, as detailed below. • 1941 photogrammetry data has been excluded from analysis, due to coarse nature of profile data and observed topographic errors.

3.6.2 Erosion

The beach volume change measured along the **Entrance Sand Spit** (Chainage 0 – 620 m) that fronts the entrance to Tuggerah Lakes was highly variable, fluctuating on average some 290 m^3/m (SD± 70 m^3/m), with a maximum envelope of beach volume change measured above 430 m^3/m (see Figure 3-28). The dune position (3 m AHD) on the spit has varied considerably; generally fluctuating within an envelope some 10 to 50 m wide (see Figure 3-29). Narrow sand spits like this one that intermittently close the entrance to large estuary systems are typically quite mobile and dynamic, as they become periodically breached during large flood events. The length of shoreline has been identified with an **entrance instability hazard**.

At **North Entrance Beach** (Chainage 620 – 3400 m), spanning from Hutton Road in the south to the Magenta Shore golf course in the north (some 800 m northward of Curtis Parade) has experienced a smaller envelope of beach change, relative to the adjoining sections of beach. Here the beach volumes have been measured to oscillate some 160 m^3/m (SD± 40 m^3/m) on average, with a maximum range measured at 270 m^3/m (see Figure 3-28). The dune position (4 m AHD) has also moved within an envelope of some 15 – 35 m width (see Figure 3-29). The greatest sand volumes were experienced during 1954, while the most eroded conditions on average were measured in 2001, 2008 and 1986, with 2006 and 1974 also experiencing depleted conditions. The dune position was also measured in its most landward position in 2001, on average.

For the long stretch of beach spanning **Magenta Shores to Pelican Beach** (chainage 3400 – 8250 m), sand volumes have fluctuated 290 m^3/m (σ 75 m^3/m) on average, with a maximum range of 475 m^3/m measured at Pelican Beach (see Figure 3-28). The most accreted conditions were experienced in 1993 while the most eroded conditions were experienced in 1974. The beach was also notably accreted in 2006. The dune face (4 m AHD) has been measured to fluctuate mostly within a band of some 30 to 55 m width (see Figure 3-29).

Tuggerah Beach Compartment has experienced a long term shift in its shoreline position, as demonstrated in Figure 3-30 (see Section 3.6.3 for details). The recession trend noted at North Entrance has implications for defining an erosion demand volume relative to 2007 conditions, considering that the 2006 beach profiles were some of the more eroded profiles on record (see Figure 3-31). The North Entrance beach profile data which is influenced by a recession trend would result in the true erosion hazard being underestimated, unless the underlying long term trend was removed from the beach profile data. As such, the North Entrance beach erosion demand volumes were estimated from the beach volume dataset which had the long-term recession trend removed, as shown on Figure 3-32.

Beach erosion demand volumes were determined to be 170 m^3/m for North Entrance Beach, and 310 m^3/m for Magenta Shores to Pelican Beach length of shoreline, relative to 2007 conditions. The Entrance Spit is exposed to entrance breakout and channel scour processes, and is therefore considered to have a coastal entrance hazard where the spit (beach and dunes) may become breached at any stage. It is noted that the Tuggerah Lakes Entrance Channel becomes intermittently open under natural conditions across the Entrance Spit with a variety of channel configurations recorded to span some 600 m length (see PWD, 1987 for history of entrance movement).

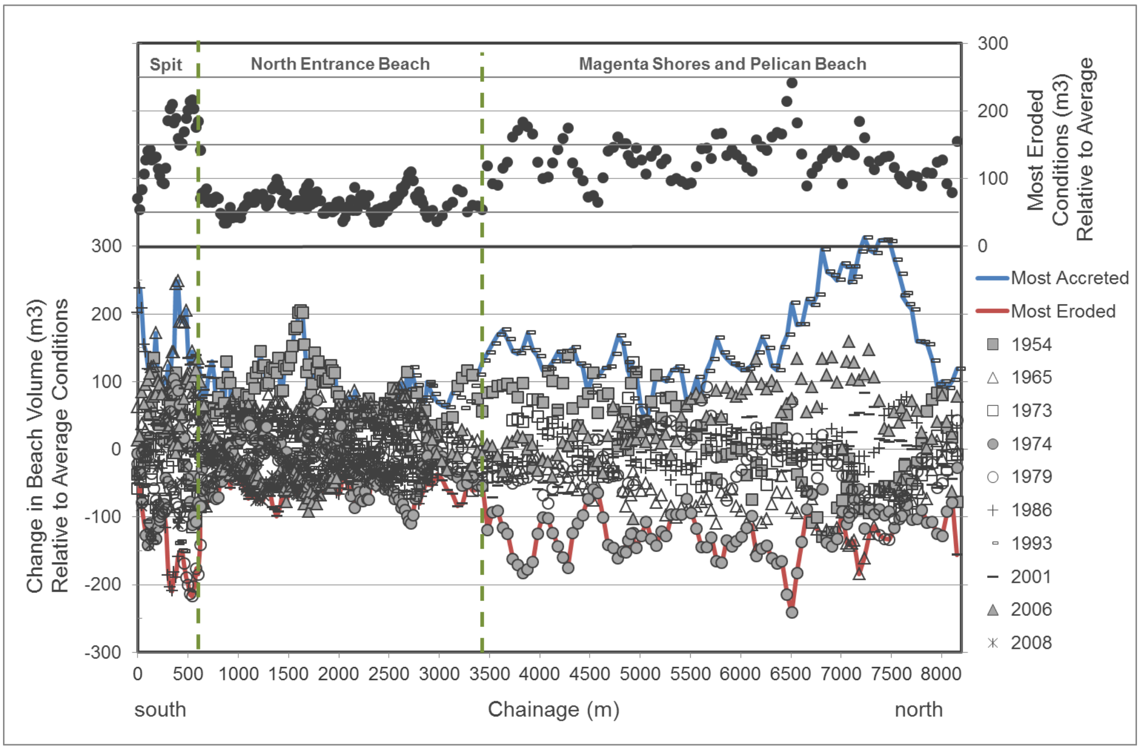


Figure 3-28 Changes in Beach Profile Volume for Tuggerah Beach Compartment, which is Split into Three Geomorphologically Related Beach Sections

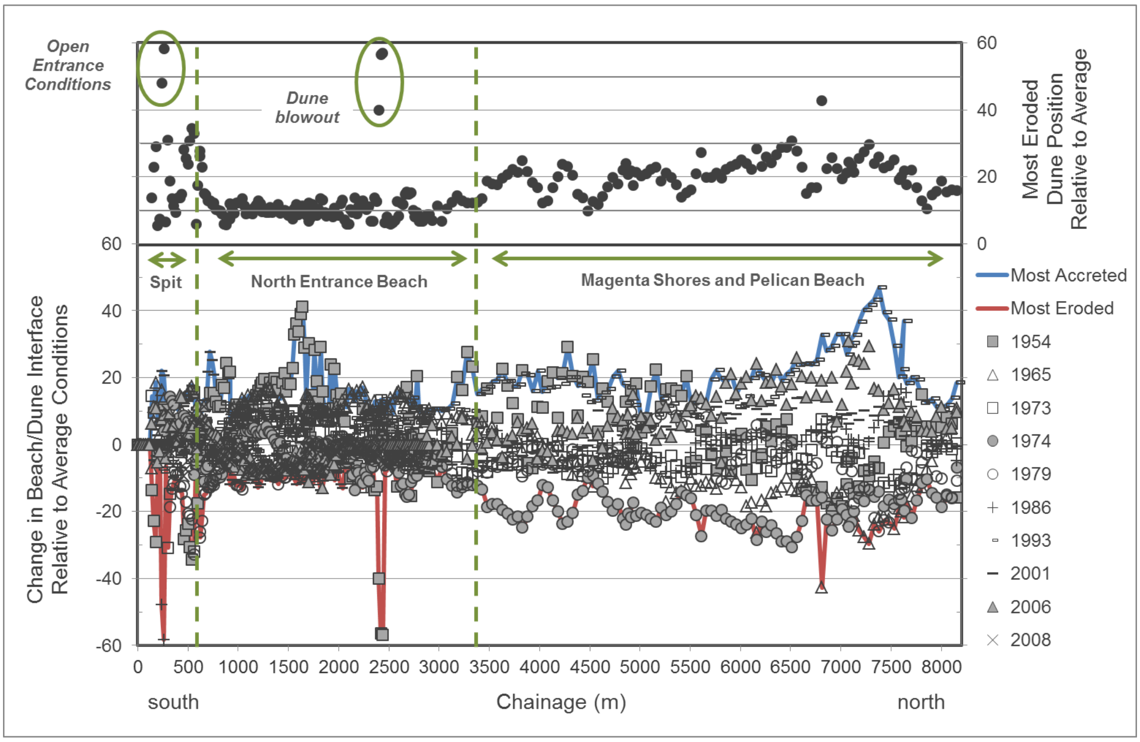


Figure 3-29 Changes in Dune Position for Tuggerah Beach Compartment

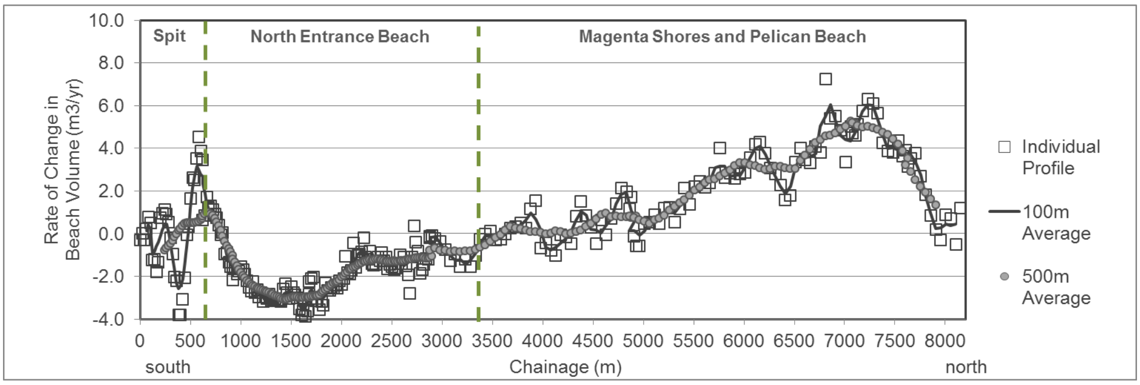


Figure 3-30 Rate of Beach Volume Change for Tuggerah Beach (1954 to 2008)

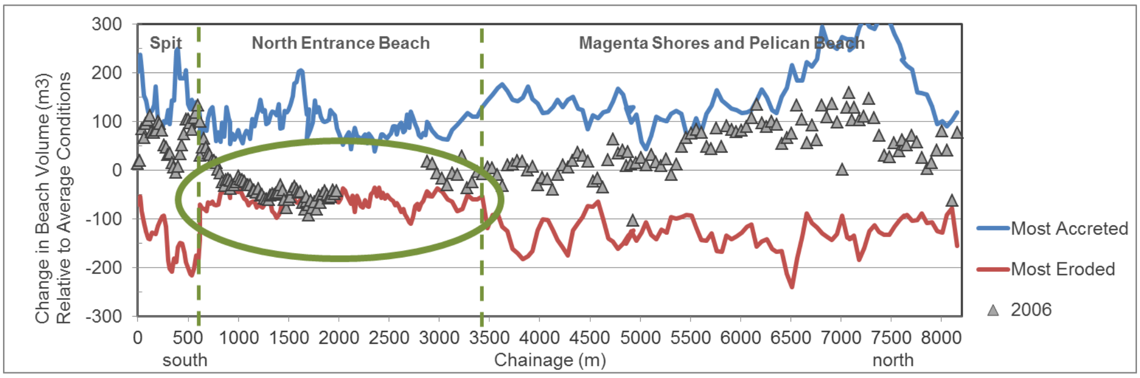


Figure 3-31 Changes in Dune Position for Tuggerah Beach Compartment

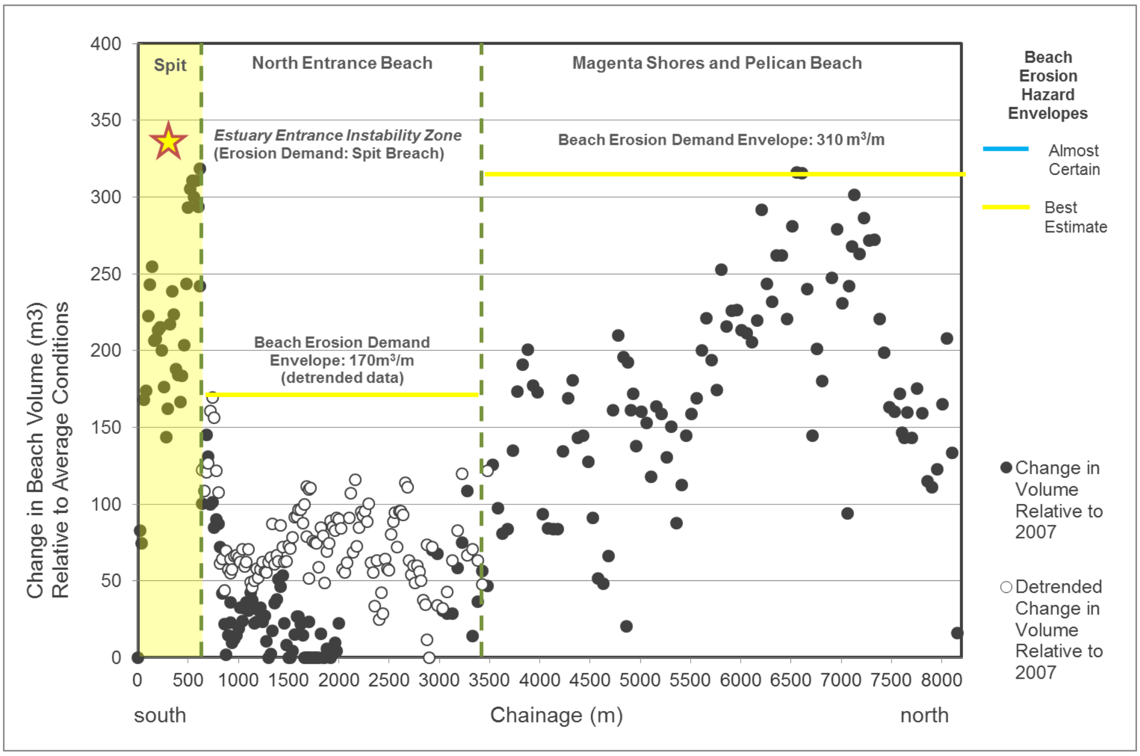


Figure 3-32 Beach Erosion Demand Volumes Relative to 2007 for The Entrance Spit (south), North Entrance (middle) and Magenta Shores to Pelican Beach (north)

3.6.3 Entrance Instability

A zone of entrance instability has been found to encompass Entrance Channel and adjoining length of Tuggerah Beach Compartment identified in this report as the **Entrance Sand Spit** (see Figure 3-26). This zone was identified primarily analysis of the available photogrammetry data (e.g. Figure 3-32). The alongshore extent of this hazard zone conforms with changes in dune morphology identified in the high resolution LiDAR topography. It is also consistent the mapping of history of entrance movement undertaken by PWD (1987). Coastal hazard mapping produced from this study identified this hazard type and extent accordingly (see Chapter 5).

3.6.4 Recession

Historical Recession

Long term trends in beach behaviour were analysed for the three geomorphologically common segments of Tuggerah Beach Compartment: the Entrance Spit (SS1); North Entrance Beach (SS2); and Magenta Shores to Pelican Beach (SS3). Analysis of temporal changes in beach volume shows that the southern third of the compartment at North Entrance Beach is experiencing net recession while the middle and northern sections of the compartment between Magenta Shores and Pelican Beach is undergoing long term accretion. These shoreline behaviour trends are clearly demonstrated on Figure 3-33. Measured changes in beach volume have been converted into rates of shoreline movement in Table 3-23 based on representative dune heights. Analysis of shoreline change based on the dune position provided comparable trends to that determined from the historical beach volume calculations (see Figure 3-34 and Table 3-24).

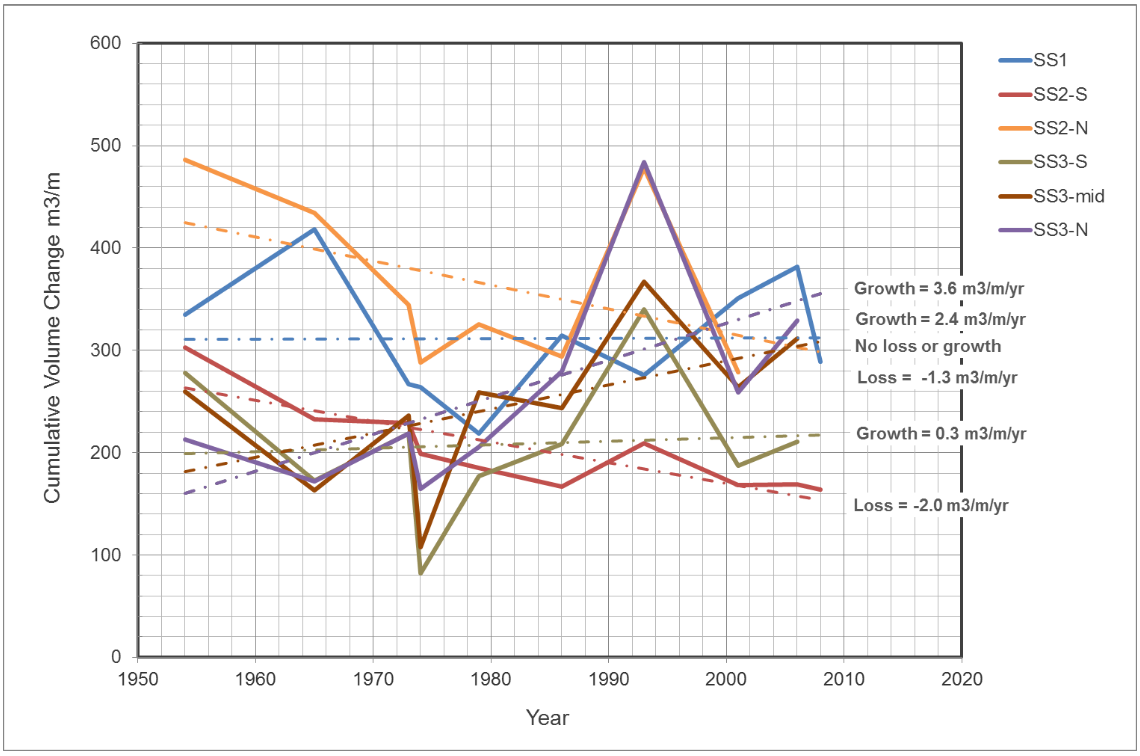


Figure 3-33 Cumulative Change in Beach Volume per metre Length of Beach for Tuggerah Beach Compartment

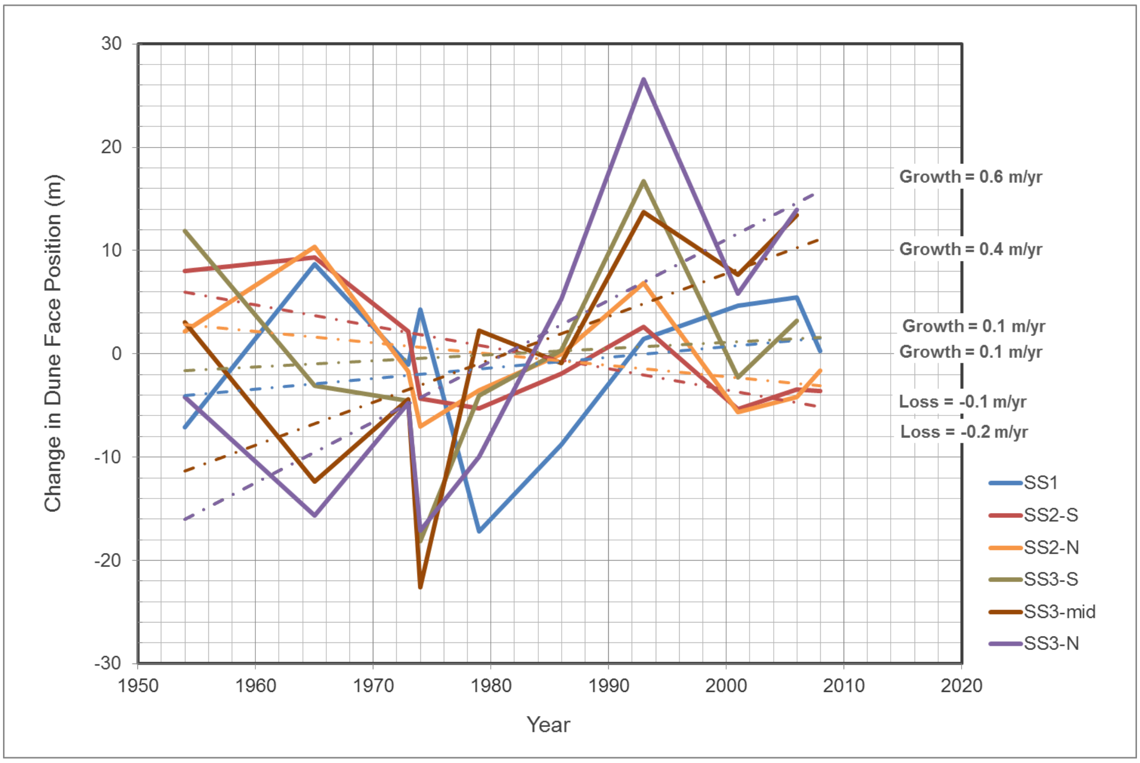


Figure 3-34 Change in Dune Face Position for the Tuggerah Beach Compartment

Table 3-23 Long Term Shoreline Change for Tuggerah Beach from Beach Volume Change

Net Volume Changes Recorded from the Active Beach System (m^3/m/yr)					
Entrance Channel	North Entrance		Magenta Shores to Pelican Beach		
SS1	SS2 – South	SS2 – North	SS3 – South	SS3 – Middle	SS3 – North
0.0	-2.0	-1.3	0.3	2.4	3.6
Adopted Dune Heights (m)					
SS1	SS2 – South	SS2 – North	SS3 – South	SS3 – Middle	SS3 – North
5.0	5.5	5.5	6.0	6.0	6.0
Historical Recession and/or Accretion Rates (m/yr)					
SS1	SS2 – South	SS2 – North	SS3 – South	SS3 – Middle	SS3 – North
0.0	-0.4	-0.2	0.1	0.4	0.6

Note: The Entrance Channel and spit (SS1) comprised Block (B) A; southern end of North Entrance Beach (SS2-S) comprised BB, BC and BD P1-P8; northern end of North Entrance Beach (SS2-N) comprised BD P9-P62 and BE P1-P1; the Magenta Shores to Pelican Beach section of shoreline was analysed in three section including the southern end (SS3-S) comprised BE P12-42 and BF P1-2; the middle section (SS3-mid) BF P3-6 and the northern end (SS3-N) comprised of BF P37-P46, BG and BH.

Table 3-24 Long Term Shoreline Change for Tuggerah Beach from Dune Movement

Historical Recession and/or Accretion Rates (m/yr)					
Entrance Channel	North Entrance		Magenta Shores to Pelican Beach		
SS1	SS2 – South	SS2 – North	SS3 – South	SS3 – Middle	SS3 – North
0.0	-0.2	-0.1	0.1	0.4	0.6

Note: The Entrance Channel and spit (SS1) comprised Block (B) A; southern end of North Entrance Beach (SS2-S) comprised BB, BC and BD P1-P8; northern end of North Entrance Beach (SS2-N) comprised BD P9-P62 and BE P1-P1; the Magenta Shores to Pelican Beach section of shoreline was analysed in three section including the southern end (SS3-S) comprised BE P12-42 and BF P1-2; the middle section (SS3-mid) BF P3-6 and the northern end (SS3-N) comprised of BF P37-P46, BG and BH.

The coastal processes occurring along Tuggerah Beach compartment and within the Entrance Channel are complex and it is beyond the scope of this study to isolate the cause(s) for the historical shoreline behaviour noted above. A couple of observations are however made herein:

- The Tuggerah Beach compartment is backed by a dune field that widens significantly in a northward direction, increasing from few hundred metres in the south to wider than two kilometres in the north. This indicates a net transport of sediment is northward over geological timescales.

- The receding segment of North Entrance Beach (SS2) is backed by active transgressive dunes for much of its length which includes regular dune blowouts. These blowouts allow beach deposited sand to be readily transported landwards of the active beach system. These dunes are clearly a contributing factor towards the net loss in beach volume through time. Historical photographs show that an extensive dune blowout was located in the vicinity of Curtis Parade, prior to the expansion of residential development into this area (Figure 3-35). The Curtis Parade houses have provided some stability to the dunes, although sand drift still occurs under stormy conditions, as experienced in the April of 2015 event (see Figure 3-36).

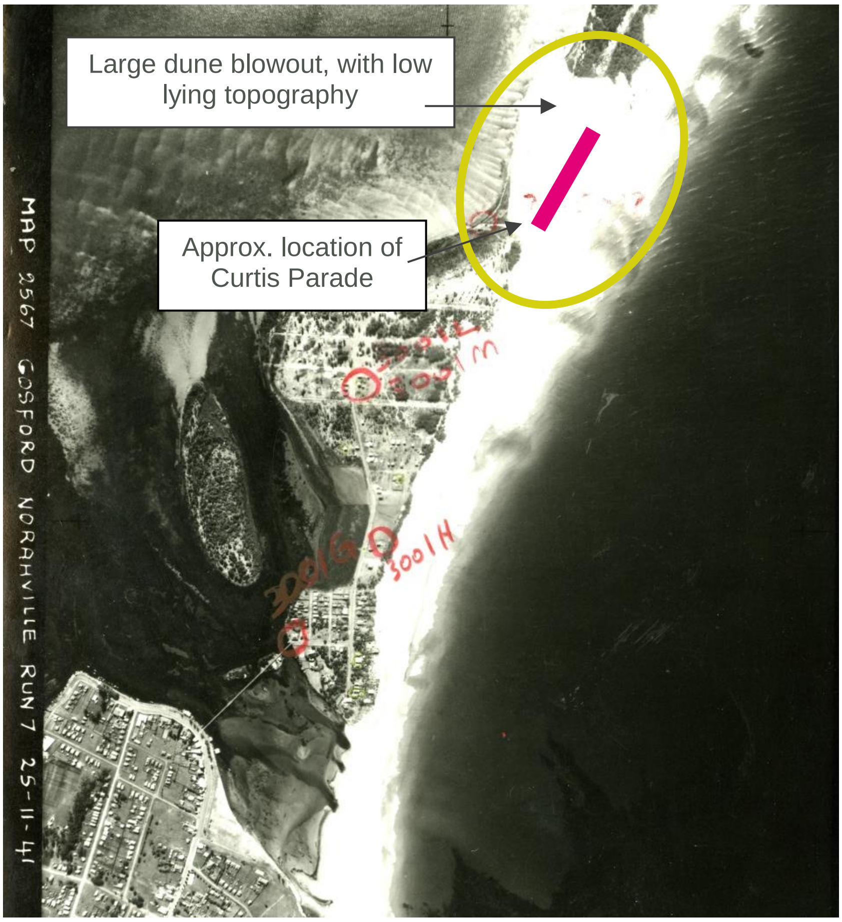


Figure 3-35 Historic Aerial Photograph of North Entrance Beach in 1941, showing the Location of a Large Dune Blowout

- The Magenta Shores to Pelican Beach segment (SS3) of shoreline is experiencing net accretion, with the rates of long term accretion generally increasing towards the northern end of the beach compartment. This stretch of beach and dunes was exposed to widespread sand mining operations in the early to mid-1970's which resulted in major reshaping of the dune fields. Mining rehabilitation efforts moved large volumes of dune sand closer to the shoreline in the form of a large continuous dune barrier that immediately backs the beach. This engineered dune topography is somewhat different to the pre-existing transgressive dune morphology which generally ramped upwards away from the beach. The positioning of this artificially constructed dune barrier may have enabled the 1974 and 1978 storms to mobilise an additional volume of sediment than this stormy period would have otherwise accessed. AWACS (1996) attributes accretion in the northern end of Tuggerah Beach to the erosion of the reshaped dune barrier.

Figure 3-36 Sand Drift at the Southern End of Curtis Parade, North Entrance, Demonstrating the Ongoing Dune Activity which may be Contributing to the Sediment Deficit at this Beach

- Umwelt (2011b) shows that the natural sediment cycle within the Entrance Channel region is complex, and that human interference (development, reclamation, channel dredging) of this area over the past half century may have cut of sediment supply to the coast.
- A number of preceding studies (e.g. Patterson Britton 1994) including the recent investigation by SMEC (2011b) have identified a long shore sediment transport 'null point' in the vicinity of North Entrance Beach. While the location of this 'null point' is thought to have moved along the beach, it must be a contributing factor to the recession experienced at North Entrance.
- It is also suggested that regular entrance opening operations that have occurred since 1993 may be reducing the natural supply of channel sediments to North Entrance Beach. Under natural conditions where the entrance channel was more commonly shoaled, the entrance breakout processes would have more regularly deposited scoured channel sands immediately offshore of the entrance mouth. Over time, some of these sands would have been directly transported onto the sand spit and in into the channel mouth (via cross-shore transport processes), while some would have been transported alongshore in a northerly direction to supply the North Entrance beach (northwards of the 'null point'). This process is demonstrated by Cardno's (2013) morphodynaimc modelling of the June 2007 event which is considered to a a 100-year ARI flood event (see Figure 3-37). It may be the case that the volume of sand supplied to North Entrance beach via this demonstrated sediment transport pathway has become reduced in response to the regular entrance clearance works which minimise the degree of channel scour occurring under moderate to large flood events. Rather than being

intermittently deposited offshore, the regularly dredged channel sands are now placed on the sand spit southward of the 'null point'. As a result, these sands become largely contained within a closed cycle and are progressively transported back into the Entrance Channel over time. The degree to which the entrance clearance works may be impacting on the net recession experienced at North Entrance is unknown and requires further investigation, in light of the new morphodynamic model available for this area.

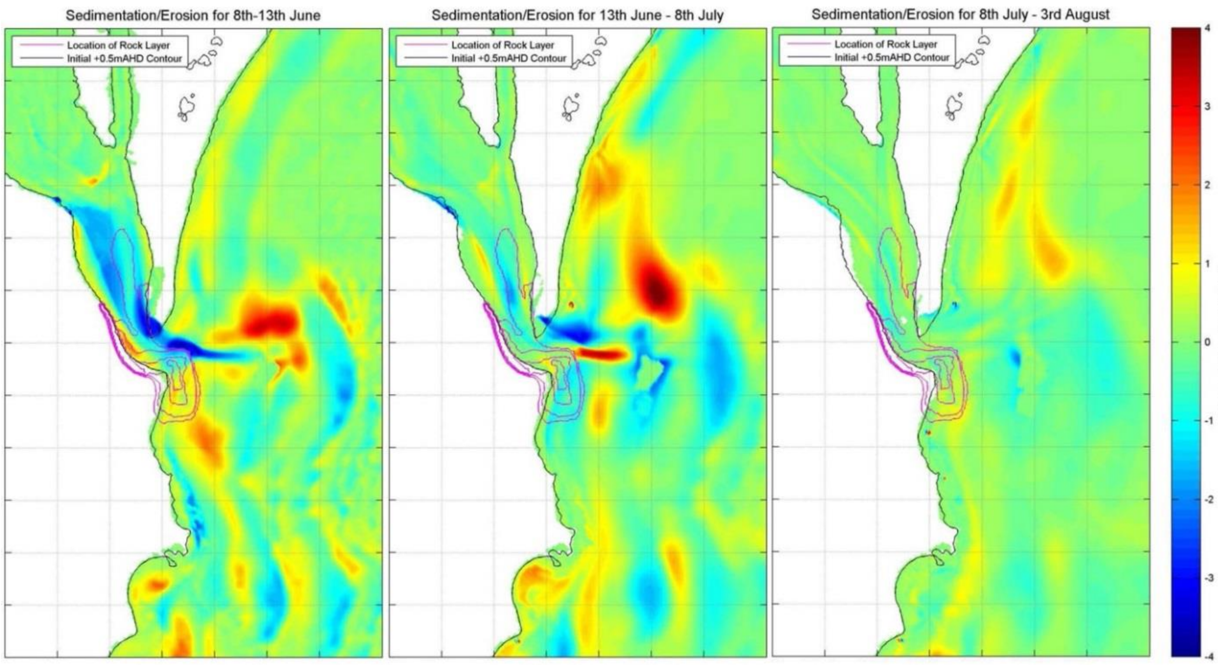


Figure 3-37 Entrance Channel Morphodynamic Modelling of June 2007 Floods by Cardno (2013) Showing Channel Sediment Scour and Transport Pathways

While no definitive reason for the observed short term recession at North Entrance and accretion between Magenta Shore and Pelican Beach can be stated, it is considered that the long term trend is clear and therefore a recession rate of 0.2 m/year has been adopted. This rate is also consistent with prior reports (SMEC, 2010). The accretionary trend observed for the Magenta Shores to Pelican Beach length of shoreline cannot be confidently projected into the future, as sea level rise will likely influence this trend. As such, Magenta Shores to Pelican Beach is assumed to be stable for the purpose of assessing future hazards.

Sea Level Rise Impacts

The estimated impact of future sea level rise on Tuggerah Beach compartment is summarised in Table 3-25. The slope factors used for the Bruun Rule estimates are provided in the below table and a representative equilibrium slope factor is plotted against in Figure 3-38.

Table 3-25 Bruun Rule and Sea Level Rise Impacts for Tuggerah Beach Compartment

Beach Location	Photogram. Available? / No. Years / No. Dates	Adopted Long Term Recession			Estimated Recession from SLR		
		Adopted Rate (m/yr)	2050 Reces-sion (m)	2100 Reces sion (m)	Active Slope (1:X)	2050 SLR Reces-sion (m) [1]	2100 SLR Reces-sion (m) [2]
The Entrance Spit	Yes / 54 yrs / 10 dates	Nil	Nil	Nil	47	15	39
North Entrance	Yes / 54 yrs / 10 dates	0.2	7	17	44	14	36
Magenta Shores to Pelican Beach	Yes / 52 yrs / 9 dates	Nil	Nil	Nil	37	12	30

* **Note** all recession distances are rounded to the nearest metre; and future beach recession hazard lines for the 2050 and 2100 sea level rise scenarios are mapped from a combining historical recession and Bruun Rule sea level rise recession estimations.

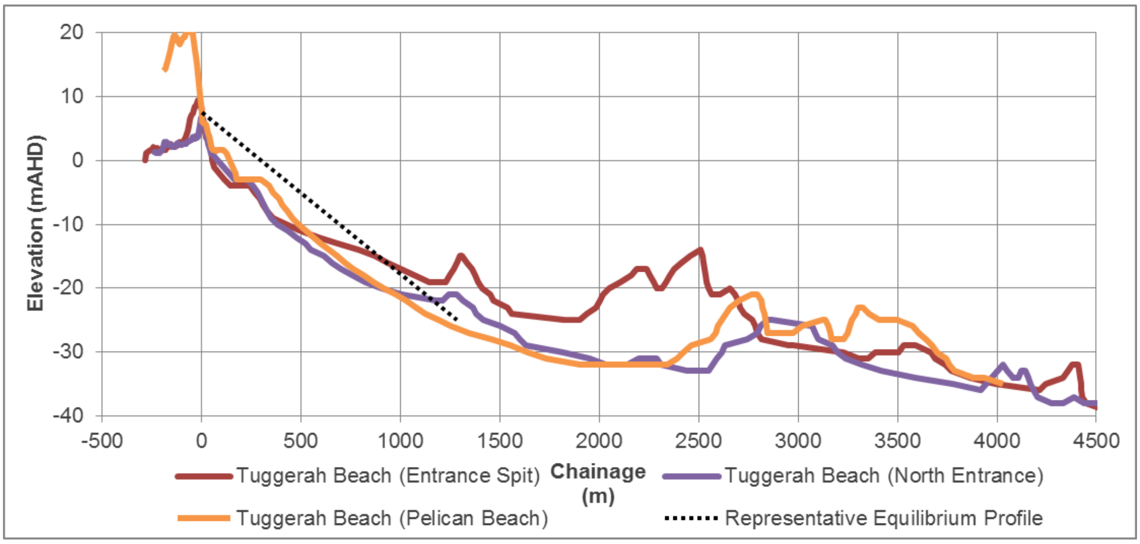


Figure 3-38 Cross Shore Profiles from Tuggerah Beach Compartment, showing the Active Profile Slopes

3.6.5 Coastal Inundation

Coastal inundation of land adjacent to the ocean from wave action during an extreme storm event was assessed along the Tuggerah Beach compartment by SMEC (2010). Under present sea level conditions, extreme water levels from wave runup processes was found to range between around 6.1 to 8.1 m AHD across the compartment, with the water levels above 8 m AHD modelled at North Entrance Beach (Curtis Parade) and in front of Magenta Shores (see Table 3-26). These modelled levels indicate that some overtopping may occur along Curtis Parade.

Table 3-26 Extreme Wave Runup Levels for Tuggerah Beach Compartment (1% AEP water levels combined with 1% AEP wave height) calculated by SMEC (2010)

Location	Water Level (m)	Maximum Wave Runup (m)	2% Wave Runup (m)	Significant Wave Runup (m)	1% AEP Offshore WL (mAHD)	Max Runup Height (mAHD)
The Entrance Spit (Karagi Reserve beach access)	1.17	3.78	3.48	2.64	1.48	**6.43**
~Hargraves St beach access	0.96	3.72	3.43	2.60	1.48	**6.16**
North Entrance SLSC	1.27	3.97	3.64	2.76	1.48	**6.72**
Florida St beach access	1.11	4.62	4.18	3.17	1.48	**7.21**
~Coogee Ave	1.16	4.93	4.44	3.36	1.48	**7.57**
Curtis Pde - middle	1.19	5.43	4.86	3.67	1.48	**8.10**
Tuggerah Compartment Chainage ~2.8km (from south)	1.19	5.43	4.86	3.67	1.48	**8.10**
Magenta Shores - south end	1.15	5.17	4.64	3.51	1.48	**7.80**
Magenta Shores - middle	1.23	5.43	4.86	3.67	1.48	**8.14**
Magenta Shores - north end	1.21	5.17	4.64	3.51	1.48	**7.86**
Pelican Beach, south of carpark	1.15	5.17	4.64	3.51	1.48	**7.80**
Northern corner of Pelican Beach	1.07	4.19	3.82	2.90	1.48	**6.74**
Northern corner of Pelican Beach	1.06	1.69	1.45	1.09	4.48	**7.23**

3.7 Soldiers Beach and Soldiers Point

Soldiers Beach is a sweeping southeast facing beach that stretches for some 900 m between Pelican and Soldiers Points, from south to north. A tall continuous sand dune backs much of the beach, which is blown out in places, and transgressive up the backing bedrock hinterland. The surf club is located on top of this dunefield, behind the northern end of the beach. Pelican Point to the south comprises a low rocky reef that is joined to the beach by a sandy tomobolo separating Soldiers and Pelican Beaches. Soldiers Point in the north comprises a more substantial rocky headland comprised of Munmorah Conglomerate (with possible dyke intrusions) which is fronted by a large rocky shelf that extend a few hundred metres offshore of the low headland cliffs. Both points protrude seaward of the sandy beach resulting in the waves becoming slightly refracted and reduced in size.

Figure 3-39 Soldiers Beach looking south from Soldiers Point, with the SLSC in the Left; note the Tall and Steep Profile of the Dunes and Presence of Many Localised Blowouts.

3.7.1 Beach Profile Data

Photogrammetry derived beach profiles from the years listed in Table 3-27 were analysed for Soldiers Beach.

Table 3-27 Summary of Beach Profile Data for Soldiers Beach

Beach Profile Years	Comments
• 1941 • 1965 • 1973 • 1974/76 • 1986 • 1993 • 1996 • 2001 • 2006 • 2008	• Beach compartment split into five photogrammetry blocks, Blocks 1 to 5 (Blocks 1 – 4 south to north, Block 5 at the SLSC) • 1941 photogrammetry data excluded from hazards analysis, due to coarse nature of profile data and observed topographic errors • Considerable transgressive dune activity has and continues to occur behind the beach. Care was taken to exclude these areas from the beach volume analysis (where possible) to ensure that volume calculations represent beach volume change driven littoral processes (as opposed to backbeach aeolian activity).

3.7.2 Erosion

Analysis of beach volume and dune position (4 m AHD) data shows that Soldiers Beach is relatively stable. On average, the beach has fluctuated some 110 m^3/m (SD± 40 m^3/m), with a maximum range of beach volume change measured near to 180 m^3/m adjacent to the Surf Life Saving Club. The most eroded beach states were measured in 1986 and 1974, while the most accreted beach states were measured in 1956, 1973 and 2006. Beach volume in the far southern end of the embayment experiences less variability due to the protection provided by the Pelican Point. Movement of the dune position (4 m AHD) has been relatively stable throughout the beach profile records, generally fluctuating within an envelope of 5 – 15 m wide.

The erosion demand volume determined for Soldiers Beach, based on the historical beach profile data and relative to the 2007 conditions, was determined to be 150 m^3/m (see Figure 3-48). This erosion demand is less than the 200 m^3/m proposed by SMEC (2010) for the northern end of the beach that was based on erosion values not produced in our analysis, which took care to exclude the actively transgressive backbeach dunes from the volumetric analysis.

To ensure the 150 m^3/m erosion demand volume did not underestimate the true erosion hazard for Soldiers Beach, the erosion hazard lines (zone of slope adjustment) produced from this assessment were compared against historical aerial photographs from the 1970's as well as the 4 m AHD and 8 m AHD contours produced from the 1974/1976 photogrammetry profiles (taken to approximate the 1974 zone of wave impact and zone of slope adjustment). This comparison found the erosion mapping was provided by this study is closely comparable with the 1970's eroded shoreline configuration, for the swell exposed northern end of the beach.

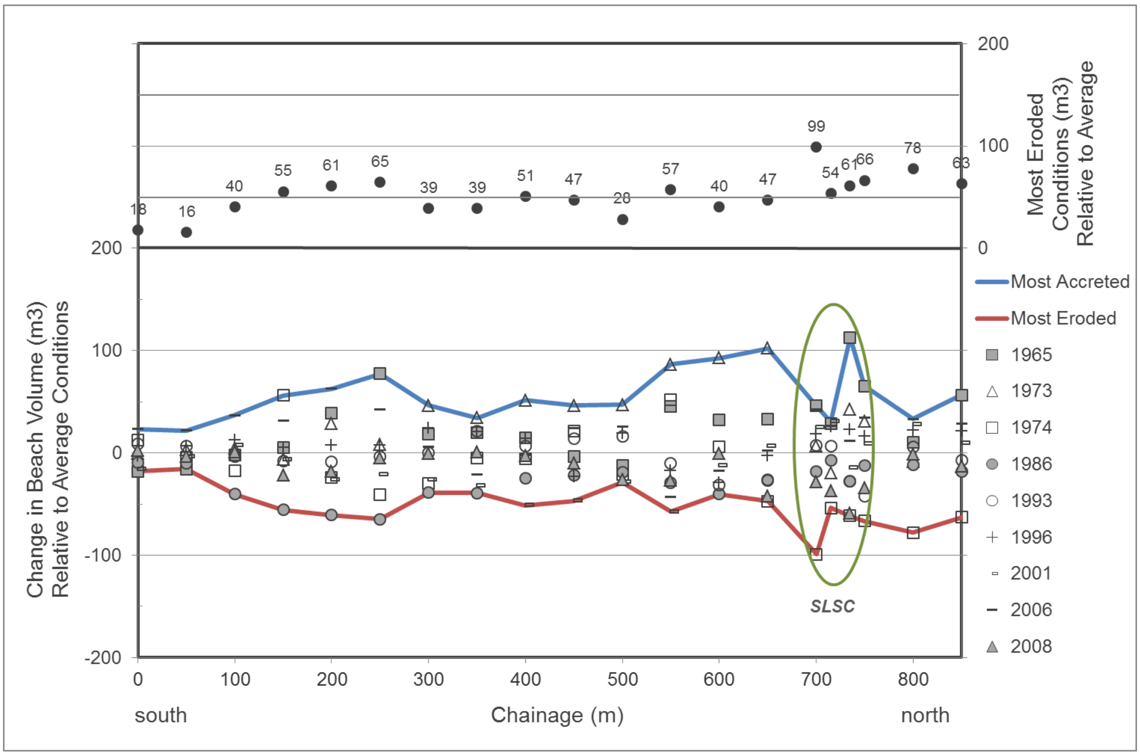


Figure 3-40 Changes in Beach Profile Volume for Soldiers Beach

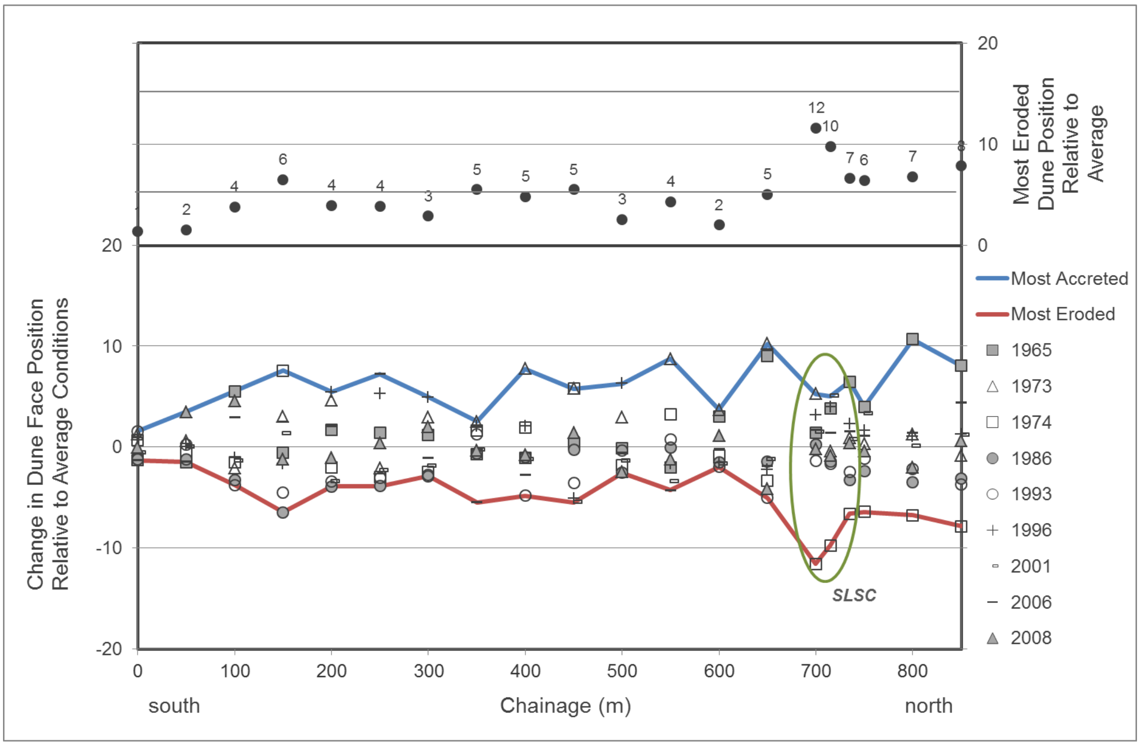


Figure 3-41 Changes in Dune Position for Soldiers Beach

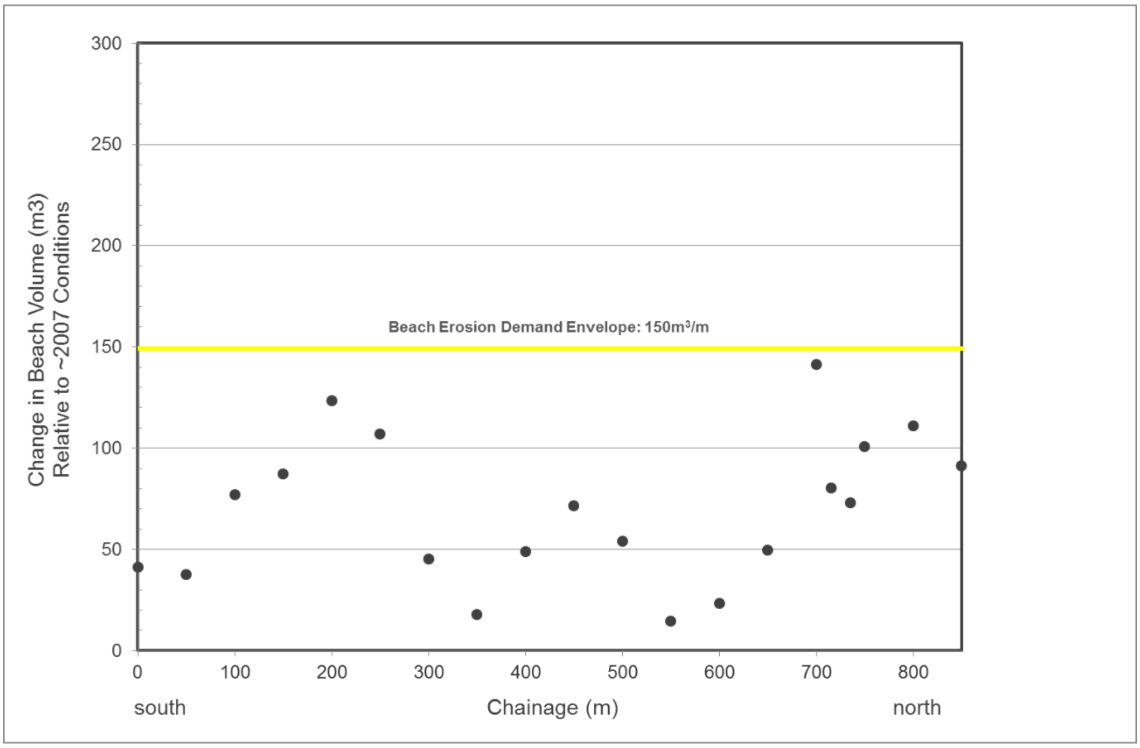


Figure 3-42 Beach Erosion Demand Volumes Relative to 2007 for Soldiers Beach

3.7.3 Recession

Historical Recession

Long term trends in beach volume and dune position were analysed for Soldiers Beach, as shown on Figure 3-43 and Figure 3-44. Table 3-28 converts the measured volumetric trends into linear rates of shoreline movement, while the linear rates of shoreline change determined from dune movement are provided in Table 3-29. Both results are comparable to one another and show Soldiers Beach to be largely stable. For the purposes of assessing future hazards, Soldiers Beach is considered to be stable.

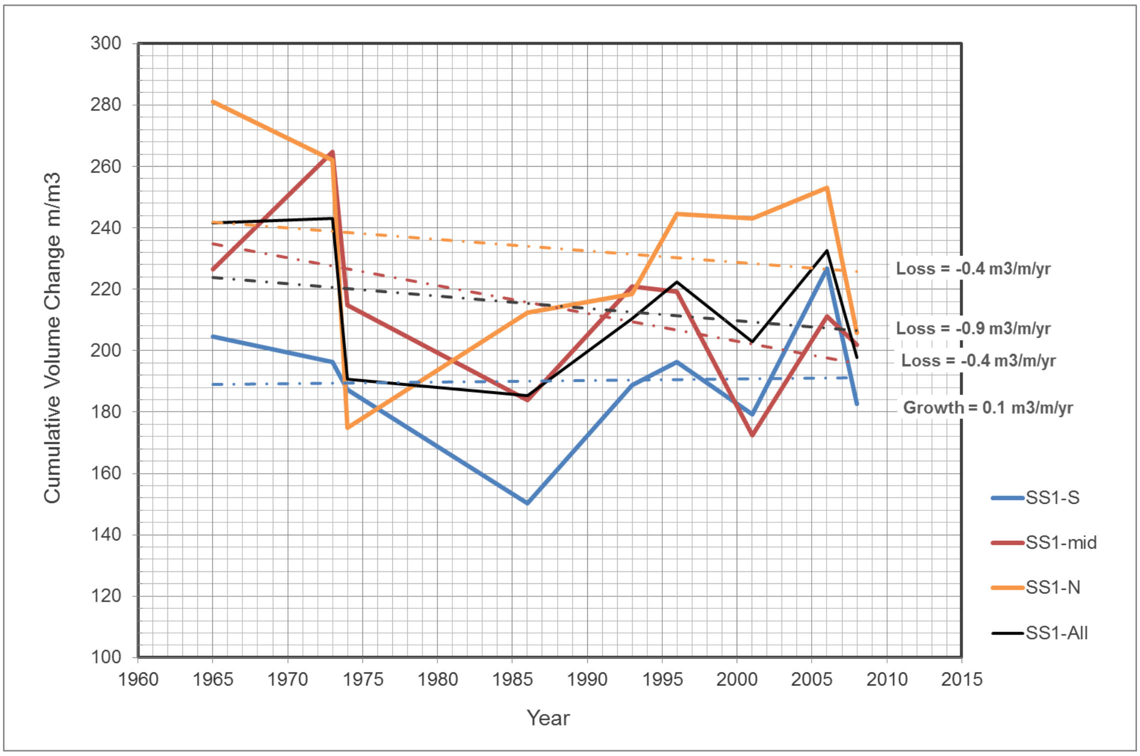


Figure 3-43 Cumulative Change in Beach Volume per metre length of Beach for Soldiers Beach

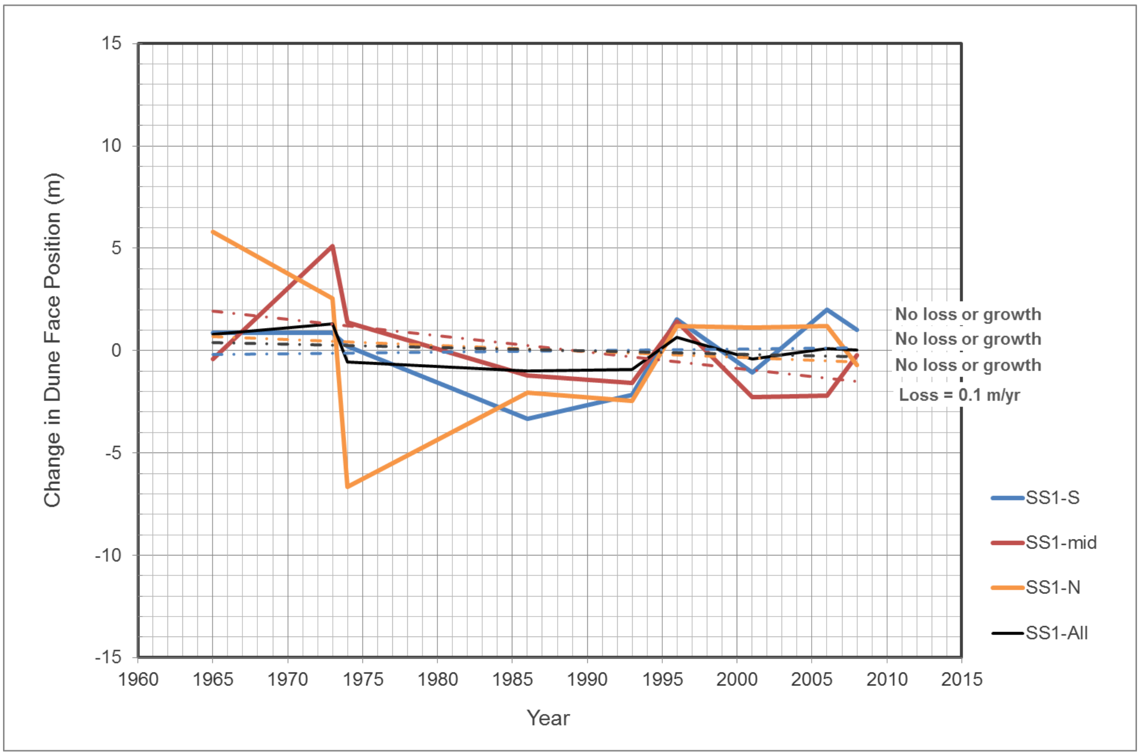


Figure 3-44 Cumulative Change in Dune Face Position for Soldiers Beach

Table 3-28 Long Term Shoreline Change for Soldiers Beach from Beach Volume Change

Net Volume Changes Recorded from the Active Beach System ($m^3/m/yr$)			
Soldiers Beach			
SS1-South	**SS1-middle**	**SS1-North**	**SS1 (All)**
0.1	-0.9	-0.4	-0.4
Adopted Dune Heights (m)			
SS1-South	**SS1-middle**	**SS1-North**	**SS1 (All)**
5.5	6.5	7.0	6.5
Historical Recession and/or Accretion Rates (m/yr)			
SS1-South	**SS1-middle**	**SS1-North**	**SS1 (All)**
0.0	-0.1	-0.1	-0.1

Note: southern Soldiers Beach (SS1-South) comprised Block 1 (B1) and B2, the centre of Soldiers Beach (SS1-middle) comprised B3 and northern Soldiers Beach comprised B4 and B5.

Table 3-29 Long Term Shoreline Change for Soldiers Beach from Dune Movement

Historical Recession and/or Accretion Rates (m/yr)			
Soldiers Beach			
SS1-South	SS1-middle	SS1-North	SS1 (All)
0.0	-0.1	0.0	0.0

Note: southern Soldiers Beach (SS1-South) comprised Block 1 (B1) and B2, the centre of Soldiers Beach (SS1-middle) comprised B3 and northern Soldiers Beach comprised B4 and B5.

Sea Level Rise Impacts

The estimated impact of future sea level rise on Soldiers Beach is summarised in Table 3-30. The slope factor used for the Bruun Rule estimates is provided in the table below and is plotted against the cross shore profile on Figure 3-45.

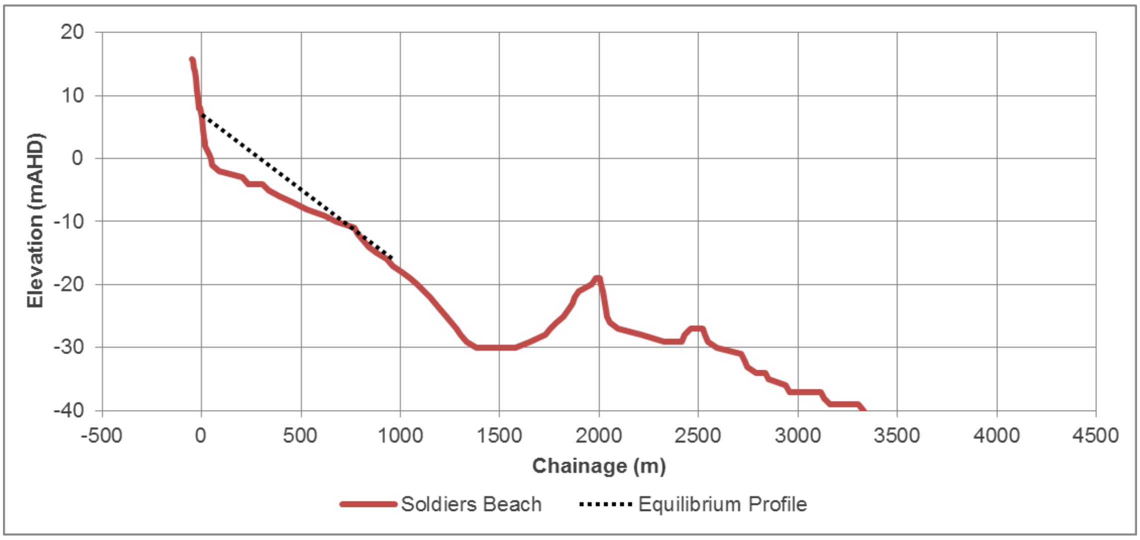


Figure 3-45 Cross Shore Profiles from Soldiers Beach, showing the Active Profile Slope

Table 3-30 Bruun Rule and Sea Level Rise Impacts for Soldiers Beach

Beach Location	Photogram. Available? / No. Years / No. Dates	Adopted Long Term Recession			Estimated Recession from SLR		
		Adopted Rate (m/yr)	2050 Recession (m)	2100 Recession (m)	Active Slope (1:X)	2050 SLR Recession (m) [1]	2100 SLR Recession (m) [2]
Soldiers Beach	Yes / 43 yrs / 9 dates	Nil	Nil	Nil	42	14	35

*** Note** all recession distances are rounded to the nearest metre; and future beach recession hazard lines for the 2050 and 2100 sea level rise scenarios are mapped from a combining historical recession and Bruun Rule sea level rise recession estimations.

3.7.4 Slope and Cliff Instability

Segments of rocky coastline at Soldiers Point are susceptible to cliff recession. Recession setback distances have been estimated based the local geological characteristics summarised in Table 3-1. Further details regarding geotechnical hazards are found in Appendix A: Coastal Geotechnical Study by JK Geotechnics.

Table 3-31 Geotechnical Characteristics for Soldiers Point

Coastal Morphology	Geology	Cliff Recession Mechanism	Recession Rate	Adopted Recession Angle	Slope Instability Hazards
Low bedrock headland with cliffs, fringed by a wide rocky shore platform	**Munmorah Conglomerate** *(4 m joint spacing; 70° jointing angle)*	Block failure and slope adjustment	1 joint spacing (4 m) per planning horizon timeframe	70° for bedrock 45° for surficial colluvial soil profile	None

3.7.5 Coastal Inundation

Coastal inundation of land adjacent to the ocean from wave action during an extreme storm event was assessed at five locations along Soldiers Beach by SMEC (2010). Under present sea level conditions, extreme water levels from wave runup processes was found to be around 7 m AHD across the compartment, with the highest level modelled at the SLSC (see Table 3-32). These modelled levels indicate that some overtopping may occur at Blue Lagoon.

Table 3-32 Extreme Wave Runup Levels for Soldiers Beach (1% AEP water levels combined with 1% AEP wave height) calculated by SMEC (2010)

Location	Water Level (m)	Maximum Wave Runup (m)	2% Wave Runup (m)	Significant Wave Runup (m)	1% AEP Offshore WL (mAHD)	Max Runup Height (mAHD)
Far south end of Soldiers Beach	1.06	4.19	3.82	2.90	1.48	**6.73**
South end of Soldiers Beach	1.15	4.12	3.76	2.85	1.48	**6.75**
Middle section of Soldiers Beach	1.17	4.27	3.89	2.95	1.48	**6.92**
Soldiers Beach SLSC	1.22	4.44	4.03	3.05	1.48	**7.14**
Far south end of Soldiers Beach	1.06	4.19	3.82	2.90	1.48	**6.73**

3.8 Pebbly Beach

Pebbly Beach is a 500 m long, southeast facing beach located between two prominent rocky headlands (see Figure 3-46). The beach is backed by tall, steep and active transgressive dunes, which climb landwards up the backing rocky slopes. The dunes are perched on a 2 to 3 m tall rocky platform in its southern end. Soldiers Point to the south and Norah Head to the north form low bluffs that that protrude seaward of the beach, providing a small level of protection to the beach. The headlands are comprised of Munmorah Conglomerate and underlain by Tuggerah Formation rocks, which have been intruded by dykes in some locations. An exposed section of cliff is located at the southern section of this beach and bedrock is exposed in the dunes deflation hollow behind the middle section of beach.

Figure 3-46 Pebbly Beach looking northward towards Norah Head from Soldiers Point, showing the Rocky Substrate Located at Both Ends of the Beach and the Tall and Active Transgressive Dune System

3.8.1 Erosion

No photogrammetry data are available to guide the erosion assessment for Pebbly Beach. As such, the erosion demand estimates for this beach are made based on interpretation of the sites geomorphic conditions. It is likely that Pebbly Beach behaves in a comparable way to Soldiers Beach, considering the similarities between the two, i.e. both beaches are located in bedrock embayed compartments, face southeast, and have actively transgressive dune systems. The main difference between the two beaches is that Pebbly beach is backed by bedrock, which will form a landward limit to erosion and recession of the sandy shoreline. For the purpose of the erosion hazard assessment, Pebbly Beach is therefore estimated to have an erosion demand volume of 150 m^3/m, relative to 2007 conditions. Considering the southeast aspect of this beach, the 150 m^3/m volume may appear small, however, similar to Soldiers Beach, it is expected that the protruding headlands provide the beach some protection from incoming waves.

3.8.2 Recession

It is assumed that Pebbly Beach, like Soldiers Beach, is stable and thus no **historical recession** has been applied to this beach for assessing future hazards at this beach.

The estimated **impact of future sea level rise** on Pebbly Beach is summarised in Table 3-33. The slope factor used for the Bruun Rule estimates are provided in the below table and plotted against a cross shore profile of Pebbly Beach on Figure 3-47.

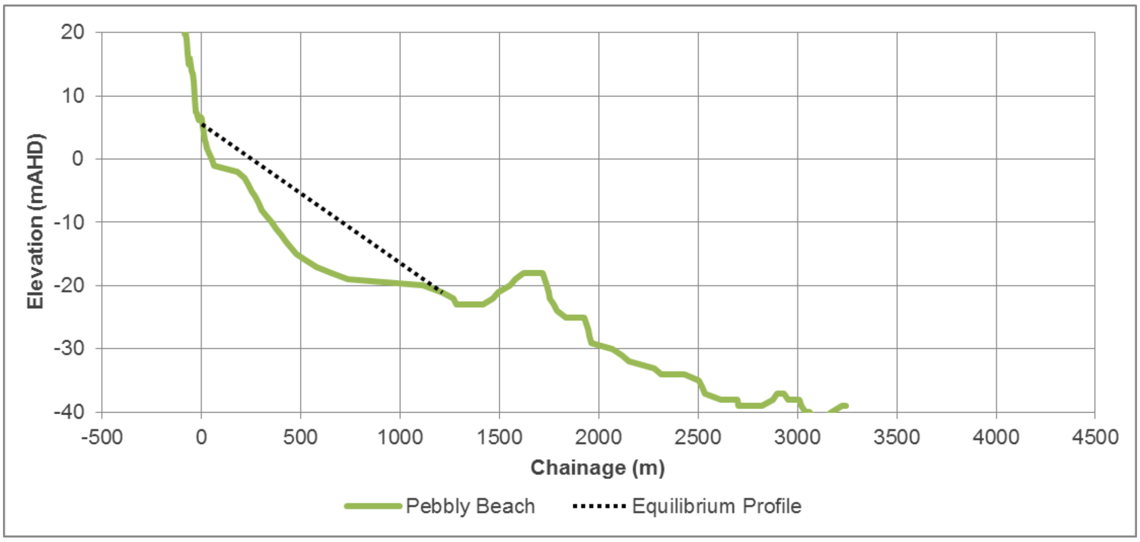


Figure 3-47 Cross Shore Profile from Pebbly Beach, showing the Active Profile Slope

Table 3-33 Bruun Rule and Sea Level Rise Impacts for Pebbly Beach

Beach Location	Photogram. Available? / No. Years / No. Dates	Adopted Long Term Recession			Estimated Recession from SLR		
		Adopted Rate (m/yr)	2050 Reces-sion (m)	2100 Reces sion (m)	Active Slope (1:X)	2050 SLR Reces-sion (m) [1]	2100 SLR Reces-sion (m) [2]
Soldiers Beach	Yes / 43 yrs / 9 dates	Nil	Nil	Nil	42	14	35

*** Note** all recession distances are rounded to the nearest metre; and future beach recession hazard lines for the 2050 and 2100 sea level rise scenarios are mapped from a combining historical recession and Bruun Rule sea level rise recession estimations.

3.8.3 Slope and Cliff Instability

Lengths of rocky coast surrounding and behind Pebbly Beach are susceptible to cliff recession. Recession setback distances have been estimated based the local geological characteristics summarised in Table 3-1.

Further details regarding geotechnical hazards are found in Appendix A: Coastal Geotechnical Study by JK Geotechnics.

Table 3-34 Geotechnical Characteristics for Pebbly Beach

Coastal Morphology	Geology	Cliff Recession Mechanism	Recession Rate	Adopted Recession Angle	Slope Instability Hazards
Bedrock slopes fronted by modern beach and dune sands	**Munmorah Conglomerate** *(4 m joint spacing; 70° jointing angle)*	Block failure and slope adjustment	1 joint spacing (4 m) per planning horizon timeframe	70° for bedrock 30° for deep sandy soil profile 45° for surficial colluvial soil profile	Some cliff-top sand dunes may be susceptible to slope instability

3.9 Norah Head and Lighthouse Beach

Norah Head is a prominent rocky headland that protrudes due east from the surrounding coastline: Pebbly Beach, Soldiers Beach and Tuggerah Beach embayment extend southwest of Norah Head; while Cabbage Tree Harbour and adjoining shorelines sweep around to the northwest.

Norah Head is considered to form a secondary level coastal compartment boundary (GA, 2013), which indicates that little to no sediment is transported either side of this landform on a decadal timescale. The low lying headland (20 to 30 m AHD) is comprised of Munmorah Conglomerate and fringed with generally wide rocky shore platforms, formed of Tuggerah Formation rocks. Both rock types are well jointed and intruded by igneous dykes in some places. These geological structures have strongly influenced the formation of the headland cliff and slopes (see Figure 3-48). Lighthouse Beach is located on the northern side of Norah Head and forms a narrow curving beach that is perched on top of rocky platforms and reefs and backed by narrow and low lying dunes.

Figure 3-48 Norah Head Headland looking southeast across Cabbage Tree Bay (left) and looking northwest showing the Relationship Between Cliff Formation and Presence of Igneous Dyke within Surrounding Sandstone Bedrock

3.9.1 Slope and Cliff Instability

Segments of rocky coastline surrounding Norah Head are susceptible to cliff recession. Recession setback distances have been estimated based the local geological characteristics summarised in Table 3-1.

Further details regarding geotechnical hazards are found in Appendix A: Coastal Geotechnical Study by JK Geotechnics.

Table 3-35 Geotechnical Characteristics for Pebbly Beach

Coastal Morphology	Geology	Cliff Recession Mechanism	Recession Rate	Adopted Recession Angle	Slope Instability Hazards
Protruding bedrock headland with cliffs and slopes, fringed by rocky shore platform with a perched sandy beach (Lighthouse Beach)	**Tuggerah Formation**, (+/- igneous dykes) Munmorah Conglomerate *(4 m joint spacing; 70° jointing angle)*	Block failure and slope adjustment	1 joint spacing (4 m) per planning horizon timeframe	70° for bedrock 45° for surficial colluvial soil profile	None

3.10 Cabbage Tree Harbour and Southern Cliffs

Cabbage Tree Harbour is a curving, northeast facing sandy embayment that forms a natural harbour. The 300 m long sandy beach is a low energy embayment that experiences significant protection by offshore reefs in addition to Norah Head that protrudes some 1 km eastward of the beach. The beach has no dunes and is immediately backed by steeply rising indurated sand cliffs and bluffs for much of its length. The embayment is bound either side by bedrock slopes and cliff faces comprised of Tuggerah Formation rocks and rocky shore platforms and cliff bases made of Munmorah Conglomerate.

Cabbage Tree Harbour has a long and well known history of slope instability and cliff line retreat, with a number of foreshore houses perched precariously on top of a retreating cliff line. The instable, indurated sand cliff has recently been protected from wave attack and undercutting by the construction of a ‘toe drainage structure’ (rock revetment) for most of its length. Edge effects are being experienced immediately adjacent the south-eastern end of this structure, where the exposed sand bluff is backed by Mazlin Reserve. Cliff slumping was observed by the authors during field work undertaken in June 2015 (see Figure 3-49). Foreshore development including a boat ramp, carpark, beach access road and foreshore houses has concealed the substrate and landform type that backs the south-eastern extent of the beach, although it is assumed this area is sandy in nature. Various structures are located at the back of the beach in this area, including engineered rock revetments and boat ramps, as well as *ad hoc* lengths of seawall.

A cliffed bedrock coastline extends for some 500 m to the north of Cabbage Tree Harbour. The east-northeast facing orientation of this shoreline segment is controlled by well-developed joint planes in the bedrock. Some very large blocks are scattered at the toe of this cliff at some locations.

Figure 3-49 Cabbage Tree Harbour Beach and Tall Sand Bluffs looking east, showing the Actively Retreating Indurated Sand Cliff (left) and Toe Protection Structure that Protects the Developed Length of Sand Bluff (middle-right).

3.10.1 Erosion

No photogrammetry data are available to guide the erosion assessment for Cabbage Tree Harbour. As such, the erosion demand estimates are made based on interpretation of the sites geomorphic condition. Cabbage Tree Harbour is a deep bedrock bound embayment that experiences significant protection from ocean swell waves, particularly from the south east due to Norah Head, but also from the north east, due to the presence of offshore reefs and adjoining rocky platforms. As such, an erosion demand of 75 m^3/m is estimated for Cabbage Tree Harbour and Lighthouse Beach. This volume is consistent with the ‘storm demand’ volumes proposed by SMEC (2010) and GBA (2001).

In the immediate term the engineered ‘toe protection structure’ that fronts the tall sand bluff and the short length of rock revetment protecting the boat ramp is considered to limit erosion extents (although slope adjustment of the backing dune profile, relative to the slopes crest height may still occur). The *ad hoc* lengths of seawall that fronts the south eastern foreshore houses are not considered to be constructed to coastal engineering standard and are therefore assumed to potentially fail under extreme erosion conditions (i.e. they were ignored for the purpose of mapping the erosion hazard).

3.10.2 Recession

Unlike for the immediate erosion hazard, the engineered protection structures at Cabbage Tree Harbour are not considered to limit future shoreline recession for the purpose of defining hazards. This approach has been adopted based on the Royal Haskoning (2014) report that outlines a design life of 15 years for the ‘toe drainage structure’. As such, there is no guarantee the structure will continue to function effectively over the coming (50 to100 year) planning timeframe.

Historical Recession

While no photogrammetry records of Cabbage Tree Harbour were available for this study, SCE (2010) reported a recession rate equivalent to about 0.3 m/yr based on historical information sourced for their study. It is noted that Cabbage Tree Harbour sand bluff acts as a ‘one-way’ shoreline due to its geological composition, that is, the relic indurated sand dune deposits are not capable of recovering from erosion. In addition, this beach has a well-known history of coastal erosion. As such, the proposed recession rate by SCE (2010) has been adopted for this study (see Table 3-36).

Table 3-36 Adopted Historical Recession Rates for Hazard Definition Purposes

Historical Recession Rates (m/yr)
Cabbage Tree Harbour Beach
0.3

Sea Level Rise Impacts

The estimated impact of future sea level rise on Cabbage Tree Harbour is summarised in Table 3-37. The slope factors used for the Bruun Rule estimates are provided in the below table and plotted against a cross shore profile of Cabbage Tree Harbour beach on Figure 3-50.

Table 3-37 Bruun Rule and Sea Level Rise Impacts for Cabbage Tree Harbour

Beach Location	Photogram. Available? / No. Years / No. Dates	Adopted Long Term Recession			Estimated Recession from SLR		
		Adopted Rate (m/yr)	2050 Reces-sion (m)	2100 Recession (m)	Active Slope (1:X)	2050 SLR Reces-sion (m) [1]	2100 SLR Reces-sion (m) [2]
Cabbage Tree Harbour	No	0.3	11	26	30	10	24

* **Note** all recession distances are rounded to the nearest metre; and future beach recession hazard lines for the 2050 and 2100 sea level rise scenarios are mapped from combining historical recession and Bruun Rule sea level rise recession estimations.

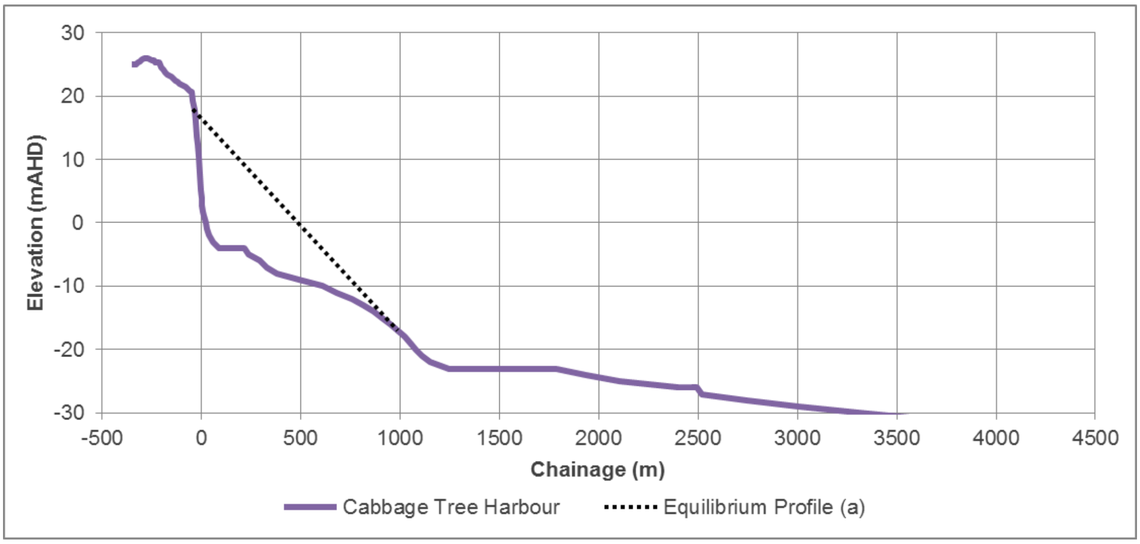


Figure 3-50 Cross Shore Profiles from Cabbage Tree Harbour, showing the Active Profile Slope

Cabbage Tree Harbour, like Bateau Bay Beach, varies from other beaches in that the active beach and dunes are backed by a tall indurated sand bluff. While the sand bluff is expected to respond to sea level rise much like that of modern beach and dunes, the significantly increased topography of this feature is expected to influence sea level recession behaviour, as discussed in Section 2.4.2. Note the mapped recession distances across the sand bluff areas will be greater than that provided in Table 3-6, as the dune bluff slumping under future timeframe scenarios has also been incorporated into the future sea level rise hazard mapping (see Section 2.4.2 for details).

As noted above, the ‘toe protection structure’ that fronts the tall sand bluff has been considered to limit the erosion hazard under the present timeframe, but not the future hazards due to recession.

3.10.3 Slope and Cliff Instability

A tall sand bluff backing Cabbage Tree Harbour is formed of indurated/cemented sand. This bluff feature represents a complex geological and geotechnical section of the study area that has, and continues, to be affected by landslides primarily triggered by elevated groundwater levels and exacerbated by coastal erosion at the base of the slopes. In addition to the coastal erosion and recession hazards, this sand bluff is also susceptible to non-coastal related landslide and soil erosion geotechnical hazards, driven by hillslope processes and groundwater flows for example. The extent of this geotechnical hazard zone extends landward of the bluff crests and seaward towards the bluff toe slopes (see Table 3-7).

Further details regarding geotechnical hazards are found in Appendix A: Coastal Geotechnical Study by JK Geotechnics.

Table 3-38 Geotechnical Characteristics for Pebbly Beach

Coastal Morphology	Geology	Cliff Recession Mechanism	Recession Rate	Adopted Recession Angle	Slope Instability Hazards
Exposed tall indurated sand bluff	Indurated / Cemented Sands	Slope adjustment in response to wave attack of toe slopes, when exposed	Historical recession of 0.3 m/year *plus* Bruun Rule estimates of SLR recession	30° for indurated sands Sand bluff slumps as per Nielsen *et al.* (1992) Zone of Slope Adjustment scheme	Slopes also susceptible to landslip hazards

3.11 Jenny Dixon Beach

Jenny Dixon Beach is a very narrow sandy beach located at the base of low bedrock cliffs bound by two rocky headlands. The east facing beach is 300 m long, and overlies shallowly buried rocky platform exposed in the middle and ends of the beach (see Figure 3-51). Rocky reefs also extend seaward from the adjoining headlands. The backing and bounding bedrock cliffs and slopes are formed of Tuggerah Formation and Munmorah Conglomerate rocks. While the beach experiences reduced waves from the offshore reefs, the investigation of the cross shore beach topography extracted from a LiDAR DEM indicates the volume of beach sand is small and could be easily eroded by an extreme storm event. Therefore, this section of coast is assessed for geohazards only.

Figure 3-51 Jenny Dixon Beach looking north, showing the Beach to be Comprised of a Thin Veneer of Sand Only that Overlies Rocky Platforms and is Backed by Steep Cliffs for Most of its Length

3.11.1 Slope and Cliff Instability

Segments of rocky coast stretching from the northern end of Cabbage Tree Harbour through to Hargraves Beach are susceptible to cliff recession. Recession setback distances have been estimated based the local geological characteristics summarised in Table 3-1.

In addition to coastal cliff recession, a length of coastline located behind Jenny Dixon Beach is also susceptible to non-coastal related landslide and soil erosion geotechnical hazards driven by hillslope processes and groundwater flows. The extent of this geotechnical hazard zone covers the gully type feature that exhibits a concave cross shore profile, as opposed to the convex cliff profile that are primarily exposed to cliff line recession hazards.

Further details regarding geotechnical hazards are found in Appendix A: Coastal Geotechnical Study by JK Geotechnics.

Table 3-39 Geotechnical Characteristics for Pebbly Beach

Coastal Morphology	Geology	Cliff Recession Mechanism	Recession Rate	Adopted Recession Angle	Slope Instability Hazards
Bedrock cliffs and slopes, backing and surrounding a perched sandy beach (Jenny Dixon Beach)	**Tuggerah Formation**, (+/- igneous dykes) *(4 m joint spacing; 70° jointing angle)*	Block failure and slope adjustment	1 joint spacing (4 m) per planning horizon timeframe	70° for bedrock 45° for surficial colluvial soil profile	Some slopes also susceptible to non-coastal geotechnical (landslip/soil creep) hazards

3.12 Hargraves Beach

Hargraves Beach is a gently curving, east facing sandy beach that stretches for 1.2 km between Jewfish Point in the north and a small rocky outcrop in the south. Two offshore rocky reefs control the planform of the beach, with a prominent sandy foreland forming in the lee of the northern reef. The submerged reefs reduce the wave heights experienced on the beach, while the adjacent Norah Head provides additional protection from the southerly directed swells. The beach is backed by a single, shore parallel dune that is low lying (4 m AHD, or less) for much of its length. Foreshore property is located on and immediately behind this dune.

Figure 3-52 Aerial Image of Hargraves Beach, showing the Two Offshore Reefs and Their Control on the Beach Form (e.g. Jew Fish Point); Note the Proximity of Residential Development to the Foreshore in the Middle Section of Beach

3.12.1 Beach Profile Data

Photogrammetry derived beach profiles from the years listed in Table 3-40 were analysed for Hargraves Beach.

Table 3-40 Summary of Beach Profile Data for Hargraves Beach

Beach Profile Years	Comments
• 1954 • 1965 • 1973 • 1974 • 1979 • 1986 • 1993 • 1996 • 2001 • 2006	• Beach compartment split into two photogrammetry blocks, Blocks I and J (south to north). • 1954 photogrammetry data excluded from hazards analysis, due to coarse nature of profile data and observed topographic errors. • Backbeach residential development has modified the dune topography in some places through time. Care was taken to exclude these areas from the volumetric analysis (where possible) to ensure the profile calculations best represent beach volume change driven coastal processes.

3.12.2 Erosion

Analysis of the beach volume photogrammetry data shows that Hargraves Beach oscillates around 110 m^3/m (SD± 25 m^3/m), with the greatest changed measured just above 170 m^3/m towards the southern send of the beach (see Figure 3-53). The most eroded beach conditions were experienced in 1974, with generally depleted beach volumes also measured in 1965 and 1986 across much of the shoreline.

Since 1986, the shoreline has been accreting, with 2006 experiencing the most accreted conditions on record. Movement of the 3 m AHD contour shows that the dune position fluctuates within an envelope of 25 m, with a maximum range of around 25 m for the middle and northern sections of beach which increases to 35 m towards the southern end (see Figure 3-54). The erosion demand volume determined for Hargraves Beach (based on the historical beach profile data and relative to the 2007 conditions) was estimated to be 180 m^3/m (see Figure 3-55).

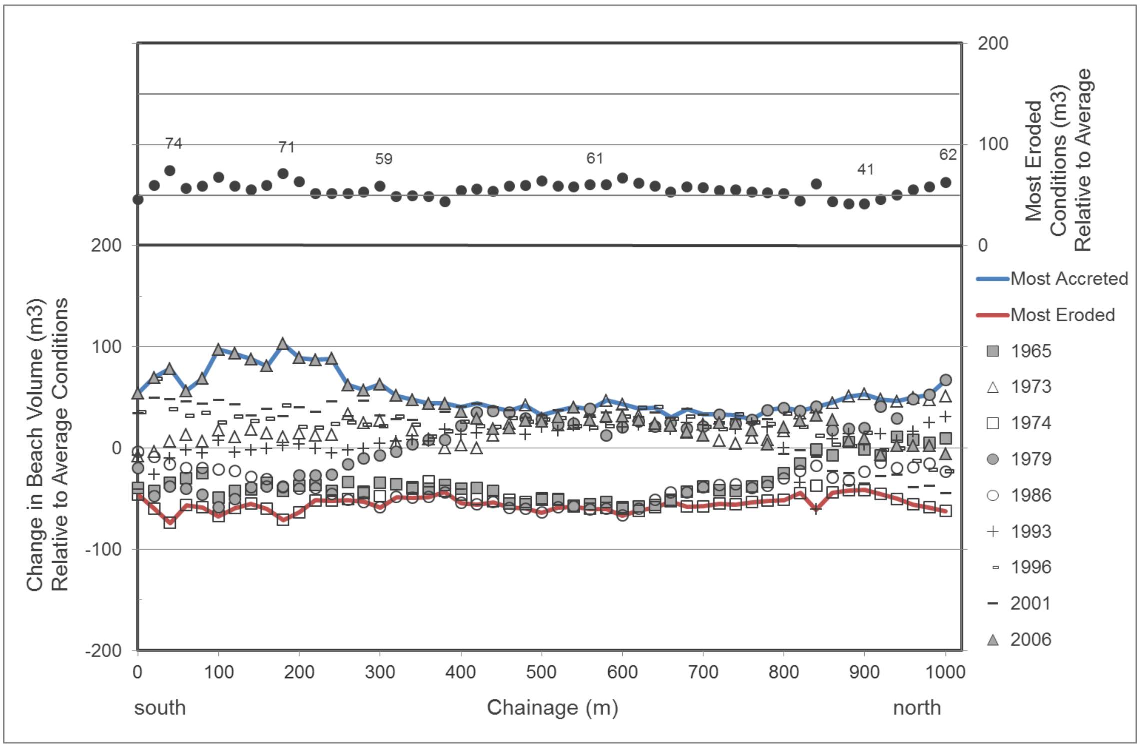


Figure 3-53 Changes in Beach Profile Volume for Hargraves Beach

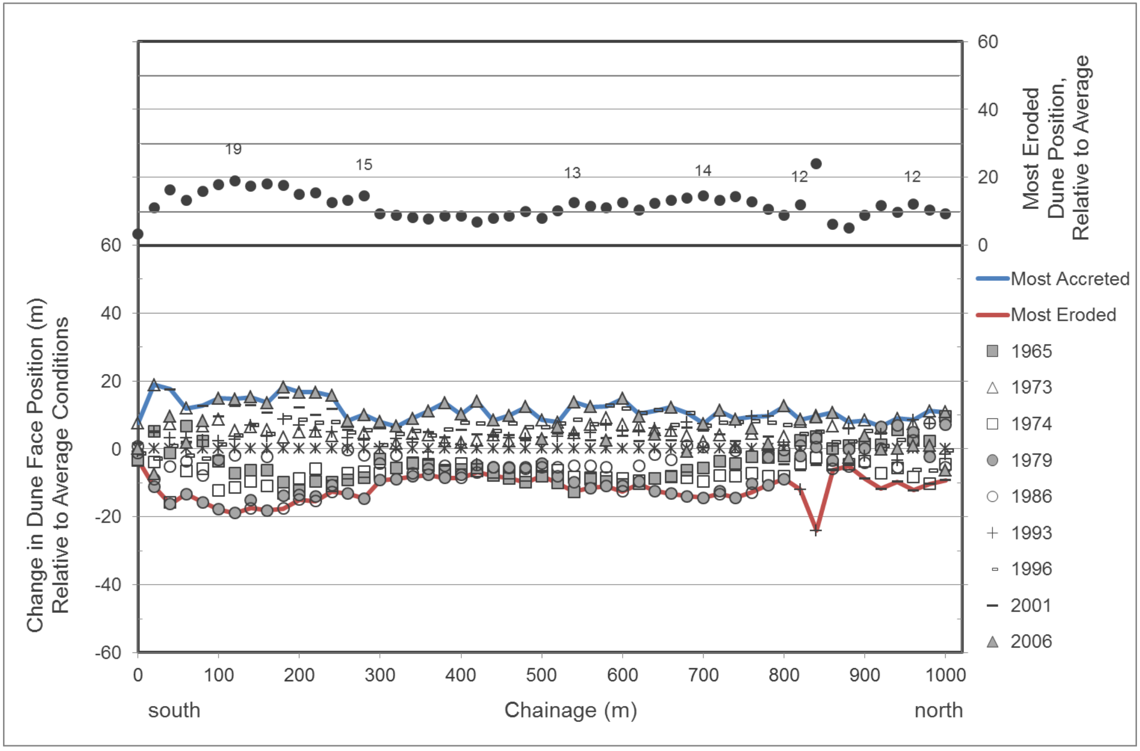


Figure 3-54 Changes in Dune Position for Hargraves Beach

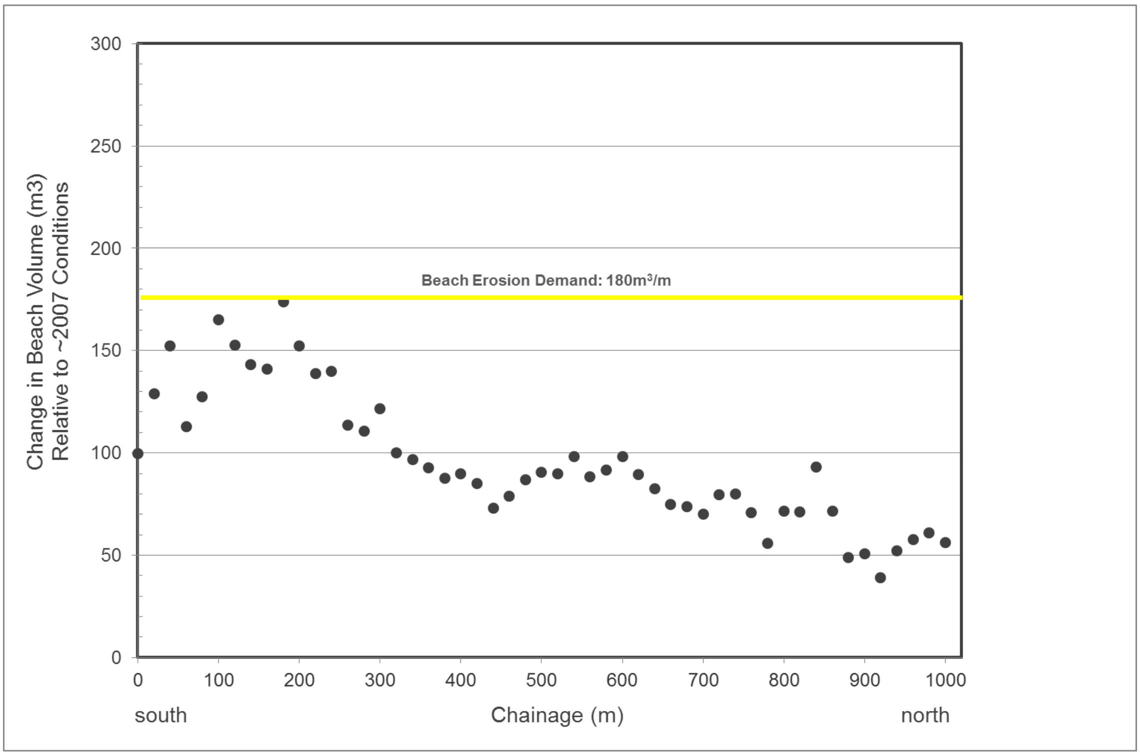


Figure 3-55 Beach Erosion Demand Volumes Relative to 2007 for Hargraves Beach

3.12.3 Recession

Historical Recession

Long term trends in beach volume and dune position were analysed for Hargraves Beach, as shown on Figure 3-56 and Figure 3-57. Table 3-41 summarises the measured volumetric trends and corresponding linear rates of shoreline movement. Separate linear rates of shoreline change estimated from dune movement are provided in Table 3-42. Both results are comparable and show Hargraves Beach to accreting. It is unclear whether this is a true long term trend or result of a favourable medium term wave climate that has promoted onshore transport of sediment from the shoreface. For the purposes of assessing future hazards, Hargraves Beach is considered to be stable as the accretion trend may not continue over the coming century as accelerating sea level rise exerts a greater influence on the shoreline behaviour.

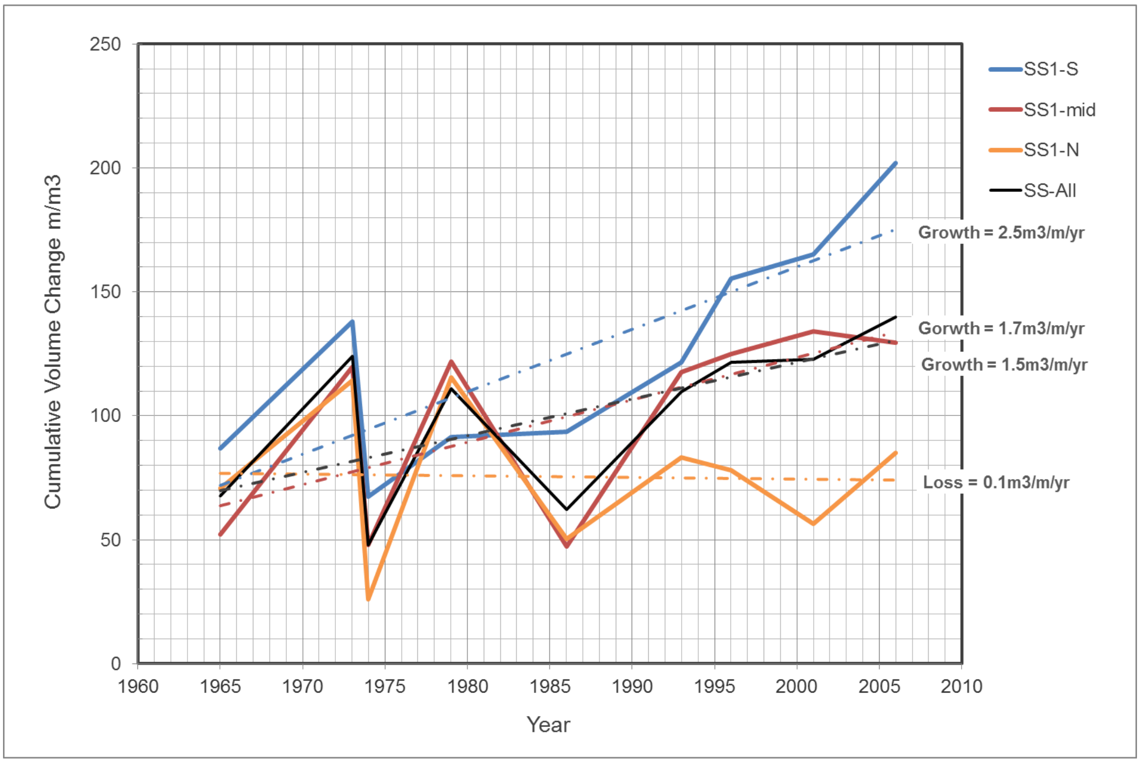


Figure 3-56 Cumulative Change in Beach Volume per metre length of Beach for Hargraves

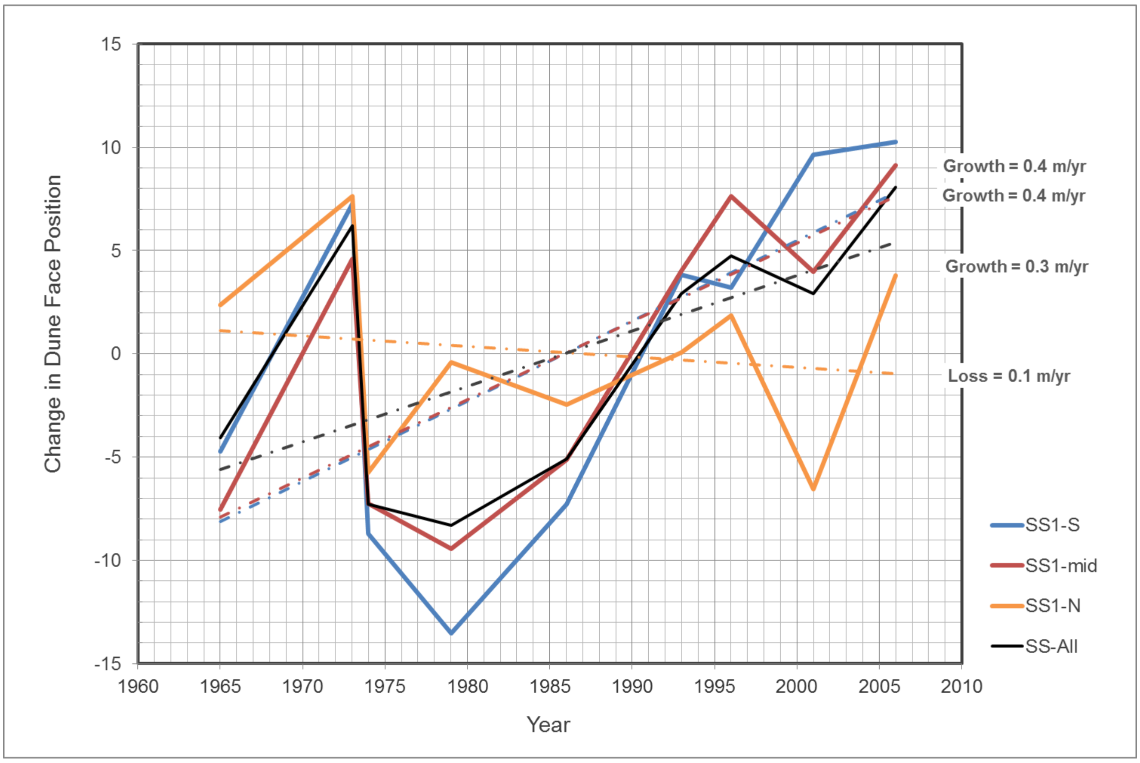


Figure 3-57 Cumulative Change in Dune Face Position for Hargraves Beach

Table 3-41 Long Term Shoreline Change for Hargraves Beach from Beach Volume Change

Net Volume Changes Recorded from the Active Beach System (m^3/m/yr)			
Hargraves Beach			
SS1-South	**SS1-middle**	**SS1-North**	**SS1 (All)**
2.5	1.7	-0.1	1.5
Adopted Dune Heights (m)			
SS1-South	**SS1-middle**	**SS1-North**	**SS1 (All)**
4.5	5.0	5.0	4.8
Historical Recession and/or Accretion Rates (m/yr)			
SS1-South	**SS1-middle**	**SS1-North**	**SS1 (All)**
0.6	0.3	0.0	0.3

Note: southern Hargraves Beach (SS1-S) comprised Block I (BI) Profile (P) 1-16; middle Hargraves Beach (SS1-mid) comprised BI P17-30 and BJ P1-8; and B3 and northern Hargraves Beach (SS1-N) comprised BJ P9-22.

Table 3-42 Long Term Shoreline Change for Hargraves Beach from Dune Movement

Historical Recession and/or Accretion Rates (m/yr)			
Hargraves Beach			
SS1-South	SS1-middle	SS1-North	SS1 (All)
0.4	0.4	-0.1	0.3

Note: southern Hargraves Beach (SS1-S) comprised Block I (BI) Profile (P) 1-16; middle Hargraves Beach (SS1-mid) comprised BI P17-30 and BJ P1-8; and B3 and northern Hargraves Beach (SS1-N) comprised BJ P9-22.

Sea Level Rise Impacts

The estimated impact of future sea level rise on Hargraves Beach is summarised in Table 3-43. The slope factors used for the Bruun Rule estimates are provided in the below table and plotted against a cross shore profile on Figure 3-58, which also shows the presence of submerged rocky reef on the shoreface.

Table 3-43 Bruun Rule and Sea Level Rise Impacts for Hargraves Beach

Beach Location	Photogram. Available? / No. Years / No. Dates	Adopted Long Term Recession			Estimated Recession from SLR		
		Adopted Rate (m/yr)	2050 Recession (m)	2100 Recession (m)	Active Slope (1:X)	2050 SLR Recession (m) [1]	2100 SLR Recession (m) [2]
Hargraves Beach	Yes / 41yrs / 9 dates	Nil	Nil	Nil	43	14	36

* **Note** all recession distances are rounded to the nearest metre; and future beach recession hazard lines for the 2050 and 2100 sea level rise scenarios are mapped from a combining historical recession and Bruun Rule sea level rise recession estimations.

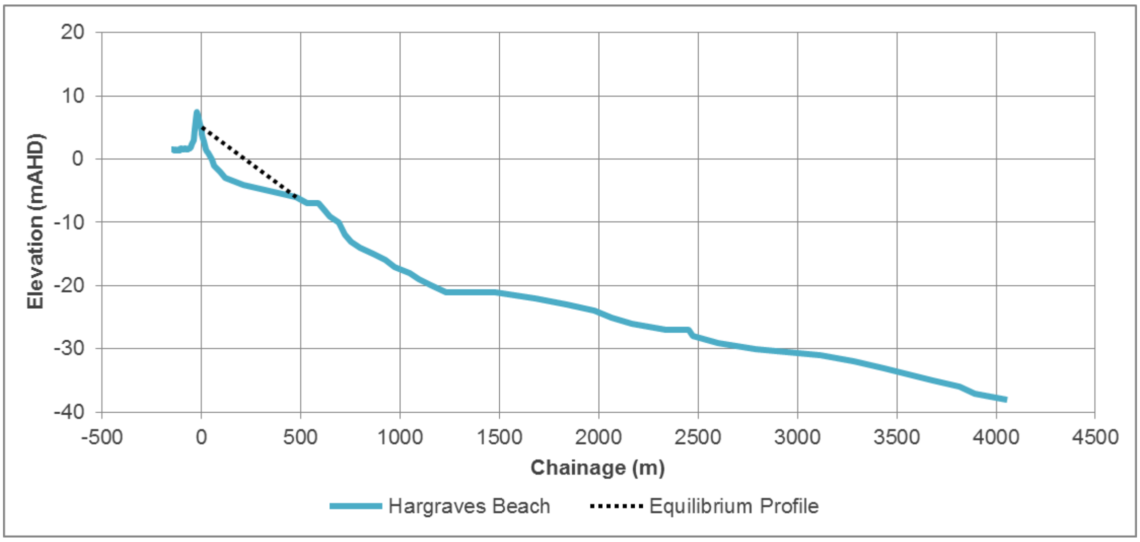


Figure 3-58 Cross Shore Profiles from Hargraves Beach, showing the Active Profile Slope

BMT WBM

3.12.4 Coastal Inundation

Coastal inundation of land adjacent to the ocean from wave action during an extreme storm event was assessed along the Hargraves Beach compartment by SMEC (2010). Under present sea level conditions, eleven locations were assessed. Extreme water levels from wave runup processes was found to range from around 5.7 to 7.1 m AHD across the compartment, with the highest level modelled across the middle to northern foreshore houses (see Table 3-44). The foreshore houses along much of Hargraves beach are fronted by low foredunes and/or incipient dunes. Many of these houses are therefore at risk from wave overtopping.

Table 3-44 Extreme Wave Runup Levels for Hargraves Beach (1% AEP water levels combined with 1% AEP wave height) calculated by SMEC (2010)

Locations (south to north)	Water Level (m)	Maximum Wave Runup (m)	2% Wave Runup (m)	Significant Wave Runup (m)	1% AEP Offshore WL (mAHD)	Max Runup Height (mAHD)
Approx. 15-17 Elizabeth Dr	1.04	3.50	3.24	2.46	1.48	**6.02**
Southern beach access	1.04	3.14	2.93	2.23	1.48	**5.66**
Approx. 37 Elizabeth Dr	1.30	3.07	2.87	2.18	1.48	**5.85**
Approx. 49 Elizabeth Dr	1.40	3.23	3.00	2.28	1.48	**6.11**
Approx. 75 Budgewoi Rd	1.21	3.84	3.53	2.68	1.48	**6.53**
Budgewoi Rd beach access	1.09	4.12	3.76	2.85	1.48	**6.69**
Approx. 113 Budgewoi Rd	1.03	4.55	3.70	2.76	1.48	**7.06**
Gomul St	0.95	4.39	3.58	2.66	1.48	**6.82**
Werepi St beach access	1.09	4.35	3.96	3.00	1.48	**6.92**
Far north end of beach	1.17	4.44	4.03	3.05	1.48	**7.09**
Approx. 15-17 Elizabeth Dr	1.04	3.50	3.24	2.46	1.48	**6.02**

3.13 Budgewoi Beach Compartment (Lakes and Budgewoi Beaches)

Budgewoi Beach compartment is a long (8 km) exposed southeast facing sandy embayment that stretches northward from the sandy foreland at Jewfish Point to a rocky headland adjacent the mouth to Birdie Lagoon. This large sandy embayment includes Lakes Beach in the far south, Budgewoi Beach (see Figure 3-59), Birdie Beach and Red Ochre Beach in the far north, with Lakes and Budgewoi Beaches included within the project study area and Birdie and Red Ochre Beach backed by Munmorah State Conservation Area.

For the purpose of defining hazards, the length of sandy shoreline within the study area has been partitioned into two geomorphological common beach segments including Lakes Beach (0 – 600 m chainage) and Budgewoi Beach (>700 m chainage). Both shorelines have varying beach and dune morphologies and exposure to waves. Lakes and Budgewoi Beaches are backed by a barrier dune that separates the ocean from Budgewoi Lake. Lakes Beach faces mostly east and experiences some protection from southerly waves from the submerged reefs fronting Hargraves Beach, as well as the protruding Norah Head. The Lakes Beach SLSC and carpark is located immediately behind the foredune. Budgewoi Beach sweeps around to face east-southeast and is more exposed to all swell directions. The Lakes to Budgewoi Beach length of sand barrier varies between 200 to +400 m in width, and comprises a narrow, high foredune (about 7 m AHD) that is backed by a low lying sand plain. Birdie and Red Orche Beaches also form a barrier dune that impounds Lake Munmorah and widens in a northward direction to greater than 1.2 km.

Figure 3-59 Budgewoi Beach Embayment looking south towards Lakes Beach

3.13.1 Beach Profile Data

Photogrammetry derived beach profiles from the years listed in Table 3-45 were analysed for Lakes Beach, which forms the far southern end the Budgewoi Beach compartment. No photogrammetry data are available for the Budgewoi Beach. As such, the erosion and historical recession assessment for Budgewoi Beach is based on interpretation of this beaches geomorphology.

Table 3-45 Summary of Beach Profile Data for Budgewoi Beach

Beach Profile Years	Comments
• 1941 • 1965/69 • 1973 • 1974 • 1985 • 1993 • 2001 • 2006 • 2008	• Beach compartment split into two photogrammetry blocks, Blocks 2 and 1 (south to north). • 1941 photogrammetry data excluded from hazards analysis, due to coarse nature of profile data and observed topographic errors. • Backbeach residential development has varied the dune topography in some placed through time. Care was taken to exclude these areas from the beach volume analysis (where possible) to ensure that volume calculations represent beach.

3.13.2 Erosion

Analysis of the beach volume photogrammetry data shows that the far southern corner of Budgewoi Beach compartment, at Lakes Beach, to fluctuate within an envelope of some 115 (SD± 50) m^3/m on average, with the greatest measured change just under 250 m^3/m recorded at Jewfish Point in the southern end of Lakes Beach (see Figure 3-60). On average, the most eroded conditions were measured in 1974, with 2006 and 1973 also notably eroded. The most accreted beach conditions were experienced in 1993 and 1985.

Analysis of the dune positon also provided insight into the erosion history for Lakes Beach. The 3 m AHD was adopted to represent the dune face at Jewfish Point (Block 2), while the 4 m AHD contour was analysed from the more swell exposed, east facing length of beach (Block 1) fronting of the SLSC. Dune movement was found to fluctuate within a 20 m envelope on average, with the maximum range of due movement recorded at nearly 30 m northward of the club house (Figure 3-61).

The erosion demand volume determined for Lakes Beach is 150 m^3/m (see Figure 3-62). This volume is based on the recorded historical beach profile data and relative to the 2007 conditions. It is noted that the Lakes Beach experiences greater protection from south to southeast swells than the remainder of the adjoining length of beach. As such the Lakes Beach photogrammetry data are not considered representative of the greater Budgewoi Beach compartment, which is exposed to ocean swell from the south, east and north sectors. The swell exposed Budgewoi Beach is therefore estimated to have an erosion demand volume of 250 m^3/m, relative to 2007 conditions, making it comparable with other swell exposed beaches in NSW and the Wyong coastline alike.

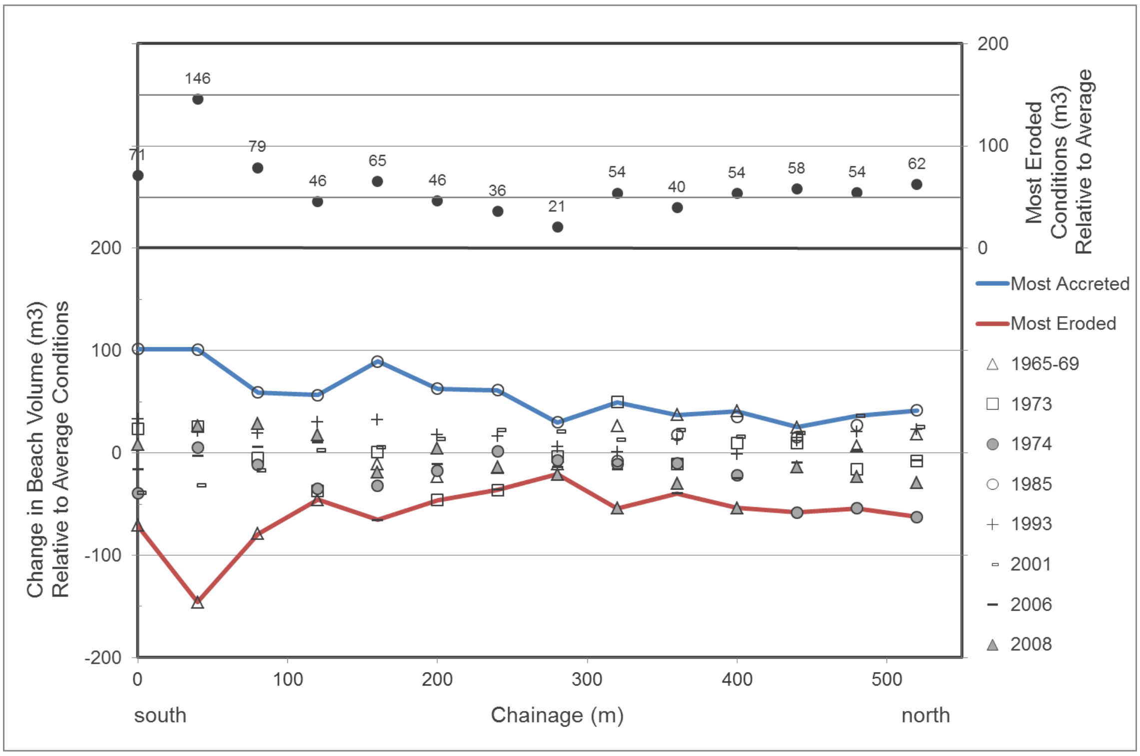


Figure 3-60 Changes in Beach Profile Volume for Lakes Beach

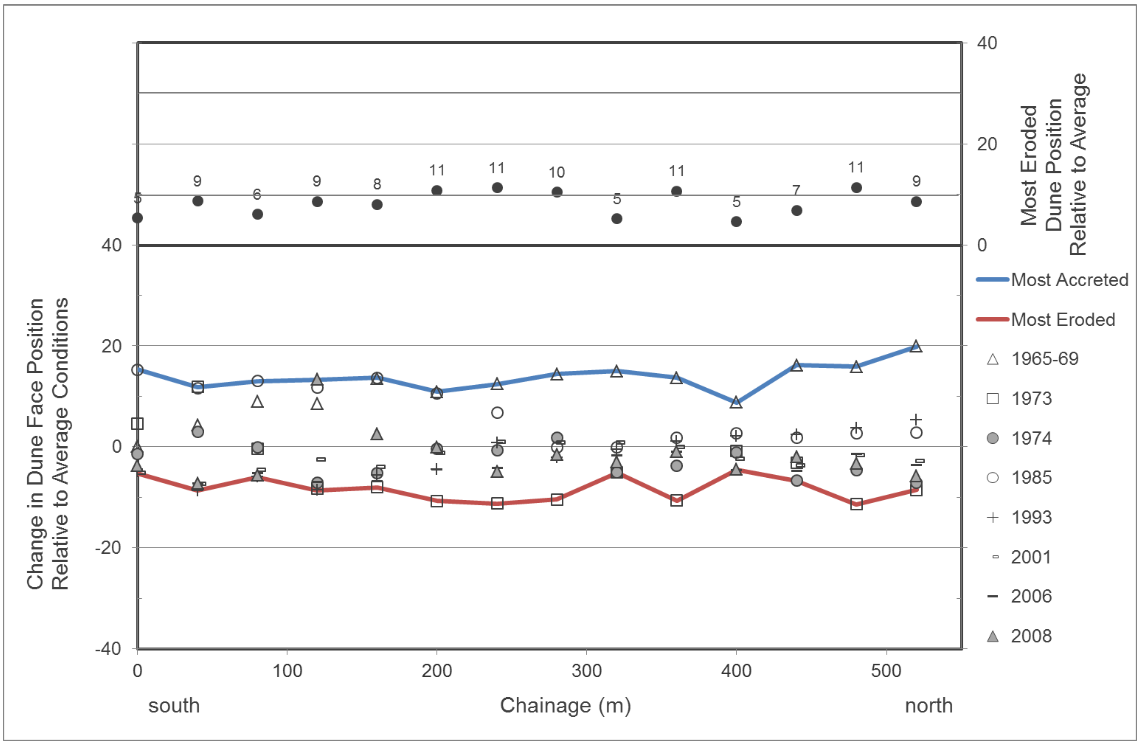


Figure 3-61 Changes in Dune Position for Lakes Beach

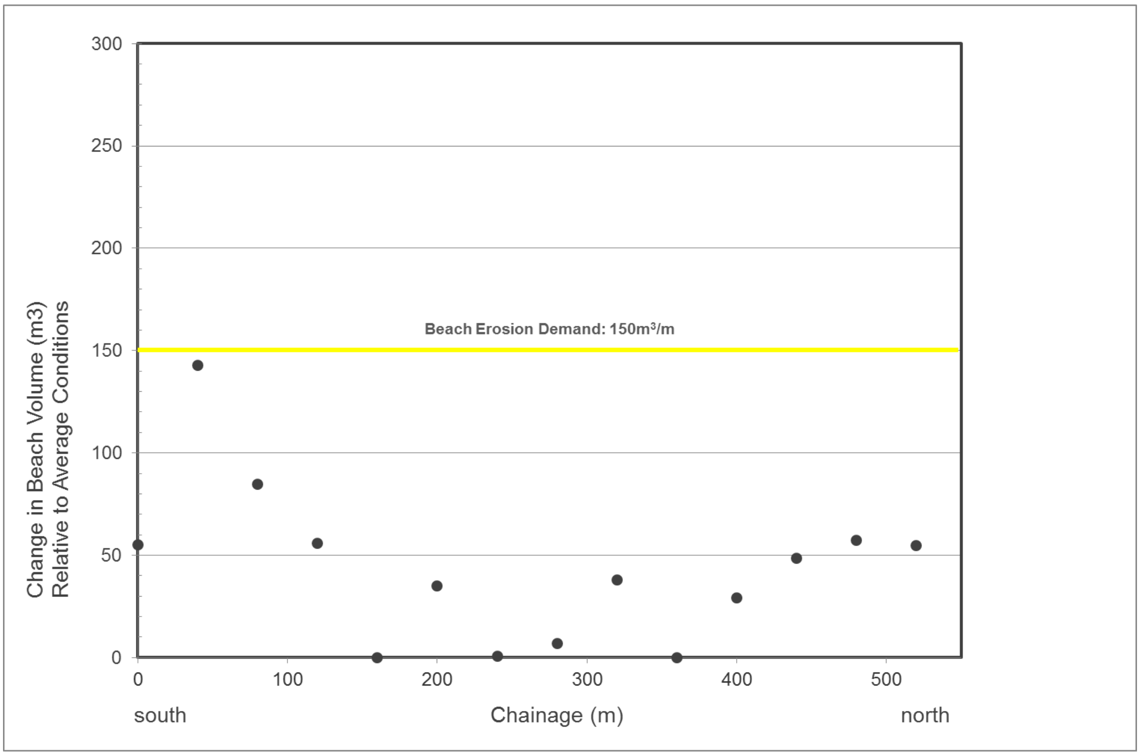


Figure 3-62 Beach Erosion Demand Volumes Relative to 2007 for Lakes Beach

3.13.3 Recession

Historical Recession

Long term trends in beach volume and dune position were analysed for Lakes Beach, as shown on Figure 3-63 and Figure 3-64. Table 3-46 converts the measured volumetric trends into linear rates of shoreline movement, while the linear rates of shoreline change determined from dune movement are provided in Table 3-47. In this instance, the converted beach volume trends show Lakes Beach to be stable while the trends in the dune face show the beach to be receding by 0.2 m/year. Based on this analysis, Lakes Beach is considered to be receding by 0.1 m/year for the purposes of assessing future hazards.

The historical recession trend for Budgewoi Beach was assessed based on interpretation of the sites geomorphology, as no photogrammetry records are available for this length of beach. Analysis of the high resolution (LiDAR) DEM for this beach section found little evidence of relic erosion escarpments in the backbeach dune topography (i.e. landward of the modern dune face / scarp). Relic dune scarps (e.g. from 1974 or 1978 storms) are often obvious in the dune topography for stable to accreting beaches, unless they have been blown out by wind erosion like at Soldiers Beach. Little to no geomorphic signature of the 1970's storm events is obvious for Budgewoi Beach. Therefore is it assumed that the beach is experiencing some historical recession. For the purpose of assessing future hazards, Budgewoi Beach is assumed to be receding by 0.1 m/year.

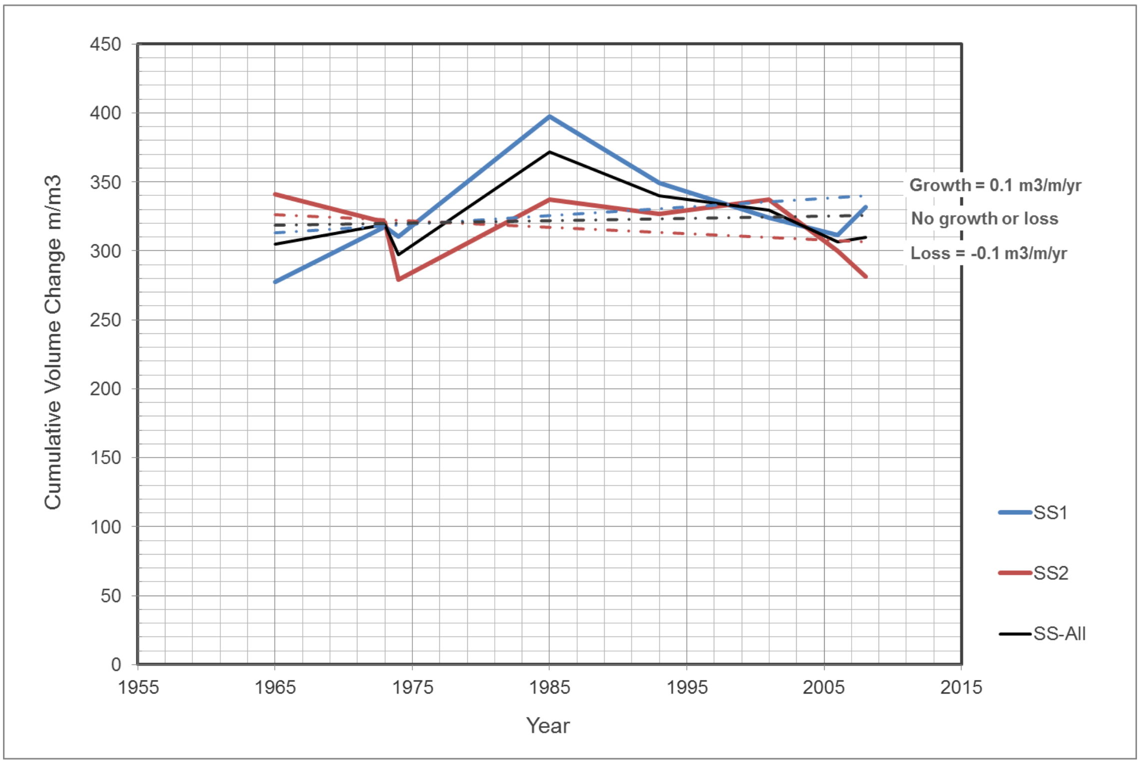


Figure 3-63 Cumulative Change in Beach Volume per metre length of Lakes Beach

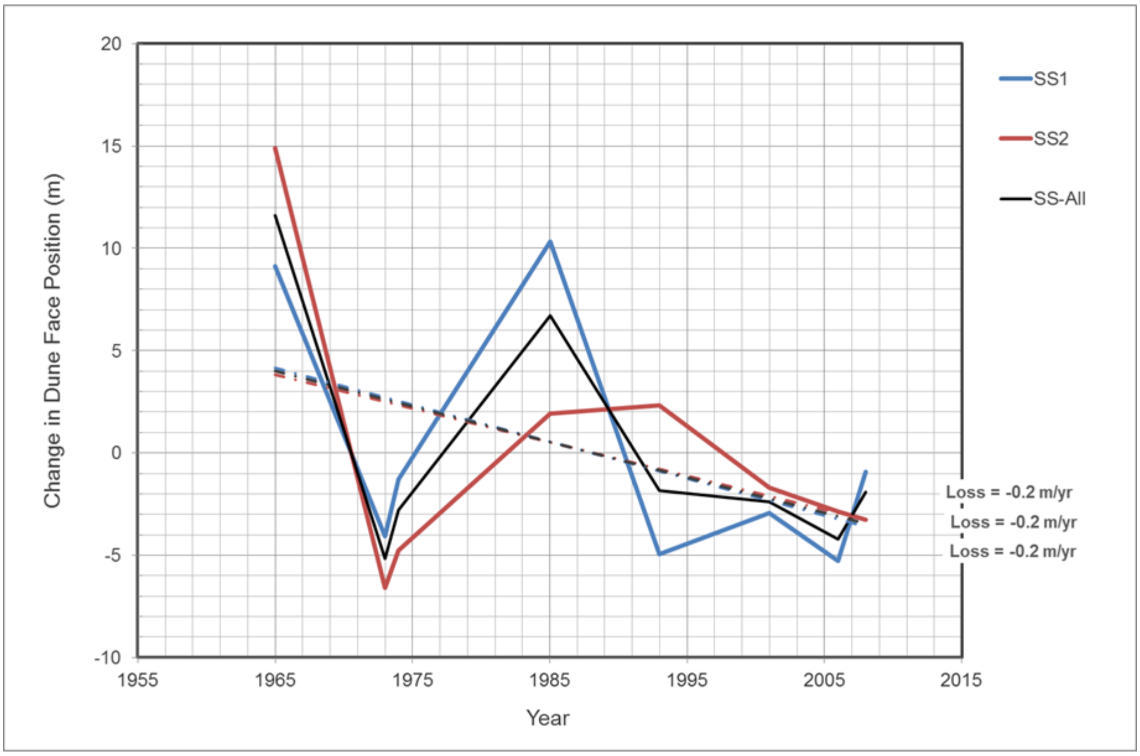


Figure 3-64 Change in Dune Face Position for Lakes Beach

Table 3-46 Long Term Shoreline Change for Lakes Beach from Beach Volume Change

Net Volume Changes Recorded from the Active Beach System (m^3/m/yr)		
Lakes Beach		
SS1-South	SS1-North	SS1-All
0.6	-0.5	0.1
Adopted Dune Heights (m)		
SS1-South	SS1-North	SS1-All
5.5	5.5	5.5
Historical Recession and/or Accretion Rates (m/yr)		
SS1-South	SS1-North	SS1-All
0.1	-0.1	0.0

Table 3-47 Long Term Shoreline Change for Lakes Beach from Dune Movement

Historical Recession and/or Accretion Rates (m/yr)		
Lakes Beach		
SS1-South	SS1-North	SS1-All
-0.2	-0.2	-0.2

Sea Level Rise Impacts

The estimated impact of future sea level rise on the Budgewoi Beach compartment is summarised in Table 3-48. The slope factors used for the Bruun Rule estimates are provided in the table below and plotted against a cross shore profiles on Figure 3-65.

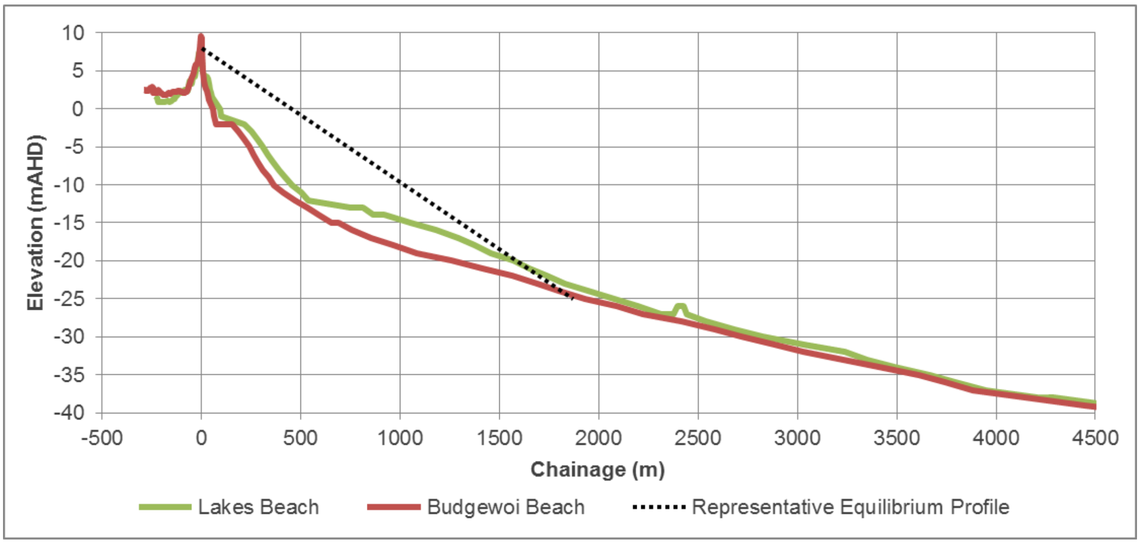


Figure 3-65 Cross Shore Profiles from the Budgewoi Beach Compartment, showing the Active Profile Slopes

Table 3-48 Bruun Rule and Sea Level Rise Impacts for the Budgewoi Beach Compartment

Beach Location	Photogram. Available? / No. Years / No. Dates	Adopted Long Term Recession			Estimated Recession from SLR		
		Adopted Rate (m/yr)	2050 Reces-sion (m)	2100 Reces sion (m)	Active Slope (1:X)	2050 SLR Reces-sion (m) [1]	2100 SLR Reces-sion (m) [2]
Budgewoi Compartment: Lakes Beach	Yes / 39 yrs / 8 dates	0.1	4	9	57	19	47
Budgewoi Compartment: Budgewoi Beach	No	0.1	4	9	56	18	46

* **Note** all recession distances are rounded to the nearest metre; and future beach recession hazard lines for the 2050 and 2100 sea level rise scenarios are mapped from a combining historical recession and Bruun Rule sea level rise recession estimations.

3.13.4 Coastal Inundation

Coastal inundation of land adjacent to the ocean from wave action during an extreme storm event was assessed at two locations along the southern end of the Budgewoi Beach Compartment by SMEC (2010). Under present sea level conditions, extreme water levels from wave runup processes were modelled at 5.2 m AHD at the Lakes Beach SLSC and 5.8 m AHD at Budgewoi Beach Dune Arm the fronts Budgewoi Lake (see Table 3-49).

Table 3-49 Extreme Wave Runup Levels at Lakes Beach (1% AEP water levels combined with 1% AEP wave height) calculated by SMEC (2010)

Location	Water Level (m)	Maximum Wave Runup (m)	2% Wave Runup (m)	Significant Wave Runup (m)	1% AEP Offshore WL (mAHD)	Max Runup Height (mAHD)
Lakes Beach SLSC	0.95	2.77	2.61	1.99	1.48	**5.20**
Budgewoi Beach Dune Arm	0.93	3.45	3.20	2.43	1.48	**5.86**

3.14 Comparison with Preceding SMEC (2010) and SCE (2010) Hazard Studies

The following provides a comparative assessment between the assessment approach and outcomes of this hazard review of the Wyong coastline and the preceding coastal hazard and geotechnical studies by SMEC (2010) and SCE (2010). Differences identified between the current and earlier studies are discussed for the following aspects:

- Study site coverage;
- Assessment approach;
- Hazard assessment outcomes; and
- Hazard mapping.

3.14.1 Site Coverage

The current study re-assessed hazards defined in Section 2.1, for the entire study area, spanning from the southern LGA boundary at Yumbool Point to the Munmorah State Conservation Reserve at Budgewoi Beach. Beach erosion related hazards were assessed for all lengths of sandy shoreline and cliff and slope instability related coastal hazard were assessed for all lengths of bedrock shoreline. A combined assessment of beach erosion and geotechnical hazards was undertaken for segments of geologically complex shoreline that comprised both sandy and rocky substrates within the active coastal zone. As part of the current assessment, individual coastal locations were not assessed in isolation, but rather consideration was made to how the hazard transitions between adjacent beaches, and between the sandy and rocky substrates.

In contrast, to the integrated assessment undertaken for this study, the preceding hazard studies were completed in a manner whereby the coastal hazard assessment and geotechnical hazard assessments were undertaken in isolation to one another. For these studies, the Wyong coastline was partitioned into lengths assessed for either coastal hazards *or* geotechnical hazards. This approach does not allow for the interactions of processes and hazard that occur between the sandy and rocky section of coastline to be assessed, as was evident in the final hazard mapping. The combined coastal and geotechnical hazard mapping included in the Umwelt (2011a) WCZMP 2011 contained a number of inconsistencies and gaps. For example, coastal hazard lines were not produced for areas identified as “Combined Bluff, Beach and Dune Zones” and no transitional mapping was produced, to sensibly align the coastal and geotechnical hazard mapping at the ends of the beaches. In addition, the coastal hazard lines were disjointed between adjacent beaches in some instances (e.g. Hargraves and Lakes beaches) and were not produced for some lengths of beach (e.g. Budgewoi Beach).

3.14.2 Assessment Approach

Coastal Hazards

The re-assessment of coastal hazards undertaken for this study applied a slightly different approach to that applied by SMEC (2010), with the aim of providing further consideration to the site geomorphology, coastal geology and site geomorphic history. The differences in assessment approach is summarised as follows:

- *Photogrammetry Assessment:* the photogrammetry data were processed and analysed for geomorphologically common segments of beach for this study, as opposed to assessing each photogrammetry block on an individual basis as undertaken in SMEC (2010). As a result, the photogrammetry derived beach erosion and historical recession estimates for this study are specific to geomorphologcally related beach sections. Care was also taken in this study to exclude non-oceanic influences to beach change (e.g. mining, dune blowout activity, urban development and stormwater).
- *Beach Erosion Hazard:* an assessment of the beach envelope was applied to determine an erosion demand volume, which represents the most eroded beach position relative to present day beach conditions. The SMEC (2010) study applied a storm bite assessment to assess the erosion hazard, which attempted to match photogrammetry dates with known storms. This approach does not consider the medium term wave climate variability, for example, which can produce heavily eroded beach states.
- *Dune Instability Hazards (ZRFC):* this study recognised that rocky reefs and rocky platforms are a common feature of Wyong's beaches, and where present this substrate extends landward beneath the beaches and dunes. Where present, this erosion resistant substrate was incorporated into the zone of reduced foundation capacity calculations, to ensure the geotechnical zones of dune instability were not over estimated. It is understood that the SMEC (2010) assessment assumed that the beach and dunes profiles comprised unconsolidated sands only for their assessment of dune instability.
- *Historical Recession:* Both the current study and preceding study utilised the available photogrammetry datasets to analyse long term trends in beach volume and dune position, to determine if historical recession was occurring for Wyong's beaches.
- *Future Recession Assuming No Sea Level Rise:* as per Councils defined scope of work, the current study has assessed future shoreline recession hazards based on Council interim sea level policy, which assumes no further sea level rise. This Council policy was not in place when SMEC (2010) completed their hazard study and therefore this extremely unlikely future scenario was not assessed in the preceding study.
- *Climate Change Impacts:* the Bruun Rule was applied to estimate the impact of future sea level rise on Wyong's beaches for both the current study and the previous assessment. High resolution marine LiDAR bathymetry was available for the entire coastline at the time of this assessment. The coverage of sand bodies extending offshore of some beaches, and the presence of submerged rocky reefs can be easily identified from this dataset. The Bruun Rule slope factors used for this study were estimated from this high resolution bathymetry data (in combination with high resolution topography data). It is understood that a range of methods

were applied by SMEC (2010) to determine the Bruun Rule slopes factor, and that the nearshore profiles assessed in their study was based on limited offshore bathymetric data.

- *Cemented/Indurated Sand Bluff Erosion and Recession Hazards:* The current study assessed and mapped coastal hazards for the tall sand bluff shoreline at Bateau Bay and Cabbage Tree Bay through application of the beach erosion and shoreline recession methods applied to the modern sandy beaches of this study site, albeit with some minor modifications. While some qualitative assessment on coastal hazard was completed for Bateau Bay and Cabbage Tree Harbour, this was not translated into hazard mapping. Cliff recession hazard mapping was produced for the parts of Cabbage Tree Bay sand bluff in SCE (2010), based on bluff recession methodology defined in that study.

- *Geological Controls on Coastal Hazards:* the current study mapped the bedrock limits to coastal erosion where present at the ends of each beach compartment and at the back of beaches in some instances. This mapping was used to highlight the alongshore and backshore extents of potentially erodible sandy (beach and dune) substrate material. The assessment and mapping of coastal hazards was subsequently undertaken to encompass all foreshore areas composed of potentially erodible materials. No such assessment of beach substrate extents was completed by SMEC (2010), as is evident in their coastal hazard mapping. This is apparent for the coastal hazard lines that abruptly finish at the ends of bedrock embayed beaches, which typically extend into areas of bedrock substrate or finish part way along the beach.

Geotechnical Hazards

A comparison of the approaches undertaken to assess geotechnical hazards between the current study and preceding SCE (2010) study is detailed in Coastal Geotechnical Study by JK Geotechnics (see Appendix A). It is noted that the method applied by SCE (2010) was suitable in light of there being no standard methodology available to map cliff recession lines (like that which exists for coastal hazards). However, this study considers elements of the SCE (2010) approach to be somewhat conservative. A summary differences between assessment approached is provided herein:

- *Cliff Recession Rates:* the current assessment found the bedrock cliff recession rates proposed by SCE (2010) to be inconsistent with field observations and relevant data published elsewhere. Recession rates where therefore approximated for the current study based on comparable published data from the Sydney region and rocky shore platform width. It is understood that bedrock recession rates were determined in SCE (2010) through an assessment of historical plans and more recent aerial and satellite imagery, although it is not clear whether those recession rates relate to the cliff toe or crest.

- *Cliff Recession Mapping:* both the current and previous studies projected cliff recession lines based on cliff face recession controlled by rock joint spacing and joint set dip angles, and soil slope adjustments controlled by bedrock levels and internal friction angle. Unlike the SCE (2010) approach, the current assessment did not apply any factor of safety to the rock joint spacing, joint set dip angles and soil friction angles. SCE (2010) also mapped an ‘immediate’ and ‘low’ hazard line for each timeframe assessed, whereas the current study mapped a single line only per timeframe.

- *Transitional Mapping:* The current study has undertaken mapping between join the coastal hazard and cliff recession hazard mapping in a geologically sensible manner. The transitional mapping occurs at the boundary between sandy and rocky substrates, and is based on the assumption that rocky substrate currently buried beneath beach and dune substrates will not be exposed to cliff line recession hazard unless it is exposed to wave action. The beach erosion and shoreline recession hazard mapping was utilised to estimate the timeframes which the buried cliff lines become exposed to cliff recession hazards. No assessment of hazards within the transitional zone between sandy and rocky substrates was undertaken by SMEC (2010) and/or SCE (2010).

3.14.3 Hazard Assessment Outcomes

Coastal Hazards

Some changes were evident in hazard assessment outcomes resulting from the varied approaches applied to this study and the earlier studies. A summary table highlighting the difference in hazard outcomes for erosion, historical recession and sea level rise is provided in Table 3-50. This shows that the majority of beaches were determined to have a comparable beach erosion hazards between the two studies. This current study however determined a reduced beach hazard level for Blue Lagoon, North Entrance Beach and Lakes Beach. Unlike SMEC (2010), the current assessment of Blue Lagoon was contained at beach sections protected by rocky reef which is why the beach erosion hazard volume is lower. At North Entrance, the larger erosion hazard determined by SMEC (2010) is based on storm bite volumes obtained from the Entrance Spit and towards Pelican Beach. This study argues that North Entrance Beach has different coastal morphologies, beach change histories and shoreline aspects to that experienced near the channel entrance and at Pelican Beach. Therefore the current erosion hazard estimate for North Entrance is based on the reduced beach volume envelope measured for this section of beach.

A larger erosion hazard was determined for Lakes Beach from the previous study. The large storm bite volume adopted by SMEC (2010) was obtained from a single photogrammetry profile that was not repeated in the current assessment of beach volume change, noting that care was applied to exclude the influences of non-oceanic processes from the analysis of photogrammetry data (e.g. sand mining, blow out activity, urban development). In fact, SMEC (2010) reports the high storm demand volume value may be indicative of dune blow out activity.

The current assessment found the erosion hazard to be larger for Magenta to Pelican Beach than stated in SMEC (2010). This is due to the differences in beach erosion hazard methods applied to both studies, noting the current study assessed the entire envelope of beach change while SMEC (2010) analysed the impact of discrete storm events only.

The assessment of historical recession undertaken for this study was found to be mostly comparable to analysis presented in SMEC (2010).

The assessment of sea level rise impacts for the current study resulted in typically larger recession estimations, as a result of more shallow equilibrium profiles being approximated from the high resolution bathymetry available to this study. It is noted however that the Bruun Rule slope factors determined for this re-assessment lie within the typical range identified elsewhere for the NSW coastline.

The dune instability (ZRFC) hazards calculations were reduced for locations where the beach was determined to be underlain by rocky substrate. No consideration for subsurface strata was made in the SMEC (2010) study. Table 2-1 demonstrates the influence of bedrock substrate on limiting dune instability widths.

Geotechnical Hazards

The current assessment of geotechnical hazards built on the existing cliff recession work undertaken by SCE (2010), which is considered to be overly conservative in some aspects. Refinements to some elements of the geotechnical mapping of the cliff recession geohazard lines were subsequently made for this study. A comparison between the mapping approach applied to the current study, with that originally formulated by SCE (2010) is provided in Table 3-51.

In addition to the cliff recession hazard mapping, a number of geotechnical hazard zones were identified and mapped. The majority of these zones were originally identified by SCE (2010).

Table 3-50 Summary and Comparative Assessment of Coastal Hazard Results

Beach Location[1]	This Study			SMEC (2010) Study		
	Erosion Demand (m^3/m)	Adopted Historical Recession (m/yr)	Bruun Rule Slope Factor (1:X) [2]	Storm Bite (m^3/m)	Adopted Historical Recession (m/yr)	Bruun Rule Slope Factor (1:X)
Bateau Bay	160	Nil	46 / 29	(100 – 200)	*Not assessed*	(20)
Blue Lagoon	50	Nil	34	200	Nil	35
Shelly Beach	290	Nil	39	250	Nil	47 - 37
Toowoon Bay	75	0.1*	35	50	0.1	13
Blue Bay	115	0.1*	34	140 - 110 - 100	0.1	11
South Entrance	*Backbeach rocky slope*	N/A	N/A	N/A	Nil	N/A
Entrance Spit	*Spit breach*	N/A	N/A	250	Nil	30
North Entrance	170	0.2	44	250	0.1 - 0.5 - 0.2 - Nil	29 - 45 - 31 - 35
Magenta to Pelican	310	Nil	37	250 - 150	Nil – 0.1	35 - 39 - 37 - 45
Soldiers Beach	150	Nil	42	100 - 130 - 160 - 200	Nil – 0.2	29 - 32 - 44 - 39
Pebbly Beach	150*	Nil*	46	(250)	*Not assessed*	(10)
Cabbage Tree Bay / Lighthouse Beach	75*	0.3*	30	(50 - 100)	*Not assessed*	(10)
Jenny Dixon Beach	*Backing cliff*	N/A	N/A	N/A	N/A	N/A
Hargraves Beach	180	Nil	43	180 - 190	Nil – 0.05	25 - 16
Lakes Beach	150	0.1	57	250	0.5	72
Budgewoi Beach	250*	0.1*	56	*Not stated*	*Not stated*	29
KEY: This Study	Decreased Hazard (< x0.8)	Comparable Hazard	Increased Hazard (> x1.2)	**KEY: SMEC (2010) Study**	Entire Beach Not Mapped	Part of Beach Not Mapped

[1] The beach location listed in the above table are consistent with the geomorphologically related beach sections identified in this current study, which in some instances do not align neatly with the way in which SMEC (2010) partitioned the coastline for their earlier assessment.

2 Bruun Rule slope factors are a key factor determining sea level rise recession estimations. A larger Bruun Rule slope factor produces a greater sea level rise recession estimates compared to a smaller Bruun Rule slope factor.

Note: Adopted beach erosion demand volumes and historical recession rates for this study are denoted with an asterisk (*). These hazard parameters are based on results obtained from geomorphologically related beaches in Wyong.

Proposed storm bite volumes and Bruun Rule slope factors in SMEC (2010) are highlighted in parenthesis ().

Table 3-51 Summary and Comparative Assessment of Cliff Recession Hazard Parameters and Hazard Lines Methods

	This Study (JK, 2016)	SCE (2010) Study
Rock Type	**Joint Spacing**	
Patonga Claystone	2 m	2 m
Tuggerah Formation	4 m	4 m
Munmorah Conglomerate	4 m	4 m
Rock Type	**Recession Rate (m/yr)**	
Patonga Claystone	0.04	0.10 – 0.15
Tuggerah Formation	0.03	0.04 – 0.08 [0.10 – 0.16]*
Munmorah Conglomerate	0.03	*Not stated*
Rock Type	**Jointing Dip Angle / Friction Angle (θ)**	
Patonga Claystone	70°	35 - 45°
Tuggerah Formation	70°	70° - 45°
Munmorah Conglomerate	70°	70° - 45°
Soil Type	**Soil Friction Angle (Φ)**	
Surface Soils	30°	32°
Residual Soils	45°	*Not assessed*
	Hazard Mapping Parameters	
No. Recession Lines/Timeframe	1	2 (high and low hazard)
Factor of Safety (FoS)	*Not applied*	Applied (1.2 – 2.0)
Block Topple	One joint spacing	One joint spacing (x1 – x3)
Cliff Face Adjustment	Project θ upwards and landwards to top rock surface	Project θ upwards and landwards to top rock surface(s) Apply FoS for Patonga Claystone
Soil Slope Adjustment	*For surface soils:* Project Φ upwards and landwards until intersect with surface *For residual soils:* Apply 2 m soil slope adjustment	*For surface and residual soils:* Project Φ upwards and landwards until intersect with surface Apply FoS.

Note: SCE (2010) provide two cliff recession rates for Tuggerah Formation cliffs. The recession rates denoted with an asterisk (*) is specific to Tuggerah Formation rocks intruded with igneous dykes.

4 Summary of Results

4.1 Coastal Processes and Hazards

Regional Geology and Geomorphology

The Wyong coastline stretching northward of Yumbool and Crackneck Points towards Budgewoi Beach comprises a diverse range of sandy and rocky shoreline types, including wide open coast beaches, semi exposed coastal embayment's, a coastal entrance to major estuary system, complex sand dune systems that include old Pleistocene-age dunes and modern Holocene-age sand dunes, rocky cliffs and bluffs and numerous offshore rocky reefs. Geologically, this coastline has formed within sandstones, shales and conglomerates of the Sydney Basin, which have been eroded into valleys and hills that are now flooded by current sea levels.

From a regional perspective, the Wyong coastline faces southeast and is exposed to the dominant southeast wave climate of the Sydney to Newcastle region. The occurrence of protruding headlands, rocky reefs and coastal embayment's on a local scale result in locally variable wave climate along the shoreline.

The Wyong coastline includes two long barrier beach systems, namely the Tuggerah Beach compartment in the south and the Budgewoi Beach compartment in the north. Together, these beaches and intervening headland area impound Tuggerah Lakes, a major coastal estuary system comprised of three large interconnected coastal lakes. Both sweeping beaches face predominantly southeast and are mostly exposed to a high energy wave climate. Norah Head forms another regionally significant coastal landform, comprising a prominent rocky headland that protrudes eastward of the surrounding coastline. It is expected this bedrock headland forms a sediment compartment boundary that limits the transport of sediment along the shoreface (over planning timeframes). On its northern side lays Cabbage Tree Harbour, a natural curving harbour that faces northeast and experiences significant shelter from south-easterly directed swells. This harbour is also starved of sediment. Together, Tuggerah Lakes and associated beach embayment, and Norah Head are two major coastal landforms which play a significant role on the form and processes occurring across the Wyong coastline.

Nearshore and Offshore Environment

Large extents of submerged rocky reef extend offshore to depths of greater than 20 m from the coastal headlands at Crackneck Point, The Entrance and Norah Head. The high resolution (marine LiDAR) bathymetry indicate that three main sediment bodies are positioned between these submarine rocky outcrops, including two major sand bodies attached to Tuggerah Beach and Budgewoi Beach, and a third moderately sized sand body adjoined to Shelly Beach. No sediment transport is expected to occur between the Tuggerah and Budgewoi sand bodies. Small sediment bodies also occur at Bateau Bay, Toowoon and Blue Bays, Soldiers Beach, Pebbly Beach, Cabbage Tree Harbour and Jenny Dixon Beach, which are considered to be either isolated or ‘leaky’. The large (greater than 2 km) extent of rocky reef and headland extending south from Bateau Bay towards Forrester’s Beach indicates that no significant supply of sediment is sourced from downcoast.

Onshore Area: Beaches and Dunes

A diverse array of sand dunes occur within Wyong's coastal zone, including: foredune systems that fringe most beaches; two major barrier dune systems that together impound Tuggerah Lakes Estuary; numerous transgressive, blowout and clifftop dunes; as well as relic (Pleistocene-age) dune remnants located at Bateau Bay, Blue Lagoon and Cabbage Tree Harbour. Large coastal dunefields occur at Shelly Beach, Tuggerah Beach compartment, Soldiers Beach, Pebbly Beach and Budgewoi Beach compartment, of which many have active dune blowouts. Transgressive and dune blowout activity is much less now than naturally occurred in the early to middle 20th century as a result of post sand-mining and contemporary dune stabilisation works. A number of active dunefields are still present at Shelly, North Entrance and Soldiers beaches, for example, with a number of these active dune features arguably adding to the aesthetic character of the diverse study area.

Most well-formed dune systems situated north of North Entrance Beach have been subject to heavy mineral mining that took place throughout the 1960's and 1970's. Remediation works associated with the Rutile mining resulted in major reshaping the natural dune topography (e.g. Pelican Beach) as well as the introduction of invasive dune stabilising vegetation (e.g. Budgewoi Beach). Wyong's coastal dunes have also been subject to intense foreshore development at Blue Lagoon, Toowoon and Blue Bays, North Entrance Beach, Cabbage Tree Harbour and Hargraves Beach, noting that all these locations with the exception of Blue Lagoon are identified as coastal erosion 'hot spots'.

Sediment Transport, Coastal Erosion and Shoreline Recession

The presence of the rocky reefs and associated headlands on Wyong's coastline control both the orientation of the beaches, and the swell protection, refraction and dissipation that occurs for a range of offshore swell directions. The response of Wyong's beaches to extreme storm events and stormy periods have been recorded in photogrammetry beach profile data for a number of beaches. Analysis completed for this study shows the envelope of beach change varies greatly depending on beach orientation and exposure. Beaches fronted by shallowly submerged rocky reefs were found to be significantly protected from stormy activity, with erosion demand volumes of 75 and 115 m^3/m determined for Blue Lagoon and Toowoon Bay respectively.

Southeast to east facing beaches that experience some protection from protruding headlands and reefs, such as Bateau Bay, Soldiers Beach, Hargraves Beach and Lakes Beach were found to have a moderate erosion hazard, with erosion demand volumes between 150 and 180 m^3/m. The wide open coast lengths of shoreline at Shelly Beach and between Magenta Shores to Pelican Beach were found to have the greatest exposure to erosion from this region, with erosion demands reaching volumes in excess of 300 m^3/m. Both these beaches are fully exposed to dominant southeast wave climate.

Analysis of available photogrammetry data shows that the majority of Wyong's beaches are predominately stable. However superimposed on the short to medium term fluctuations that occur at all beaches, some sandy shorelines appear to be actively accreting while others are subject to progressive shoreline recession. For example, analysis undertaken for this study found North Entrance Beach to be receding at approximately 0.2 m/year. While the cause of this trend is not definitively understood, it may be in response to sediment loss associated with dune blow out activity and/or human intervention within the estuary entrance interrupting the natural sediment cycle for coastal compartment. It is generally considered that no significant net longshore transport of sediment occurs within the Central Coast region; however, an imbalance in alongshore sediment supply cannot be ruled out as a possible cause for the recession occurring at North Entrance Beach. Especially so considering the significant and long term accretion noted towards the middle and northern extents of the Tuggerah Beach embayment.

Lakes Beach, located in the far southern end of the Budgewoi Beach embayment, is also found to be receding with a recession rate measured at 0.1 m/year. While no photogrammetry records are available north of Lakes Beach, a near continuous 20 – 40 m wide dunefield has accreted seaward of a prominent relic (circa 1970's) erosion escarpment preserved in a tall barrier style dune along the northern half of this embayment. This varying south to north dune morphology of the Budgewoi Beach compartment has parallels with the Tuggerah Beach compartment, i.e. both southern ends are generally eroded while the middle reaches and northern ends are notably accreted. In addition, the barrier width significantly increases to the north of both beach compartments (from about 0.5 to 2 km at Tuggerah and about 0.3 to 1.2 km at Budgewoi beach embayments), indicating a net northward transport of sediment over geological timescales. More work is however required to determine if the above observations are the result of a long term coastal processes that continue today, or rather a medium term (inter-decadal) response varying wave climate.

Cabbage Tree Harbour is another receding beach, with a measured recession rate of 0.3 m/year presented in SCE (2010). This low energy shoreline is backed by a tall indurated sand bluff that has a long history of landslide activity. Local slumping of the bluff face is reported to occur from periods of increased groundwater flows and/or as a result of wave erosion of the toe slopes. Unlike modern beach-dune systems, the relic sand bluff behaves as 'one-way' erodible 'soft rock' shoreline which cannot naturally recover once eroded (hence a 'one-way' shoreline). Furthermore, the harbour beach is located within a sediment starved embayment positioned in the far southern corner of 'Newcastle Coast' sediment compartment (secondary level compartment) (GA, 2013). Longshore transport of sediments that occurs from the south to southeast wave climate cannot bypass Norah Head, which forms a major controlling feature on the coastal processes and sediment movement. Therefore Cabbage Tree Harbour does not receive a longshore supply of northward migrating sediments.

Relic Pleistocene-age dunes in the form of indurated and cemented sandy bluffs also occur at Bateau Bay and Blue Lagoon. Unlike Cabbage Tree Harbour, the sand bluffs at Bateau Bay and Blue Lagoon are protected by modern beach-dune systems that experience accretion and recovery after erosion and therefore do not behave as a 'one-way' shoreline. These two coastal slopes are however susceptible to geotechnical instability mechanisms of non-coastal origin, like Cabbage Tree Harbour.

Coastal Cliffs, Bluffs and Geotechnical Hazards

Recession of the rocky cliff faces along Wyong's coast is considered to occur primarily due to preferential weathering of sedimentary layers occurring at the cliff toe slopes, which subsequently causes the overlying sandstone blocks to topple. The sandstone blocks become detached along joint and bedding planes that are controlled by the parent geology. The primary coastal bedrock units occurring across Wyong's coastline include Patonga Claystone, Tuggerah Formation, Munmorah Conglomerate, with 2 m joint spacing occurring in the former rock unit and 4 m joint spacing occurring in the later. In addition to the joint controlled cliff face recession, it is considered that the soil profiles that overlie the bedrock substrate will also experience some readjustment in response to cliff recession.

In addition to cliff recession, there are some coastal areas susceptible to landslide and soil erosion activity. While these zones of geotechnical hazard occur within the coastal zone, the underlying geotechnical instability processes are typically not coastal related (e.g. landslide activity, soil erosion). A geotechnical hazard zone occurring at Cabbage Tree Harbour is one exception to the above rule, where the well documented landslip hazard is driven by a range of complex processes which includes toe erosion from wave action.

Coastal Inundation Hazard

The wave runup levels determined by SMEC (2010) along the Wyong coastline were generally around 6-7 m AHD, with a maximum value of 8.1m AHD at North Entrance. SMEC (2010) identified a number of areas that could be exposed to coastal inundation from wave runup SMEC (2010), which include:

- the caravan park at Blue Lagoon;
- the caravan park at Toowoon Bay;
- some low lying houses along the southern half of Blue Bay;
- the surf club, boat shed and swimming pool at South Entrance;
- several houses along Curtis Parade at North Entrance;
- most foreshore houses along Hargraves Beach.

In many instances, the calculated wave runup levels exceeded the local crest elevations (dune, coastal structure etc.) indicating that overtopping could occur if the calculated runup levels were experienced. The locations that SMEC (2010) identified to be at risk of wave overtopping include Blue Lagoon caravan park, the southern end of Blue Bay, at swimming pool at South Entrance, along Curtis Parade at North Entrance and along Hargraves Beach.

4.2 Summary of Coastal Hazards Results

The Wyong coastline is affected by a range of coastal hazards that will become potentially more acute or far-reaching with future climate change induced sea level rise, specifically in relation to beach hazards. The key coastal hazards include:

- the erosion hazard, including components of immediate storm erosion and future shoreline recession;
- dunes zones of reduced foundation capacity;
- coastal cliff and slope instability; and
- coastal inundation associated with wave run-up and overtopping of a dune barrier or foreshore structure.

Beach erosion, shoreline recession, cliff instability and dune instability hazards have been remapped by BMT WBM as part of this hazard study review. An assessment of geotechnical instability hazards were also completed for this study. In addition to these individual hazard elements, the geological boundaries between sandy and rocky coastal substrates were mapped as part of this study, which enabled transitional hazard mapping between beach/dune and cliff/bluff areas. Coastal inundation from wave runup was previously and adequately mapped by SMEC (2010) and was therefore not remapped for this current study. The SMEC (2010) wave runup mapping has also been reproduced within this report.

Table 4-1 presents a summary of the beach related coastal hazards findings, Table 4-2 summaries key elements of the geotechnical hazards occurring within Wyong's coast and Table 4-3 presents the elevated water and wave runup levels determined by SMEC (2010). Coastal hazard mapping is presented in Chapter 5.

Table 4-1 Summary Table for Beach Erosion Hazards

Beach Location	Beach Length (km)	Beach Orien-tation	Beach Descrip-tors[1]	Photogram. Available? / No. Years / No. Dates[2]	Erosion Demand (m^3/m)[3]	Historical Recession			Recession from SLR		
						Adop-ted Rate (m/yr)[4]	2050 Reces-sion (m)[5]	2100 Reces-sion (m)[5]	Meas-ured Beach Slope	2050 SLR Reces-sion (m)[6]	2100 SLR Reces-sion (m)[6]
Bateau Bay *(bluff recession 2050 onwards)*	0.5	SE	SP, H, R	Yes / 46yrs / 6 dates	160	Nil	Nil	Nil	46 / 29	15	29
Blue Lagoon (Shelly Beach Compartment)	0.5	E	P, R	Yes / 54yrs / 8 dates	50	Nil	Nil	Nil	34	11	28
Shelly Beach (Shelly Beach Compartment)	2.0	SE	O	Yes / 54yrs / 8 dates	290	Nil	Nil	Nil	39	13	32
Toowoon Bay	0.7	E	P, ~B, R, T	Yes / 35yrs / 9 dates	75	0.1*	4	9	35	11	28
Blue Bay	0.4	ESE	SP, R, T, C	Yes / 35yrs / 9 dates	115	0.1*	4	9	34	11	28
South Entrance Beach	0.4	E	SP, B, R, E	Yes / 54yrs / 9 dates	*Backing revetment*	N/A	N/A	N/A	N/A	N/A	N/A
The Entrance Spit (Tuggerah Compartment)	0.6	ESE	SP, R, E	Yes / 54yrs / 10 dates	*Spit breach*	N/A	N/A	N/A	N/A	N/A	N/A
North Entrance (Tuggerah Compartment)	2.8	ESE - SE	O	Yes / 54yrs / 10 dates	170	0.2	7	17	44	14	36
Magenta to Pelican (Tuggerah Compartment)	4.8	SE - SSE	O, ~H, ~T	Yes / 52yrs / 9 dates	310	Nil	Nil	Nil	37	12	30
Soldiers Beach	1.0	SE	SP, H	Yes / 43yrs / 9 dates	150	Nil	Nil	Nil	42	14	35
Pebbly Beach	0.4	SE	SP, B, H	No	150*	Nil	Nil	Nil	46	15	38
Cabbage Tree Bay	0.3	NE	P, H, R	No	75*	0.3	11	26	30	10	24

Beach Location	Beach	Beach	Beach	Photogram.	Erosion	Historical Recession			Recession from SLR		
Jenny Dixon Beach	0.3	ESE	SP, B, ~H, R	No	*Backing cliff*	N/A	N/A	N/A	N/A	N/A	N/A
Hargraves Beach	1.1	E	SP, ~B, ~H, R	Yes / 41yrs / 9 dates	180	Nil	Nil	Nil	43	14	36
Lakes Beach (Budgewoi Compartment)	1.0	ENE - E	SP, ~R, T	Yes / 39yrs / 8 dates	150	0.1	4	9	57	19	47
Budgewoi Beach (Budgewoi Compartment)	2.2	E - ESE	O	No	250*	0.1*	4	9	56	18	46

[1] **Beach Descriptors**: (O) open beach; (SP) semi protected beach, (P) protected beach, (B) bedrock backed beach (H) protruding headland & rocky platforms, (R) nearshore reefs present, (T) tombolo or salient present, (E) lake entrance present (C) minor creek present.
[2] **Photogrammetry** refers to beach profile information used for this hazard review which includes LiDAR topography data for some beaches.
[3] **Erosion Demand** values relative to ~2007 conditions, as discussed in Section 2.3.2. Volumes denoted with an asterisk (*) have been adopted from geomorphological comparable beaches.
[4] **Adopted Historical Recession Rates** are based on photogrammetry analysis of beach volume and dune movement, coupled with a geomorphic appraisal of long term beach behaviour, as discussed in Section 2.4.1
[5] **Future Recession Estimates** (i.e. 2050, 2100) based on historical shoreline behaviour (i.e. adopted historical recession rates) are rounded to the nearest metre. These estimations are made relative to 2015. Recession estimation will not be realised where bedrock in encountered in the immediate backbeach environment
[6] **Sea Level Rise (SLR) Recession Estimations** are based on Councils previous benchmarks of 0.4 m by 2050 and 0.9 m by 2100, relative to 1990, and estimated based on the Brunn Rule calculations (only). These estimates have assumed a sea level rise of 3 mm/year rise between 1990 and present, as recommended by DECCW (2009b). Again, recession distances are rounded to the nearest metre. Recession estimation will not be realised where bedrock in encountered in the immediate backbeach environment
Note that future beach recession hazard lines mapped for the 2050 and 2100 sea level rise scenarios are based on a combination of historical recession estimates and Brunn Rule estimations, rounded to the nearest metre.

Table 4-2 Summary Table for Coastal Cliff and Slope Hazards

Cliff / Bluff Location	Coastal Morphology	Geology	Cliff Recession Mechanism	Recession Rate	Adopted Recession Angle	Other Slope Instability Hazards
Crackneck Point and surrounds	Tall bedrock headland with cliffs and slopes, fringed by an often wide rocky platform	Terrigal Formation, **Patonga Claystone**, Tuggerah Formation *(2 m joint spacing; 70° jointing angle)*	Block failure and slope adjustment	1 joint spacing (2 m) per planning horizon timeframe	70° for bedrock 45° for surficial colluvial soil profile	Slopes also susceptible to non-coastal geotechnical (landslip/soil creep) hazards
Bateau Bay coastal slopes	Tall indurated sand bluff (relic coastal cliff) fronted by modern beach and dune sands	**Indurated / Cemented Sands**	Slope adjustment in response to wave attack of toe slopes, when exposed	As per Bruun Rule estimates of recession due to SLR	35° for indurated sands; Sand slump as per Nielsen *et al* (1992) Zone of Slope Adjustment Schema	Slopes also susceptible to non-coastal geotechnical (landslip/soil creep) hazards
Unnamed headland, between Bateau Bay and Blue Lagoon	Bedrock headland with steep cliffs and fringed by a wide rocky platform	**Patonga Claystone**, Tuggerah Formation *(2 m joint spacing; 70° jointing angle)*	Block failure and slope adjustment	1 joint spacing (2 m) per planning horizon timeframe	70° for bedrock 30° for soil profile	None
Blue Lagoon coastal slopes	Indurated sand bluff (relic coastal cliff) protected by modern beach and dune sands	**Indurated / Cemented Sands**	*Coastal erosion unlikely in 100 year planning timeframe*			Slopes susceptible to non-coastal geotechnical (landslip/soil creep) hazards
Little Bay coastal slopes	Bedrock cliffs and rocky platform with a perched sandy beach	**Patonga Claystone**, Tuggerah Formation *(2 m joint spacing; 70° jointing angle)*	Block failure and slope adjustment	1 joint spacing (2 m) per planning horizon timeframe	70° for bedrock 30° for soil profile	None
Toowoon and Blue Bays coastal slopes	Localised bedrock cliff at Toowoon Bay and more widespread relic coastal slopes protected by beach and dunes	**Patonga Claystone**, Tuggerah Formation *(2 m joint spacing; 70° jointing angle)* (+/- highly weathered bedrock and colluvium in relic coastal slopes)	Block failure and slope adjustment (for active cliffs at Toowoon Bay only)	1 joint spacing (2 m) per planning horizon timeframe	70° for bedrock 30° for soil profile	Some slopes also susceptible to non-coastal geotechnical (landslip/soil creep) hazards

Cliff / Bluff Location	Coastal Morphology	Geology	Cliff Recession Mechanism	Recession Rate	Adopted Recession Angle	Other Slope Instability Hazards
The Entrance coastal slopes	Bedrock headland with cliffs and slopes, and fringed by rocky platform with a perched sandy beach at South Entrance	**Patonga Claystone**, Tuggerah Formation *(2 m joint spacing; 70° jointing angle)*	Block failure and slope adjustment	1 joint spacing (2 m) per planning horizon timeframe	70° for bedrock 30° for soil profile	None
Soldiers Point	Low bedrock headland with cliffs, fringed by a wide rocky shore platform	**Munmorah Conglomerate** *(4 m joint spacing; 70° jointing angle)*	Block failure and slope adjustment	1 joint spacing (4 m) per planning horizon timeframe	70° for bedrock 45° for surficial colluvial soil profile	None
Pebbly Beach	Bedrock slopes fronted by modern beach and dune sands	**Munmorah Conglomerate** *(4 m joint spacing; 70° jointing angle)*	Block failure and slope adjustment	1 joint spacing (4 m) per planning horizon timeframe	70° for bedrock 30° for deep sandy soil profile 45° for surficial colluvial soil profile	Some cliff-top sand dunes may be susceptible to slope instability
Norah Head	Protruding bedrock headland with cliffs and slopes, fringed by rocky shore platform with a perched sandy beach (Lighthouse Beach)	**Tuggerah Formation**, (+/- igneous dykes) Munmorah Conglomerate *(4 m joint spacing; 70° jointing angle)*	Block failure and slope adjustment	1 joint spacing (4 m) per planning horizon timeframe	70° for bedrock 45° for surficial colluvial soil profile	None
Cabbage Tree Harbour	Exposed tall indurated sand bluff	Indurated / Cemented Sands	Slope adjustment in response to wave attack of toe slopes, when exposed	Historical recession of 0.3 m/year *plus* Bruun Rule estimates of SLR recession	30° for indurated sands Sand bluff slumps as per Nielsen *et al.* (1992) Zone of Slope Adjustment scheme	Slopes also susceptible to non-coastal geotechnical (landslip) hazards
Jenny Dixon Beach coastal cliffs and slopes	Bedrock cliffs and slopes, backing a perched sandy beach (Jenny Dixon Beach)	**Tuggerah Formation**, (+/- igneous dykes) *(4 m joint spacing; 70° jointing angle)*	Block failure and slope adjustment	1 joint spacing (4 m) per planning horizon timeframe	70° for bedrock 45° for surficial colluvial soil profile	Some slopes also susceptible to non-coastal geotechnical (landslip/soil creep) hazards

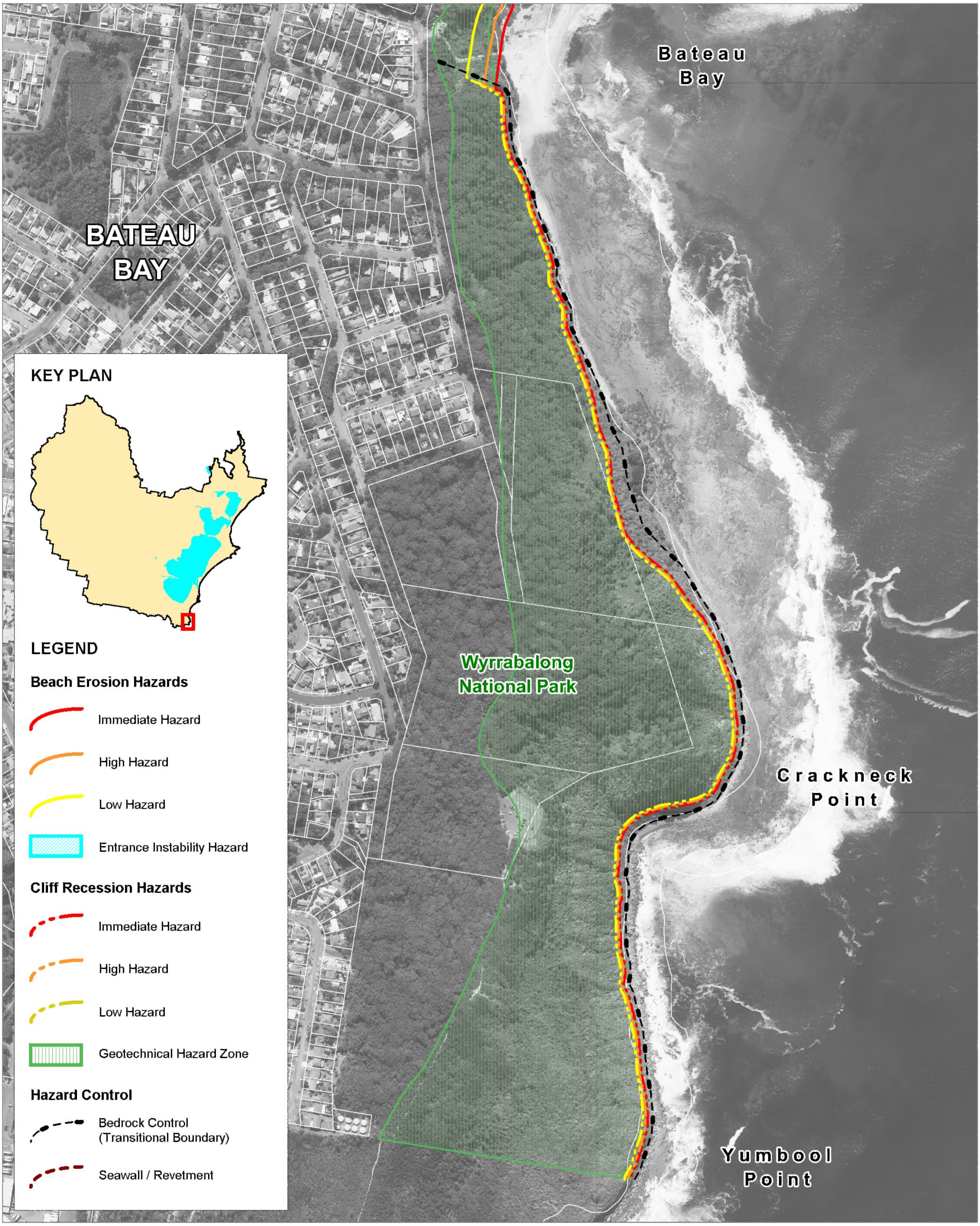
Table 4-3 Extreme Wave Runup Levels for Wyong (1% AEP water levels combined with 1% AEP wave height) calculated by SMEC (2010)

Beach	Location	Water Level (m)	Maximum Wave Runup (m)	2% Wave Runup (m)	Significant Wave Runup (m)	1% AEP Offshore WL (mAHD)	Max Runup Height (mAHD)
Shelly Compartment	Blue Lagoon Resort - south end	1.21	4.62	4.18	3.17	1.48	**7.31**
Shelly Compartment	Blue Lagoon Resort - north end	0.99	4.35	3.96	3.00	1.48	**6.82**
Shelly Compartment	Shelly Beach SLSC	1.01	4.44	3.96	3.00	1.48	**6.93**
Shelly Compartment	North carpark beach access	1.05	4.27	3.89	2.95	1.48	**6.80**
Shelly Compartment	Far northern corner of beach	1.05	4.19	3.82	2.90	1.48	**6.72**
Toowoon Bay	Toowoon Bay SLSC car park	1.11	2.96	2.77	2.11	1.48	**5.55**
Toowoon Bay	Middle section of Toowoon Bay (~Kims Beachside Retreat)	1.20	2.92	2.74	2.09	1.48	**5.60**
Toowoon Bay	Between Toowoon Bay Rd and Beenbah Ave	1.18	3.03	2.84	2.16	1.48	**5.69**
Toowoon Bay	Far northern end of Toowoon Bay	1.14	3.07	2.87	2.18	1.48	**5.69**
Blue Bay	Southern Blue Bay	1.19	3.84	3.53	2.68	1.48	**6.51**
South Entrance	South Entrance SLSC	1.32	3.56	3.29	2.50	1.48	**6.36**
South Entrance	Boatshed	1.17	3.78	3.48	2.64	1.48	**6.43**
Tuggerah Comp't	The Entrance Spit (Karagi Reserve beach access)	1.17	3.78	3.48	2.64	1.48	**6.43**
Tuggerah Compartment	~Hargraves St beach access	0.96	3.72	3.43	2.60	1.48	**6.16**
Tuggerah Compartment	North Entrance SLSC	1.27	3.97	3.64	2.76	1.48	**6.72**
Tuggerah Compartment	Florida St beach access	1.11	4.62	4.18	3.17	1.48	**7.21**
Tuggerah Compartment	~Coogee Ave	1.16	4.93	4.44	3.36	1.48	**7.57**
Tuggerah Compartment	Curtis Pde - middle	1.19	5.43	4.86	3.67	1.48	**8.10**
Tuggerah Compartment	Tuggerah Compartment Chainage ~2.8km (from S)	1.19	5.43	4.86	3.67	1.48	**8.10**
Tuggerah Compartment	Magenta Shores - south end	1.15	5.17	4.64	3.51	1.48	**7.80**
Tuggerah Compartment	Magenta Shores - middle	1.23	5.43	4.86	3.67	1.48	**8.14**
Tuggerah Compartment	Magenta Shores - north end	1.21	5.17	4.64	3.51	1.48	**7.86**
Tuggerah Compartment	Pelican Beach, south of carpark	1.15	5.17	4.64	3.51	1.48	**7.80**
Tuggerah Compartment	Pelican Beach - north corner	1.07	4.19	3.82	2.90	1.48	**6.74**
Tuggerah Compartment	Pelican Beach - north corner	1.06	1.69	1.45	1.09	4.48	**7.23**
Soldiers Beach	Soldiers Beach - far south end Beach	1.06	4.19	3.82	2.90	1.48	**6.73**

Beach	Location	Water Level (m)	Maximum Wave Runup (m)	2% Wave Runup (m)	Significant Wave Runup (m)	1% AEP Offshore WL (mAHD)	Max Runup Height (mAHD)
Soldiers Beach	Soldiers Beach - south end of beach	1.15	4.12	3.76	2.85	1.48	**6.75**
Soldiers Beach	Middle section of Soldiers Beach	1.17	4.27	3.89	2.95	1.48	**6.92**
Soldiers Beach	Soldiers Beach SLSC	1.22	4.44	4.03	3.05	1.48	**7.14**
Lakes Beach	Lakes Beach SLSC	0.95	2.77	2.61	1.99	1.48	**5.20**
Hargraves Beach	Approx. 15-17 Elizabeth Dr	1.04	3.50	3.24	2.46	1.48	**6.02**
Hargraves Beach	Southern beach access	1.04	3.14	2.93	2.23	1.48	**5.66**
Hargraves Beach	Approx. 37 Elizabeth Dr	1.30	3.07	2.87	2.18	1.48	**5.85**
Hargraves Beach	Approx. 49 Elizabeth Dr	1.40	3.23	3.00	2.28	1.48	**6.11**
Hargraves Beach	Approx. 75 Budgewoi Rd	1.21	3.84	3.53	2.68	1.48	**6.53**
Hargraves Beach	Budgewoi Rd beach access	1.09	4.12	3.76	2.85	1.48	**6.69**
Hargraves Beach	Approx. 113 Budgewoi Rd	1.03	4.55	3.70	2.76	1.48	**7.06**
Hargraves Beach	Gomul St	0.95	4.39	3.58	2.66	1.48	**6.82**
Hargraves Beach	Werepi St beach access	1.09	4.35	3.96	3.00	1.48	**6.92**
Hargraves Beach	Far north end of beach	1.17	4.44	4.03	3.05	1.48	**7.09**
Budgewoi Beach	Dune Arm	0.93	3.45	3.20	2.43	1.48	**5.86**

5 Hazard Mapping

5.1 Combined Coastal and Geotechnical Hazard Mapping with Sea Level Rise, for Current and Future Timeframes



Title:

Coastal and Geotechnical Hazard Definition Sea Level Rise Scenario - Crackneck

Figure: **A-01**

Rev: **A**

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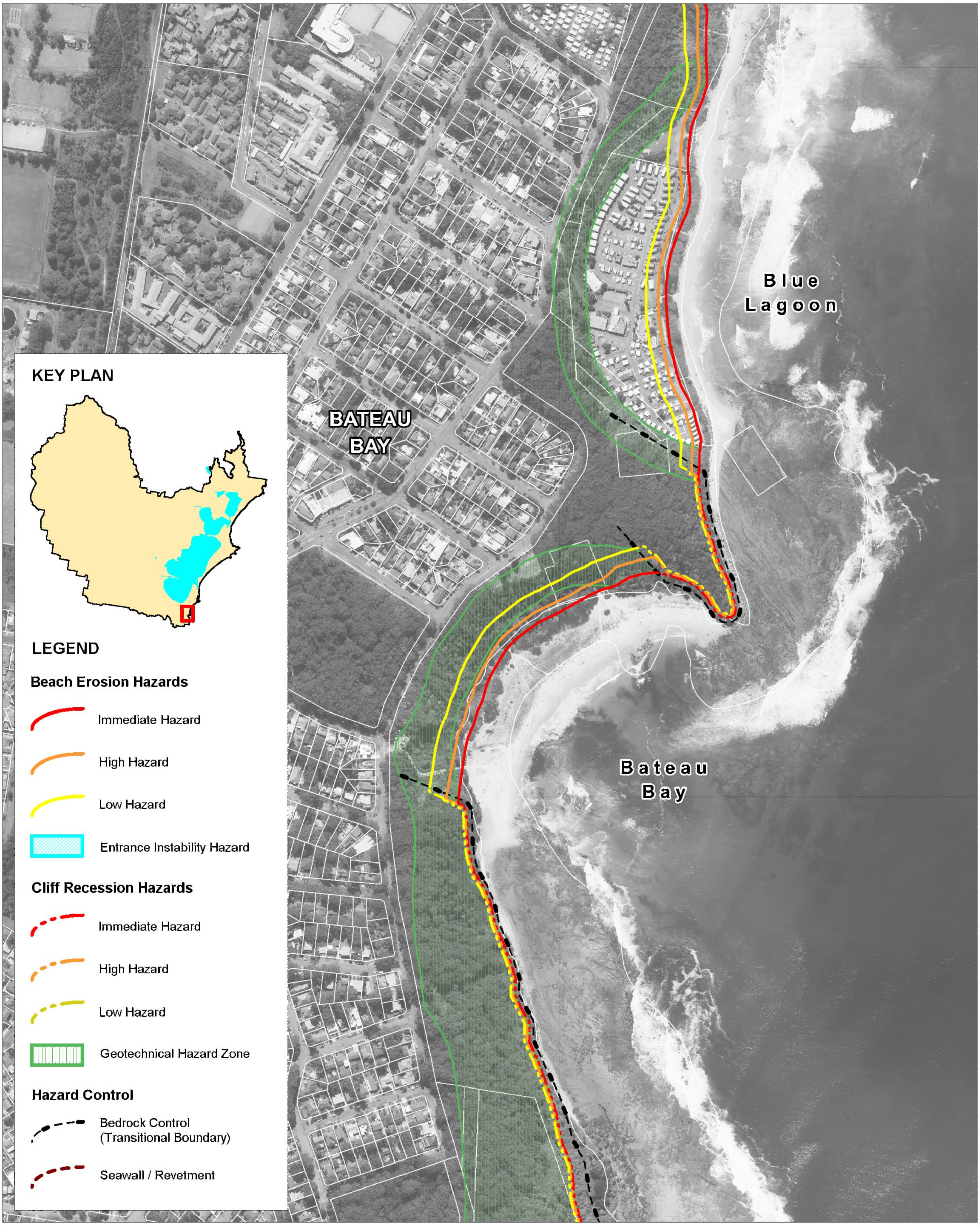

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Rev: **A**

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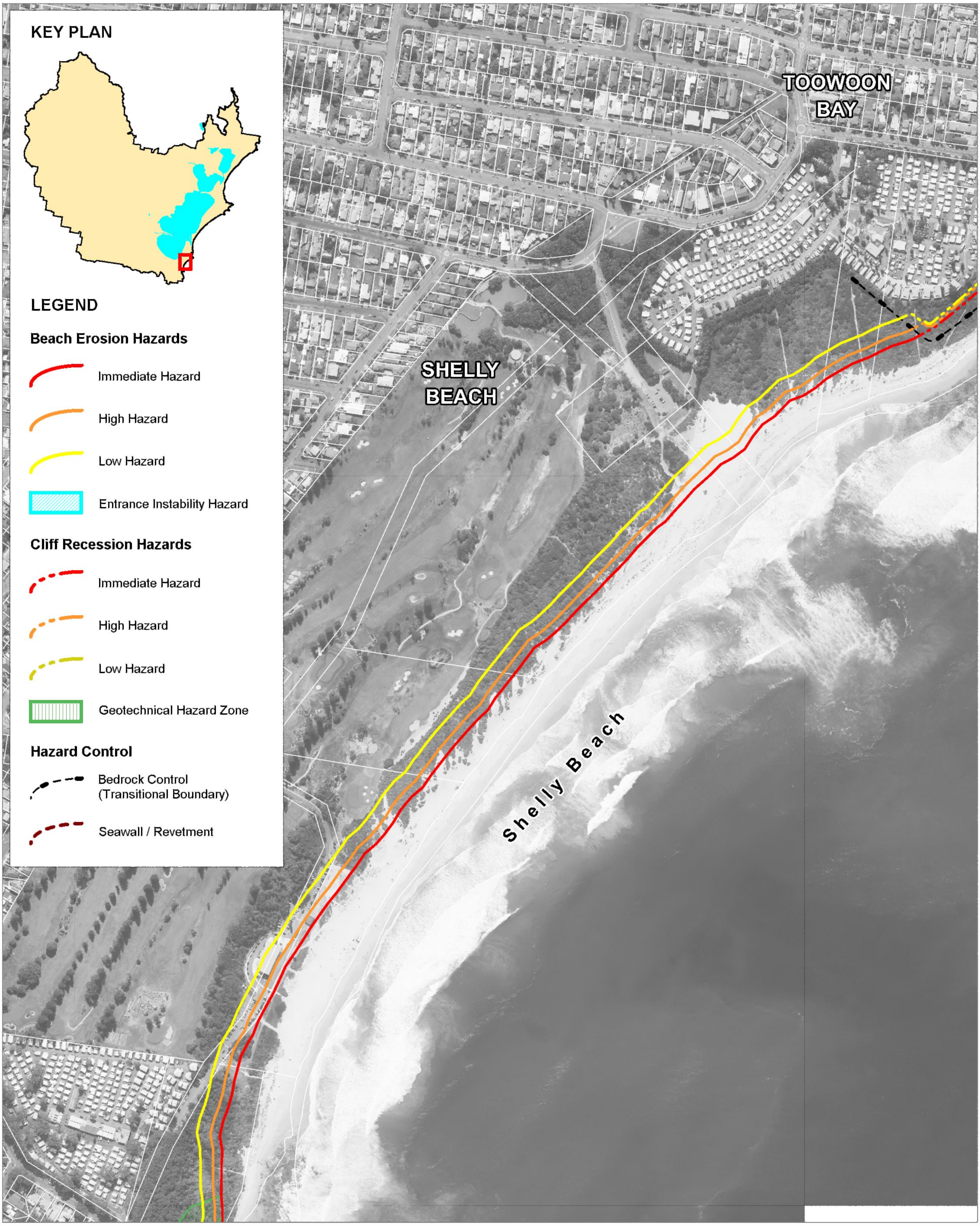

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Coastal and Geotechnical Hazard Definition
Sea Level Rise Scenario - Shelly Beach

Figure: A-03

Rev: A

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Approx. Scale

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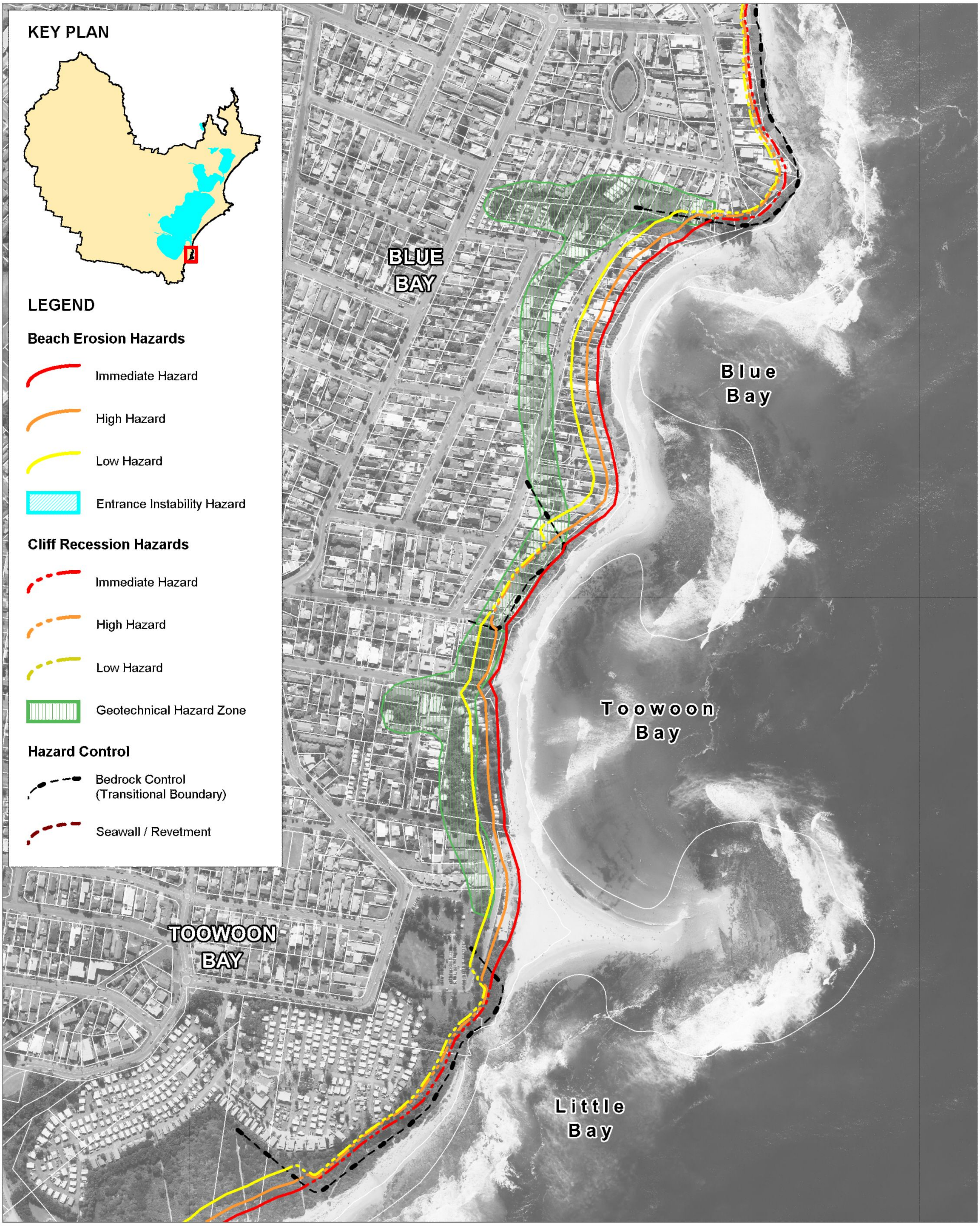

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Coastal and Geotechnical Hazard Definition
Sea Level Rise Scenario - Toowoon and Blue Bay

Figure: **A-04**

Rev: **A**

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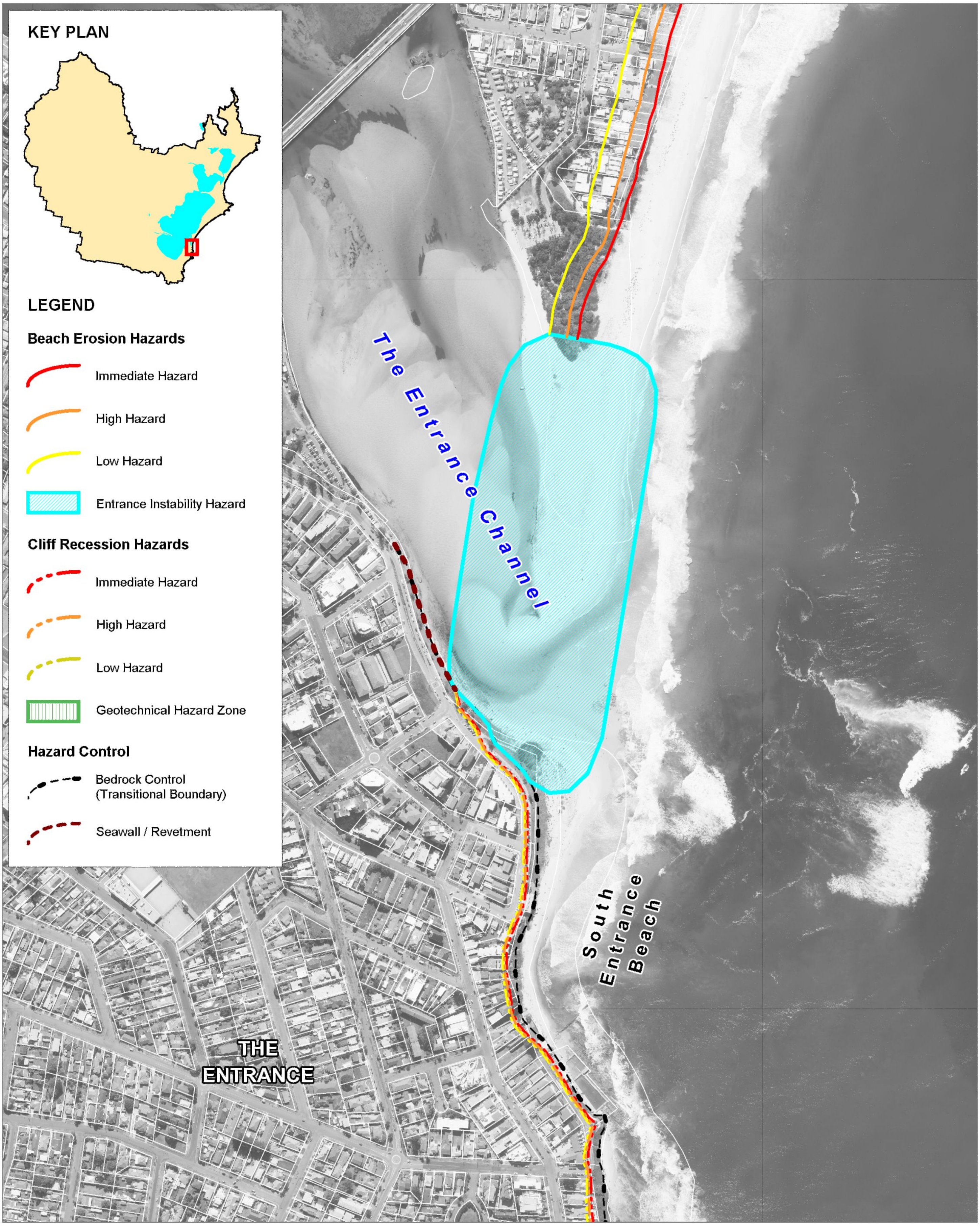

Title:

Coastal and Geotechnical Hazard Definition Sea Level Rise Scenario - The Entrance

Figure: A-05

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Approx. Scale

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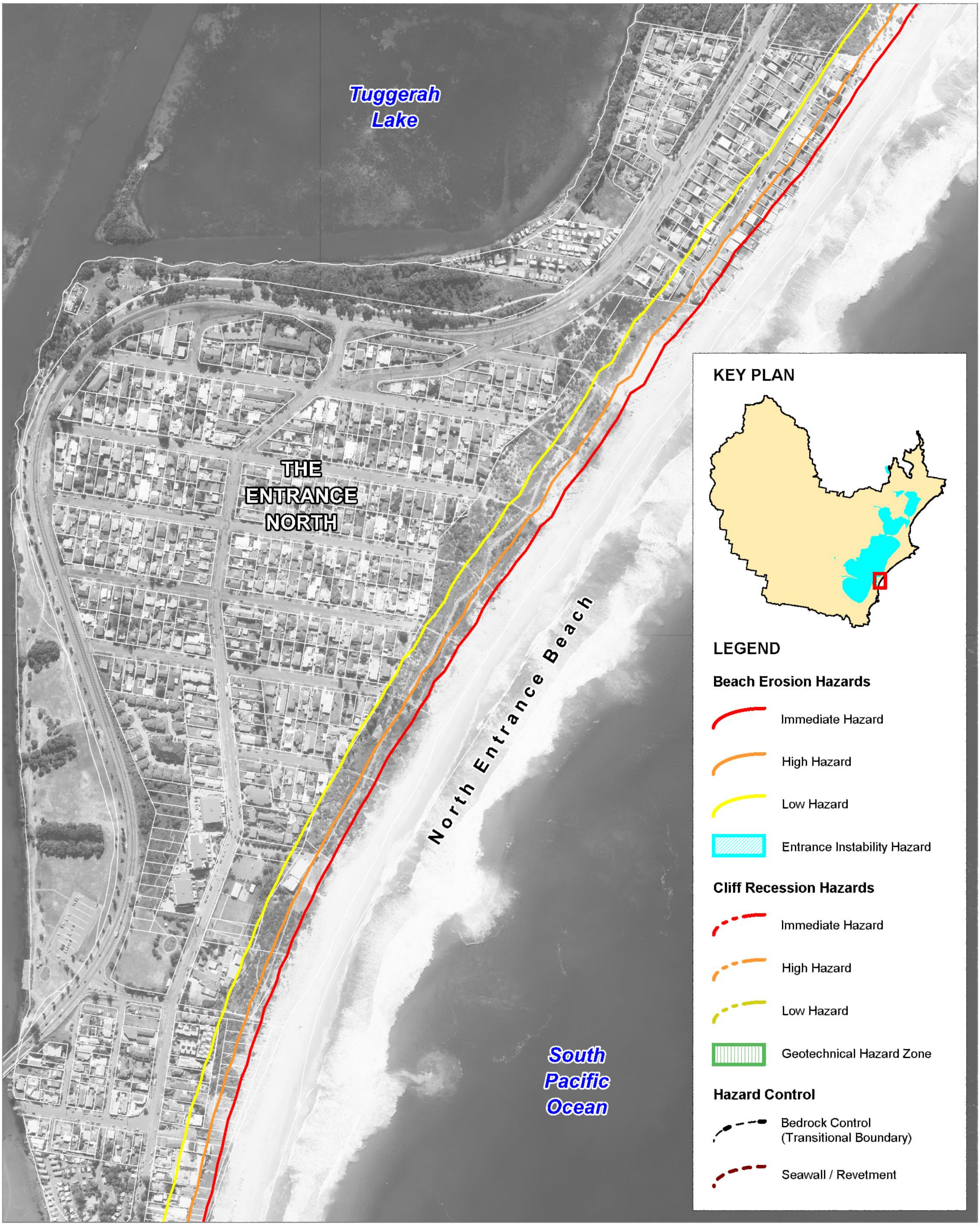

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Coastal and Geotechnical Hazard Definition
Sea Level Rise Scenario - North Entrance Beach

Figure: **A-06**

Rev: **A**

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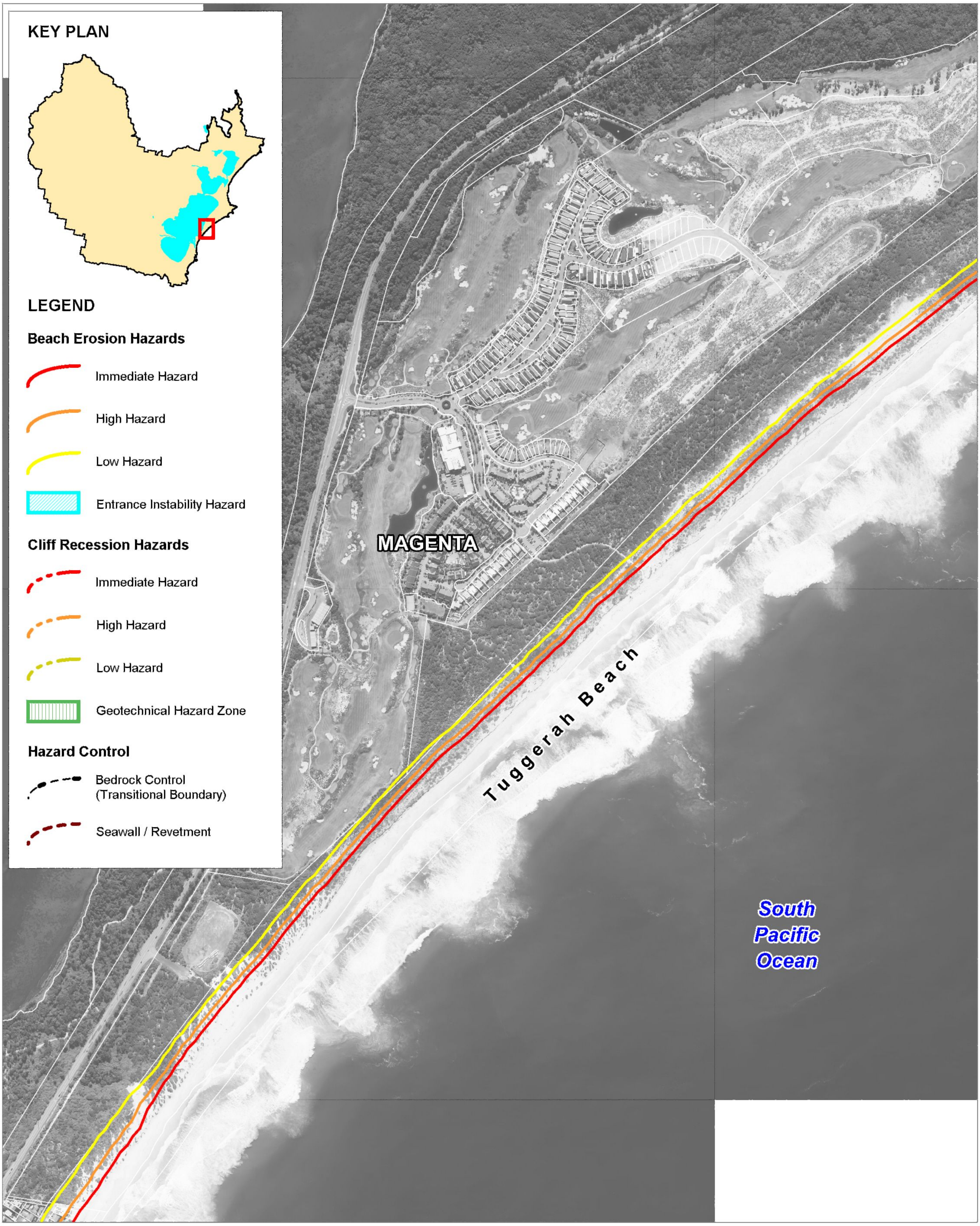

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Coastal and Geotechnical Hazard Definition
Sea Level Rise Scenario - Tuggerah Beach (Magenta)

Figure: A-07

Rev: A

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Approx. Scale

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Filepath :

Title:

Coastal and Geotechnical Hazard Definition
Sea Level Rise Scenario - Pelican Beach

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Figure: **A-08**

Rev: **A**

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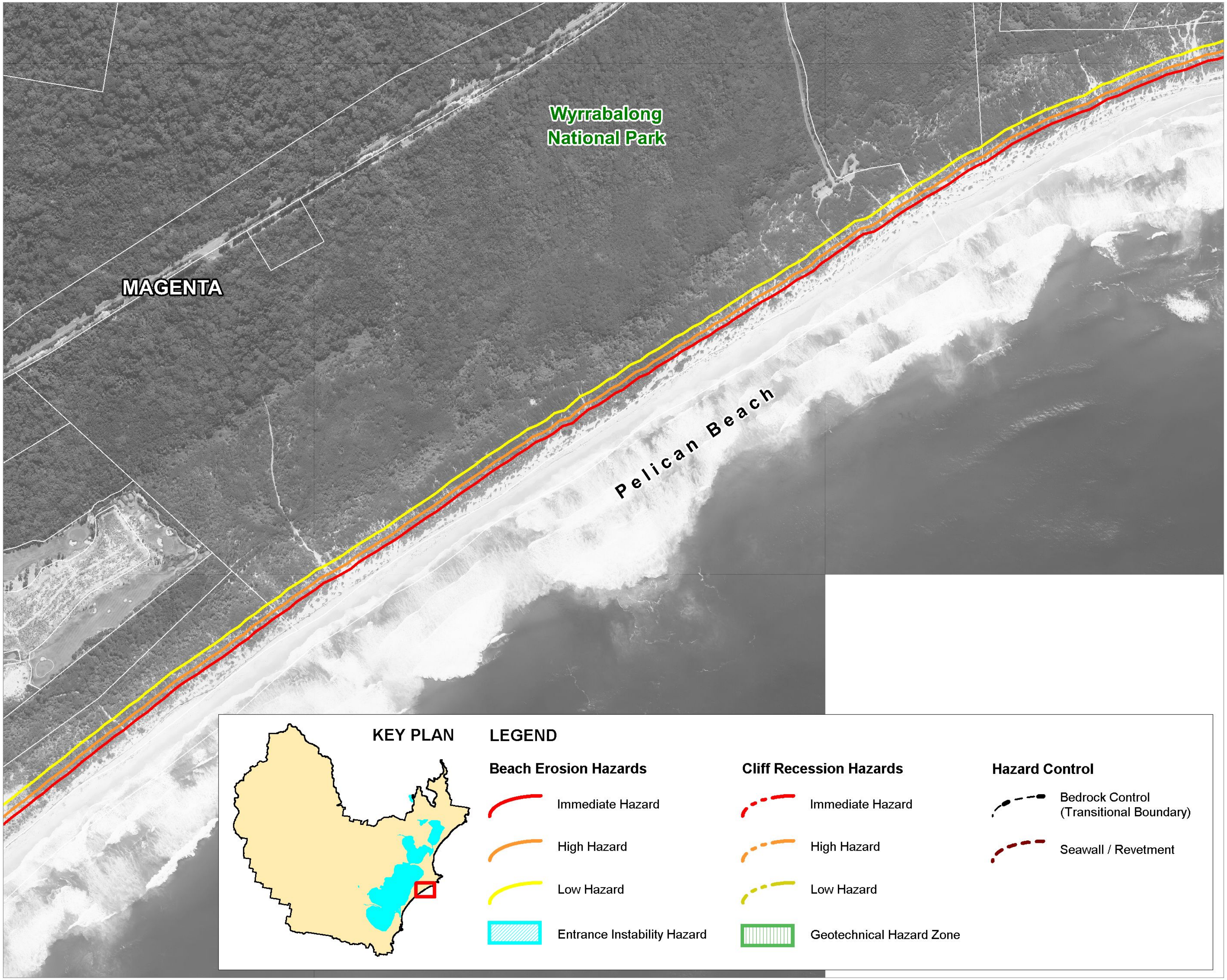
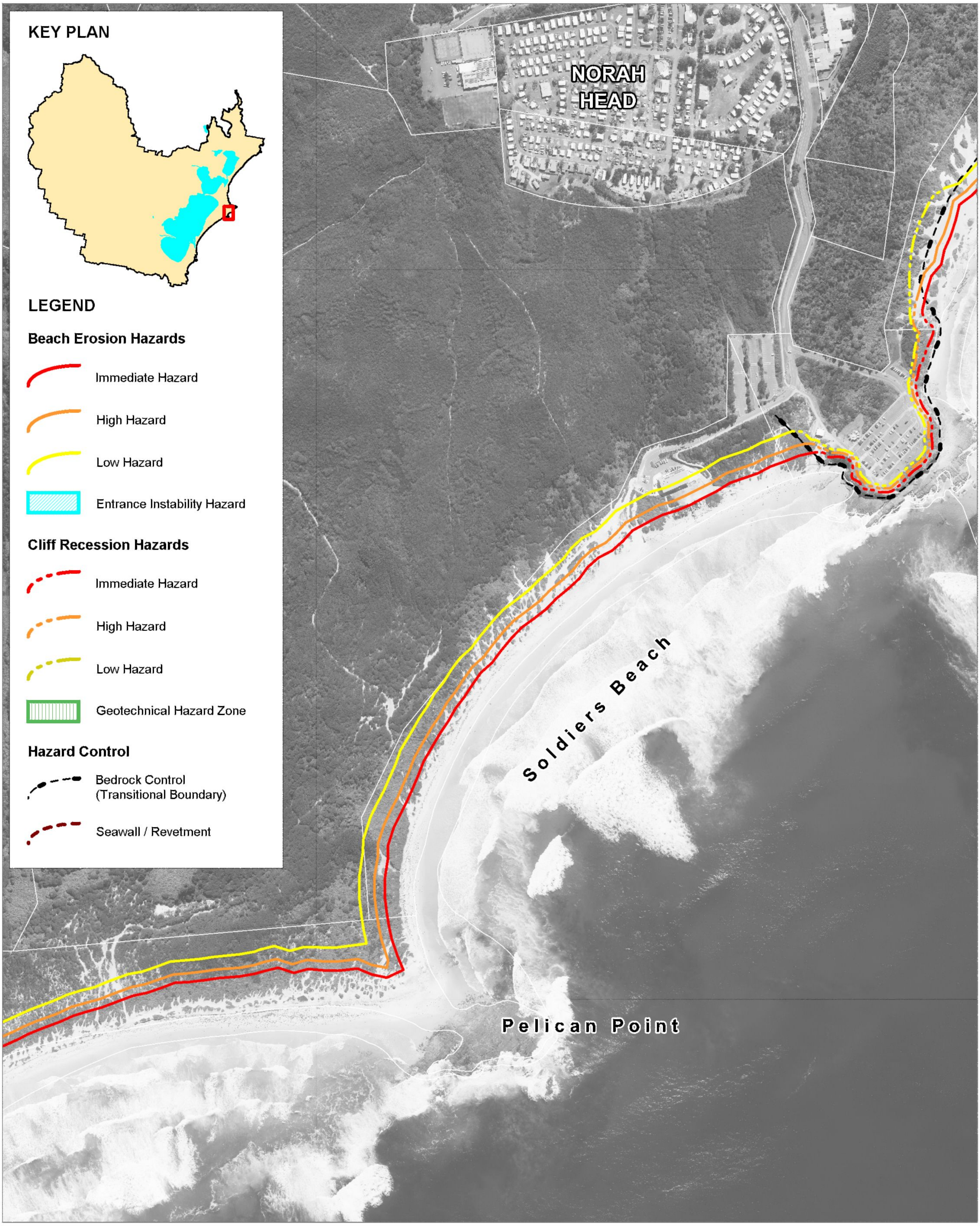
www.bmt.org





Title:

Coastal and Geotechnical Hazard Definition
Sea Level Rise Scenario - Soldiers Beach

Figure: **A-09**

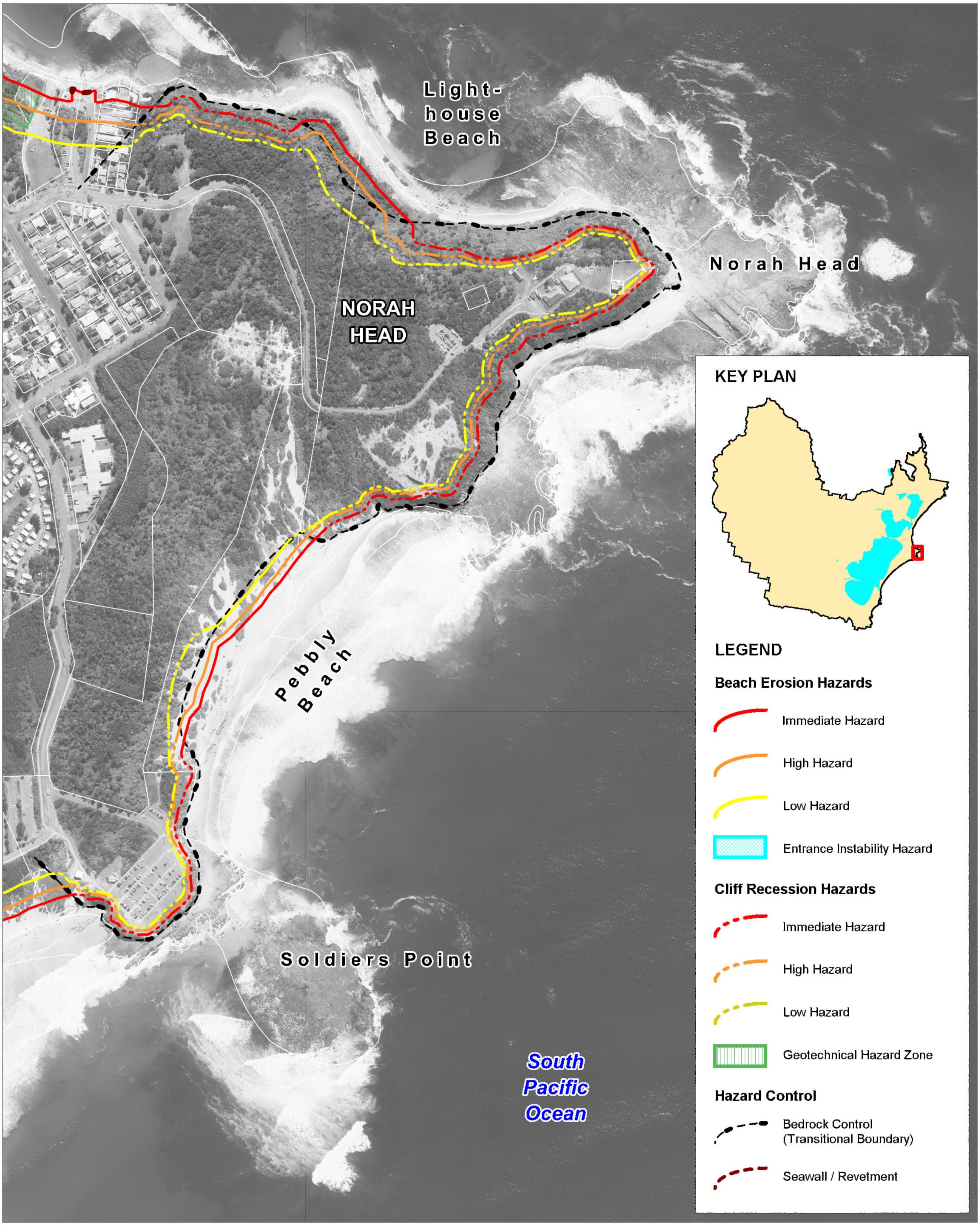
Rev: **A**

N

0 125 250m
Approx. Scale

BMT WBM
www.bmt.org

Filepath :



Title:

Coastal and Geotechnical Hazard Definition
Sea Level Rise Scenario - Norah Head

Figure: **A-10**

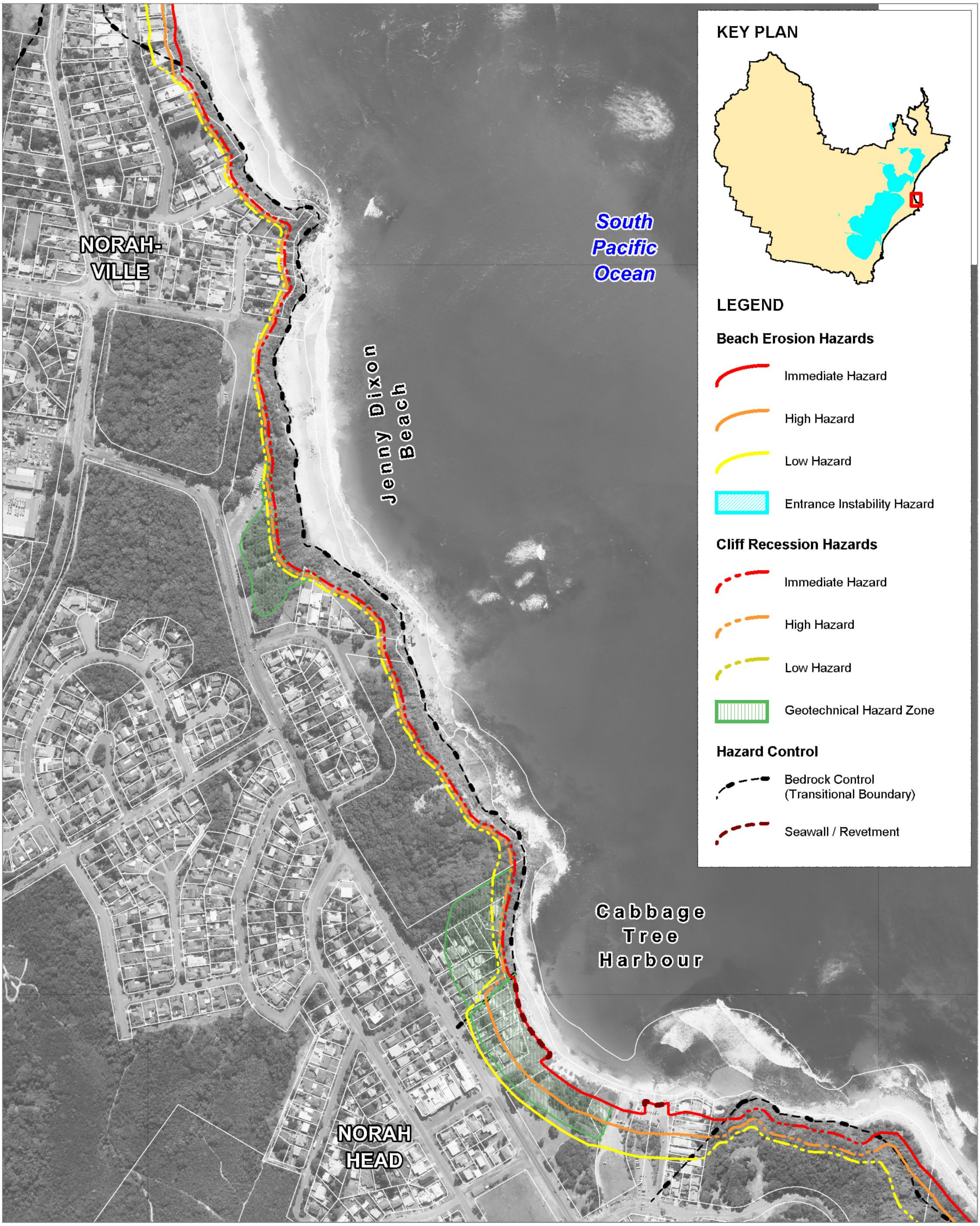
Rev: **A**

N

0 125 250m
Approx. Scale

BMT WBM
www.bmt.org

Filepath :



Title:

Coastal and Geotechnical Hazard Definition
Sea Level Rise Scenario - Cabbage Tree Harbour

Figure: **A-11**

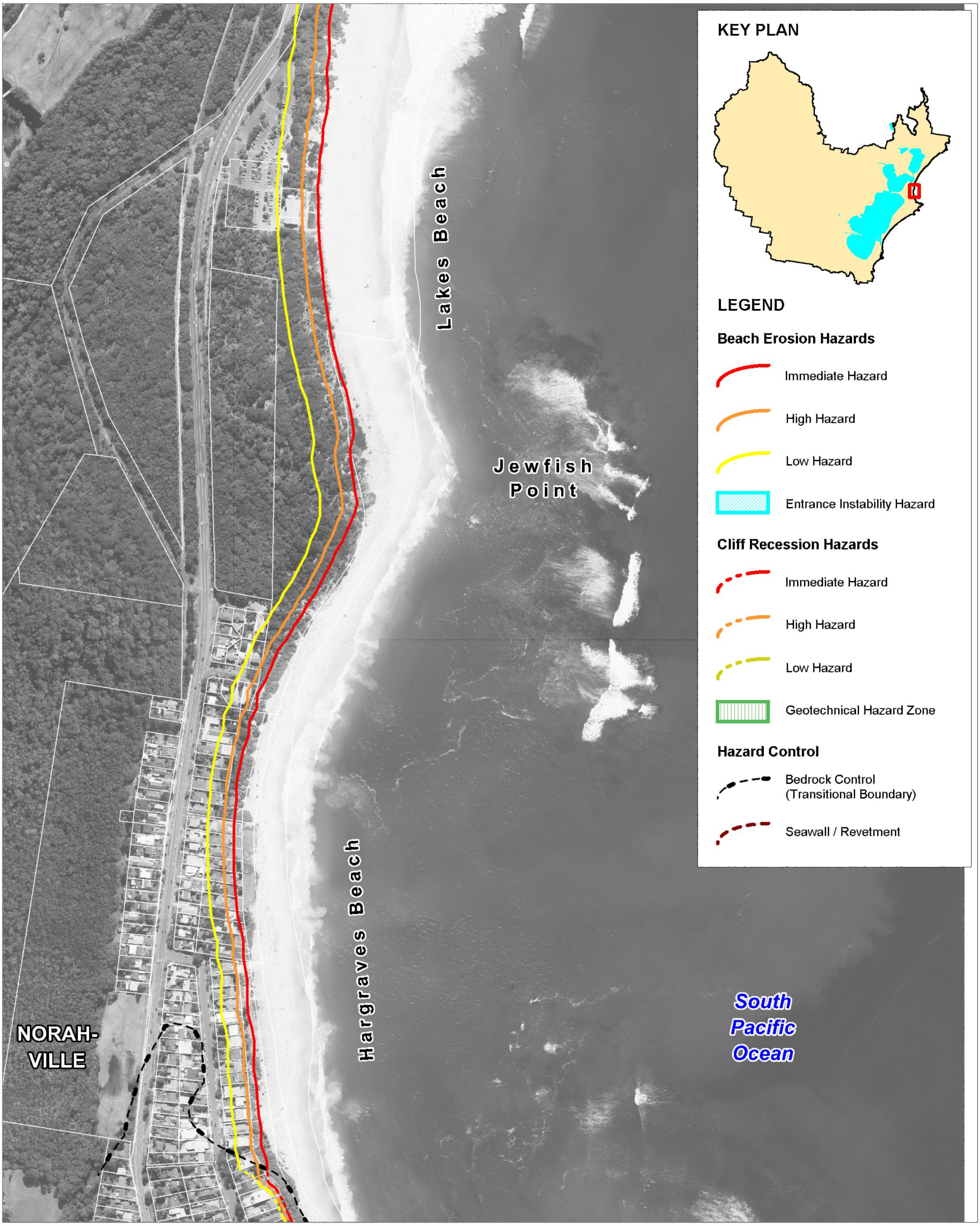
Rev: **A**

N

0 125 250m
Approx. Scale

BMT WBM
www.bmt.org

Filepath :



Title:

Coastal and Geotechnical Hazard Definition
Sea Level Rise Scenario - Hargraves Beach

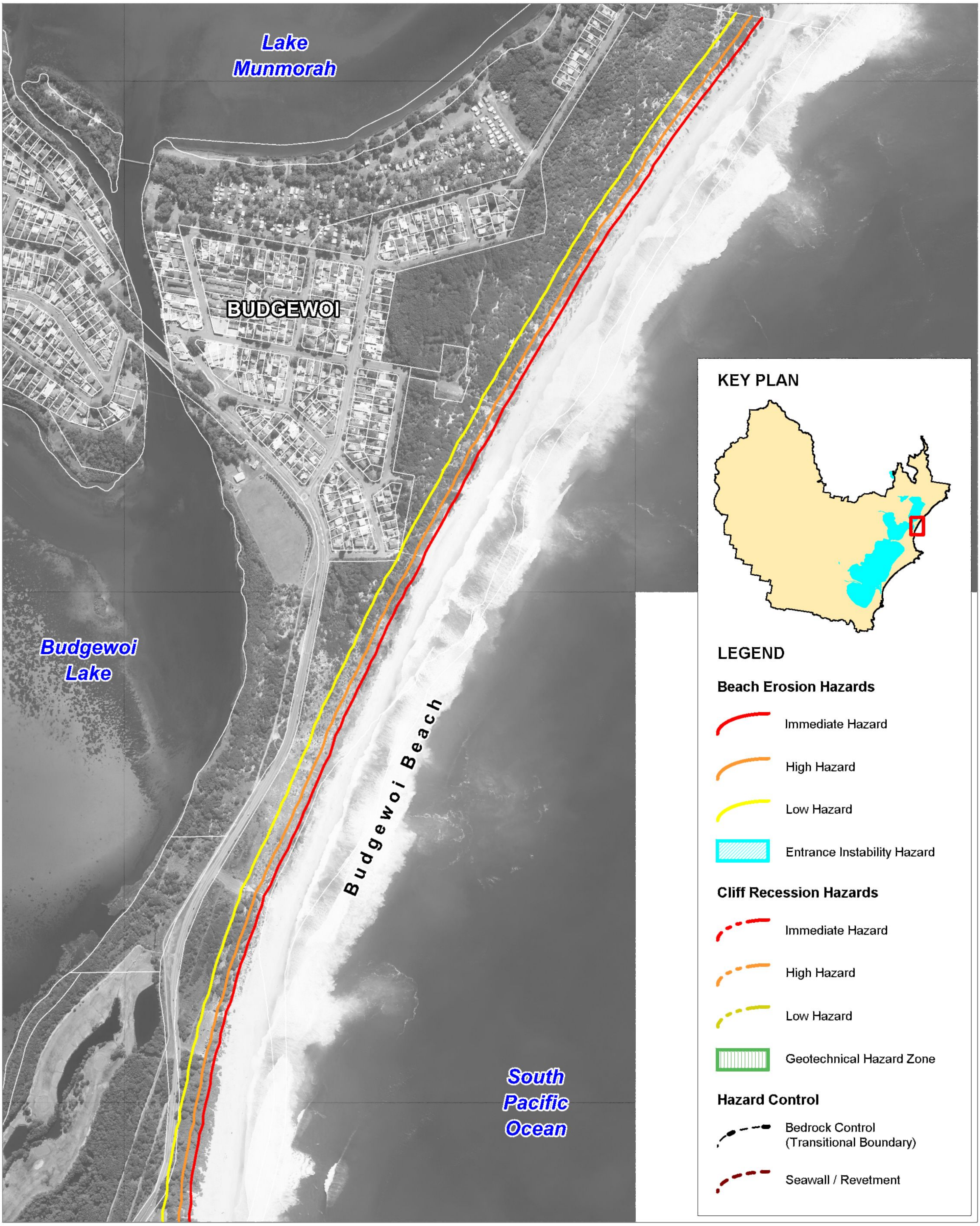
Figure: **A-12**

Rev: **A**

BMT WBM endeavours to ensure that the information provided in this map is correct at the time of publication. BMT WBM does not warrant, guarantee or make representations regarding the currency and accuracy of information contained in this map.

BMT WBM
www.bmt.org

Filepath :



Title:

Coastal and Geotechnical Hazard Definition Sea Level Rise Scenario - Budgewoi Beach

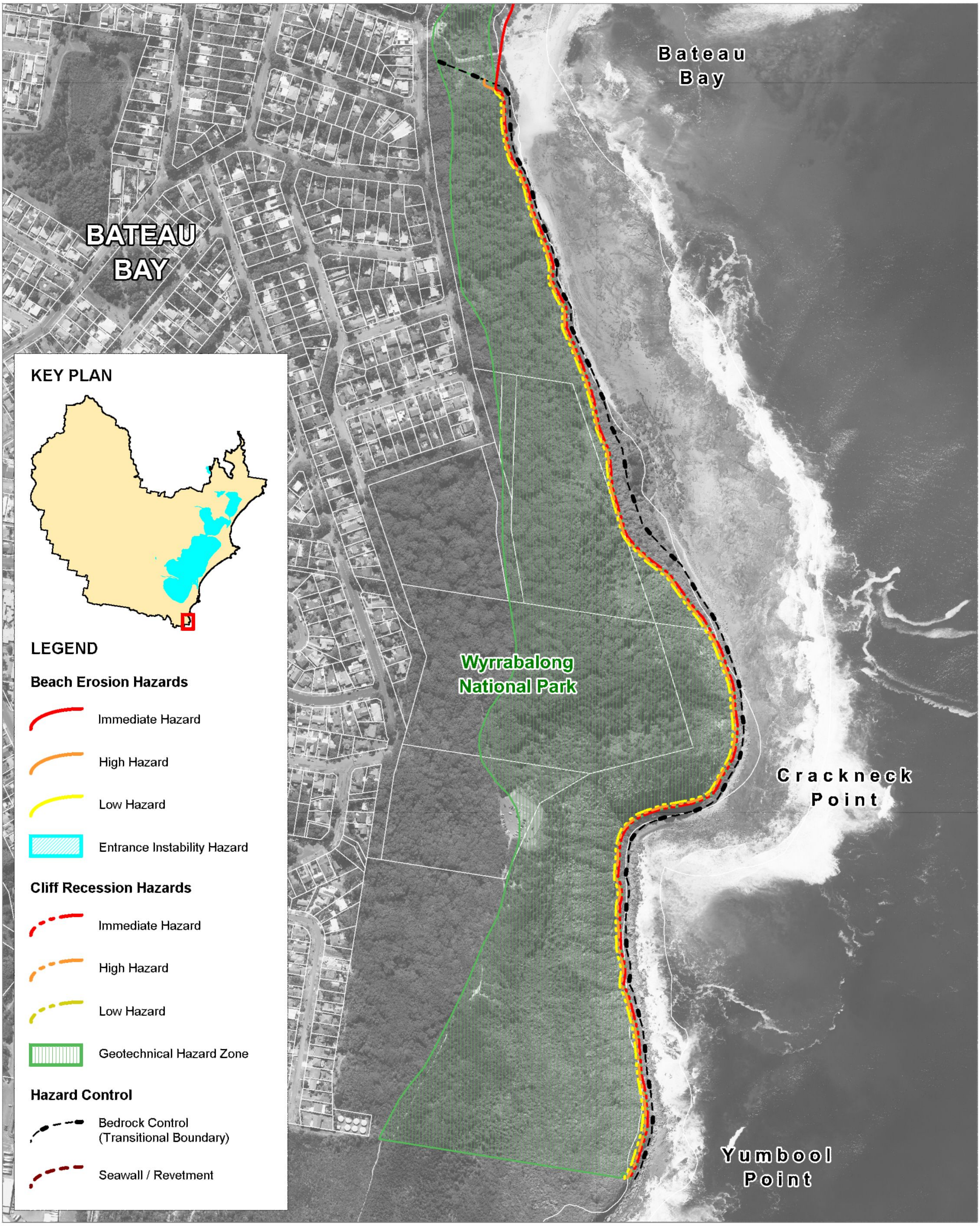
Figure: **A-13**

Rev: **A**

BMT WBM
www.bmt.org

Filepath :

5.2 Combined Coastal and Geotechnical Hazard Mapping without Sea Level Rise, for Current and Future Timeframes



Title:

Coastal and Geotechnical Hazard Definition
No Sea Level Rise Scenario - Crackneck

Figure: **B-01**

Rev: **A**

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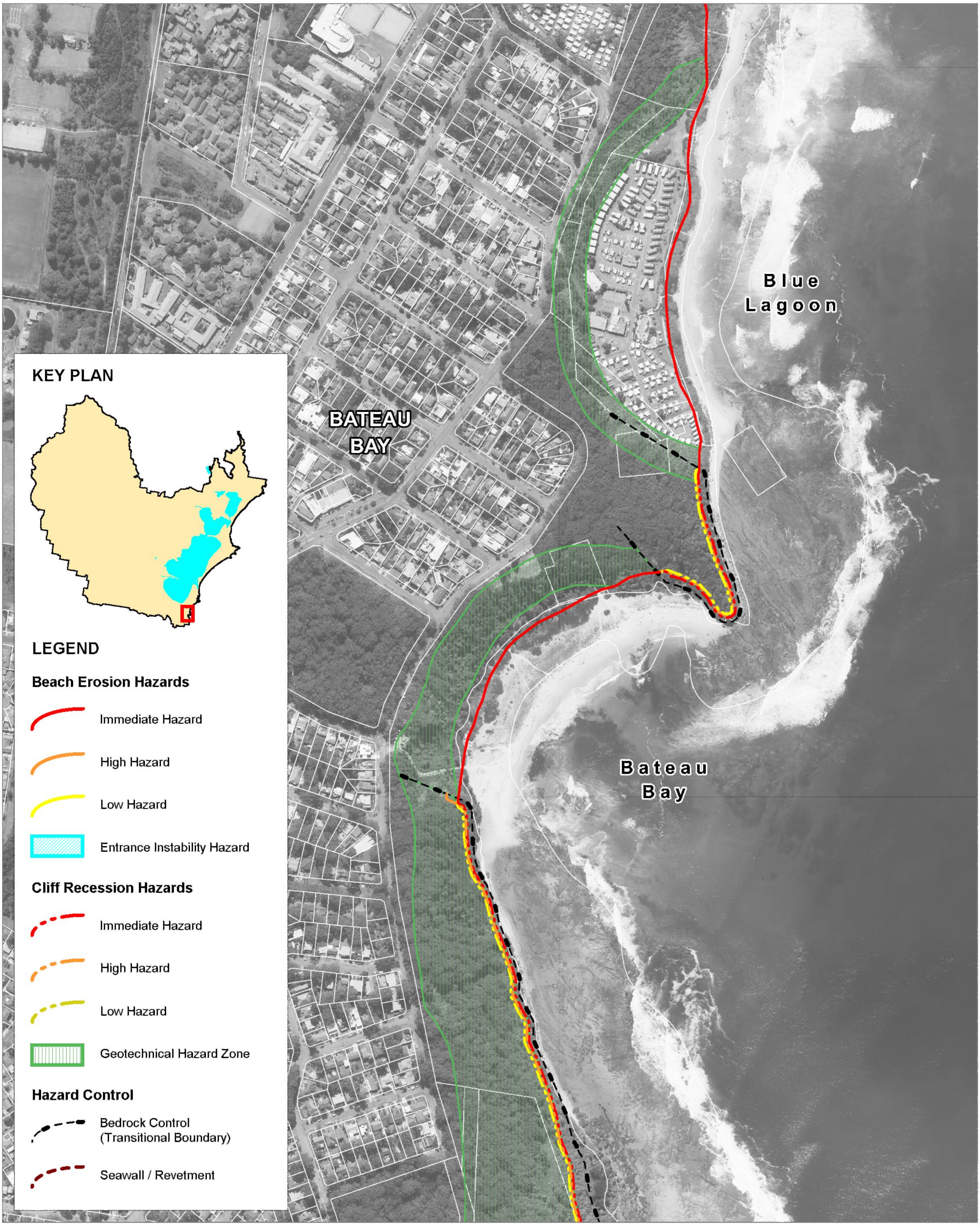
Approx. Scale

BMT WBM
www.bmt.org

Filepath :



Title:

Coastal and Geotechnical Hazard Definition
No Sea Level Rise Scenario - Bateau Bay

Figure: **B-02**

Rev: **A**

N

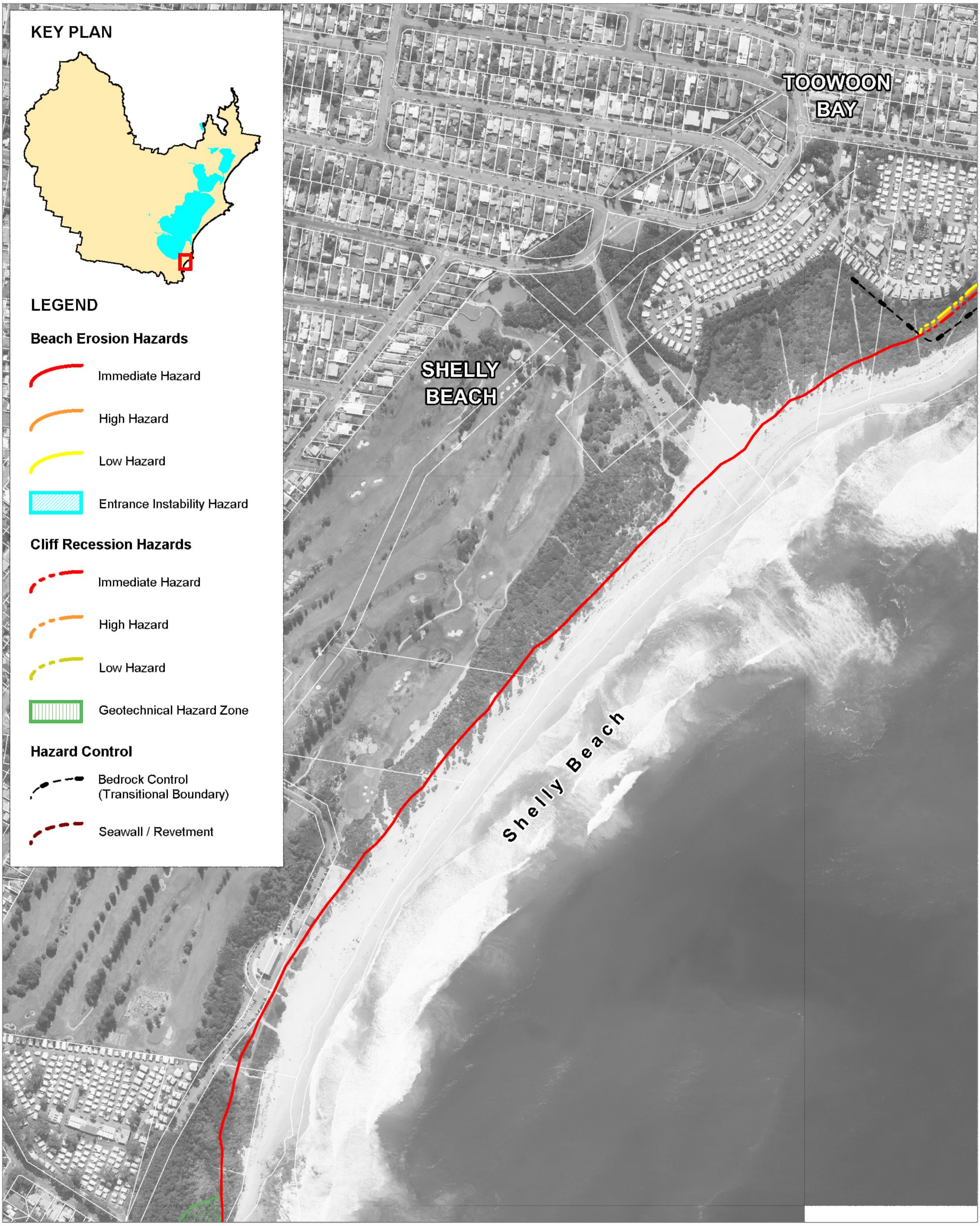
0 125 250m

Approx. Scale

BMT WBM

www.bmt.org

Filepath :



Title:

Coastal and Geotechnical Hazard Definition
No Sea Level Rise Scenario - Shelly Beach

Figure: B-03

Rev: A

BMT WBM endeavours to ensure that the information provided in this map is correct at the time of publication. BMT WBM does not warrant, guarantee or make representations regarding the currency and accuracy of information contained in this map.

N

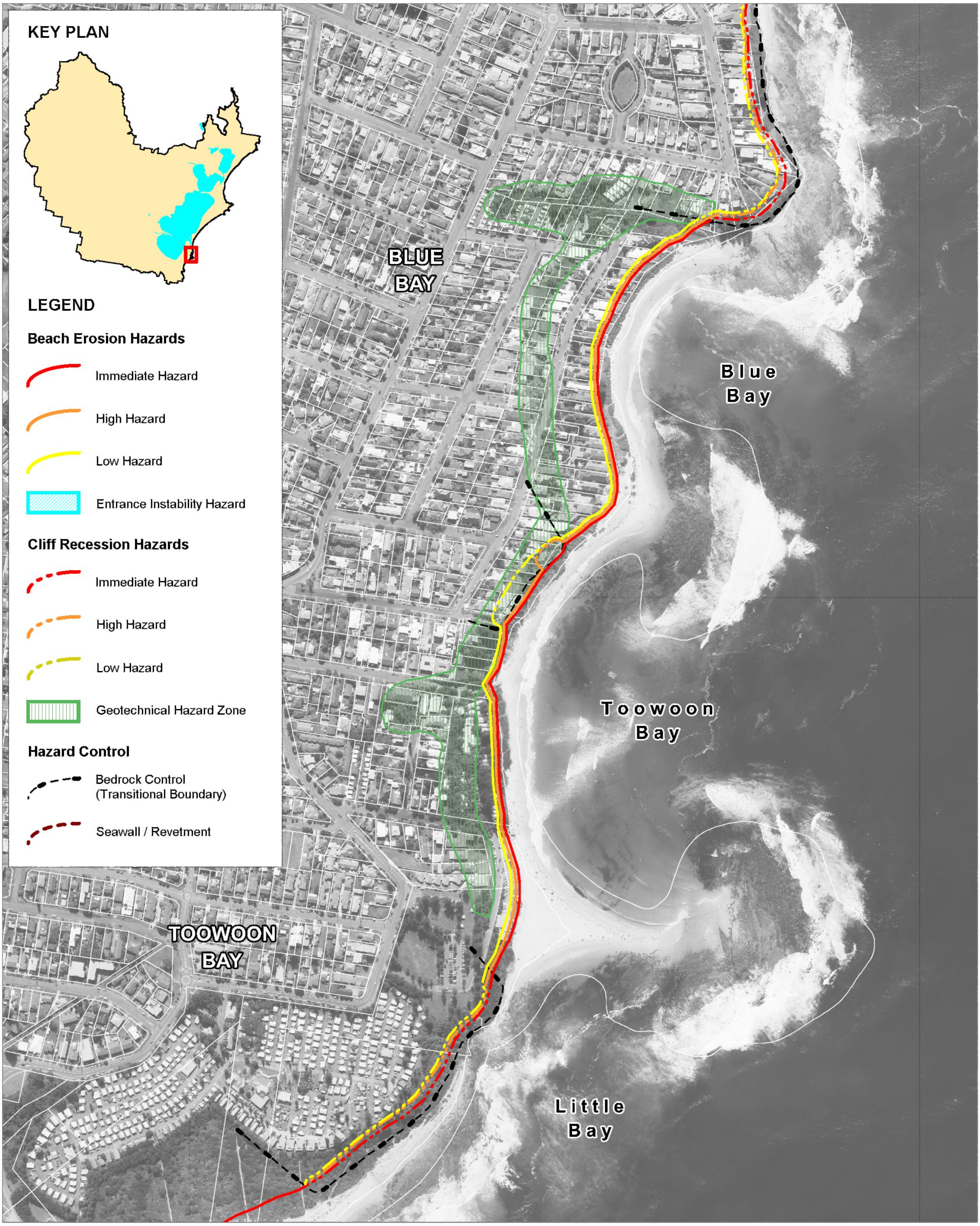
0 125 250m

Approx. Scale

BMT WBM

www.bmt.org

Filepath :



Title:

Coastal and Geotechnical Hazard Definition
No Sea Level Rise Scenario - Toowoon and Blue Bay

Figure: **B-04**

Rev: **A**

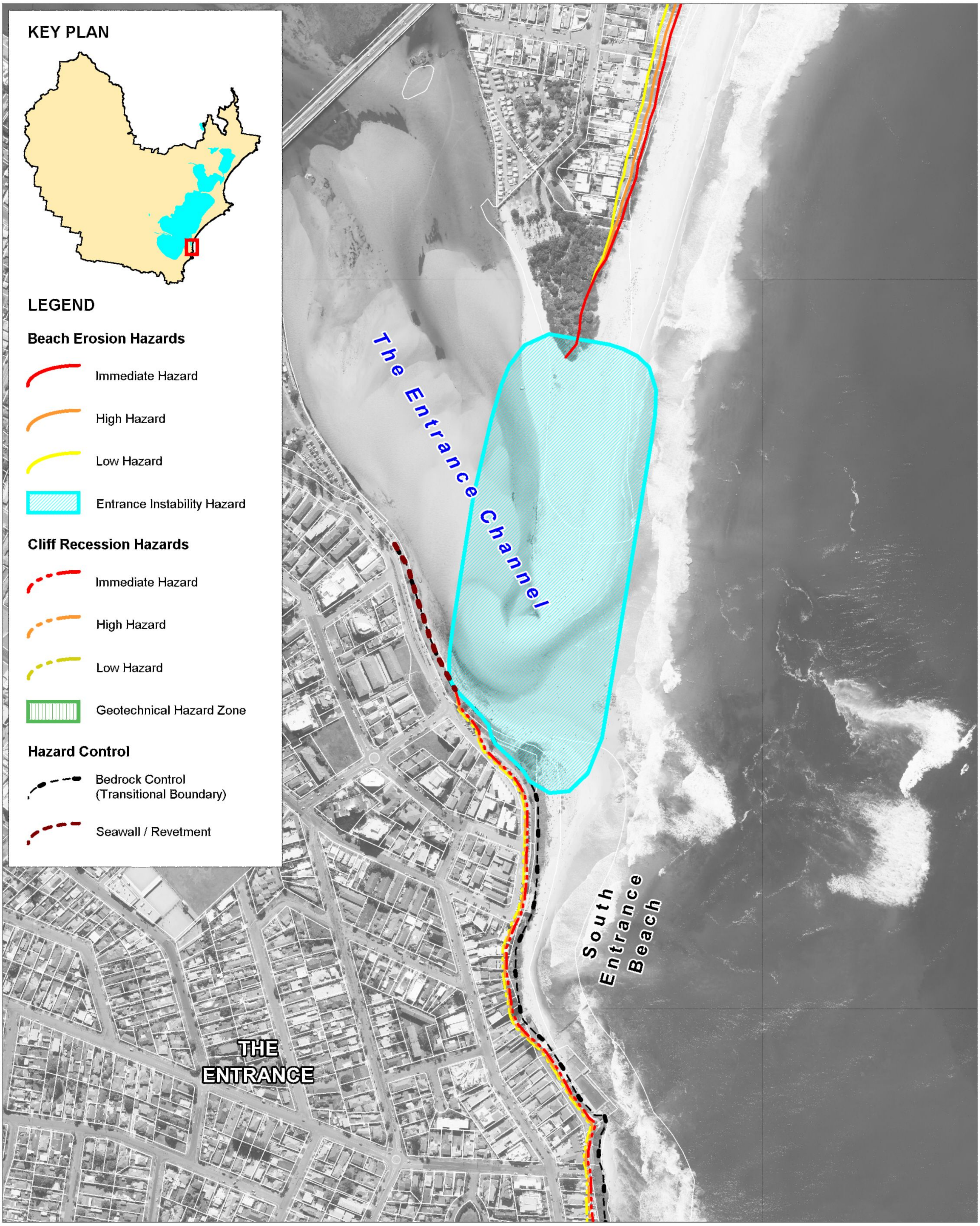
BMT WBM endeavours to ensure that the information provided in this map is correct at the time of publication. BMT WBM does not warrant, guarantee or make representations regarding the currency and accuracy of information contained in this map.

N

0 125 250m
Approx. Scale

BMT WBM
www.bmt.org

Filepath :



Title:

Coastal and Geotechnical Hazard Definition No Sea Level Rise Scenario - The Entrance

Figure: B-05

Rev: A

N

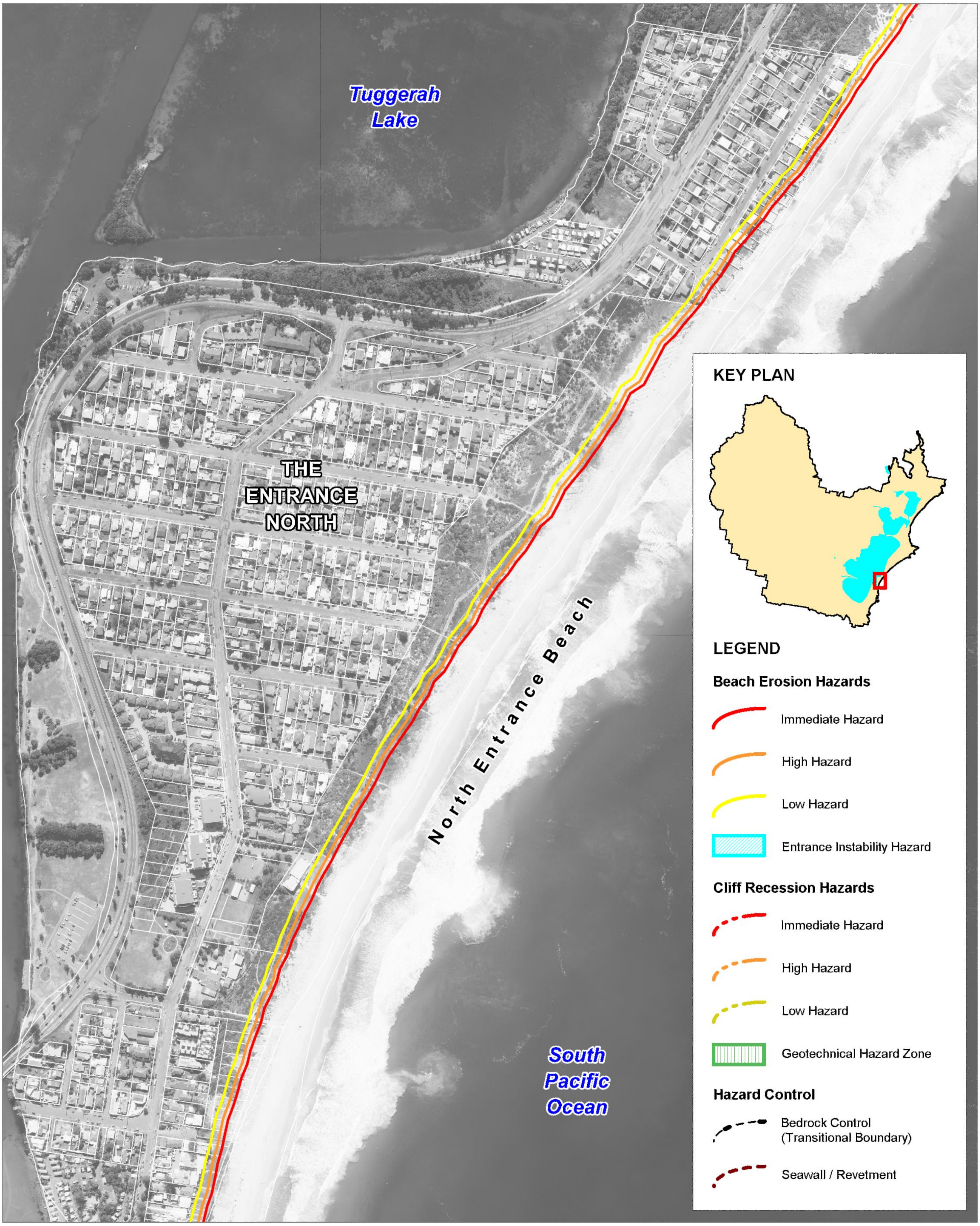
0 125 250m

Approx. Scale

BMT WBM

www.bmt.org

Filepath :



Title:

Coastal and Geotechnical Hazard Definition
No Sea Level Rise Scenario - North Entrance Beach

Figure: **B-06**

Rev: **A**

BMT WBM endeavours to ensure that the information provided in this map is correct at the time of publication. BMT WBM does not warrant, guarantee or make representations regarding the currency and accuracy of information contained in this map.

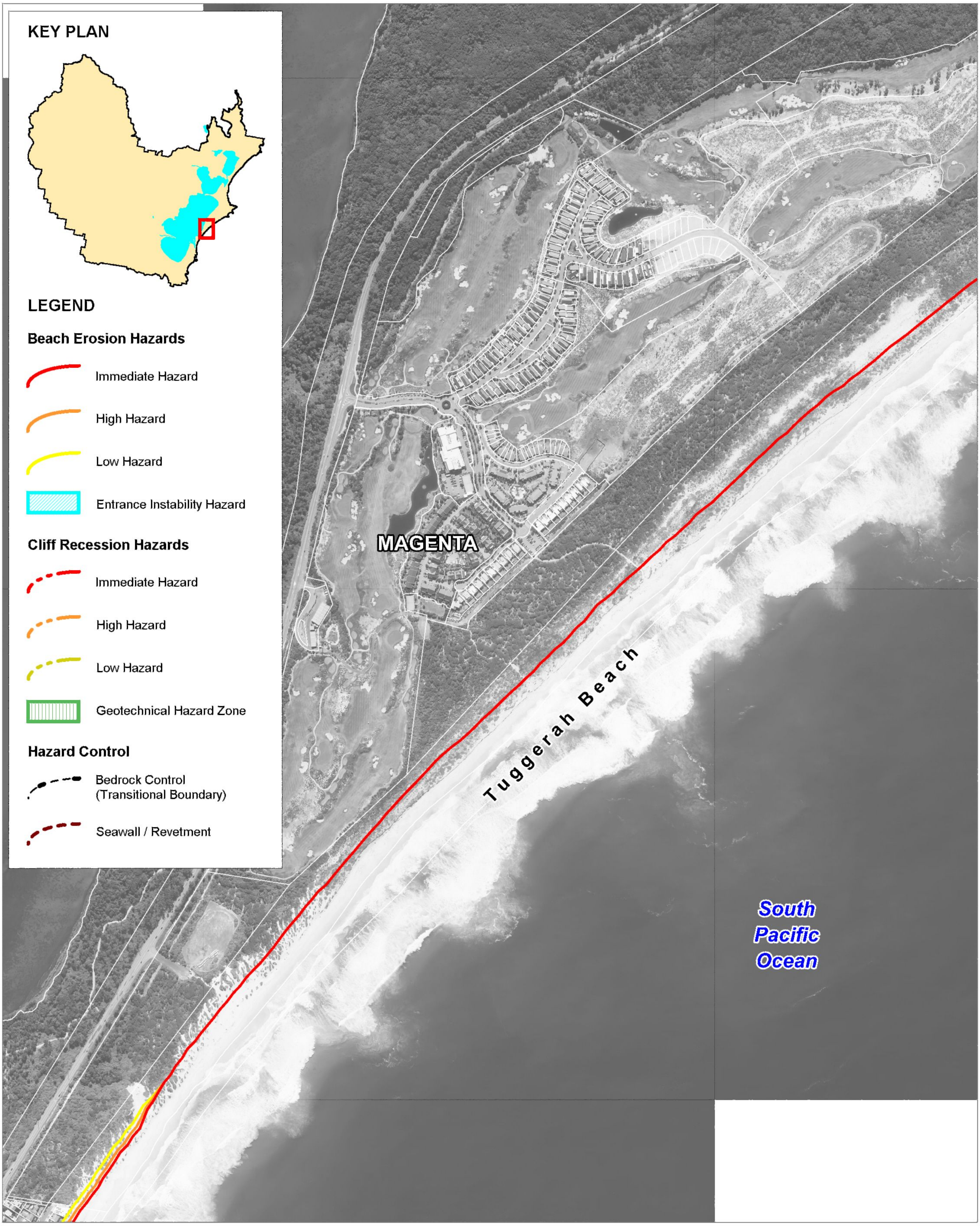
N

0 125 250m

Approx. Scale

BMT WBM
www.bmt.org

Filepath :



Title:

Coastal and Geotechnical Hazard Definition
No Sea Level Rise Scenario - Tuggerah Beach (Magenta)

Figure: B-07

Rev: A

N

0 200 400m

Approx. Scale

BMT WBM

www.bmt.org

Filepath :

Title:

Coastal and Geotechnical Hazard Definition
No Sea Level Rise Scenario - Pelican Beach

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N

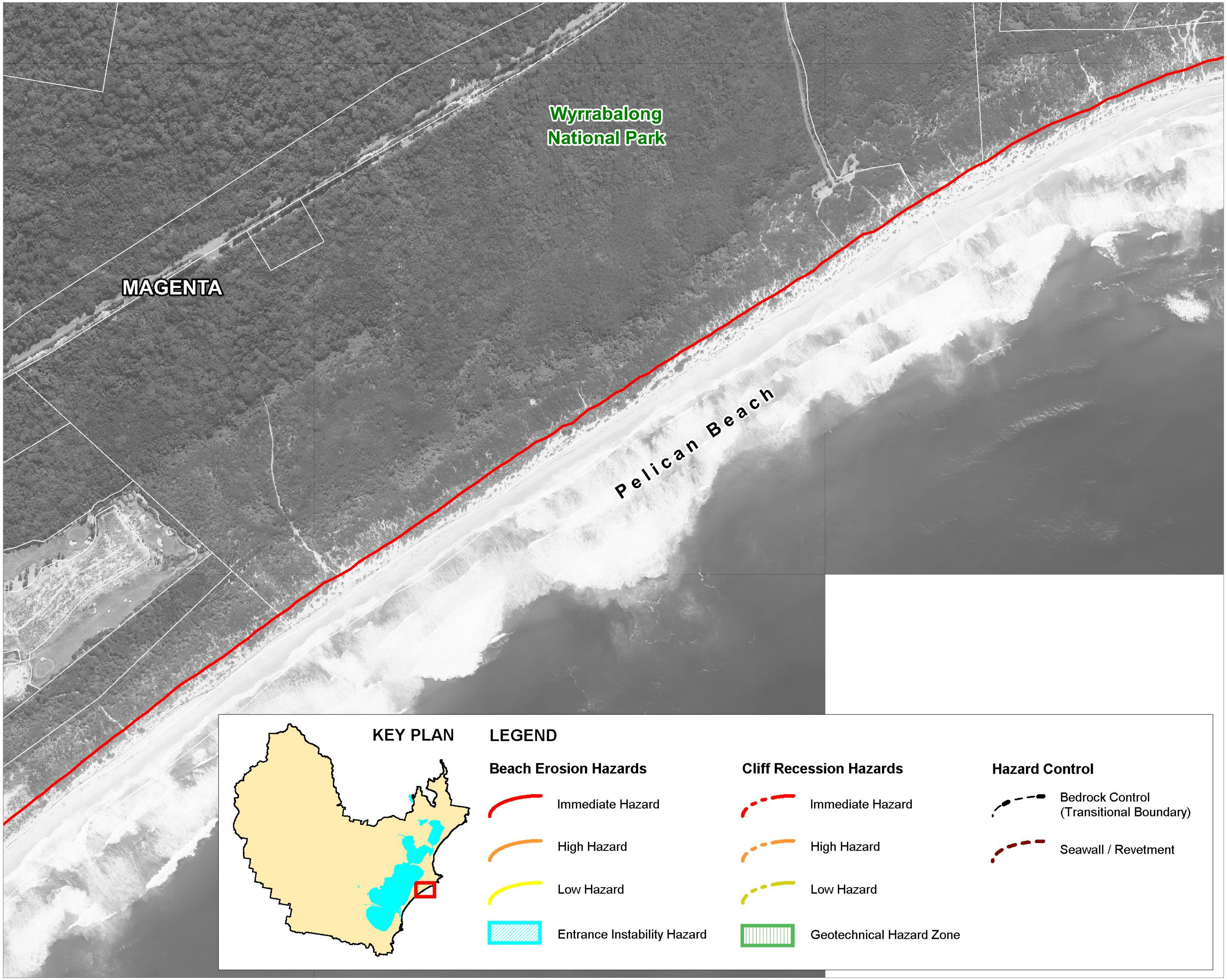
0 200 400m
Approx. Scale

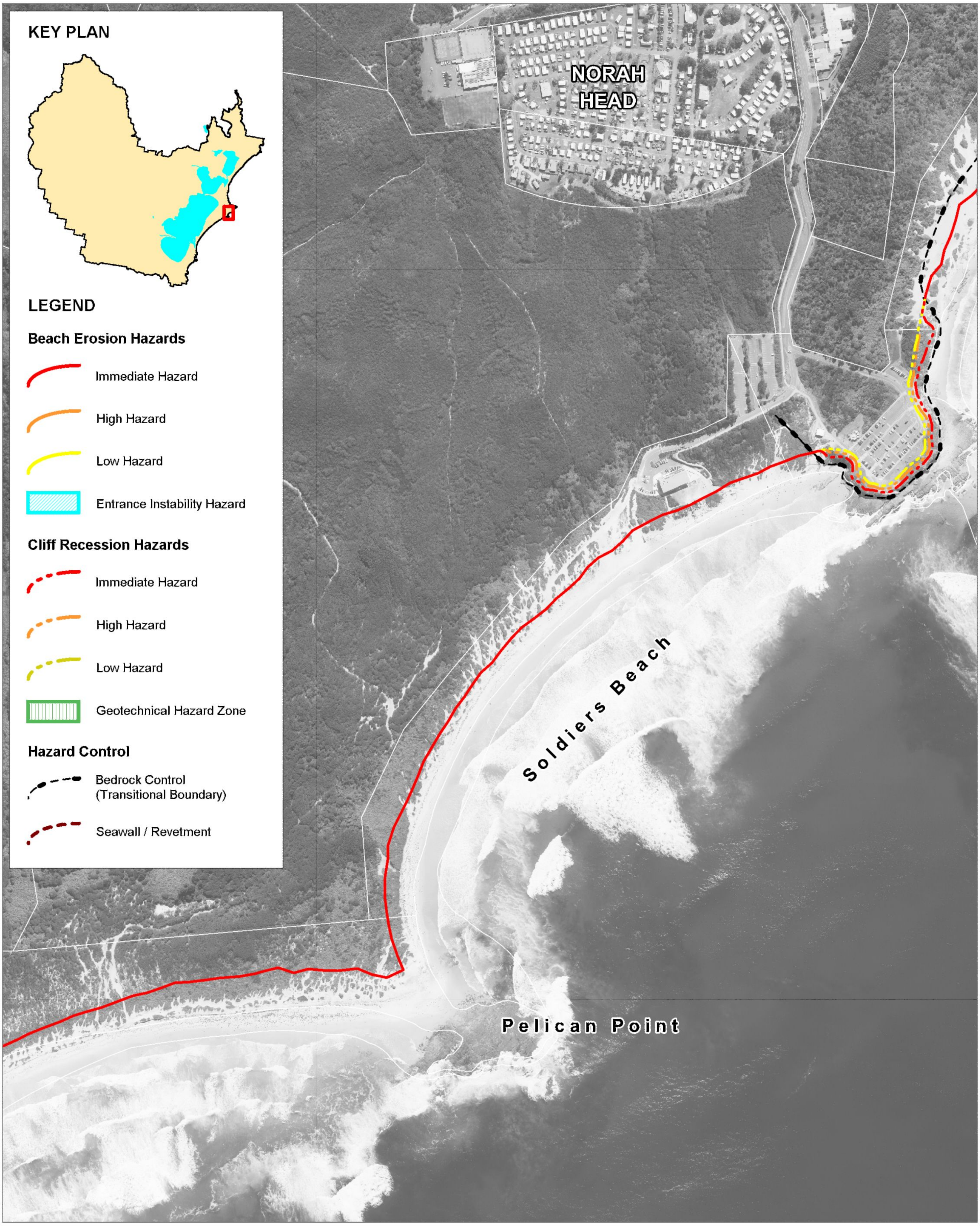
Figure:
B-08

Rev:
A

BMT WBM
www.bmt.org

Filepath :





Title:

Coastal and Geotechnical Hazard Definition
No Sea Level Rise Scenario - Soldiers Beach

Figure: **B-09**

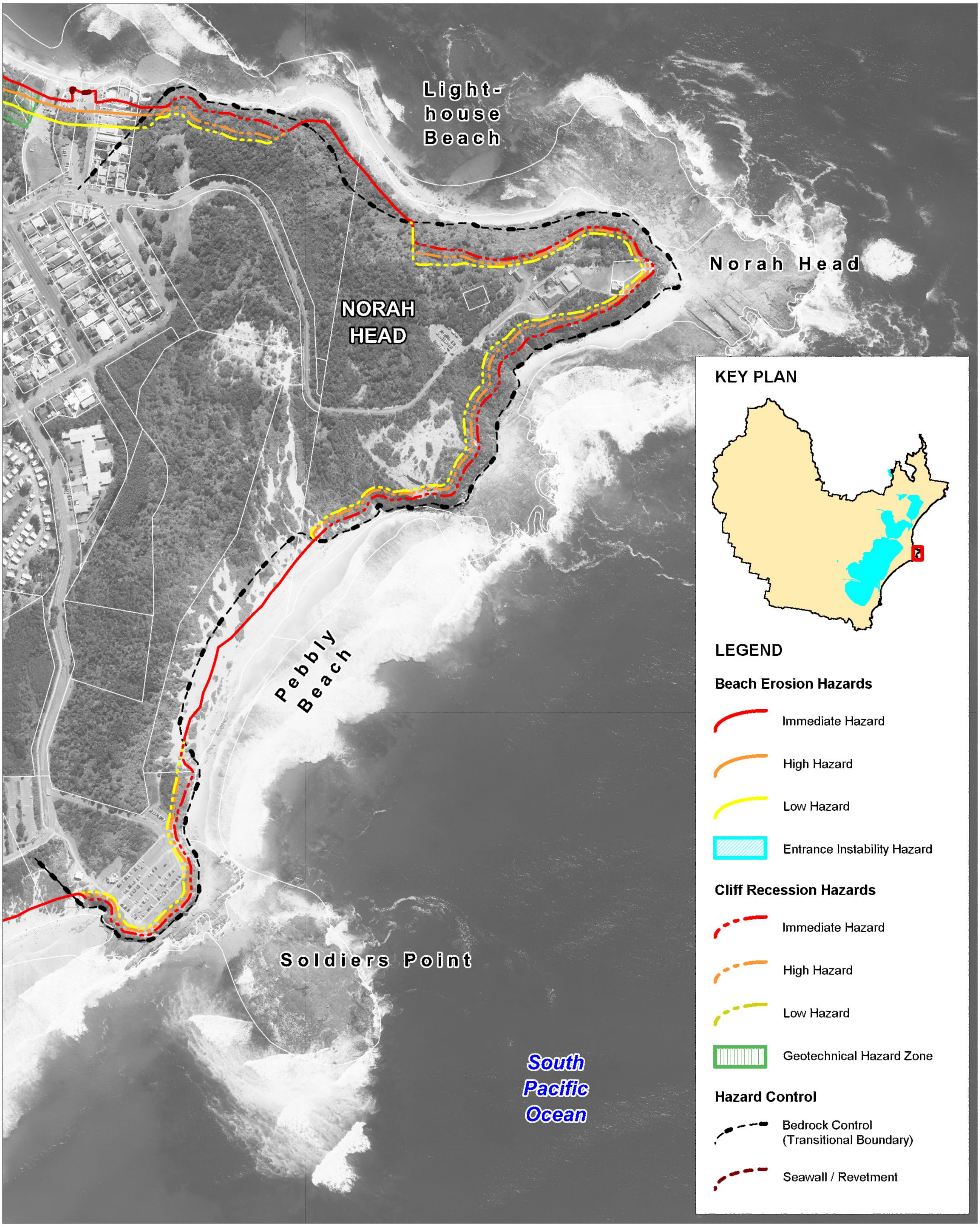
Rev: **A**

N

0 125 250m
Approx. Scale

BMT WBM
www.bmt.org

Filepath :



Title:

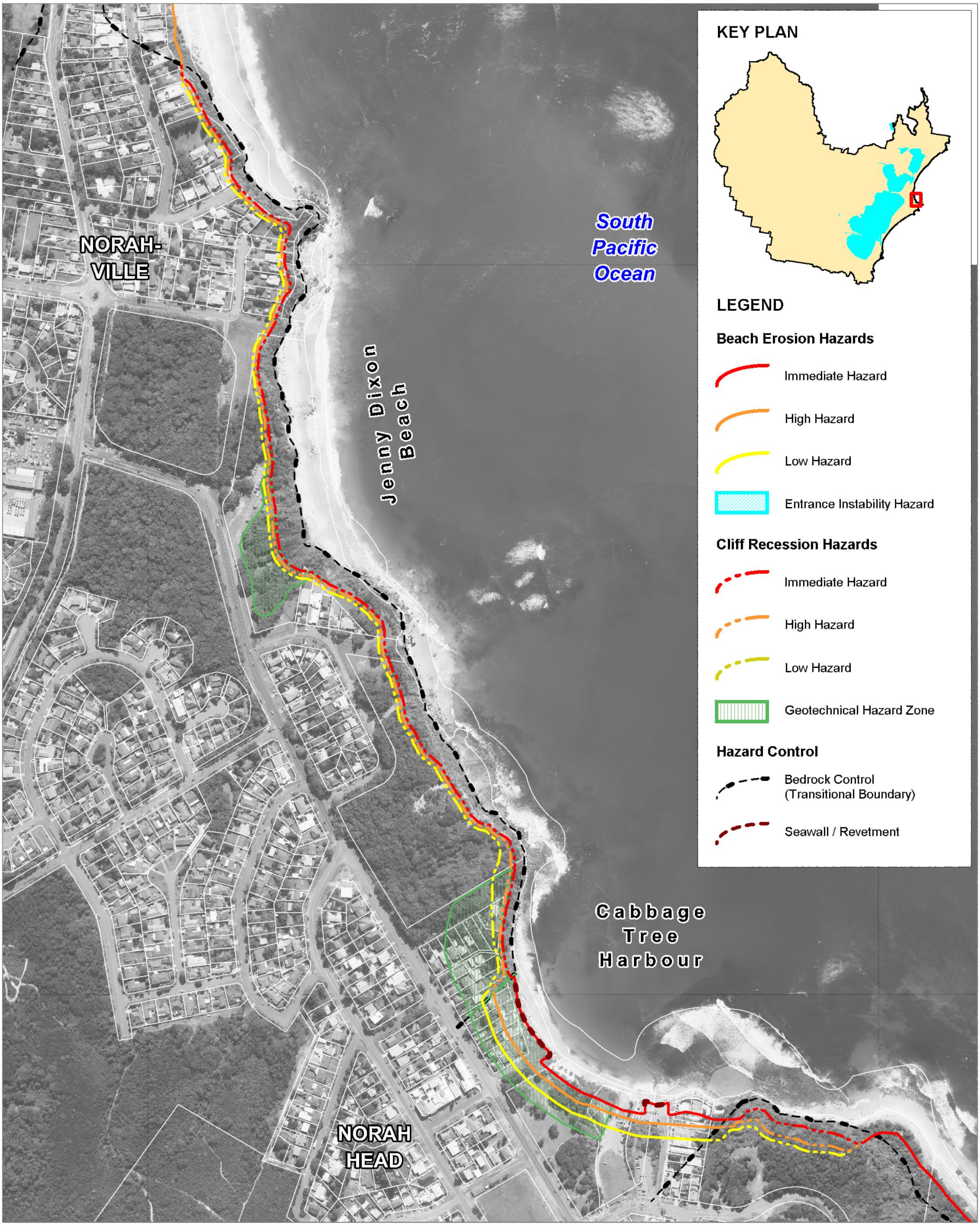
Coastal and Geotechnical Hazard Definition
No Sea Level Rise Scenario - Norah Head

Figure: **B-10**

Rev: **A**

BMT WBM
www.bmt.org

Filepath :



Title:

Coastal and Geotechnical Hazard Definition
No Sea Level Rise Scenario - Cabbage Tree Harbour

Figure: **B-11**

Rev: **A**

N

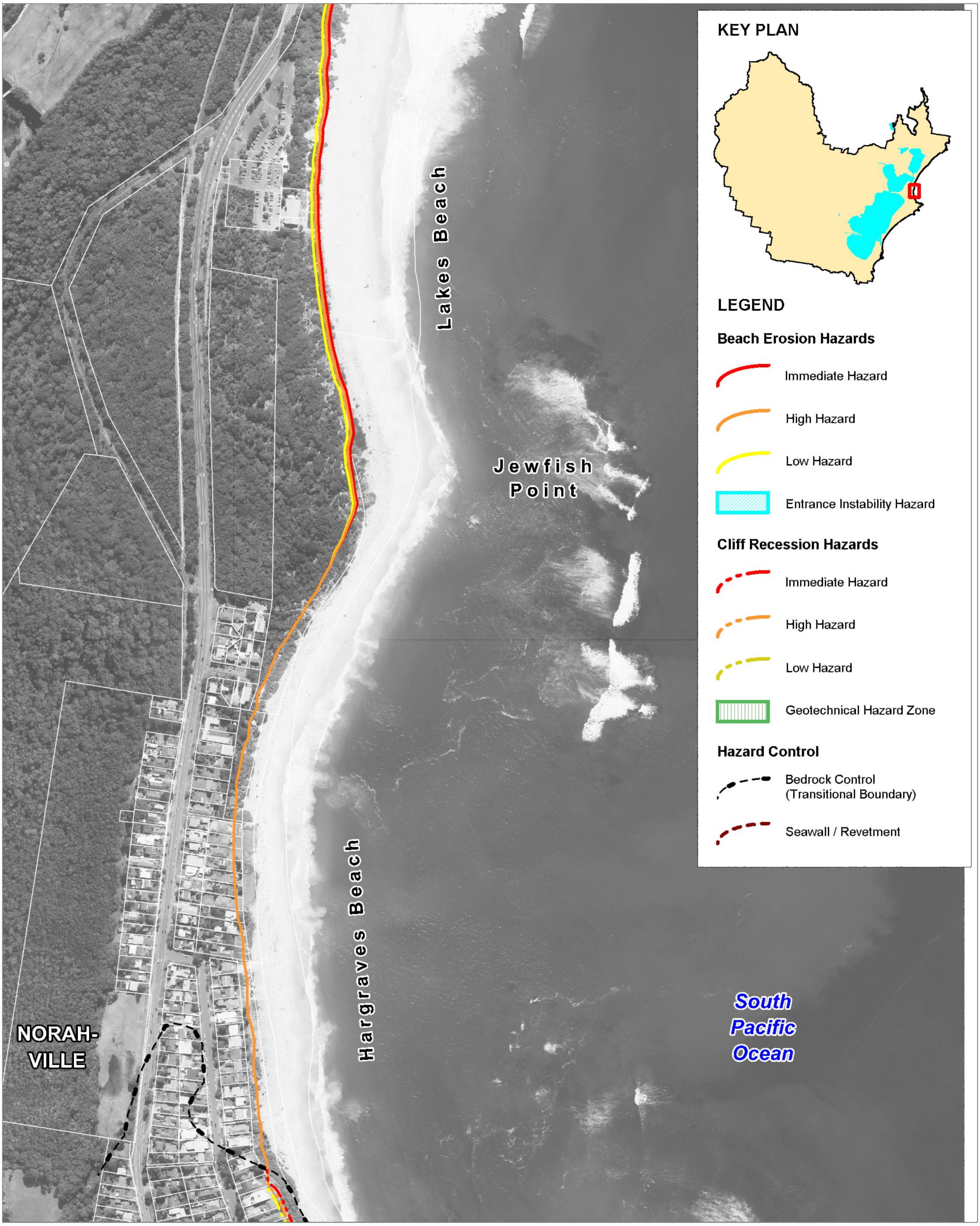
0 125 250m

Approx. Scale

BMT WBM

www.bmt.org

Filepath :



Title:

Coastal and Geotechnical Hazard Definition No Sea Level Rise Scenario - Hargraves Beach

Figure: B-12

Rev: A

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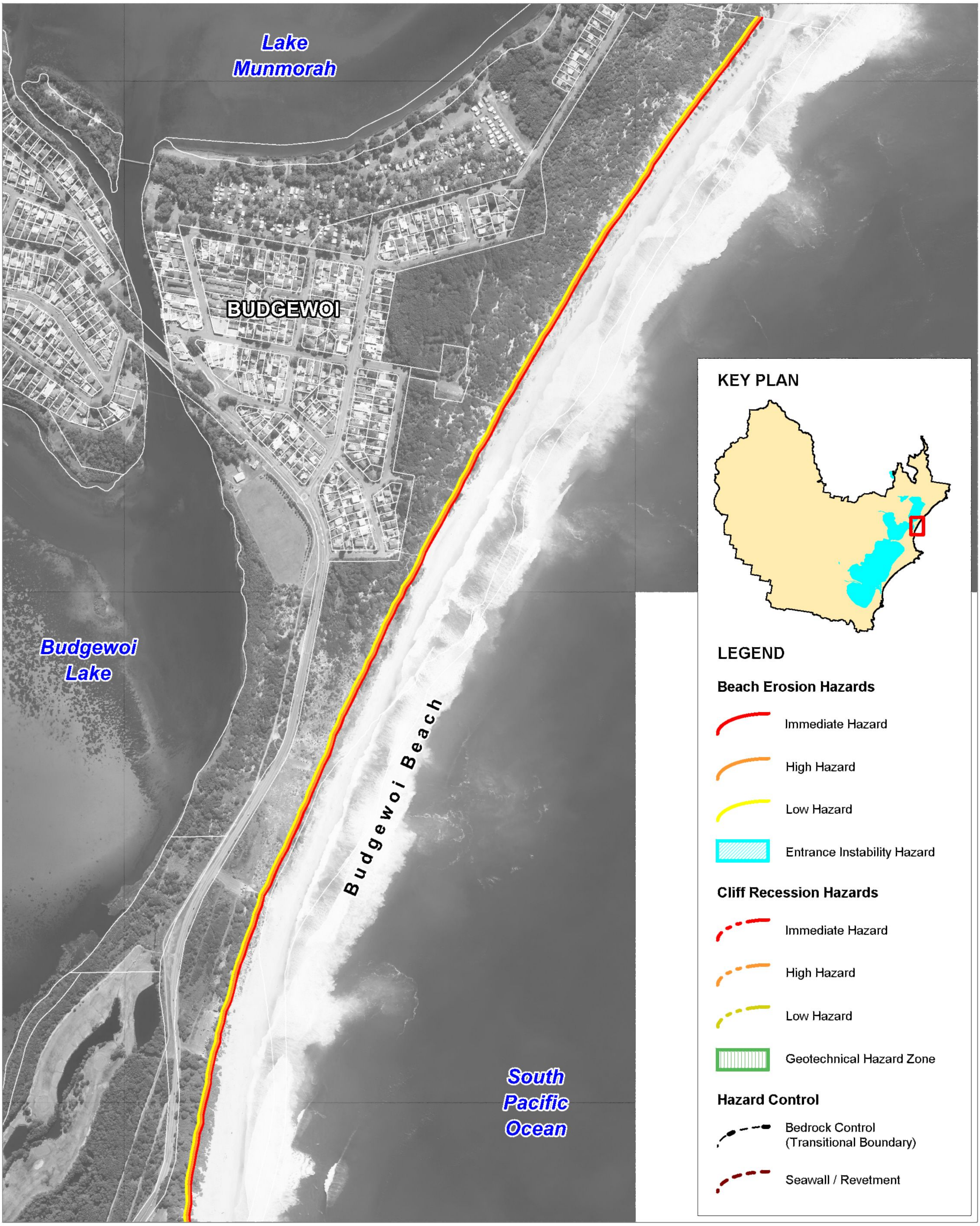


Title:

Coastal and Geotechnical Hazard Definition
No Sea Level Rise Scenario - Budgewoi Beach

Figure: **B-13**

Rev: **A**

N

0 200 400m

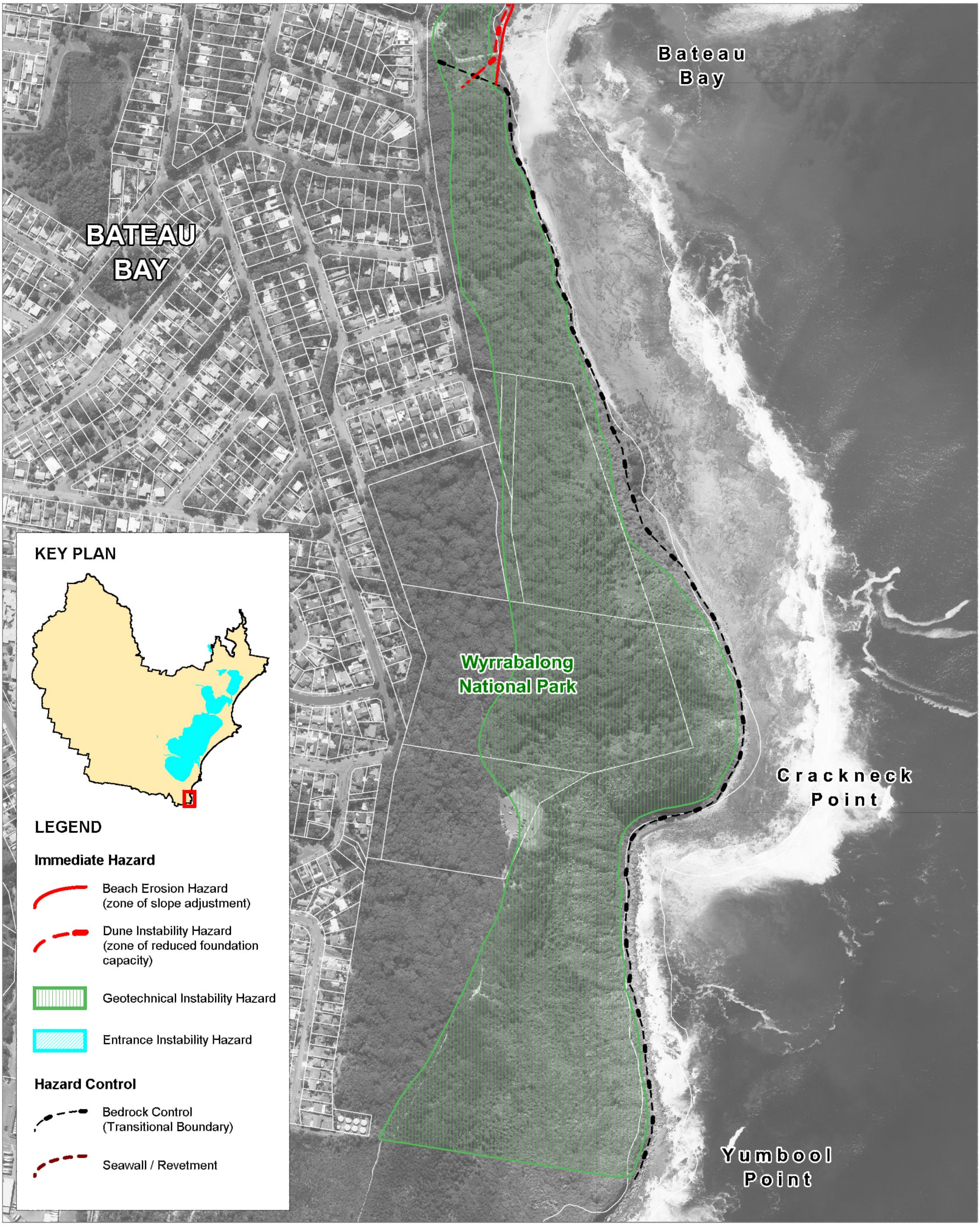
Approx. Scale

BMT WBM

www.bmt.org

Filepath :

5.3 Immediate Dune Instability Hazard Mapping



Title:

Dune Instability Hazard Definition Immediate Timeframe Only - Crackneck

Figure: C-01

Rev: A

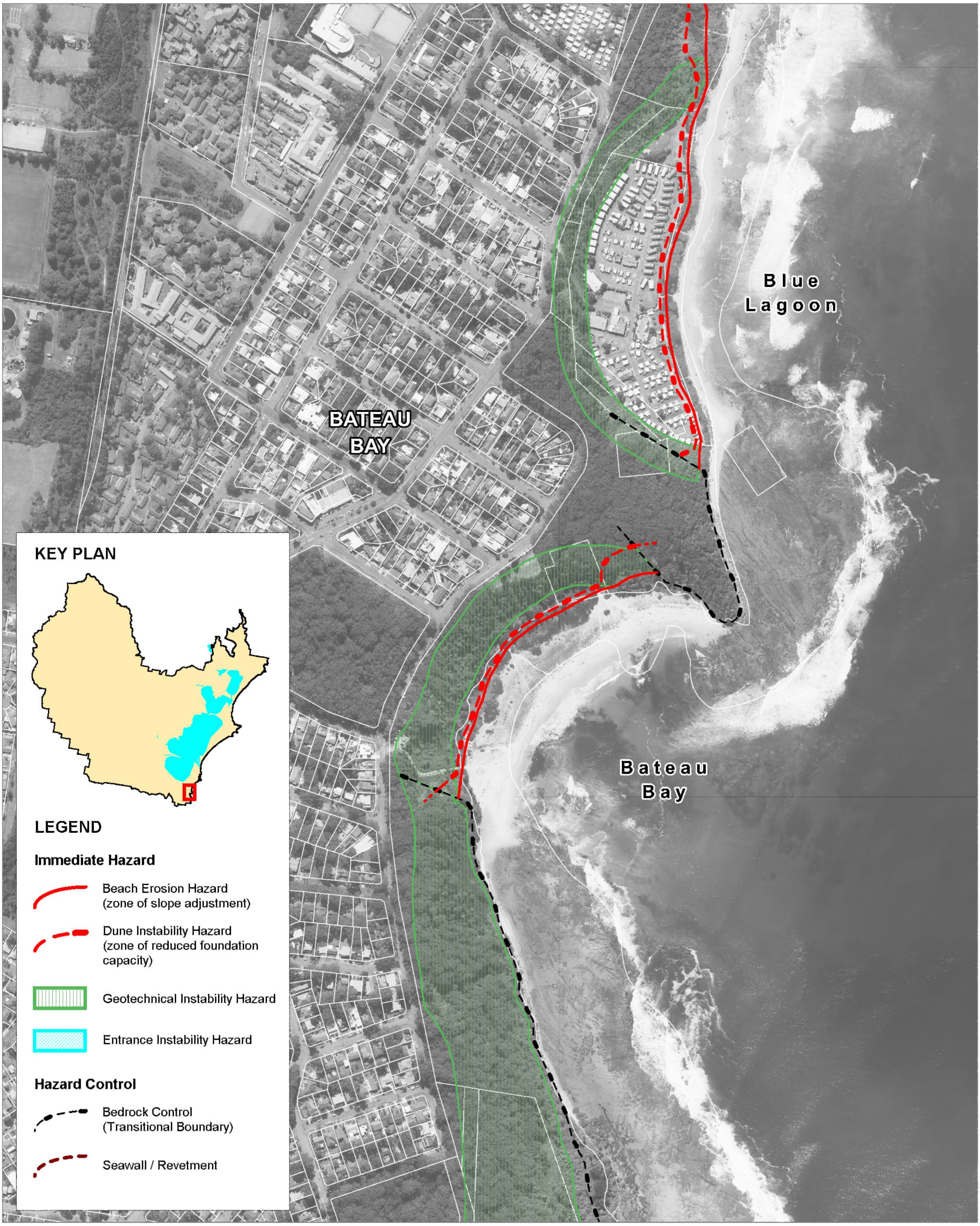
N

0 125 250m

Approx. Scale

BMT WBM
www.bmt.org

Filepath :



Title:

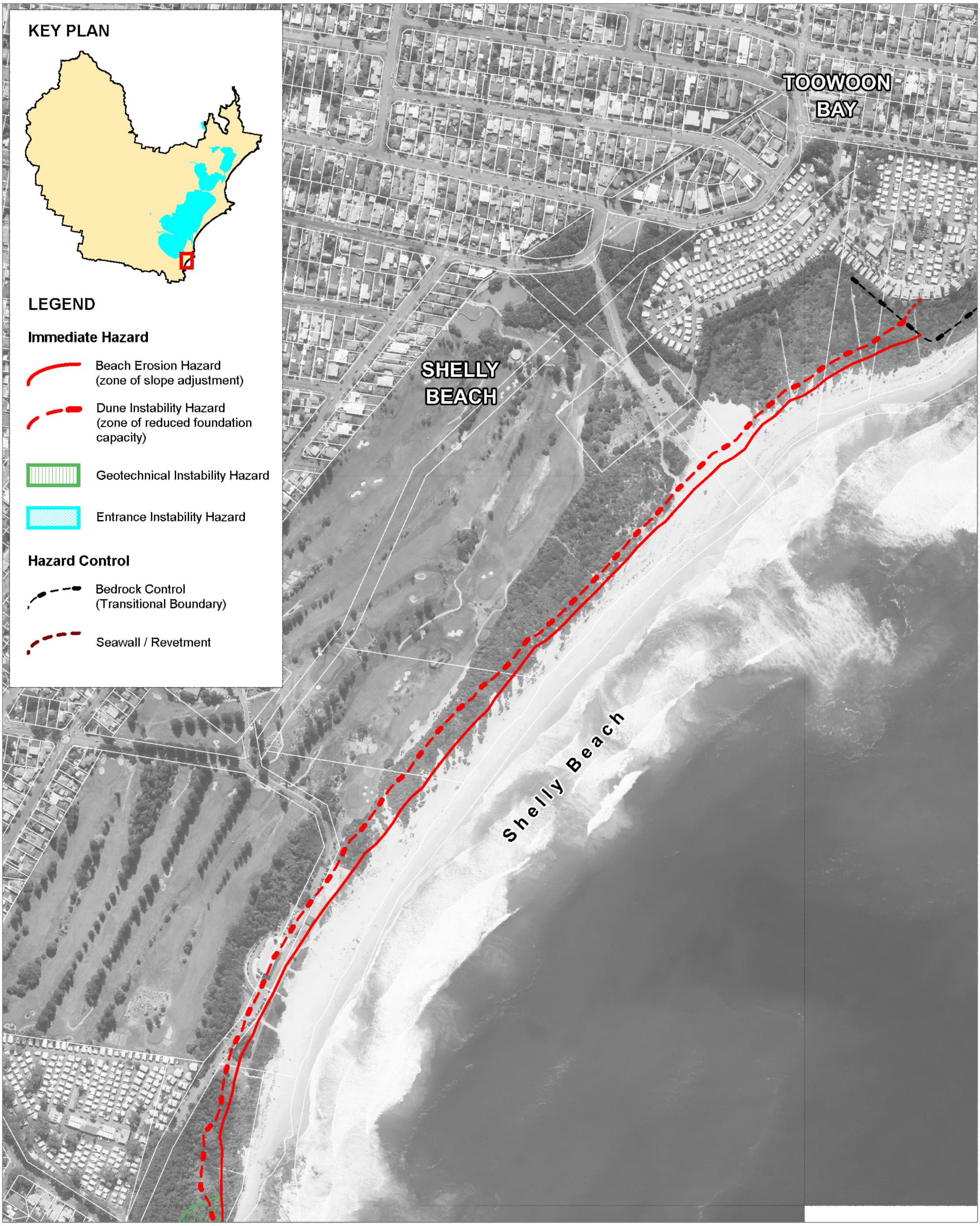
Dune Instability Hazard Definition Immediate Timeframe Only - Bateau Bay

Figure: C-02

Rev: A

BMT WBM
www.bmt.org

Filepath :



Title:

Dune Instability Hazard Definition
Immediate Timeframe Only - Shelly Beach

Figure: C-03

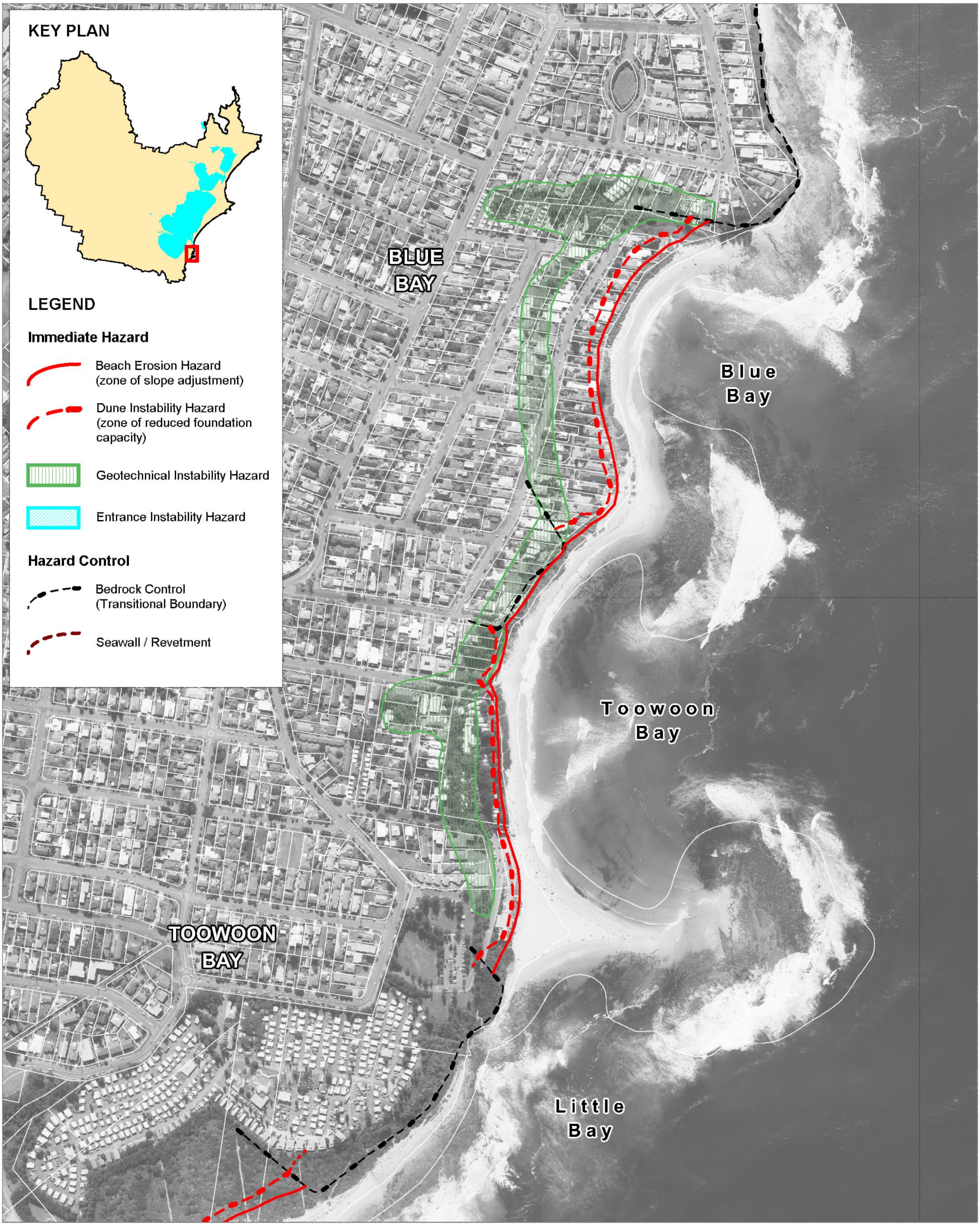
Rev: A

N

0 125 250m
Approx. Scale

BMT WBM
www.bmt.org

Filepath :



Title:

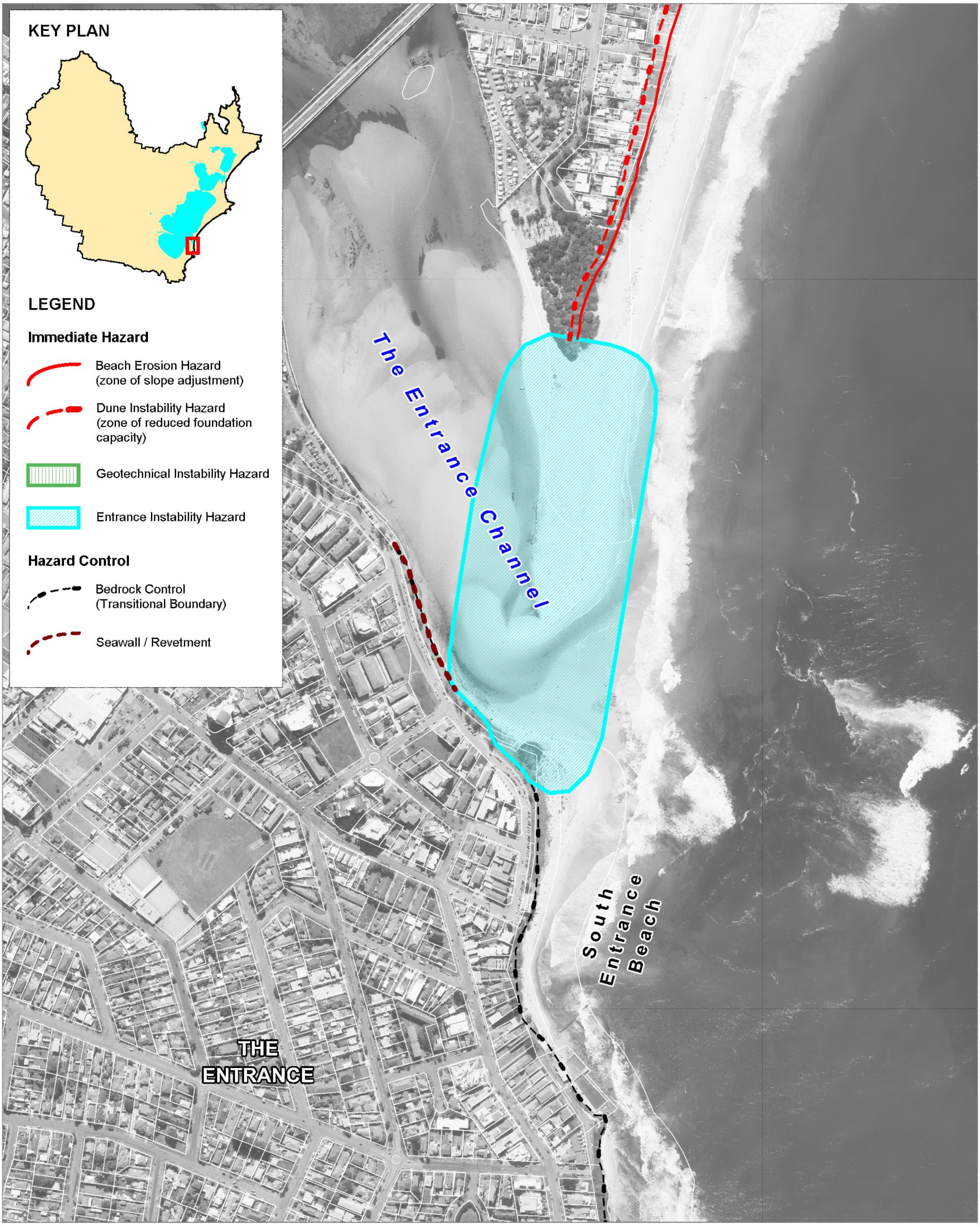
Dune Instability Hazard Definition Immediate Timeframe Only - Toowoon and Blue Bay

Figure: C-04

Rev: A

BMT WBM
www.bmt.org

Filepath :



Title:

Dune Instability Hazard Definition
Immediate Timeframe Only - The Entrance

Figure: C-05

Rev: A

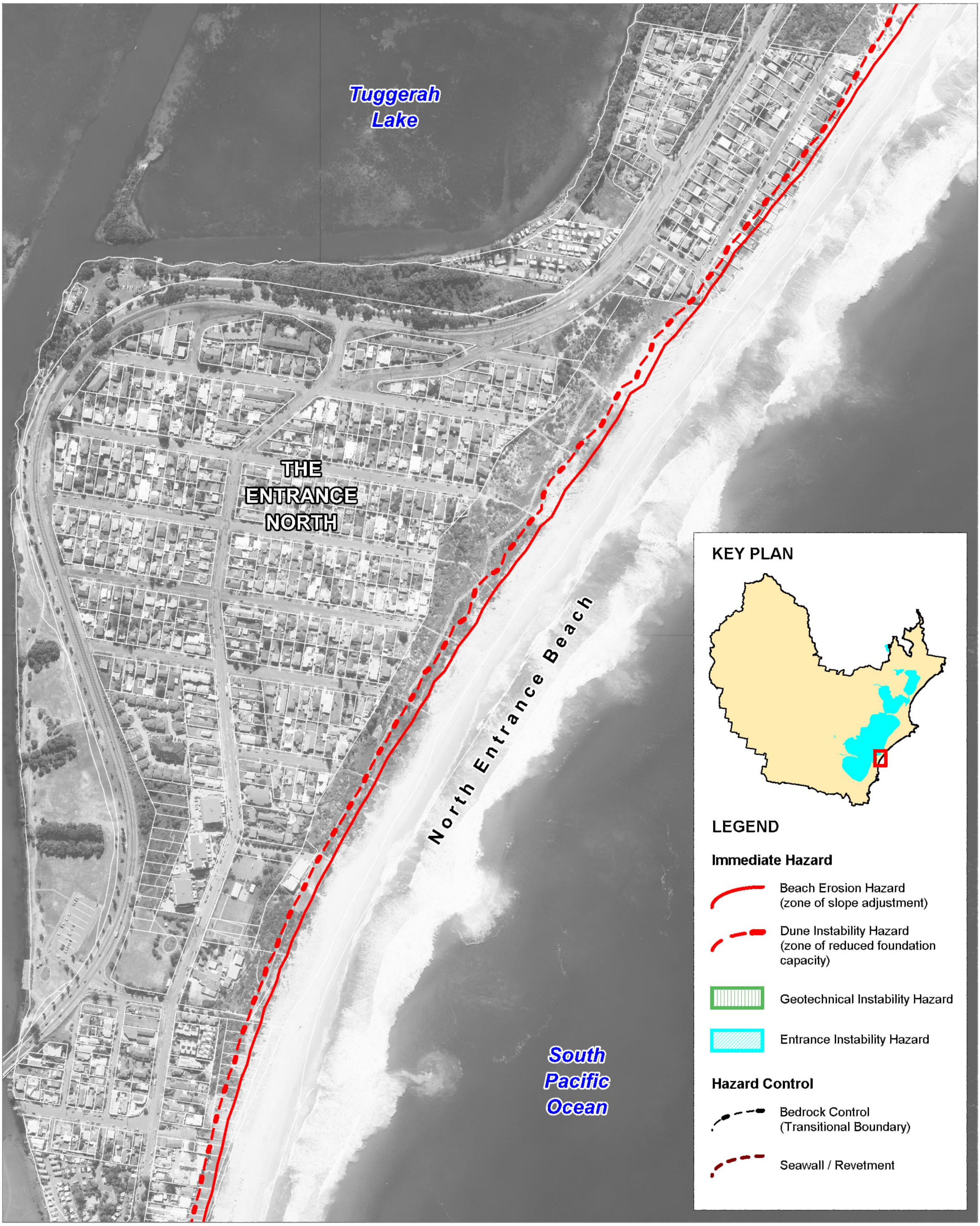
N

0 125 250m

Approx. Scale

BMT WBM
www.bmt.org

Filepath :



Title:

Dune Instability Hazard Definition
Immediate Timeframe Only - North Entrance Beach

Figure: **C-06**

Rev: **A**

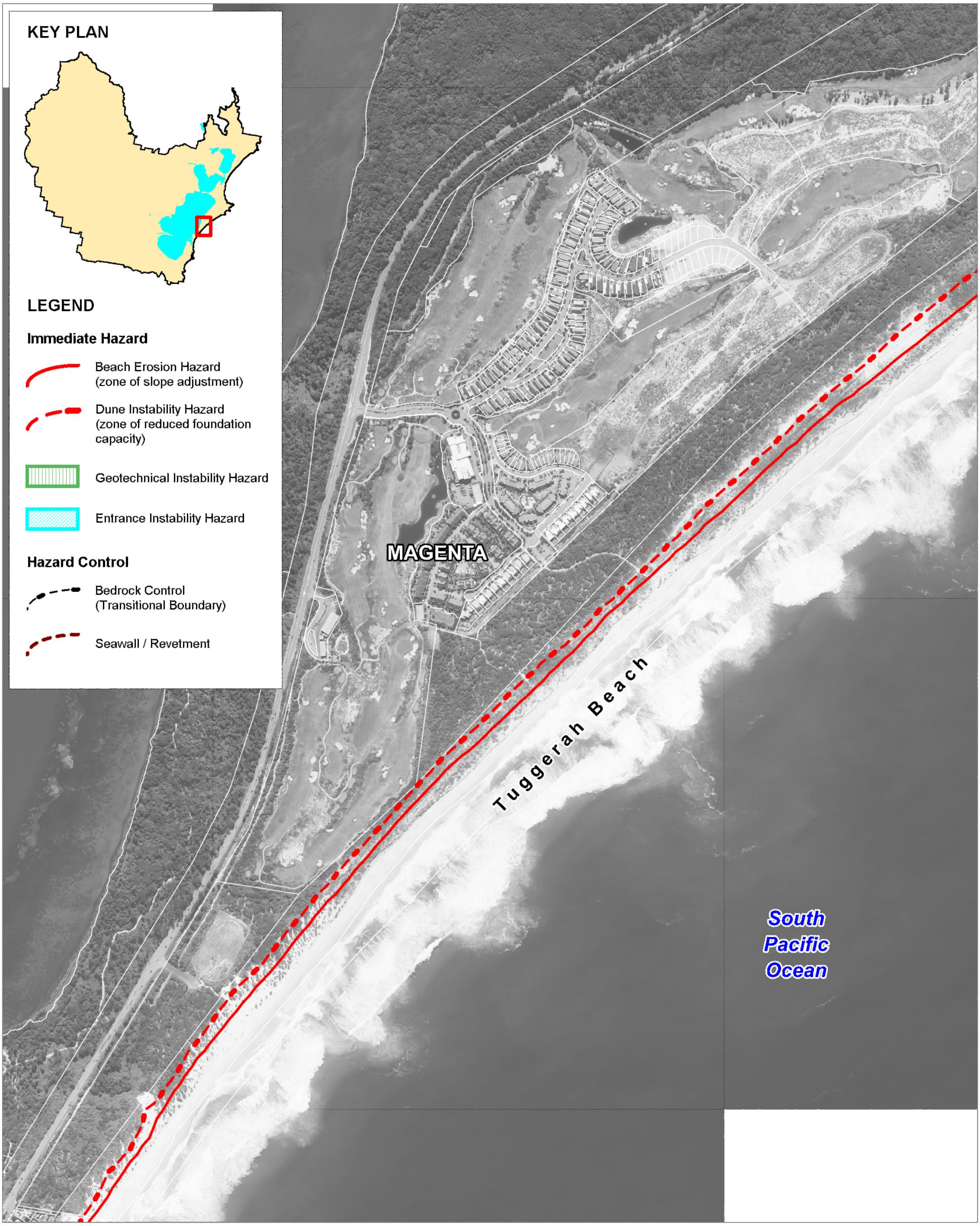
N

0 125 250m

Approx. Scale

BMT WBM
www.bmt.org

Filepath :



Title:

Dune Instability Hazard Definition Immediate Timeframe Only - Tuggerah Beach (Magenta)

Figure: C-07

Rev: A

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Filepath :

Title:

Dune Instability Hazard Definition
Immediate Timeframe Only - Pelican Beach

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N

0 200 400m

Approx. Scale

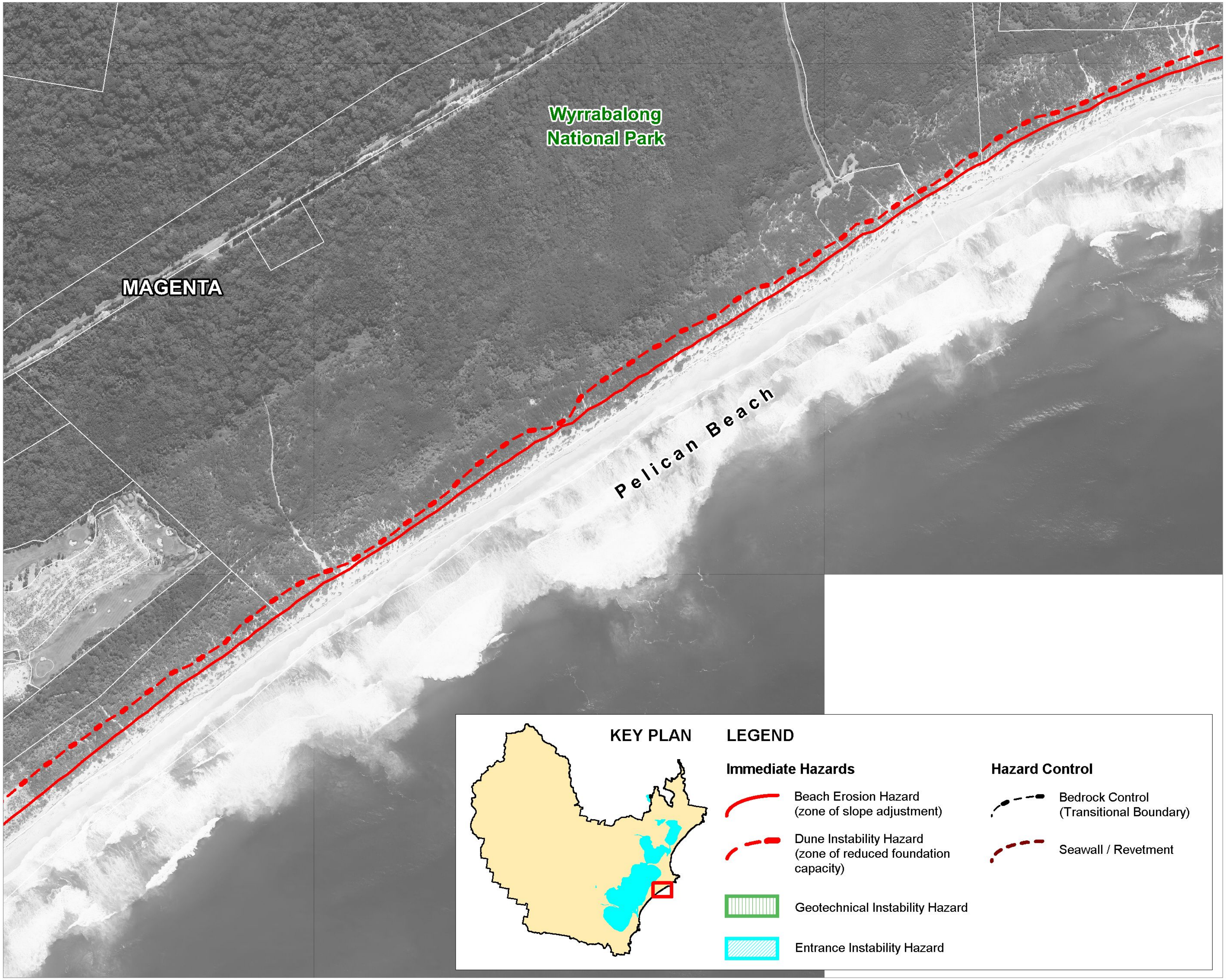
Figure: C-08

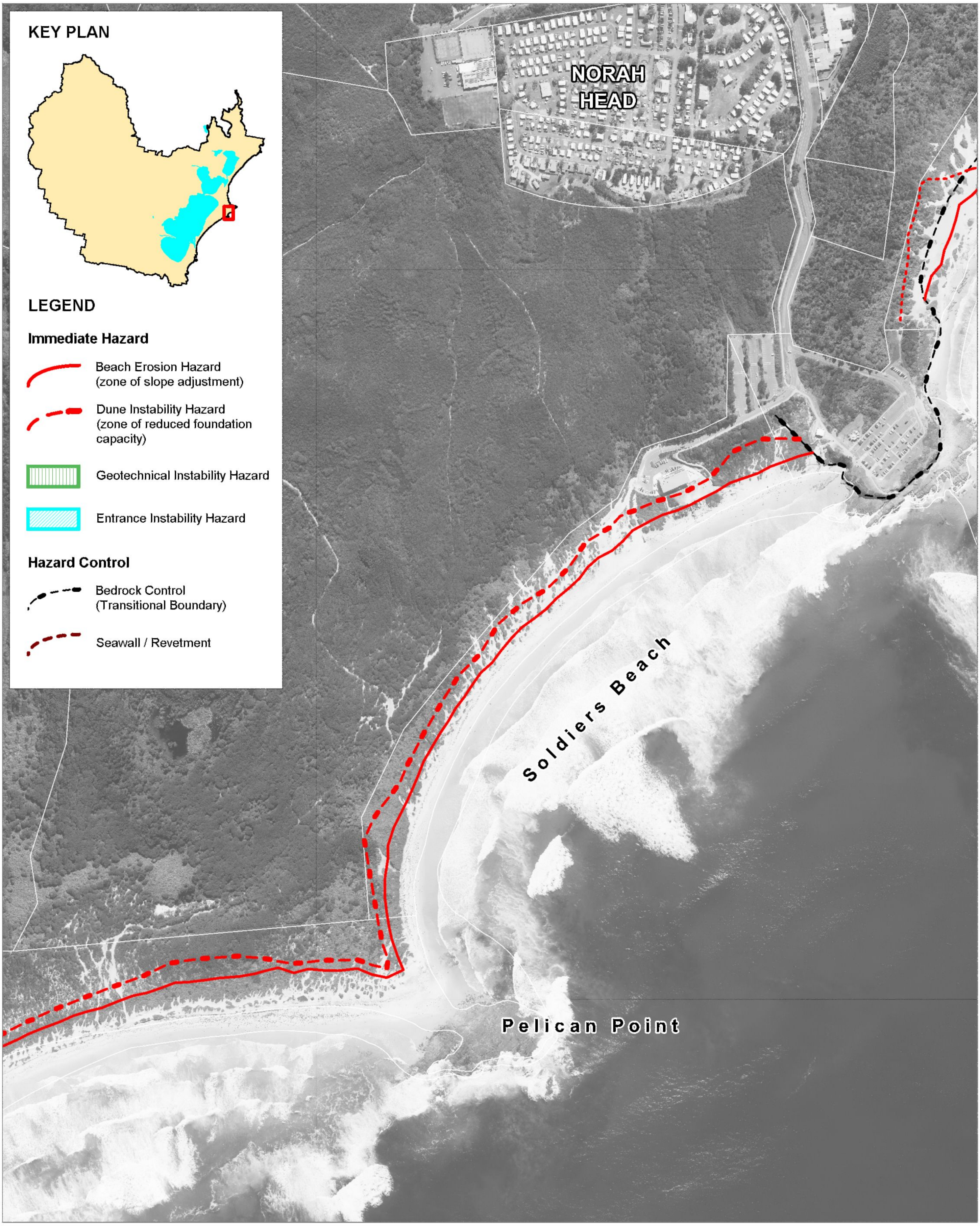
Rev: A

BMT WBM

www.bmt.org

Filepath :





Title:

Dune Instability Hazard Definition Immediate Timeframe Only - Soldiers Beach

Figure: C-09

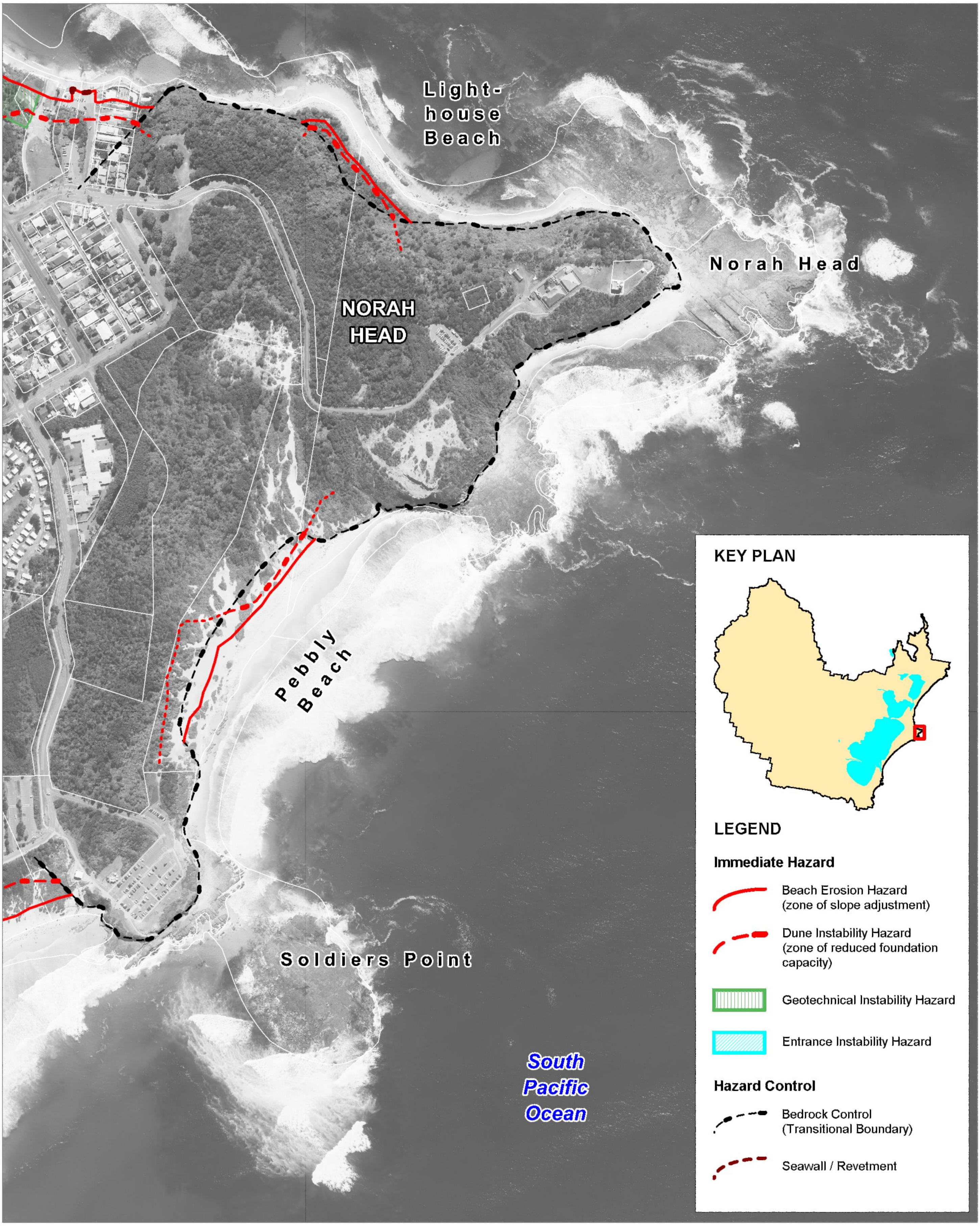
Rev: A

N

0 125 250m
Approx. Scale

BMT WBM
www.bmt.org

Filepath :



Title:

Dune Instability Hazard Definition Immediate Timeframe Only - Norah Head

Figure: C-10

Rev: A

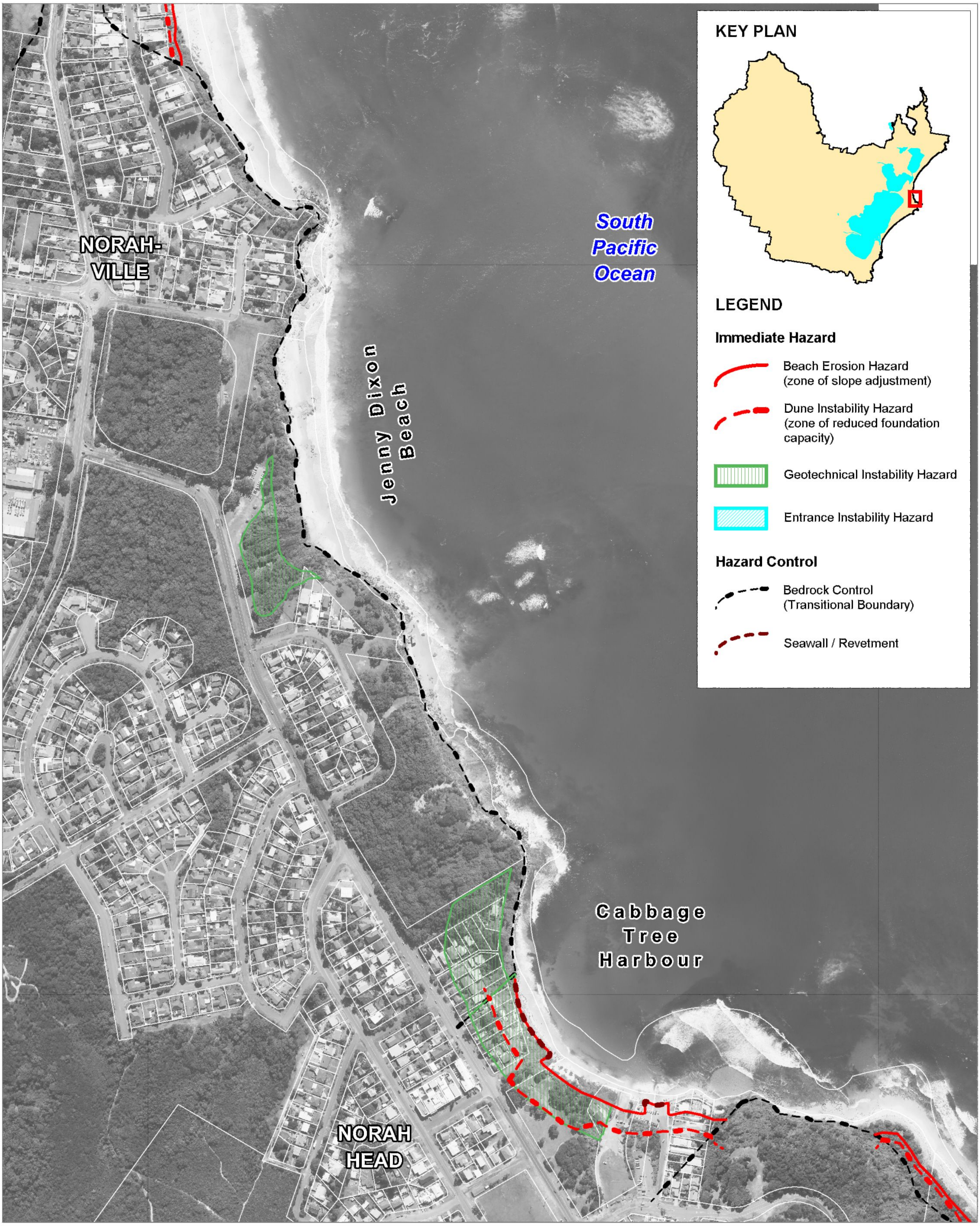
N

0 125 250m

Approx. Scale

BMT WBM
www.bmt.org

Filepath :



Title:

Dune Instability Hazard Definition Immediate Timeframe Only - Cabbage Tree Harbour

Figure: C-11

Rev: A

N

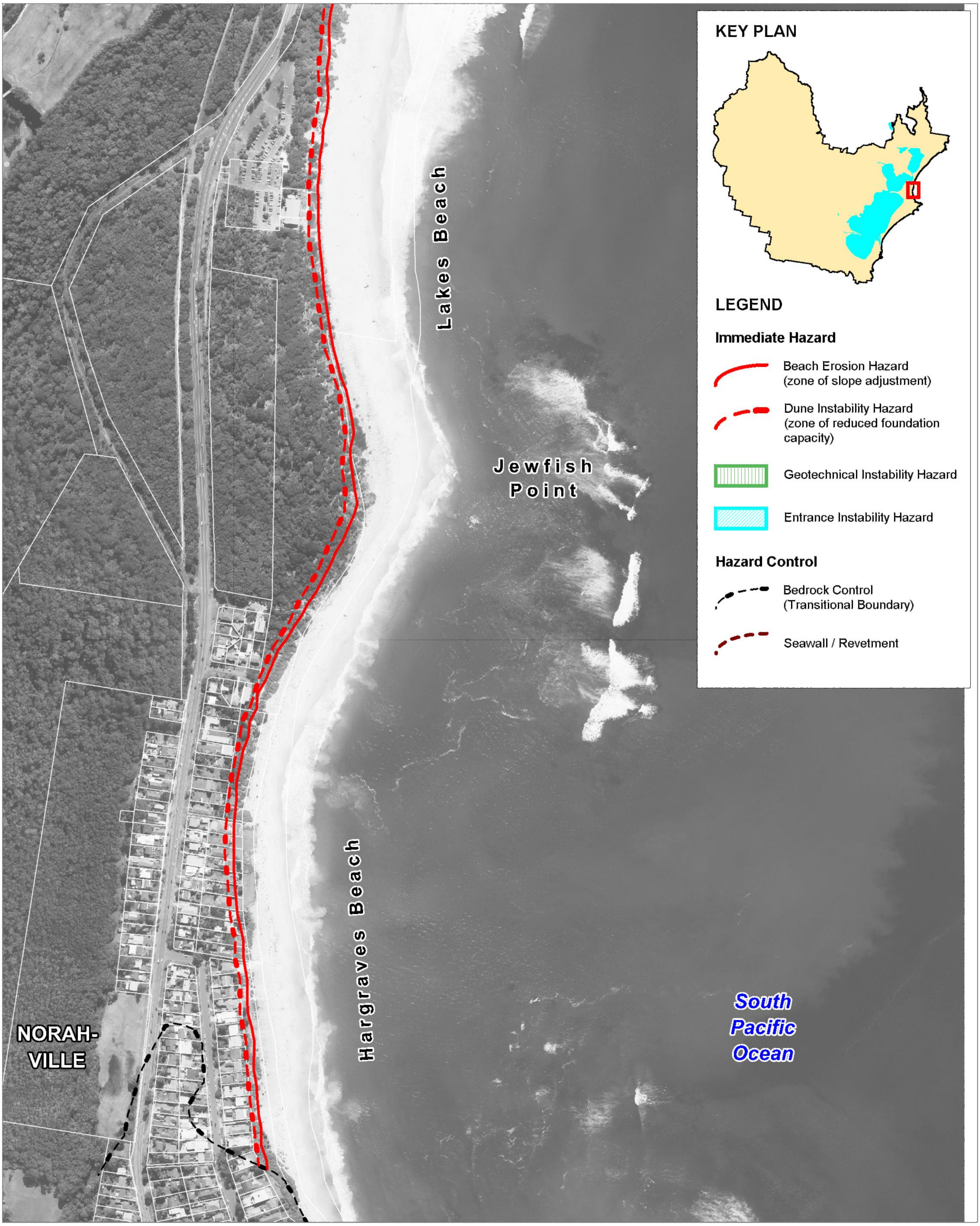
0 125 250m

Approx. Scale

BMT WBM

www.bmt.org

Filepath :



Title:

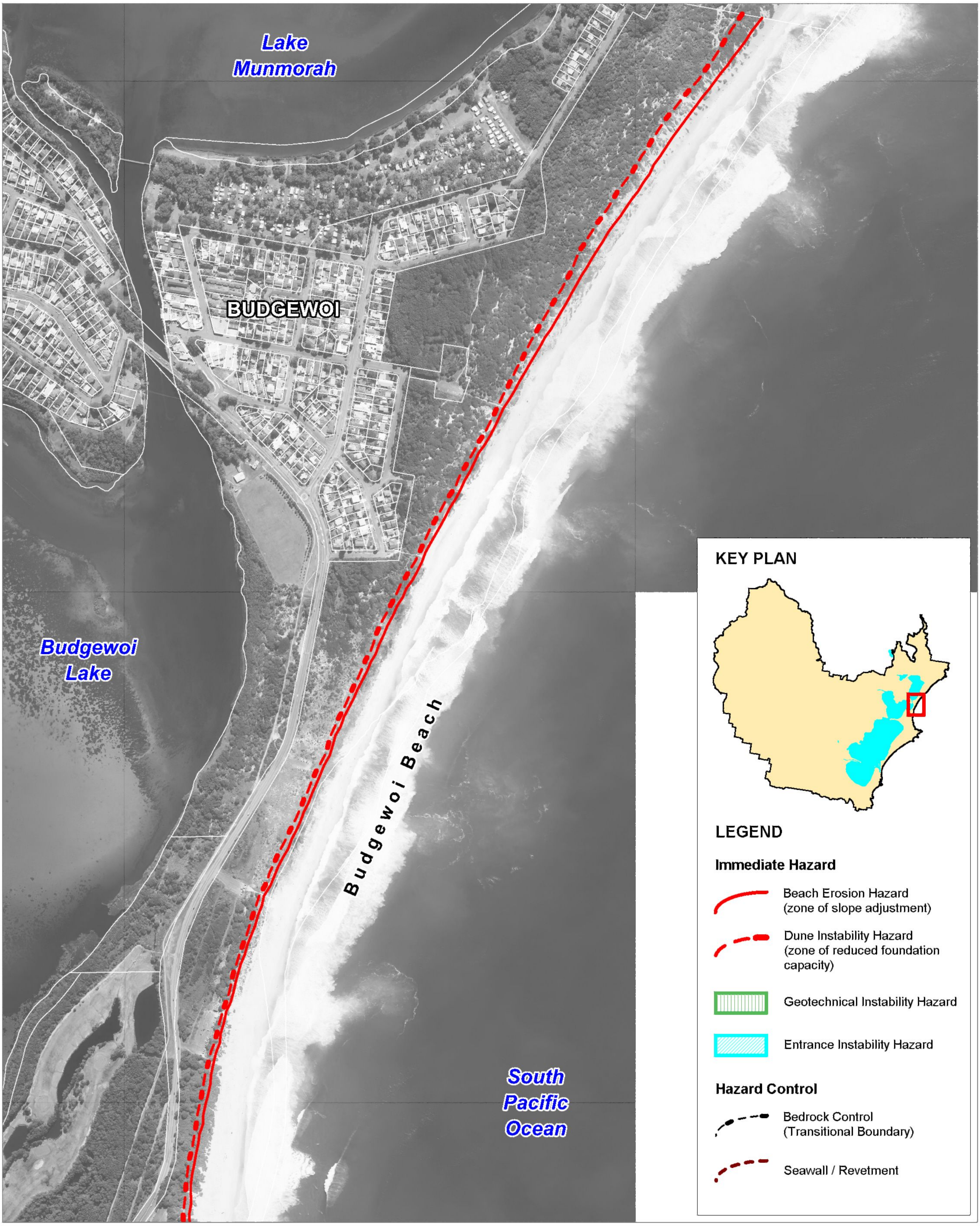
Dune Instability Hazard Definition
Immediate Timeframe Only - Hargraves Beach

Figure: C-12

Rev: A

BMT WBM
www.bmt.org

Filepath :



Title:

Dune Instability Hazard Definition
Immediate Timeframe Only - Budgewoi Beach

Figure: C-13

Rev: A

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N

0 200 400m

Approx. Scale

BMT WBM

www.bmt.org

Filepath :

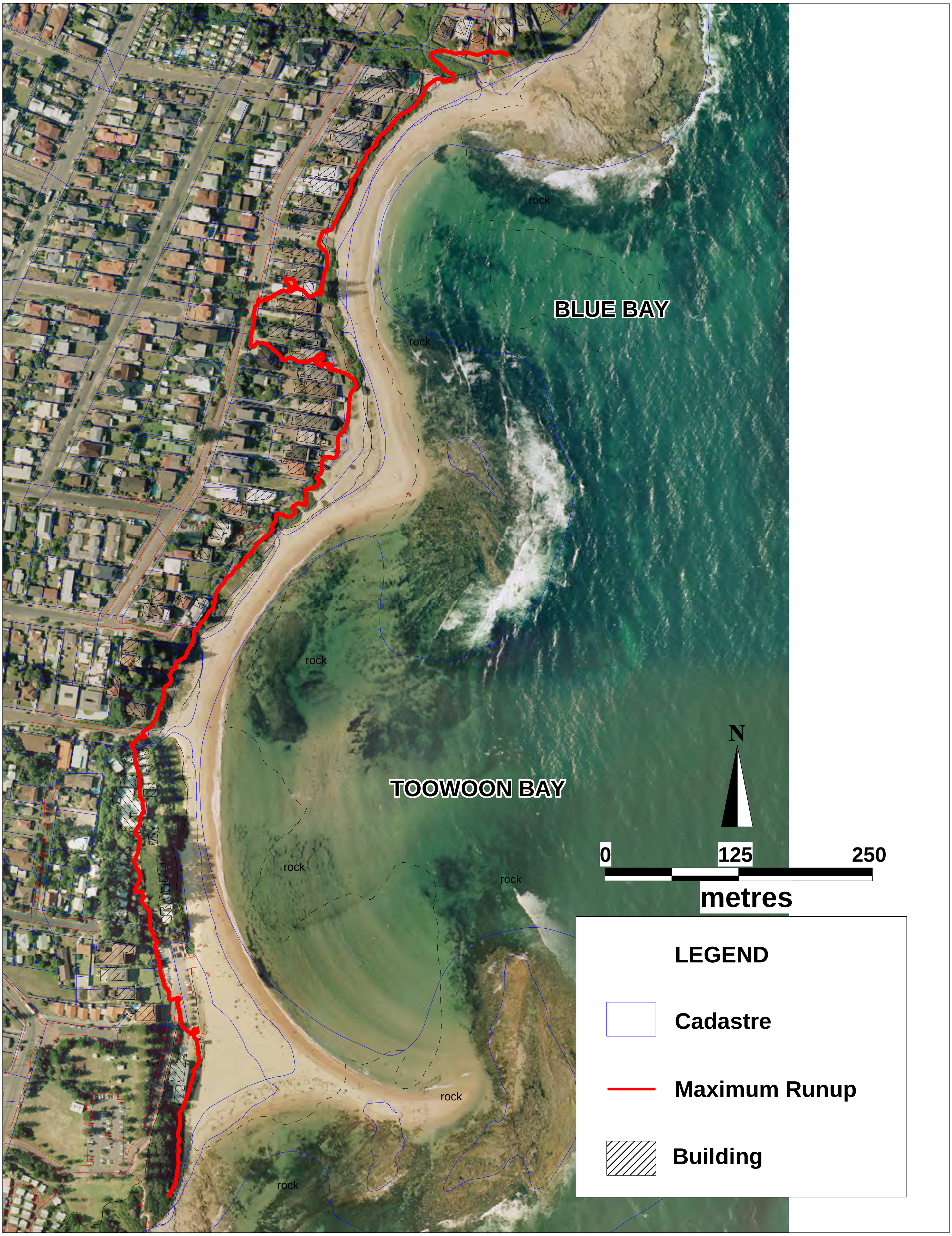
5.4 Wave Runup Mapping by SMEC

Wave runup mapping for the immediate timeframe produced by SMEC for the Wyong Coastal Hazard Study completed in October 2010 is provided below.

SMEC

Maximum Wave Runup
Shelly Beach

WYONG COASTAL
HAZARD STUDY



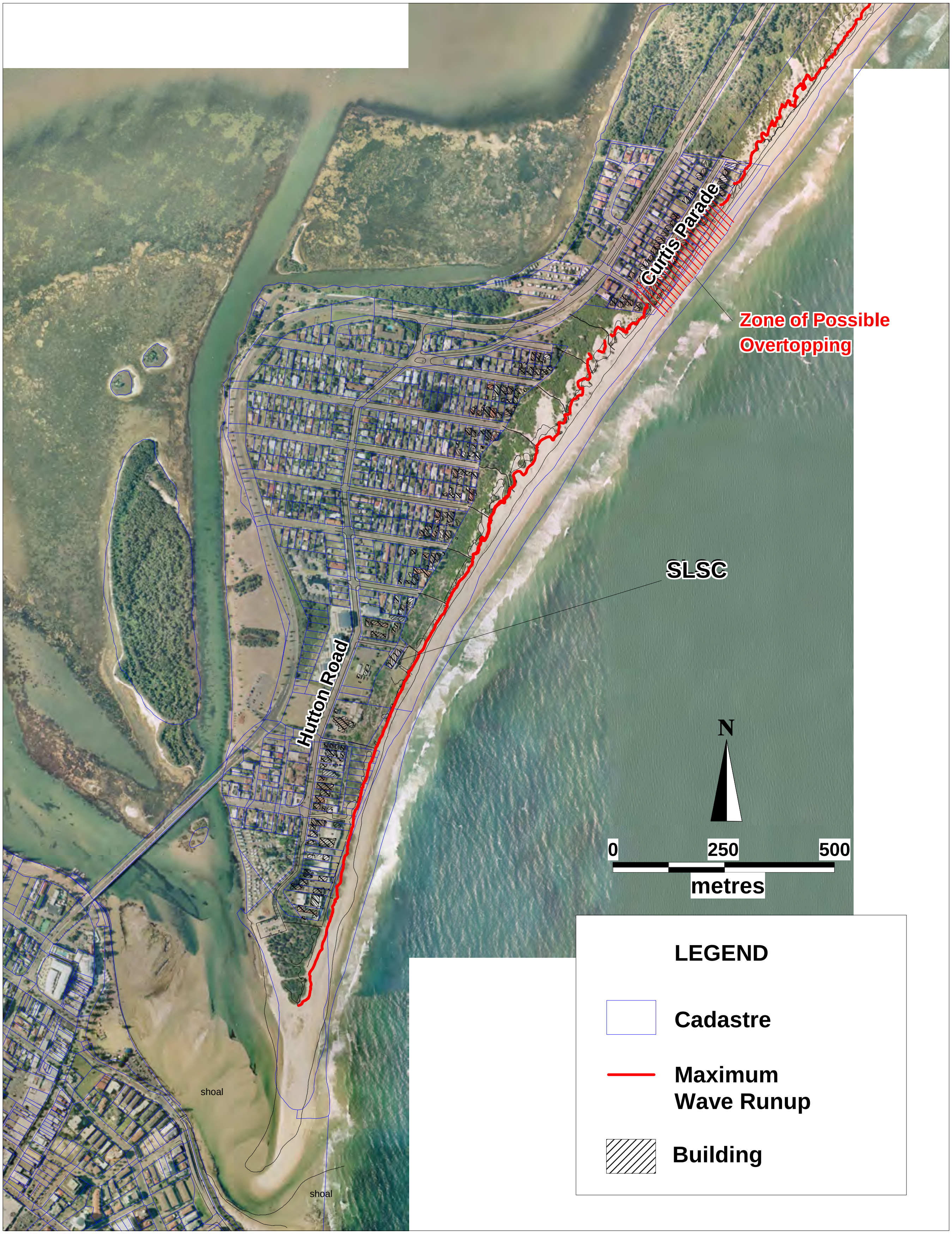
Maximum Runup
Toowoon and Blue Bays

WYONG COASTAL
HAZARD STUDY

SMEC

WYONG COASTAL HAZARD STUDY

Maximum Wave Runup South Entrance



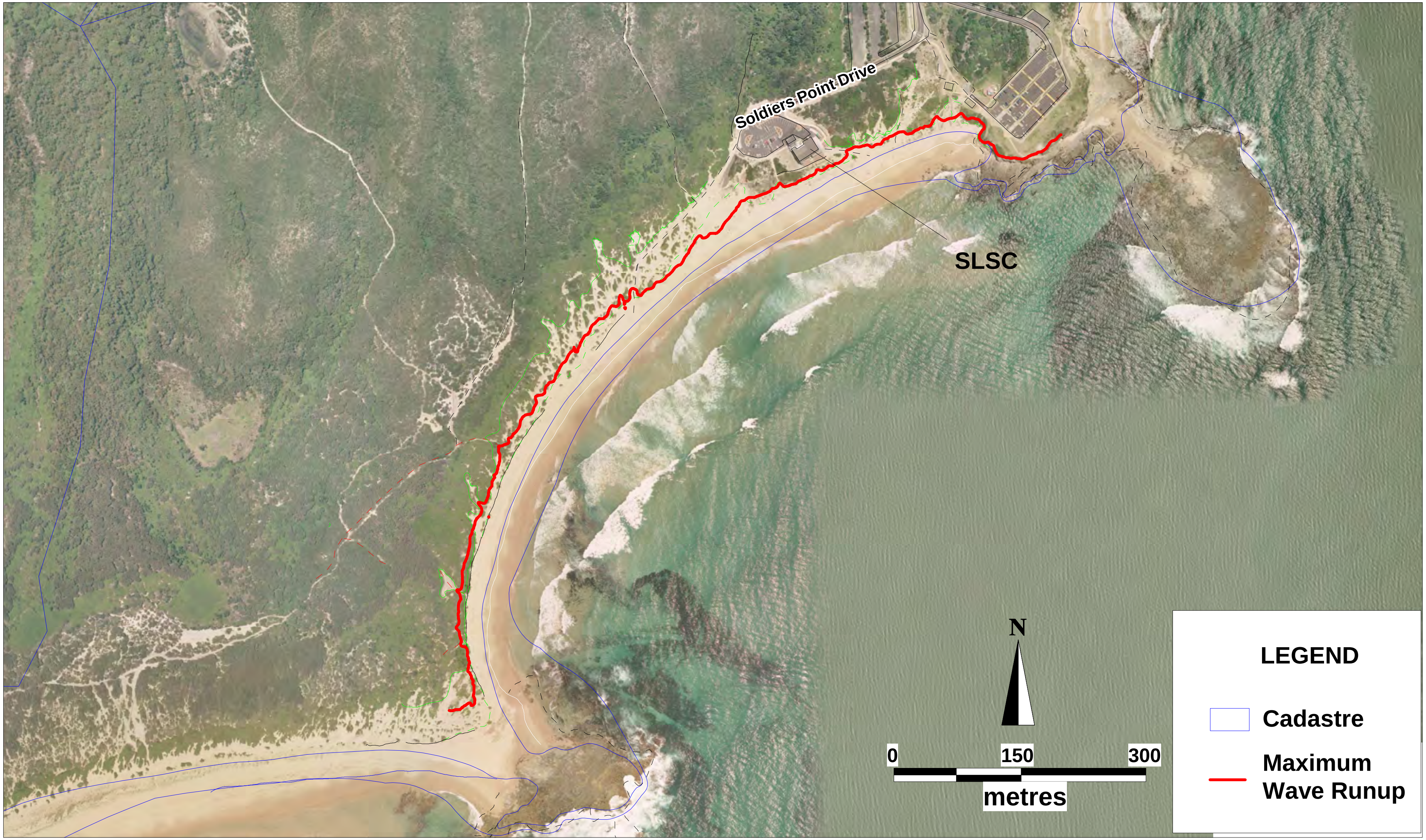
SMEC

Maximum Wave Runup North Entrance

WYONG COASTAL HAZARD STUDY

WYONG COASTAL HAZARD STUDY

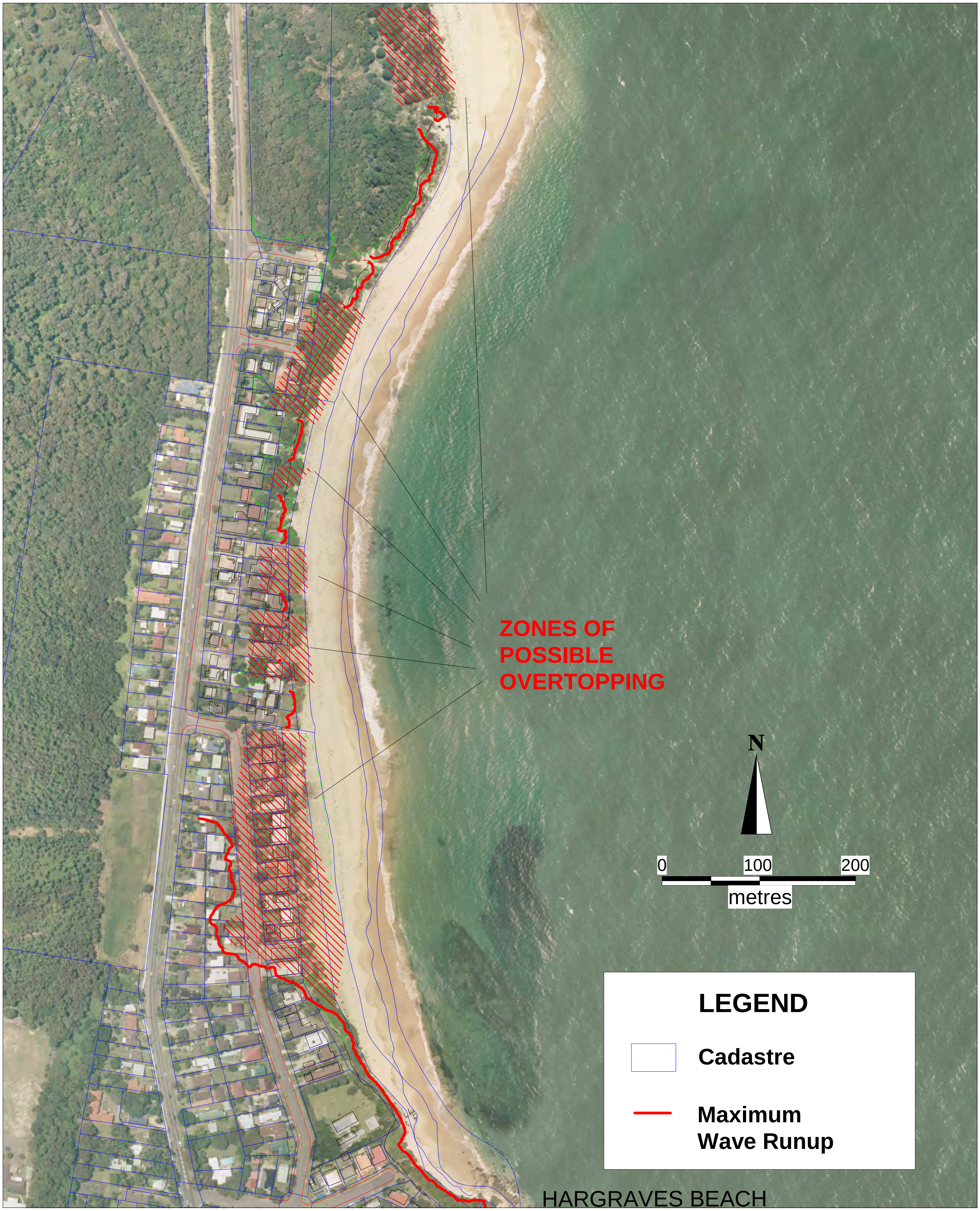
Maximum Wave Runup
North Entrance



SMEC

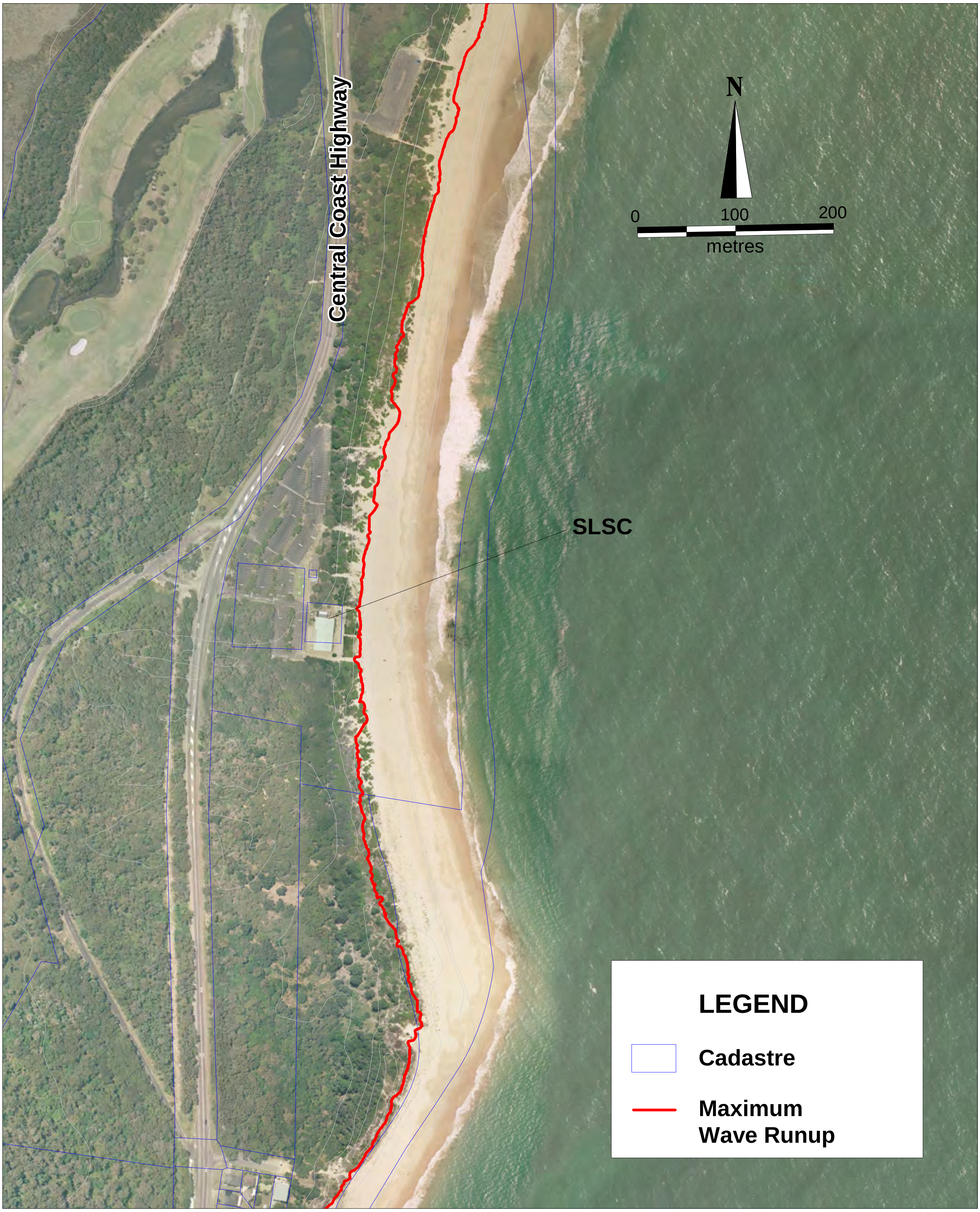
WYONG COASTAL
HAZARD STUDY

Maximum Wave Runup
Soldiers Beach



Maximum Wave Runup
Hargraves Beach

WYONG COASTAL
HAZARD STUDY



Maximum Wave Runup
Lakes Beach

SMEC

WYONG COASTAL HAZARD STUDY

Maximum Wave Runup
North of Lakes Beach

SMEC

WYONG COASTAL
HAZARD STUDY

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Appendix A Coastal Geohazard Assessment by JK Geotechnics

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BMT WBM Brisbane	Level 8, 200 Creek Street, Brisbane 4000 PO Box 203, Spring Hill QLD 4004 Tel +61 7 3831 6744 Fax +61 7 3832 3627 Email bmtwbm@bmtwbm.com.au Web www.bmtwbm.com.au
BMT WBM Denver	8200 S. Akron Street, #B120 Centennial, Denver Colorado 80112 USA Tel +1 303 792 9814 Fax +1 303 792 9742 Email denver@bmtwbm.com Web www.bmtwbm.com
BMT WBM London	International House, 1st Floor St Katharine's Way, London E1W 1AY Email london@bmtwbm.co.uk Web www.bmtwbm.com
BMT WBM Mackay	PO Box 4447, Mackay QLD 4740 Tel +61 7 4953 5144 Fax +61 7 4953 5132 Email mackay@bmtwbm.com.au Web www.bmtwbm.com.au
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