Great Lakes

Coastal Hazards Study

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GLOSSARY

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

Inshore	(1) The region where waves are transformed by interaction with the sea bed. (2) In beach terminology, the zone of variable width extending from the low water line through the breaker zone.
Inshore current	Any current inside the surf zone.
Inter-tidal	The zone between the high and low water marks.
Littoral	(1) Of, or pertaining to, a shore, especially a seashore. (2) Living on, or occurring on, the shore.
Littoral currents	A current running parallel to the beach, generally caused by waves striking the shore at an angle.
Littoral drift	The material moved parallel to the shoreline in the nearshore zone by waves and currents.
Littoral transport	The movement of littoral drift in the littoral zone by waves and currents. Includes movement both parallel (long shore drift) and perpendicular (cross-shore transport) to the shore.
Longshore	Parallel and close to the coastline.
Longshore drift	Movement of sediments approximately parallel to the coastline.
Low water (LW)	The minimum height reached by each falling tide. Non-technically, also called low tide.
Mean high water (MHW)	The average elevation of all high waters recorded at a particular point or station over a considerable period of time, usually 19 years. For shorter periods of observation, corrections are applied to eliminate known variations and reduce the result to the equivalent of a mean 19-year value. All high water heights are included in the average where the type of tide is either semidiurnal or mixed. Only the higher high water heights are included in the average where the type of tide is diurnal. So determined, mean high water in the latter case is the same as mean higher high water.
Mean high water springs (MHWS)	The average height of the high water occurring at the time of spring tides.
Mean low water (MLW)	The average height of the low waters over a 19-year period. For shorter periods of observation, corrections are applied to eliminate known variations and reduce the result to the equivalent of a mean 19-year value.
Mean low water springs (MLWS)	The average height of the low waters occurring at the time of the spring tides.
Mean sea level	The average height of the surface of the sea for all stages of the tide over a 19-year period, usually determined from hourly height readings.
Morphology	The form of a river/estuary/lake/seabed and its change with time.
Nearshore	In beach terminology, an indefinite zone extending seaward from the shoreline well beyond the breaker zone.
Nearshore circulation	The ocean circulation pattern composed of the nearshore currents and the coastal currents.
Nearshore current	The current system caused by wave action in and near the breaker zone, and which consists of four parts: the shoreward mass transport of water; longshore currents; rip currents; and the longshore movement of the expanding heads of rip currents.
Refraction	The process by which the direction of a wave moving in shallow water at an angle to the bottom contours is changed. The part of the wave moving shoreward in shallower water travels more slowly than that portion in deeper water, causing the wave to turn or bend to become parallel to the contours.
Rip current	A strong current flowing seaward from the shore. It is the return of water piled up against the shore as a result of incoming waves. A rip current consists of three parts: the feeder current flowing parallel to the shore inside the breakers; the neck, where the feeder currents converge and flow through the breakers in a narrow band or "rip"; and the head, where the current widens and slackens outside the breaker line.
Runup	The rush of water up a structure or beach on the breaking of a wave. The amount of run-up is the vertical height above still water level that the rush of water reaches. It includes wave setup.

SBEACH	A computer program, developed by the US Army Corps of Engineers, that is used to determine, among other things, wave transformation across the surf zone, beach and dune erosion and levels of wave runup on natural beaches.
Setup	Wave setup is the elevation of the nearshore still water level resulting from breaking waves and may be perceived as the conversion of the wave's kinetic energy to potential energy.
Shoal	(1) (noun) A detached area of any material except rock or coral. The depths over it are a danger to surface navigation. (2) (verb) To become shallow gradually.
Shore	That strip of ground bordering any body of water which is alternately exposed or covered by tides and/or waves. A shore of unconsolidated material is usually called a beach.
Shoreface	The narrow zone seaward from the low tide shoreline permanently covered by water, over which the beach sands and GRAVELS actively oscillate with changing wave conditions.
Shoreline	The intersection of a specified plane of water with the shore.
Significant wave	A statistical term relating to the one-third highest waves of a given wave group and defined by the average of their heights and periods.
Significant wave height	Average height of the highest one-third of the waves for a stated interval of time.
Spring tide	A tide that occurs at or near the time of new or full moon, and which rises highest and falls lowest from the mean sea level (MSL).
Storm surge	A rise or piling-up of water against shore, produced by strong winds blowing onshore. A storm surge is most severe when it occurs in conjunction with a high tide.
Sub-aerial beach	That part of the beach which is uncovered by water (e.g. at low tide sometimes referred to as drying beach).
Surf zone	The nearshore zone along which the waves become breakers as they approach the shore.
Swell	Waves that have traveled a long distance from their generating area and have been sorted out by travel into long waves of the same approximate period.
Tide	The periodic rising and falling of the water that results from gravitational attraction of the moon and sun acting upon the rotating earth. Although the accompanying horizontal movement of the water resulting from the same cause is also sometimes called the tide, it is preferable to designate the latter as tidal current, reserving the name tide for the vertical movement.

1 INTRODUCTION

Great Lakes Council (Council) is located on the NSW mid north coast approximately 300 km north of Sydney. The study area is comprised of the Council Local Government Area (LGA) coastline from Yacaaba Headland in the south to the northern end of Nine Mile Beach in the north (Figure 1).

Coastal processes have impacted sections of the coast, with some areas experiencing damage to public assets and impacts on recreational amenity. The coastal hazard is likely to increase with time given current scenarios for climate change and projected sea level rise. Current legislative policy requires that, the State Government's sea level rise planning benchmarks of a 0.4 m rise by 2050 and 0.9 m rise by 2100 relative to 1990 mean sea levels (DECCW, 2009a and 2009b) be considered when assessing coastal processes. Increasing pressures on the natural resources along the coast are significant, and include population growth, growing residential development demands along the foreshore, coastal township expansion and tourism.

1.1 Great Lakes Council's Planning Benchmarks

Council has adopted as policy the NSW Sea Level Rise Policy Statement, (NSW Govt, 2009). The policy statement establishes sea level rise projections (benchmarks) for the years 2050 and 2100 relative to 1990 mean sea levels. These are 40 cm and 90 cm respectively.

Consistent with state benchmarks Council employs a rolling benchmark period of approximately 50 years out from the current year. This represents the nominal design life of a development whether residential or commercial, in the coastal zone. This better meets the needs of development assessment and strategic planning. At present Great Lakes sea level rise benchmark years are: 2010, 2060 and 2100 equating to 13 cm, 50 cm and 90 cm respectively, above 1990 mean sea levels. Following the anticipated review of sea level rise and associated mapping in 2015 Council benchmark years will then become 2015, 2065 and with 2115 possibly becoming the overall planning horizon.

The current benchmarks (2010, 2060, & 2100) are therefore applied to calculations, discussion and mapping related to coastal processes within these reports. It is further noted that where warranted, by virtue of development importance or anticipated life, the 2100 benchmark may be applied in order to provide a reasonable likelihood of achieving suitable investment performance.

1.2 The Coastal Zone Management Plan

The Coastal Zone Management Plan (CZMP) will help Council identify sustainable ways to manage coastal hazards and protect the coastal zone. It will reflect the most up-to-date coastal hazard information.

Funded by Council and Office of Environment & Heritage (OEH), the Great Lakes Coastal Zone Management Plan is being prepared under the NSW Coastal Protection Act and NSW Coastal Policy.

The new "Guidelines for Preparing Coastal Zone Management Plans (2010)" was gazetted on 31 December 2010 which provides strategic guidance for the development of Coastal Zone Management Plans, explained in Table 1.

Table 1: Indicative phasing for Coastal Zone Management Plan preparation

Phase	Description	Options for staging preparation of a CZMP	
		CZMP for coastlines	CZMP for estuaries
1	Identify hazards/management issues and their severity	Coastal hazard study	Estuary condition study
2	Identify and evaluate management options	Coastal Zone Management Plan for Great Lakes Coastline	Coastal Zone Management Plan for Great Lakes estuary
3	Propose management actions in implementation schedule		

Councils are to submit draft CZMPs to the Minister administering the *Coastal Protection Act 1979* for certification under the Act.

This report covers the first stage of the CZMP process, preparation of a Coastal Hazard Study for the Council coastline.

1.3 Coastal Hazard Zone Definition

Coastal hazard zones (or areas) are essential for land-use planning and development assessment purposes. The immediate hazard area represents the landward extent of beachfront land that could be at direct threat from beach erosion resulting from a single extreme event or from several very severe beach erosion events in close succession with cumulative impacts, commonly referred to as 'storm bite'. In addition to storm bite, an adjoining zone of reduced foundation capacity will exist landward of an erosion escarpment in sandy dunal systems, as described by Nielsen *et al* 1992 (see Figure 2).

It is also important to estimate the extent of land that could be impacted upon by coastal processes and hazards (including sea level rise) over longer-term planning horizons (such as 2050 and 2100). These areas encompass the immediate hazard area whilst incorporating allowances for underlying long-term recession of the shoreline that could result from long term sediment imbalance within the active beach system or from measured and projected sea level rise. In addition to underlying recessionary trends, projected sea level rise will increase recession rates over the adopted planning period, resulting in a landward movement of coastal hazard areas over time (see Figure 2).

Further details regarding coastal hazard zones are provided in Section 5.

1.4 The Great Lakes Council Coastline

The Council coastline comprises long open-coast beaches (e.g. Nine Mile Beach or Seven Mile Beach) and several cliffs or bluffs backing pocket beaches (e.g. Burgess Beach or Pebbly Beach). T he beaches of Great Lakes are mainly directly exposed to the open-coast wave climate. Some erosion is visible on the dunes and foredunes at the various beaches all along the coast. Infrastructure such as beach access has been directly impacted by erosion, although the impacts are relatively minor. Large dune blow-outs (resulting from wind processes) are visible at various locations such as the northern end of Bennetts Beach and the northern end of One Mile Beach.

The Council coastline is mostly composed of undeveloped beaches with only a few locations where the coastline is backed by urban development (e.g. Forster or Seal Rocks).

The beaches which are subject of this study are listed from north to south below:

- Nine Mile Beach: long open-coast beach with the dune in a mostly natural state
- Forster Main Beach: small beach backed by development
- Pebbly Beach: small pocket beach with rock outcrops at either end
- One Mile Beach: open-coast beach backed by urban development
- Burgess Beach: pocket beach protected by rock outcrops all along the beach
- Seven Mile Beach: long open-coast beach
- Elizabeth Beach: pocket beach
- Shelly Beach: pocket beach
- Sandbar Beach: open-coast beach fronting Smiths Lake
- Number One Beach: open-coast beach
- Boat Beach: pocket beach backed by development
- Lighthouse Beach: open-coast beach
- Treachery Beach: long open-coast beach
- Bennetts Beach: long open-coast beach
- Jimmys Beach: estuary beach on the northern shoreline of Port Stephens backed by some development

The location of the different beaches along Great Lakes coastline is represented in Figures 3 and 4.

Two main estuaries are included within the study area:

- Wallis Lake: its entrance is located between Tuncurry and Forster. The entrance is trained by breakwater on both southern and northern sides
- Smiths Lake: its entrance is located along Sandbar Beach. This lake is an ICOLL (intermittently close and open lake or lagoon) and its entrance is natural

Most development areas within the study area have significant setbacks from the coastline.

This report documents a detailed coastal hazard assessment of the aforementioned beaches, which has been undertaken using photogrammetric data analysis and analytical assessments. It describes the coastal processes affecting the Great Lakes beaches and the impact of these processes on the areas of the beach where properties or assets are at risk. The report quantifies the observed long-term beach changes along Council's shoreline as well as estimating the shoreline recession that may be caused by projected sea level rise as a result of climate change. The risk to property is defined in terms of the present day risk, 2060 planning period and the 2100 planning period.

Some additional beaches are located along the Council coastline but are located within National Parks (i.e. McBrides Beach, Fiona Beach and Mungo Beach) or have already been subject of a coastal hazard study (i.e. Blueys and Boomerang Beach). These beaches are not considered herein. Due to the unique coastal processes operating at Jimmys Beach, Jimmys Beach is the subject of a separate coastal processes/hazard study, included within this study as Appendix E.

1.5 Geomorphology

The Tasman Sea margin of southeast Australia is 1,500 km long and is relatively narrow and sediment deficient by world standards (Boyd et al. 2004). The coast is also subject to strong littoral drift from south to north. It is generally well accepted for northern NSW (north of Seal Rocks) that there is a net northward littoral drift of sand with transport rates of approximately 500,000 m^3 per year (Carley et al. 2005).

Council lies close to the southern end of the subtropical zone where the East Australia Current brings warm water from offshore of tropical Queensland south along the NSW coast. This water mixes with cooler temperate waters from further south, and the boundary between these two zones is close to the Great Lakes area. Figure 5 is a diagram showing sea surface temperatures off the NSW coast, which illustrate the influence of the East Australia Current. The East Australia current results in southward transport of fine sediment from rivers such as the Macleay at the outer zone of the continental shelf, leaving depressions in the continental shelf filled with coarse grained sand.

The present coastline was formed over the last 6,500 years since the end of the last Ice Age. Sea levels rose from 120 m below present values to 1 – 2 m above present around 6,500 years ago. Between 6,500 and 3,000 years ago, sea levels fell to around their present level and have remained stable ever since. In New South Wales, Pleistocene and Holocene barriers were built within rocky embayments along the coastline and the morphology of the Forster-Tuncurry coastal zone confirms this phenomenon. The sedimentary environment of the Forster-Tuncurry coastal zone covers around 270 km^2 and includes various types of sediments as shown in Figure 6 (Melville, 1984).

The coastal zone of Great Lakes comprises two compartments that were established by the presence of a centrally located offshore island known as Cape Hawke Island (DECCWc, 2009). In the northern compartment, three bay barriers were formed during the late Pleistocene as part of a coastal progradation creating Nine Mile Beach while in the southern compartment the refracted waves have formed a tombolo-like lagoon barrier between Seven Mile Beach and Wallis Lake by joining Cape Hawke to Booti Hill headland (Figure 6).

Within the northern bay, the Holocene barrier shows a significant coastal progradation with a broad backbarrier and around sixty beach ridges whereas Holocene sediments in the southern bay were superimposed upon low-lying and partly eroded late Pleistocene lagoon barrier.

From the backbarrier and beach ridges characteristics it can be seen that the shoreline of the embayment north of Cape Hawke migrated in a seaward direction by around 2,200 m in the last 6,000 years.

A summary of the creation of the coastal zone of Forster-Tuncurry is represented in Figures 7a and 7b.

Nearshore marine habitat mapping using side-scan sonar has recently been conducted by the former Department of Environment, Climate Change and Water along the NSW coastline (DECCW, 2009c). This mapping has identified sediment distribution and bathymetry at a fine scale offshore of different locations along the Great Lakes LGA coastline for the purposes of mapping seabed habitats. The nearshore area consists of a series of complex reefs, interspersed by sandy or gravelly sediments. An extract from the mapping illustrating the extent of the reef is illustrated in Figure 8.

2 SITE OBSERVATIONS

2.1 Introduction

In addition to the assessment of coastal hazards by analysis of the available data, site observations were made about the different beaches and characteristic places along Council coastline. A site visit was conducted by SMEC's project team between 21 and 23 July 2010. Notes from that site visit are provided below.

2.2 Nine Mile Beach

Nine Mile Beach is a long open-coast beach.

2.2.1 Northern Half

This part of the beach is located along Darawank Nature Reserve. A beach access is located at the northern end of the beach, at the northern boundary of Great Lakes Council. This access allows four-wheel drives (4WD) to reach the beach but a lack of formal management of the 4WD access is noticeable as some tracks are visible through the incipient foredune (Figure 9). It may be beneficial to formalise 4WD access and fence the incipient dune to avoid further damage.

A significant erosion escarpment (around 2 m high) due to the full exposure to wave climate (Figure 10) was observed. However, there are large reserves of sand in the dune and the dune vegetation is in good condition. No public or private assets appear to be exposed to immediate coastal erosion risk in this area.

2.2.2 Southern Half

The Golf Club at Tuncurry is located approximately 200 m from the beach and does not appear to be at imminent risk from coastal erosion.

An entrance breakwater is located at the southern end of the beach to stabilise Wallis Lake entrance. The breakwater is generally in good condition with large rock armour. However, a short section where the breakwater and back beach dune system coincide has suffered damage due to localised scour and reshaping of small armour rocks placed for repairs (Figure 11). The landward part of the breakwater could be subject to overtopping which may generate risk for pedestrians (Figure 11). Some armour rocks appear to be missing at the top of the seawall located within the entrance (Figure 12) which may be indicative of this overtopping. A very strong ebb tide current was observed within the entrance channel making difficult for fishing boats to motor against the current.

Dune rehabilitation was undertaken in 1993 in this area. The dune has been fenced and some wind protection has been installed to prevent dune blow-out (Figure 13). A two-metre erosion escarpment was observed behind the fences (Figure 14) but no development appears at immediate risk due to extensive dune sand reserves and healthy vegetation. The board and chain access to the beach is very steep which could lead to user safety issues (Figure 15).

2.3 Main Beach

2.3.1 Northern Half

An entrance breakwater is located at the northern end of the beach to stabilise Wallis Lake entrance. Hanbars have been used to protect the head of the breakwater (Figure 16) indicating significant wave energy exposure.

The northern part of the beach has suffered from erosion with a steep dune face as the beach is relatively exposed to ocean waves. However, there is no development immediately behind the dune (Figure 17). A gully has formed due to uncontrolled access and formal access may be beneficial in this area (Figure 18).

2.3.2 Southern half

The southern half of the beach is backed by a vertical seawall protecting the roadway, car park and buildings located along the beach (Figure 19). A cafe and the SLSC are also protected by this vertical seawall (Figure 20). This seawall appears to be in good condition. However, the depth to which the seawall is founded is unknown. The integrity of the seawall is reliant on maintained adequate toe embedment following storm erosion to -1 m AHD.

An ocean swimming pool has been built on the natural rock outcrop at the southern end of the beach (Figure 21). A stormwater outlet is located adjacent to the swimming pool and some rock protection has been placed in front of the outlet. Litter was observed on the rocks in front of this stormwater outlet (Figure 22). There are good facilities for day visitors (e.g pool, picnic area, shelters or change room).

There is no dune in front of the seawall but the beach berm is relatively wide (Figure 19). The southern part of the beach is more protected from wave energy than the northern part due to the presence of the headland and reefs at the southern end. The coastal bluff directly south of Main Beach has a very steep slope and may be impacted by wave action (Figure 23).

2.4 Pebbly Beach

Pebbly Beach is a small north-facing pocket beach with rock outcropped at either end (Figure 24). A dune system is present backing the western side of the embayment while the eastern side of the embayment is backed by clay material. A small storm bite was visible along the beach but no development appears to be at immediate risk from coastal erosion. The dune system is well vegetated. The wave climate is low due to the presence of rock and the beach orientation. A toilet block is close to the beach founded on clay material outcrops.

East of Pebbly Beach, Bennetts Head Drive is located close to the coastal bluff edge near the intersection with Boundary Street (Figure 25). At this location new fences have been built closer to the road than the old fences to manage pedestrian safety.

2.5 One Mile Beach

One Mile Beach is an open-coast beach.

2.5.1 Northern Half

A significant dune is present at the northern end of the beach (Figure 26). This dune is subject to stability issues with dune blow-out causing sand to impact houses behind the beach (Figure 27) and user safety issues with the sand covering the fences at the top of the coastal bluff (Figure 28). Fencing of the coastal bluff should be maintained for pedestrian safety. There is the potential for long term sand loss from the beach system to occur through the mechanism of wind-blown sand.

A significant erosion escarpment around three metres high was observed along the beach (Figure 29). A small creek flowing out of the Golf Course had been opened by heavy rains at the time of the site visit but it is expected that the creek entrance would be closed rapidly by sand buildup at the beach berm (Figure 30). An old board and chain access to the beach was damaged at the northern end and may need to be replaced (Figure 31).

2.5.2 Southern Half

The surf club is relatively close to the beach and may be at long-term risk from coastal erosion or inundation. Houses are located further back from the beach but may be at long term risk from coastal erosion. The dune along the southern half of One Mile Beach (Figure 32) is well vegetated and seems relatively stable. A stormwater pipe in relatively good condition discharges onto the rock platform at the southern end of the beach. A large cavity was observed at the bottom of the coastal bluff at the southern end of the beach (Figure 33).

2.6 Burgess Beach

Burgess Beach is a small pocket beach well protected by natural rock outcrops. The wave climate is relatively low and no infrastructure appears to be at risk of coastal erosion or inundation. However, the lookout may be at risk from slope stability and some houses south of the beach and the road may be at long-term risk from slope stability (Figure 34). There is no dune on the beach and it is underlain by bedrock outcrops and backed by a steep rock coastal bluff.

2.7 Seven Mile Beach

Seven Mile Beach is a very long open-coast beach. Most of the beach is located within the Booti Booti National Park and remains in a natural condition and the road behind the dune is located a significant distance from the active beach system. The dune is in good condition and well vegetated.

At the southern end of the beach, one dwelling is located directly behind the beach dune (Figure 35). A remnant one-metre erosion escarpment is visible at the back of the beach while a smaller more recent escarpment is noticeable at the front (Figure 36) indicating insipient dune growth (recovery) occurs in this location. The camping area and Tiona Caravan Park are relatively low and could be subject to inundation from Wallis Lake.

2.8 Elizabeth Beach

Elizabeth Beach is a pocket beach facing north-east. Large swells were observed at the beach at the time of the site visit. There may be possible sand movement between Shelly and Elizabeth Beach. A large escarpment around 1.5-2.0 m high was observed along the beach and the lack of incipient dune despite the wide berm indicates that the beach may be subject to recession (Figure 37). However, no infrastructure appears to be at immediate coastal risk. The surf club is being redeveloped. The toilet block and SLSC (Figure 38) may be at long-term risk from coastal erosion.

The northern end of the beach may benefit from dune revegetation and the pedestrian pathway could be formalised. At the southern end, a creek flowing out below Lakeside Crescent creates a gully on the beach. The outlet is trained by concrete blocks and large rocks without geotextile, and the gully has exposed a concrete apron covered with sand (Figures 39-40). This apron appears to be an old boat ramp. The arch used as a base for the bridge is corroding and appears to be close to the end of its design life. A 4WD access located at the southern end to launch boats from the beach appears to have been lost due to erosion.

2.9 Shelly Beach

Shelly Beach is a natural pocket beach facing north and is subject to a moderate wave climate. The eastern half of the beach has an incipient dune, is stable, well-vegetated and the dune is fenced, while the western half appears to be exposed to potential erosion events due to less protection from the rocks and headland located at the eastern end of the beach.

A creek creates a large gap in the dune at the centre of the beach (Figure 41). No development is present behind the beach.

2.10 Sandbar Beach

Sandbar Beach is located forming barrier dune systems to Smiths Lake and is an open-coast beach. A visible erosion escarpment was apparent along the beach at the time of the site visit (Figure 42). Smiths Lake is an ICOLL and was closed at the time of the site visit (Figure 43). The lake tends to break through the entrance berm along the southern end of the beach. No infrastructure appears to be at threat from coastal erosion.

4WD access appears to be uncontrolled and fenced along the beach north of the entrance berm as existing fences have been cut and some 4WD tracks were observed through the incipient dune in violation of signs placed in the area (Figure 44).

2.11 Number One Beach

Seal Rocks Road is moderately exposed to ocean waves and appears to be at immediate risk to erosion as some large trees have already been lost, there is a visible erosion escarpment and no dune to protect the road (Figures 45-46). Some rocks have been dumped to protect the road (Figure 47).

2.12 Boat Beach

Boat Beach is less exposed to wave climate than Number One Beach but is subject to slope stability issues. Some gabions have already been put in place at the top of the bluff to protect Kinka Road (Figure 48). Some picnic tables were observed at the southern end of the beach. There is no dune and a visible erosion escarpment of 0.5-1.0 m along the beach (Figure 49) and some ad hoc erosion protection has been provided (Figure 50). A boat ramp has been undermined due to erosion (Figure 51). The road appears to be at risk from coastal erosion and slope stability.

2.13 Lighthouse Beach

Lighthouse Beach is an open-coast beach and comprises a significant dune system and a wide berm where a high erosion escarpment is visible (Figure 52). The beach is subject to a dune blow-out area at the northern end. The incipient dune at the front of this blow-out appears to have stabilised. However, evidence of 4WD impact are prevalent. Ongoing management of this area is required. Windblown sand over the access steps to the beach needs to be regularly removed. However, no development appears to be at risk.

2.14 Treachery Beach

Treachery Beach is an open-coast beach and is comprised of a significant dune system (Figure 53). The beach appears to be recovering from previous dune blow out impact with recent vegetation establishment. No development is at risk from coastal erosion as the caravan park is located a significant distance from the foreshore. However, remnants of dune blowouts need to be monitored to manage dune vegetation recovery and prevent long term dune transgression toward the caravan park.

2.15 Bennetts Beach

Bennetts Beach is a long open-coast beach.

2.15.1 Northern Half

This part of the beach is located within Myall Lakes National Park. Transgressive landward movement of the dune due to wind was observed and the dune is close (i.e. around 20 m) to Mungo Brush Road in some areas (Figure 54).

2.15.2 Southern Half

A remnant erosion escarpment was observed along the beach but the beach seems to have mostly recovered and stabilised (Figure 55). The surf club does not appear to be at immediate risk given the wide buffer provided by a well-vegetated dune (Figure 56) but may be at long-term risk. The houses and the road are located a significant distance from the foreshore and do not appear to be at risk from coastal erosion. Fencing of the dune should be maintained to avoid damage to dune vegetation due to uncontrolled access (people were observed walking over the dune during the site visit). Some fences have been damaged and need maintenance (Figure 57). The spit between Hawks Nest and Jimmys Beach (Yacaaba) is around 100 m wide. At this location, there is a dune blow-out issue due to an unprotected and unvegetated dune resulting in mobile sand driven by wind force. The dune is transgressing landward and is threatening the old access road (Figure 58). The dune fencing is damaged in some areas and some additional fencing is recommended to better establish dune vegetation and help stabilisation.

3 HISTORIC PHOTOGRAPH OBSERVATIONS

3.1 Aerial Photograph Observations

Historic aerial and ground photographs held by Council were observed by SMEC's project team at Council during the site visit. A summary of the observations are provided below.

Nine Mile Beach

- ***September 1952:*** The dune at the northern end of Seven Mile Beach is mobile and unstable due to limited vegetation. The road behind the dune has already been created.
- ***December 1976:*** Nine Mile Beach Golf Course is not present but the beach appears similar to the existing conditions.
- ***January 1984:*** Nine Mile Beach golf course has been created. The dune is more vegetated than under existing conditions. No shoreline recession is noticeable.
- ***March/April 1986:*** Nine Mile Beach appears stable.

Main Beach

- ***September 1952:*** Green Point and Forster are nonexistent and there is no development except for some farms.
- ***March/April 1986:*** The dune directly south of the breakwater at Main Beach is less vegetated.

One Mile Beach

- ***1980:*** One Mile Beach appears more eroded than under existing conditions at the northern end.
- ***August 1997:*** More dune blowout is visible along One Mile Beach.

Burgess Beach

- ***September 1952:*** Burgess Beach had no sand and One Mile Beach had no incipient dune.
- ***March / April 1986:*** Poorer vegetation cover was also observed along Burgess Beach.

Seven Mile Beach

- ***January 1964:*** Tiona Caravan Park has already been created.
- ***September 1971:*** The sand almost reaches the road along Seven Mile Beach and some sand mining is visible in the photograph at the northern end.
- ***1978:*** The sand dune at Seven Mile Beach is very close to the road along the southern half and the land strip widens northwards but the sand is still closer to the road than under existing conditions
- ***August 1997:*** Seven Mile Beach is similar to present day conditions at the southern end but appears more mobile at the northern end. The beach looks wider at the northern end and narrow at the centre.

Elizabeth Beach	• ***December 1976 – January 1977:*** Armco Arch is constructed to form the foundation of a small bridge above the small creek discharging on Elizabeth Beach.
Shelly Beach	• ***January 1964:*** Shelly Beach appears stable. • ***August 1997:*** Shelly Beach appears less vegetated than under existing conditions.
Sandbar Beach	• ***January 1964:*** Smiths Lake entrance is closed and there is no development near the entrance. The caravan park already exists and the shallows at the lake entrance have a different shape than those of today with a greater number of shoals visible. The road at Sandbar is built but there is no development. • ***September 1971:*** Smiths Lake appears open at the northern end of the entrance berm. • ***August 1977:*** Smiths Lake entrance is closed. The dune looks narrow at the northern end of the lake and on the southern corner of Sandbar Beach. • ***May 1980:*** The entrance of Smiths Lake is closed. • ***March 1982:*** Smiths Lake has been artificially opened. • ***August 1991:*** Smiths Lake entrance is closed. • ***August 1997:*** Smiths Lake is closed. • ***February 2007:*** The beach dune at Sandbar is relatively accreted and the entrance is closed.
Seal Rocks (Boat Beach/ Number One Beach)	• ***January 1964:*** There is no development. • ***August 1977:*** The dune looks narrow. • ***August 1997:*** The beach at Seal Rocks is narrow in parts.
Lighthouse Beach	• ***January 1964:*** There is no development. • ***August 1977:*** The dunes are mobile on Lighthouse Beach similar to present day conditions.
Treachery Beach	• ***January 1964:*** There is no development.
Bennetts Beach	• ***September 1952:*** Bennetts Beach is composed of mobile sand dunes. • ***August 1963:*** The dune at Hawks Nest is unstable and mobile but the dune blowout is located further seaward relative to existing conditions. The road located behind the dune at the northern end of Bennetts Beach is more seaward than the existing road.

- ***February 1969:*** Bennetts Beach was sandmined prior to February 1969. The sand dune is very mobile and is in the first stage of rehabilitation.
- ***May 1970:*** Bennetts Beach SLSC is located on the main dune and there is no vegetation in front of it.
- ***September 1974:*** The dune is mobile and threatening the road at Bennetts Beach near Broughton Island. The beach at Mungo Brush is close to Myall Lake, being very narrow in some areas with the sand unevenly distributed.
- ***1976:*** The beach is very close to the carpark at Hawks Nest and no dune is visible.
- ***1977:*** The carpark is on the frontal dune at Hawks Nest.
- ***August 1977:*** The tombolo at Yacaaba is devoid of vegetation. The dune at Bennetts Beach appears covered in bitou bush and is mobile. Bennetts Beach SLSC looks very close to the beach. Housing and the road also appear much closer to the beach than today.
- ***March/April 1986:*** The dune at Hawks Nest is much less vegetated than under existing conditions.
- ***June 1994:*** Bennetts Beach dune appears mobile in places north of the Golf Club and the beach appears in an accreted state.
- ***December 1996:*** The dune along the southern half of Bennetts Beach is more mobile than under existing conditions. The development appears similar to the current development.

4 COASTAL PROCESSES

4.1 Introduction

The beach is often perceived to be the sandy area between the waterline and the dunes. It includes the beach berm, where sand-binding grasses may exist, and any incipient foredune formations. Typically, however, on an open coast the overall beach system extends from some several kilometres offshore, in water depths of around twenty metres to the back beach dune or barrier region, which may extend up to several hundred metres inland (Figure 59). When examining the coastal processes of a beach system it is necessary to consider this wider definition.

The principal hazards induced by the coastal processes that are relevant for a coastal hazard risk assessment of the beaches along the Council coastline include:

- short-term coastal erosion including that resulting from severe storms, the behaviour of estuary entrances and slope instability
- long term coastline recession including that resulting from imbalances in the sediment budget (such as Aeolian sand transport), climate change and beach rotation
- oceanic inundation of low lying areas

The hydrodynamic forcing controlling these processes and resultant hazards comprise the prevailing wave climate and water levels.

4.2 Short Term Coastal Erosion

4.2.1 Storm Bite

A beach typically comprises unconsolidated sands that can be mobilised under certain meteorological conditions. The dynamic nature of beaches is witnessed often during storms when waves remove the sand from the beach face and the beach berm and transport it, by a combination of longshore and rip currents, beyond the breaker zone where it is deposited in the deeper waters as sand bars (Figure 59). During severe storms, comprising long durations of severe wave conditions, the erosion continues into the frontal dune and a steep erosion escarpment is formed. This erosion process usually takes place over several days to a few weeks.

The amount of sand eroded from the beach during a severe storm will depend on many factors including the state of the beach when the storm begins, the storm intensity (wave height, period and duration), direction of wave approach, the tide levels during the storm and the occurrence of rips. Storm bite is the volume of beach sand that can be eroded from the subaerial (visible) part of the beach and dunes during a *design* storm. Usually, it has been defined as the volume of eroded sand as measured above mean sea level (~ 0 m AHD datum). For a particular beach, the storm bite (or storm erosion demand) may be quantified empirically with data obtained from photogrammetric surveys, or it may be quantified analytically using a calibrated and verified numerical model.

For the hazard assessment, it has been assumed that all beaches where no outcropping rocks were observed are not overlying bedrock. Some beaches such as Burgess Beach are backed by a coastal bluff which limits the landward extent of beach erosion. Without detailed geotechnical survey information for each beach it is possible that the assumption of a sandy profile is quite conservative[1]. For beaches where significant rock outcropping

[1] The application of this conservative assumption is conventional for planning purposes in the coastal zone.

was observed the hazard assessment considered this presence of rock. These beaches noted in the results of the storm bite assessment in Section 5.2.1. Section 5.2.1 also provides further discussion of the hazards associated with 'storm bite'.

The history of severe storm erosion demand for the beaches at Great Lakes is detailed in Appendix B and the hazard risk assessment is detailed in Appendix D.

4.2.2 Slope Instability

Slope instability refers to the instability of both; sandy areas (dunes), and rocky areas (bluffs and headlands).

For the former, following storm bite the dune face dries out and may slump. This occurs due to dune sediments losing their apparent cohesive properties that come from the negative pore pressures induced by the water in the soil mass. This subsequent slumping of the dune face causes further dune erosion.

Dune slumping is treated as a slope instability hazard and can be quantified by stability computations, which can serve as a guide to determining safe setback distances on frontal dunes that are prone to wave attack during, and slumping following storms.

Bluffs and headlands with varying slope angles and heights are common features along the coastline. Potential slope instability in bluffs and headlands constitutes a foreshore hazard, also referred to as a slope instability hazard.

Slope instability of bluffs and headlands is a result of the continuing operation of physical processes as well as anthropogenic activities within a particular geological and geomorphological setting in the coastal landscape. The physical processes could include rainfall, climate, rock weathering and disintegration, surface and ground water movement, soil erosion, sea level fluctuation, wave impact and earthquakes. On the other hand, coastal urbanisation and land use, destruction of vegetation, either intentionally or otherwise (such as by bush fire or logging activities) may be regarded as anthropogenic factors. Slope failures in bluffs and headlands (both in rock and unconsolidated sediments) are one of several coastal hazards that threaten the coastal community and values. A condition of slope instability may create public safety hazards, threaten existing infrastructure and affect sustainable development and use of coastal areas.

Appendix F documents an assessment of the slope instability risk for bluffs and headlands along the Great Lakes coastline.

4.2.3 Behaviour of Estuary Entrances

Various coastal hazards can be created by both trained and natural estuary entrances. Wallis Lake entrance is located between Nine Mile Beach at Tuncurry and Main Beach at Forster. This entrance is trained on both its northern and southern bank by breakwaters extending up to 150 m offshore from the foreshore. The banks on the inside of the entrance are largely protected by seawalls. Therefore, the entrance is relatively stable. The presence of the breakwalls has led to a long term change in the tidal prism of Wallis Lake, which has pushed the entrance regime toward an unstable scouring mode. This change has led to a long term increase in the tidal range of Wallis Lake which is expected to continue to occur well into the future. This change is documented in Nielsen and Gordon (2007).

Smiths Lake entrance is located along Sandbar Beach and is intermittently open and closed. However, according to historical photographs, the lake appears to be mostly closed and has been opened artificially in the past (e.g. in March 1982). The current form of the beach berm closing the lake entrance indicates that the entrance tends to open on the southern end of the berm with a less likely narrow opening on the northern side of the sand bar possible. Smiths Lake is subject to an existing opening strategy. The Smiths Lake Coastal Zone Management Plan Review (BMT WBM, 2010) has recommended that the opening strategy should be updated to be in accordance with the *Marine Parks Act 1997*.

It is considered unlikely for Wallis Lake that a major flood or future storm event within the next 50 years could cause breakthrough at unexpected locations along Seven Mile Beach.

4.3 Longer Term Beach Changes and Shoreline Recession

Following storms, ocean swell transports sand from the offshore bars onto the beach face where onshore winds move it back onto the frontal dune. This beach accretion phase, typically, may span many months to several years. Following the build-up of the beach berm and the incipient foredunes through this accretion, and the re-growth of the sand trapping grasses, it can appear that the beach has fully recovered and beach erosion has been offset by beach accretion (Figure 60).

However, in some instances, not all of the sand removed from the berm and dunes during the erosive phase is replaced during the beach accretion phase. Sand can be lost to sediment sinks (estuaries, offshore canyons) or entrapment by reef systems transported beyond the beach compartment limits (offshore or alongshore) by storm processes. Accordingly, long term ongoing recession of the shoreline can occur. Further, over decadal time scales, changes in wave climate can result in beach rotation.

4.3.1 Sediment Budget Deficit

Once the sand has been transported offshore into the surf zone, it may be moved alongshore under the action of the waves and currents and out of the beach compartment. Some of the sand that is transported directly offshore during storms may become trapped in offshore reefs, thereby preventing its return to the beach. Other direct losses of material from the beach may include the inland transport of sand under the action of onshore winds; this mechanism being called Aeolian sand transport. Longer term, should the amount of sand taken out of the compartment by alongshore or offshore processes exceed that moved into the compartment from adjacent beaches or other sources, there will be a direct and permanent loss of material from the beach and a deficit in the sediment budget for the beach (Figure 61). This results in a landward migration of the active profile over time, known as shoreline recession (Figure 62).

Long term rates of shoreline recession have been quantified for the different beaches along the Council coastline based on photogrammetric techniques and precautionary principles (Appendix B).

Historical photogrammetry data provides valuable information about the medium to long term beach and shoreline change. However, this information is provided as descrete ‘snapshots in time’. Beach morphological change is continually evolving and can be episodic (i.e. beach erosion and recovery during and following storm events). Furthermore, at best the available history of photogrammetry spans only the last 60 years.

Defining coastal hazard parameters for planning purposes based on limited measured data at discrete points in time necessitates the adoption of a conservative, precautionary approach.

4.3.2 Beach Rotation

Studies of embayed beaches on the NSW coast have identified a sensitivity of shoreline alignment to wave direction (Short *et al*., 2000). This has been linked to the Southern

Oscillation Index (SOI; Ranasinghe *et al.*, 2004; Goodwin, 2005), which is a number calculated from the monthly or seasonal fluctuations in the air pressure difference between Tahiti and Darwin. Goodwin (2005) showed that from 1884 to 2004 the annual Mean Wave Direction (MWD) for the NSW coast has varied from around 127°TN to 140°TN and that the MWD varied with a strong annual cycle, coupled to mean, spectral-peak wave period.

Sustained negative values of the SOI usually are accompanied by sustained warming of the central and eastern tropical Pacific Ocean, a decrease in the strength of the Pacific Trade Winds and a reduction in rainfall over eastern and northern Australia. This is called an *El Niñ*o episode. During these episodes, a moderate south-easterly wave climate is expected on the NSW coast.

Positive values of the SOI are associated with stronger Pacific trade winds and warmer sea temperatures to the north of Australia, popularly known as a *La Niña* episode. Waters in the central and eastern tropical Pacific Ocean become cooler during this time. Together, these give an increased probability that eastern and northern Australia will be wetter than normal and, during these episodes, severe storms may be expected on the Australian Eastern seaboard. Accordingly, an energetic, more easterly wave climate is expected on the NSW coast.

At Great Lakes, analysis of the photogrammetric data showed little evidence of beach rotation taking place at the beach compartments of Great Lakes beaches.

Potential beach rotation was estimated by way of analysis of mean approach wave directions, and was estimated to result in a movement within the beach berm of approximately:

- ±50 m on Nine Mile Beach (Tuncurry Beach)
- ±2m on Main Beach
- ±5m on One Mile Beach
- ±40m on Seven Mile Beach
- ±5m on Number One Beach
- ±8m on Lighthouse/Treachery Beach
- ±60m on Bennetts Beach

Further explanation of beach rotation processes is provided in Appendix C to this report, and the extent of beach rotation is quantified also in Appendix C.

4.3.3 Climate Change

Potential climate change impacts include sea level rise, increased rainfall frequency and intensity, increased coastal storms and storm surge levels and changes to local wave climate. Climate change considerations are discussed below.

4.3.3.1 Sea Level Rise

The principal impact of climate change on coastal processes along the Great Lakes coastline would be associated with projected rise in mean sea level. Some research on the evidence of sea level indicates that we are currently tracking at the upper end of the Intergovernmental Panel on Climate Change's (IPCC) projections. Ocean thermal expansion and melting of non-polar glaciers and ice caps are the largest contributors to recent sea level rise.

Sea level projections were reported in the IPCC Fourth Assessment Report (AR4) of 2007 for a range of future emission scenarios. The range of AR4 model projections (with a 90% confidence range) were a mean sea level rise of 18 – 59 cm in the 2090 to 2100 decade. The AR4 predicted range of sea level rise does not include for the potential dynamic response of ice-sheets, however, qualifying statements in AR4 make an allowance for 10 - 20 cm to account for this possibility. The total projected range would be 18 – 79 cm, if a contribution for the dynamic response of ice-sheets was included. The AR4 specifically states *Larger values cannot be excluded, but understanding of these effects is too limited to assess their likelihood of providing a best estimate or an upper bound for sea level rise*. It is noted that sea level projections for the 21st century from AR4 of 2007 are similar to the IPCC Third Assessment report (TAR) of 2001 when the qualifying statements in the AR4 are considered.

Increase in sea level would not occur uniformly across ocean basins, with some regions experiencing higher levels of sea level rise and others lower. Variations in the mean sea level anomaly are related to spatial variations in the thermal expansion of the ocean due to large scale atmospheric and oceanographic patterns. McInnes *et al.* (2007) estimated that the future sea level rise along the NSW coast would be slightly higher than the global averages, with an estimated upper limit contribution of 12 cm by 2070.

In other reports several long term water level measurements have been analysed from the four longest term gauges in Australia and New-Zealand (Watson, 2011) and from 25 gauges along the US coast and a couple from various worldwide gauges (Houston & Dean, 2011). From analysis of these long-term gauges (i.e. measurements longer than 60 years), although the sea level rise rate is relatively high, a global deceleration in sea level rise rates was found. In Australia and New-Zealand, the rise in mean sea level between 1920 and 2000 was found to be slowing down by on average 0.02-0.04 m/yr^2 (Watson, 2011).

The NSW Government's *Sea Level Rise Policy Statement* (DECCW, 2009a) adopts sea level rise planning benchmarks of an increase above 1990 mean sea levels of 0.4 m by 2050 and 0.9 m by 2100. The primary purpose of the benchmarks is to provide consistency in consideration of sea level rise impacts. The *Guidelines for Preparing Coastal Zone Management Plans* (DECCW 2010a) require the *Sea Level Rise Policy Statement* to be taken into account, and accordingly the planning benchmarks have been adopted for this study.

4.3.3.2 OTHER CLIMATE CHANGE IMPACTS

Recent research has indicated a potential increase in the frequency and intensity of storms along the NSW coast as a result of climate change. Changes to storm patterns will impact on extreme rainfall events and coastal storm events. OEH Guidelines (DECC, 2007b) indicate that an increase in design rainfall intensities of between 10 and 30 % should be considered when assessing long term flooding. Increased frequency and intensity of coastal storms will impact on coastal erosion; this was considered in estimating storm demand and hence the hazard lines.

Modest to moderate increases in average and maximum cyclone intensities are expected in the Australian region in a warmer world. However, cyclone frequency and intensity are strongly associated with the El Niño/ Southern Oscillation (ENSO) phenomenon. How this phenomenon will vary in a warmer world is currently unknown (CSIRO, 2007).

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

If overall weather patterns change as a result of global warming, there is potential for a change in the dominant wave direction (Moratti and Lord, 2000). McInnes *et al*., (2007) predict small changes in dominant wave height and direction. For a long beach such as the Nine Mile Beach compartment, a small change in the dominant wave direction may cause significant realignment (rotation) of the shoreline resulting in recession and accretion at different locations along the beach.

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

There are no predictions for any increase in; winter storm wind speeds and, hence, extreme wave heights for this part of the NSW coast as a result of climate change (Figure 63). Foreshore recession resulting from a *Greenhouse*-induced sea level rise has been assessed using the *Bruun Rule* (Appendix C).

4.4 Coastal Inundation

An increase in water level at the shoreline results from the breaking action of waves causing what is termed wave setup and wave run-up. Wave setup can be explained as a result of the conversion of part of the wave's kinetic energy into potential energy. The amount of wave setup will depend on many factors including, among other things, the type, size and periods of the waves, the nearshore bathymetry and the slope of the beach and foreshore. Typically, wave setup on an open-coast beach during severe storms can be around 1 m to 2 m.

The energy of a wave is dissipated finally as the water runs up the beach or shoreline. Wave run-up is the vertical distance the wave will reach above the level of the tide and storm surge (See Section 4.5.3) and can be several metres. Wave run-up at any particular site is a function of the wave height and period, the foreshore profile and slope, surface roughness and other shoreline features on which the waves break. Wave set up is implicitly included in wave run up levels.

Should dune levels below or the foreshore not protected by dunes, flooding and damage to structures can result from the coincidence of elevated ocean water levels (See Section 4.5.3) and wave run-up.

An assessment of coastal inundation due to wave run-up for Great Lakes has been carried out in Appendix D.

4.5 Hydrodynamic Forcing

4.5.1 Introduction

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

4.5.2 Wave Climate and Storms

The offshore swell wave climate (wave height and period occurrences) has been recorded by the NSW Government Manly Hydraulics Laboratory by a network of Waverider buoys along the NSW coast (including Sydney and Crowdy Head) for many years. The Waverider buoy located at Sydney has measured also wave direction since 1992.

Summary wave statistics are available from the Manly Hydraulics Laboratory (Kulmar Lord and Sanderson, 2005). The wave data show that the predominant swell wave direction is south-southeast (SSE) with over 70% of swell wave occurrences directed from the SE quadrant. The average deep water *significant* wave height, as measured at Crowdy Head, is around 1.5 m (Figure 64) and the average wave period is around 10 s (Kulmar Lord and Sanderson, 2005). Analysis of storms recorded at Crowdy Head has provided wave height/duration data for various annual recurrence intervals.

Shand *et al.,* (2010) provides a comprehensive review of coastal wave heights, as recorded by the network of wave rider buoys. This study also reviews the synoptic types of storms causing extreme waves, the duration of these events and the direction of extreme waves along the NSW coastline.

Some large storms occurred during the 1970s and the late 1990s. These storms included the storms of May-June 1974 whose impacts were greatest felt on the NSW central coast. Because nearshore waves causing dune erosion are depth-limited, nearshore water levels and wave duration of moderate wave heights become more important factors for dune erosion than peak offshore wave heights of short duration.

In early March 1995, Cyclone Violet reached a distance of around 400 km from the Great Lakes coastline which caused erosion at the north facing beaches.

A storm in May 1997 lasted more than 3 days between 9 May and 12 May 1997. A significant wave height of around 6.3 m was measured at Crowdy Head during this event.

Occasionally the relative quiet of the Australian subtropics in winter is disturbed by an east coast low, with its gales and flood rains. Three such storm events in June 1967 battered the coastline of southern Queensland and northern NSW, generating gale force winds, heavy rains and huge south-easterly swells with a peak significant wave height of around 7.7 m at Great Lakes. The approach direction of this storm caused extensive erosion at the beaches facing north-east such as Elizabeth Beach.

Such storms, which occur along the NSW coastline at irregular intervals, are responsible for episodic events of sand transport and beach erosion, which are evident when examining photogrammetric data. It is important, therefore, to document the history of storms along Great Lake Council's coastline to ascertain whether the observed beach changes can be related to the specific occurrence of such storms. The aim is to delineate which observed changes are caused by episodic events, such as large coastal storms, and which changes have underlying causes that may be due to long-term cycles, natural fluctuations or are caused by anthropogenic influences.

This study draws upon storm histories developed from synoptic charts, as well as historical data from the NSW Government Waverider buoys, to determine the dates and severity of the extreme storm events that have occurred over the period of the photogrammetry. Appendix A provides detail on the analysis of these storms and estimates of the relevant storm parameters.

4.5.3 Extreme Water Levels

During storms, the ocean water level and that at the shoreline is elevated above the normal tide level. While these higher levels are infrequent and last only for short periods, they may exacerbate any storm damage on the foreshore. Elevated water levels allow larger waves to cross the offshore sand bars and reefs and break at higher levels on the beach. Furthermore, they may cause flooding of low lying areas and increase tail water control levels for river flood discharges.

The components of these elevated water levels comprise the astronomical tide, barometric water level setup, wind setup, wave setup and runup (Figure 65). All of the components do not act or occur necessarily independently of each other but their coincidence and degree of inter-dependence, generally, is not well understood.

The tides of the NSW coast are semidiurnal with a diurnal inequality. This means that there are two high tides and two low tides each day and there is a once-daily inequality in the tidal range. The mean tidal range is around one metre and the tidal period is around 12.5 hours. Tides vary according to the phases of the moon. The higher spring tides occur near and around the time of new or full moon and rise highest and fall lowest from the mean sea level. The average spring tidal range is 1.3 m and the maximum range reaches two metres. Neap tides occur near the time of the first and third quarters of the moon and have an average range of around 0.8 m.

Storm surge is the increase in water level above that of the normal tide that results from the low barometric pressures, which are associated with severe storms and caused localised sea level to rise, and strong onshore winds that pile water up against the coast. Measured values of storm surge at Sydney include 0.59 m for the extreme storm event of 25 – 26 May 1974 and 0.54 m for the extreme storm event of 31 May – 2 June 1978 (Haradasa *et al*., 1991). Both of these extreme events were coincident with spring high tides with the water level in the 1974 event reaching the maximum recorded at Fort Denison of 1.48 m AHD.

Return periods for ocean water levels comprising tidal level and storm surge for Sydney, which are representative of the study region, are presented in Figure 66.

5 COASTAL HAZARD ASSESSMENT

5.1 Introduction

The coastal hazard assessment for Great Lakes comprised quantifying the three principal hazards, namely:

- short-term storm beach fluctuations
- long term shoreline recession
- oceanic inundation

For the beaches of the Great Lakes, the storm bite (or storm erosion demand) has been quantified empirically with data obtained photogrammetrically. An *equivalent* storm erosion volume has been derived empirically based on the schema presented in Nielsen *et al.* (1992). A detailed description of the protocol and the derivation of the results are provided in Appendix D.

5.2 Short Term Beach Fluctuations

5.2.1 Design Storm Erosion

Design storm erosion volumes for the Great Lakes coastline are calculated in Appendix D. An analysis of equivalent storm erosion volumes resulting from a design storm followed the schema of Nielsen *et al.* 1992 (see Figure 67). The following four stability zones (*Zone of Wave Impact*, *Zone of Slope Adjustment*, *Zone of Reduced Foundation Capacity* and *Stable Foundation Zone*) have been delineated as follows (after Nielsen *et al*., 1992):

- The *Zone of Wave Impact* delineates an area where any structure or its foundations would suffer wave attack during a severe storm. It is that part of the beach that is seaward of the dune erosion escarpment.
- A *Zone of Slope Adjustment* was delineated to encompass that portion of the seaward face of the dune that would slump to the natural angle of repose of the dune sand following removal by wave erosion of the *Design Storm Erosion Demand*. That presents the steepest stable dune profile under the conditions specified.
- A *Zone of Reduced Foundation Capacity* for building foundations was delineated to take account of the reduced bearing capacity of the sand adjacent to the dune erosion escarpment. It was considered that structural loads should be transmitted only to soil foundations outside the zone within which the *Factor of Safety* was less than 1.5 during extreme scour conditions at the face of the dune. This allows for the design assumption that the soil may develop its full bearing capacity.
- The *Stable Foundation Zone* is that portion of the dune that is unaffected by the wave erosion processes and within which no special foundation requirements need to be made.

Figure 68 illustrates the procedure used to estimate the *equivalent* storm erosion volume. This storm erosion demand consists of the sum of the measured volume difference between pre and post-storm photogrammetric profiles (Volume 1) and the assumed post-storm recovered volume (Volume 2) obtained by applying the protocol from Nielsen *et al.* (1992). This equivalent storm erosion volume corresponds to the *Zones of Wave Impact and Slope Adjustment* illustrated in Figure 67.

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

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

There are no known measurements of storm bite available at Great Lakes beaches. The equivalent storm erosion volumes were derived at the locations where the maximum storm erosion was estimated to have occurred. The maximum equivalent storm erosion volumes were then applied to the whole beach, to take account of the formation of rip-heads and to arrive at a conservative estimate of storm erosion demand for the beach.

Equivalent storm erosion volumes were obtained from the analysis for the beachfront areas along the Great Lakes coastline. From this analysis, an envelope of values for the loss of sand volume was obtained for the different beaches along the Great Lakes coastline. Table 2 shows the results of this analysis as well as the selected storm used for the determination of the storm bite value at each beach.

Table 2: Design storm bite assessment at the different beaches along Great Lakes coastline

Beach Name	Design Storm Bite (m^3/m)	Storm event associated with the photogrammetric data date*	Parameter Potentially Influencing Storm Bite
Nine Mile Beach (Tuncurry Beach)	230 ~ 240	Cyclone Violet (March 1995) May 1997 storm	N/A
Forster Main Beach	200	Cyclone Violet (March 1995) May 1997 storm	Presence of a seawall at the back of the beach
One Mile Beach	220	May - June 1974 storms	N/A
Burgess Beach	35	May - June 1974 storms	Presence of a coastal bluff at the back of the beach, rock outcrop and underlying rocks
Seven Mile Beach	320 for southern end; 200 for the main section of the beach	Cyclone Violet (March 1995) May 1997 storm	N/A
Elizabeth Beach	150 for southern end; 180 for central and northern end	June 1967 storm	N/A
Sandbar Beach	230	Cyclone Violet (March 1995), May 1997 storm	Presence of Smith Lake Entrance
Number One Beach	120 for southern end and 90 for northern end	Cyclone Violet (March 1995) May 1997 storm	Presence of rocks at the back of the beach and potential underlying rocks
Boat Beach	30-50 for eastern end; 120 for middle section and 80 for western end	Cyclone Violet (March 1995) May 1997 storm	Presence of rocks at the back of the beach and potential underlying rocks
Bennetts Beach	250	June 2007 storms	N/A
Jimmys Beach	20 - 70	May - June 1974 storms	N/A

**The storm event presented in this table is not the only storm event that has impacted the beach but is the one that is the most clearly visible within the photogrammetric data.*

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

5.2.2 Estuary Entrance Instability

Short term beach fluctuations can be enhanced at estuary entrances such as the entrance of Smiths Lake or Wallis Lake. Estuary entrance instability is discussed in Appendix B and Appendix G. Outside of the entrance area, the entrance dynamics may influence dune erosion, though the existence of a training breakwater on both sides of Wallis Lake entrance minimises the potential for breakthrough of the lake entrance at unexpected locations.

The tidal prism of Wallis Lake has been increasing over time as a response to construction of the entrance breakwalls during the 1960s. An Escoffier stability analysis has been carried out to examine the stability of Wallis Lake Entrance and this is presented in Appendix G.

5.3 Long Term Recession

5.3.1 Introduction

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

5.3.2 Long Term Shoreline Recession

The two methods used for this measurement were the measurement of eroded sand volumes and the measurement of the translation of the dune face over time. Further assessments in the future may change the prognosis for long term shoreline recession as more photogrammetry data are collected and analysis techniques improve.

Detailed measurements of the sediment budget for the beaches along the Great Lakes coastline were beyond the scope of this study. However, an assessment of the long term shoreline recession rate has been made empirically using photogrammetric data, and this is described in Appendix B, together with factors that may have influenced the apparent recession rates.

Table 3 summarises the long term recession rates measured by sand volume changes and foredune location at each beach in the study area, together with the adopted recession rates.

Table 3: Adopted recession rate at different beaches along Great Lakes Coastline

Beach Name	Adopted Long term recession rate (m/year)	Measurement of Eroded Sand Volumes[2]	
		Average volume change per year from lines of best fit ($m^3/m/year$)	Measurement of Translation of Dune Face (m/year)
Nine Mile	1	Nil	Nil
Tuncurry Beach	0.5	Nil	Nil
Main Beach	0.4	0.9	0.4
One Mile Beach	Nil	Nil	Nil
Burgess Beach	Nil	Nil	Nil
Seven Mile Beach	Nil	Nil	Nil
Elizabeth Beach	0.1	0.5	Nil
Sandbar Beach	Nil	Nil	Nil
Number One Beach	0.1	0.8	Nil
Boat Beach	Nil	Nil	Nil
Bennetts Beach North	Nil	Nil	Nil
Bennetts Beach South	0.1	0.4	Nil
Jimmys Beach Pre-nourishment	0.1 ~ 0.9	0.5 ~ 3.8	0.4 ~ 0.9
Jimmys Beach Post-nourishment	Nil to 0.3	Nil to 0.9	Nil to 0.3

5.3.3 Future Shoreline Recession – Sea Level Rise

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

Figure 69 illustrates the concept of shoreline recession as a result of sea level rise. Appendix C provides detail on the *Bruun* analysis carried out for the beaches of the Great Lakes coastline. In general for open coast beaches an active slope of 1:50 has been adopted in applying the Bruun Rule (refer to extract on the following page).

Table 4 provides estimates of the overall long-term recession expected along the Great Lakes coastline due to adopted sea level rise projections. These estimates are considered conservative, as the Bruun analysis does not take account of the presence of bedrock underlying sand layers. However, where data were available to estimate the

[2] Note that the units of these two measurements are different and not directly comparable.

depth of underlying bedrock, this was taken into account when determining the nearshore equilibrium slope to use with the Bruun Rule calculations.

In May, 1979, offshore sediments and seabed bathymetric data were collected by the Public Works Department in conjunction with the New South Wales Geological Survey as part of an investigation into sand movements at the entrance to Wallis Lake and the adjacent coastline. The survey comprised bathymetric profiling and sediment sampling offshore to depths of 65 m. Three profile runs were made off Boomerang Beach as shown on the survey vessel's track plots in Figure G.4. Also shown are the locations where surface sediment samples were taken. The seabed bathymetry and surface sediment grading parameters are shown in Figure G.5.

These data show that the offshore beach slope is fairly constant at 1:50 to a depth of about 40 m, seaward of which there is an abrupt steepening of the slope to 1:20 to a depth of 50 m. Seaward of the 55 m contour, the inner shelf slope flattens out to about 1:130. Across this slope the sand grain size varies from about 0.35 mm on the beach face, fining to 0.20 mm at 65 m water depth.

Extract from: PWD (1985), Boomerang Beach and Blueys Beach Coastal Engineering Advice. Public Works Department Civil Engineering Division.

Table 4: Projected Future Beach Erosion and Recession due to Sea Level Rise

Beach Location	Total Predicted Sea Level Rise[1] (m)			Equilibrium Nearshore Slope[2] (1:X)	Total Shoreline recession (m)			Total Beach Erosion (m^3/m)		
	2050	2060[3]	2100		2050	2060[3]	2100	2050	2060[3]	2100
Nine Mile Beach Golf Course	0.34	0.44	0.84	50	17.0	22.0	42.0	78.2	101.2	193.2
Nine Mile Beach	0.34	0.44	0.84	50	17.0	22.0	42.0	83.3	107.8	205.8
Nine Mile Beach South	0.34	0.44	0.84	50	17.0	22.0	42.0	93.5	121.0	231.0
Main Beach North	0.34	0.44	0.84	50	17.0	22.0	42.0	102.0	132.0	252.0
Main Beach South	0.34	0.44	0.84	50	17.0	22.0	42.0	105.4	136.4	260.4
Pebbly Beach	0.34	0.44	0.84	50	17.0	22.0	42.0	200.6	259.6	495.6
One Mile Beach North	0.34	0.44	0.84	50	17.0	22.0	42.0	144.5	187.0	357.0
One Mile Beach Centre North	0.34	0.44	0.84	50	17.0	22.0	42.0	110.5	143.0	273.0
One Mile Beach Centre South	0.34	0.44	0.84	50	17.0	22.0	42.0	127.5	165.0	315.0
One Mile Beach South	0.34	0.44	0.84	50	17.0	22.0	42.0	93.5	121.0	231.0
Seven Mile Beach North	0.34	0.44	0.84	50	17.0	22.0	42.0	95.2	123.2	235.2
Seven Mile Caravan Park	0.34	0.44	0.84	50	17.0	22.0	42.0	183.6	237.6	453.6
Seven Mile Beach South	0.34	0.44	0.84	50	17.0	22.0	42.0	132.6	171.6	327.6
Elizabeth Beach North	0.34	0.44	0.84	50	17.0	22.0	42.0	125.8	162.8	310.8
Elizabeth Beach SLSC	0.34	0.44	0.84	50	17.0	22.0	42.0	119.0	154.0	294.0
Shelly Beach	0.34	0.44	0.84	56	19.0	24.6	47.0	81.8	105.9	202.1
Sandbar Beach	0.34	0.44	0.84	50	17.0	22.0	42.0	144.5	187.0	357.0
Sandbar Entrance	0.34	0.44	0.84	54	18.3	23.7	45.3	91.7	118.6	226.5
Number One Beach	0.34	0.44	0.84	50	17.0	22.0	42.0	54.4	70.4	134.4
Number One Beach South	0.34	0.44	0.84	50	17.0	22.0	42.0	103.7	134.2	256.2
Boat Beach	0.34	0.44	0.84	50	17.0	22.0	42.0	57.8	74.8	142.8
Lighthouse Beach	0.34	0.44	0.84	67	22.7	29.4	56.0	190.5	246.5	470.7
Treachery Beach	0.34	0.44	0.84	50	17.0	22.0	42.0	83.3	107.8	205.8
Bennetts Treatment Plant	0.34	0.44	0.84	50	17.0	22.0	42.0	96.9	125.4	239.4
Bennetts Beach Golf Course	0.34	0.44	0.84	50	17.0	22.0	42.0	105.4	136.4	260.4
Bennetts Beach SLSC	0.34	0.44	0.84	50	17.0	22.0	42.0	124.1	160.6	306.6
Bennetts Beach South	0.34	0.44	0.84	50	17.0	22.0	42.0	76.5	99.0	189.0
Jimmys Beach East	0.34	0.44	0.84	15	5.0	6.5	12.4	23.0	29.8	56.8
Jimmys Beach Centre-East	0.34	0.44	0.84	18	6.0	7.8	14.9	32.6	42.2	80.6
Jimmys Beach Centre-West	0.34	0.44	0.84	17	5.8	7.5	14.4	31.4	40.6	77.5
Jimmys Beach West	0.34	0.44	0.84	17	5.9	7.6	14.6	44.8	58.0	110.7

* Note 1: The total predicted sea level rise is that advocated by the NSW Sea Level Rise Policy, discounted for sea level rise that has already occurred between 1990 and 2010.
* Note 2: The equilibrium nearshore slope has been established based on actual bathymetric data and estimated inner depth of closure *i.e.* seaward limit of the active zone for onshore – offshore sand transport.
* Note 3: The 2060 Sea Level Rise has been interpolated between the 2050 and 2100 sea level planning benchmarks from the NSW Government Sea Level Rise Policy 2009.

5.4 Inundation

Coastal inundation along Great Lakes coastline due to wave runup would only occur if the frontal dune is low enough to allow overtopping during a major storm. Wave runup levels on the beaches of the Great Lakes coastline were estimated using parameters from long term wave statistics at the Crowdy Head Waverider buoy, as detailed in Appendix D.

As the Great Lakes coastline is relatively exposed to swell waves, it can be assumed that the peak wave height reached offshore at the different beaches along this coast would be similar to what could be expected at Crowdy Head except at the beaches facing north (e.g. Shelly Beach or Boat Beach) where the wave climate will be reduced.

Table 5 gives the results for the wave runup assessment. Design incident wave conditions for the assessment of wave runup were determined for a maximum deepwater offshore wave height corresponding to the 1% AEP (Annual Exceedance Probability). Based on the work of Shand et al (2010) the one hour exceedance 100 year ARI offshore wave height of 8.5 m at the Crowdy Head Waverider buoy (which is representative of the study region) was adopted.

Following future sea level rise, maximum runup levels would be expected to increase by at least the value of future sea level rise. As the shoreline alignment will be expected to change in the future along sandy shorelines, it is not possible to accurately predict the future limits of inundation due to wave runup. However, an indicative future runup level for 2050 and 2100 has been estimated, assuming that the nearshore beach slopes and wave climate are unchanged. This would provide only a rough estimate of the extent of future wave runup but provides an indication of infrastructure which may be at risk from future inundation due to wave runup.

Maximum runup calculations assumed a 1% AEP ocean[3] water level of 1.5 m AHD as derived from Lord and Kulmar (2000). This is a conservative assumption, as the 1% AEP water levels would not necessarily occur concurrently with 1% AEP wave heights. Maximum wave runup elevations were estimated by summing together nearshore wave setup, maximum offshore water levels and maximum wave runup.

Table 5: Wave Runup levels for Great Lakes, 0.1% AEP (1000 year ARI) storm event*

Location	Nearshore Water Level	2% Wave RunUp from ACES	Maximum Wave RunUp from ACES	2% Wave RunUp	Maximum RunUp	2050 Max RunUp	2100 Max RunUp	Minimum Dune Height Along Frontage (Indicative only)[4]
	m	m	m	m AHD	m AHD	m AHD	m AHD	m AHD
Nine Mile Beach Golf Course	2.0	2.5	3.0	4.6	5.0	5.4	5.9	4.8
Nine Mile Beach	2.3	3.3	4.0	5.6	6.3	6.7	7.2	4.9
Nine Mile Beach South	2.6	3.8	4.7	6.4	7.3	7.6	8.1	5.6
Main Beach North	2.4	4.0	5.0	6.5	7.4	7.8	8.3	6.0

[3] Ocean water level is that representative of conditions seaward of wave breaking and includes astronomical tide and storm surge.

[4] Minimum dune heights are based on preliminary analysis of LiDAR, small local depressions in the frontal dunes may not be picked up (e.g. beach access ways)

Location	Nearshore Water Level	2% Wave RunUp from ACES	Maximum Wave RunUp from ACES	2% Wave RunUp	Maximum RunUp	2050 Max RunUp	2100 Max RunUp	Minimum Dune Height Along Frontage (Indicative only)[4]
	m	m	m	m AHD	m AHD	m AHD	m AHD	m AHD
Main Beach South	2.3	2.3	2.7	4.6	5.0	5.3	5.8	6.9
Pebbly Beach	1.7	3.1	3.7	4.8	5.4	5.8	6.3	>10
One Mile Beach North	2.5	3.3	4.0	5.8	6.5	6.8	7.3	8.6
One Mile Beach South	2.5	2.9	3.4	5.4	5.9	6.3	6.8	6.0
Burgess Beach	2.4	2.8	3.4	5.2	5.8	6.1	6.6	>10
Seven Mile Beach North	2.5	2.4	2.8	4.8	5.3	5.6	6.1	5.6
Seven Mile Beach Caravan Park	2.4	3.0	3.7	5.4	6.1	6.5	7.0	>10
Seven Mile Beach South	2.5	2.6	3.1	5.0	5.5	5.9	6.4	7.1
Elizabeth Beach SLSC	2.6	2.0	2.3	4.5	4.9	5.2	5.7	7.0
Sandbar Beach	2.5	2.4	2.9	4.8	5.3	5.6	6.1	8.5
Number One Beach North	2.38	4.78	5.98	7.16	8.36	8.8	9.2	>10
Number One Beach South	2.46	2.31	2.75	4.77	5.21	5.65	6.05	8.7
Boat Beach	3.20	2.75	3.39	5.95	6.59	7.03	7.43	7.4
Lighthouse Beach	2.61	3.01	3.65	5.62	6.26	6.7	7.1	8.4
Treachery Beach	2.37	2.04	2.35	4.41	4.72	5.16	5.56	9.0
Bennetts Beach treatment Plant	2.44	3.90	4.80	6.34	7.24	7.68	8.08	>10
Bennetts Beach Golf Course	2.38	3.18	3.87	5.56	6.25	6.69	7.09	6.8
Bennetts Beach SLSC	2.38	3.36	4.10	5.74	6.48	6.92	7.32	7.3
Bennetts Beach South	2.49	2.54	3.04	5.03	5.53	5.97	6.37	5.6
Jimmys Beach East	1.45	2.33	2.77	3.78	4.22	4.66	5.06	4.7
Jimmys Beach Centre-East	1.55	3.72	4.54	5.27	6.09	6.53	6.93	5.4
Jimmys Beach Centre-West	1.57	3.10	3.74	4.67	5.31	5.75	6.15	6.1
Jimmys Beach West	1.58	1.83	2.10	3.41	3.68	4.12	4.52	7.4

5.5 Slope Instability Hazard

Slope risk assessments were undertaken at Seal Rocks where slope stability has been identified as a significant coastal hazard. Slope risk assessments at the two Seal Rocks sites defined potential slope failure mechanisms presenting a risk to property and/or individuals due to susceptibility to landslides.

Qualitative assessments have been used to define the risk to property at each of the sites visited. Quantitative assessments have been used to define the risk to life at each of the sites visited.

The failure mechanism identified as most commonly occurring at these sites were debris slides ranging from 25 m^3 to 350 m^3. In addition there was some potential for rock falls at Boat Beach. Risk assessments were undertaken on those potential failures deemed significant in terms of potential to cause property damage or risk to life.

The qualitative risk assessments undertaken for property, predominantly public infrastructure such as roads varies from very low to moderate. Quantitative risk to life assessments of individual susceptibility during the occurrence of failure events also showed that the debris slides resulting in loss of life had a risk varying between 1.1×10^{-5} and 4.5×10^{-7}. The risk of loss of life from rock falls was 6.3×10^{-7}.

The AGS 2007 guidelines show an example of evaluating the risks in terms of a tolerable acceptance criteria for property loss and loss of life. In this instance, the individual or property risks are accepted due to being tolerable or risk mitigation measures are undertaken to reduce the risk to more tolerable levels.

The AGS 2007 guidelines indicate that the regulator is the appropriate authority to set the standards for tolerable risks relating to perceived safety in relation to other risks and government policy. However, the AGS 2007 recommendation of tolerable risk to life on existing developed slopes is 10^{-4} and 10^{-5} on slopes where existing landslides exist. For the two sites at Seal Rocks a value of 10^{-5} has been used as the tolerable level. For both sites the risk of loss of life is tolerable.

In terms of property, AGS 2007 recommends the importance level of the property or structure be rated in terms the societal requirements particularly during or after extreme events. In this case Seal Rocks Road is the only access road into Seal Rocks and therefore would be considered an important structure. A risk to property of moderate has been determined at both sites. The implications for a moderate risk level is that it may be tolerated in certain circumstances (subject to regulator's approval) but requires investigation, planning and implementation of treatment options to reduce the risk to low.

Table 6 summarises the slope instability hazard at Boat Beach and Number One Beach. The slope instability hazard is documented in detail in Appendix F.

Table 6: Risk Assessment Results, Slope Instability Hazard

Site Location	Hazard	Risk to Property	Risk of loss of life	Mitigation Measures
Boat Beach	Rock fall (1 m long boulder)	No direct damage to property but can facilitate landslips in overlying overburden materials.	6.3 x10^{-7}	• Protective measure either side of the gabion wall and control of surface water overflow the gabion wall • Further inspection on the stability of the slope
	Debris Slide (1 5m in length & 75 m^3)	• Failure of the gabion wall and undermine the pavement • Damage to the Kinka Road and pavement and affect the buried services in the roadway	1.26 x10^{-5}	
	Debris Slide (25 m in length & 370 m^3)		1.1 x 10^{-5}	
Number One Beach	Soil Creep	Continued recession from a combination of rainfall, storm water runoff, wave action and sea level and eventually loss of road	4.5 x 10^{-7}	• Protective measures such as geotextile layer to prevent further erosion of existing failure scars • Control of surface water runoff on to the slope • Stop public parking above the slope and accessing the slope • Further inspection on the stability of the headland
	Debris Slide (50m^3)	Loss of ground, damage to fences and retaining structures, cracking of infrastructure on the terraces etc.	4.5 x 10^{-6}	

5.6 Wind-Driven Dune Instability Hazard

Windborne sediment transport can result from destruction of the dune vegetation canopy – removal of dune vegetation can lead to areas of sand being destabilised by the wind, leading to a dune “blowout”. This phenomenon has been observed at a minor scale at the southern end of Nine Mile Beach and at wider scale at One Mile Beach, Lighthouse Beach, Treachery Beach and Bennetts Beach. dune blowout is causing the dune transgression towards the private dwelling located behind the dune at the northern end of One Mile Beach and Mungo Brush Road behind Bennetts Beach.

6 HAZARD MAPPING AND RISK ASSESSMENT

6.1 Hazard Mapping

The derivation of the dune erosion hazard for the present day, 2060 and 2100 planning periods is presented in detail in Appendix D. For each planning period, the erosion hazard has been defined as:

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

Sea level rise planning benchmarks for 2060 and 2100 were based on the NSW Sea Level Rise Policy. The mapping has been based on analysis of the photogrammetric data and aerial laser scan data of the coastline.

The baseline position used to transcribe the hazard parameters was obtained from the 2006 ALS data which are the latest available data.

6.2 Risk Assessment

A risk assessment for the present day, 2060 and 2100 planning period has been carried out for the urban area of Council. This risk assessment was carried out to:

- Quantify the number of properties impacted by the present, 2060 and 2100 hazard lines marking the boundary of the Zone of Slope Adjustment (ZSA) and the Zone of Reduced Foundation Capacity (ZRFC) for the different Great Lakes beaches
- Quantify what public assets and infrastructure are impacted by the present, 2060 and 2100 hazard lines at each beach (public building and facilities, length of road, carparks, etc)

The results of this risk assessment are summarised in Table 7 below. The hazard maps are given in Appendix D for the present day, 2060 and 2100 planning period along the Great Lakes coastline.

Table 7: Great Lakes coastal hazards risk assessment for present, 2060 and 2100 planning periods

Beach Location	Coastal Areas Risk Assessment for Present, 2060 and 2100 Planning Horizons					
	Immediate Hazard		2060 Planning Horizon		2100 Planning Horizon	
	ZSA	ZRFC	ZSA	ZRFC	ZSA	ZRFC
Nine Mile/Tuncurry	▪ Nothing impacted except foredune	▪ Nothing impacted except foredune	▪ Nothing impacted except foredune	▪ Nothing impacted except foredune	▪ 50% of the Carpark near Tuncurry Beach	▪ 50% of the Carpark near Tuncurry Beach
Main Beach with Seawall (assuming that the existing seawall would hold up against the design storm event)	▪ Nothing impacted except foredune	▪ Nothing impacted except foredune	▪ Beach accessway to Main Beach	▪ Beach accessway to Main Beach	▪ Seaward section of the park north of the Caravan Park ▪ Beach accessway to Main Beach	▪ Seaward section of the park north of the Caravan Park and seaward corner of the Caravan Park ▪ Beach accessway to Main Beach
One Mile Beach	▪ 20% of Cape Hawke Surf Club building ▪ 30% of Carpark at the southern end	▪ 50% of Cape Hawke Surf Club building ▪ 80% of Carpark at the southern end seaward of the hazard line	▪ 60% of Cape Hawke Surf Club building ▪ 90% of Carpark at the southern end seaward of the hazard line ▪ 10 lots slightly affected along the seaward boundary	▪ Whole Surf Club building ▪ 25 Lots ▪ Whole Carpark at the southern end	▪ Whole Surf Club ▪ 25 Lots partly eroded ▪ Whole Carpark at the southern end eroded ▪ 16 buildings partly eroded Part of Cliff Road, Konda Place, Palmgrove Place and Burrawong Place	▪ Whole Surf Club ▪ 27 Lots ▪ 24 buildings ▪ Whole Carpark at the southern end ▪ Part of Cliff Road, Konda Place, Palmgrove Place and Burrawong Place

Beach Location	Coastal Areas Risk Assessment for Present, 2060 and 2100 Planning Horizons					
	Immediate Hazard		2060 Planning Horizon		2100 Planning Horizon	
	ZSA	ZRFC	ZSA	ZRFC	ZSA	ZRFC
Elizabeth Beach	▪ 30 m of roadway along Lakeside Crescent	▪ 40 m of roadway along Lakeside Crescent	▪ 120 m along Lakeside Crescent ▪ Corner of the Carpark at the northern end	▪ 150 m of roadway along Lakeside Crescent ▪ Northern end Carpark ▪ 10% of Surf Club building	▪ 170 m of roadway along Lakeside Crescent ▪ Northern end Carpark	▪ 180 m along Lakeside Crescent ▪ 30% of Surf Club building ▪ Northern Carpark
Boat Beach	▪ Boat ramp at the central Kinka Road	▪ 180 m along Kinka Road ▪ Part of one building	▪ 250 m along Kinka Road ▪ Part of two buildings	▪ 250 m along Kinka Road ▪ Part of six buildings	▪ 250 m along Kinka Road ▪ 11 buildings	▪ 250 m along Kinka Road ▪ 14 houses
Number One Beach	▪ 80 m along Seal Rocks Road	▪ 110 m along Seal Rocks Road ▪ Two Lots at the western corner	▪ 150 m along Seal Rocks Road ▪ Five lots at the western corner	▪ 160 m along Seal Rocks Road ▪ Six lots at western corner ▪ Three lots on eastern side	▪ 160 m along Seal Rocks Road ▪ Nine lots at western corner ▪ Five lots on eastern side	▪ 170 m along Seal Rocks Road ▪ Nine lots at western corner ▪ Eight lots on eastern side
Bennetts Beach	▪ Nothing impacted except foredune	▪ Nothing impacted except foredune	▪ 20% of Hawks Nest SLSC building ▪ 80 m of southern beach access way	▪ Whole Hawks Nest SLSC building ▪ 90% of car park ▪ 120 m of southern beach access way affected	▪ Whole Hawks Nest SLSC building and the adjacent car park ▪ 350 m of southern beach access way	▪ Whole Hawks Nest SLSC building and the adjacent car park ▪ Most of Beach Road Impacted including southern access

Beach Location	Coastal Areas Risk Assessment for Present, 2060 and 2100 Planning Horizons					
	Immediate Hazard		2060 Planning Horizon		2100 Planning Horizon	
	ZSA	ZRFC	ZSA	ZRFC	ZSA	ZRFC
						▪ Border of four lots
Sandbar Beach	▪ Nothing impacted except foredune	▪ Nothing impacted except foredune	▪ Nothing impacted except foredune	▪ Nothing impacted except foredune	▪ Nothing impacted except foredune	▪ Nothing impacted except foredune
Seven Mile Beach	▪ Beach accessways	▪ Beach accessways ▪ One dwelling at the southern end of the beach	▪ Beach accessways ▪ The park at the southern end of the beach ▪ One dwelling at the southern end of the beach	▪ Beach accessways ▪ The park at the southern end of the beach ▪ One dwelling at the southern end of the beach ▪ Southern end of Tiona Park	▪ Beach accessways ▪ Larger area of the southern end park ▪ One dwelling at the southern end of the beach ▪ 70% of Tiona Park ▪ Two dwellings in Tiona area	▪ Beach accessways ▪ Larger area of the southern end park ▪ One dwelling at the southern end of the beach ▪ 80% of Tiona Park ▪ Three dwellings in Tiona area

7 SUMMARY

Detailed technical studies using an updated empirical database have allowed for the quantification of the coastal hazards at Great Lakes. The assessment has been made on the basis of detailed photogrammetric survey data.

AS4997-2005 "*Guidelines for the design of maritime structures*" (AS, 2005) recommends that a storm event having a 5% probability of being exceeded over a 50 year period be adopted for risk analyses. Several large storm events occurred over the period of the photogrammetric data record, including a major storm in May-June 1974. The exceedance probability of these storms at Great Lakes is not known, but as they are the largest storms to have occurred over the period of the photogrammetric record, they were adopted for analysis for One Mile Beach and Burgess Beach. As the impact of the 1974 storms was not visible on the photogrammetric data for Nine Mile Beach, Main Beach, Boat Beach and Number One Beach, the 1995 and 1997 storm bite has been estimated for these beaches. Due to the orientation of these beaches with respect to the approach direction of these storms, it is considered that the 1995-1997 storms caused the greatest amount of erosion for these beaches. The maximum measured erosion between consecutive dates of photogrammetric data which encompasses these large storm events, were adopted as the design storm erosion.

The available photogrammetric data has indicated that the beaches at Great Lakes except for Main Beach, Elizabeth Beach and Number One Beach are not undergoing long term recession but are accreting on average. The long term rate of change has been set to zero for the accreting beaches.

Projections for planning purposes for future sea level rise, as a result of global warming, could increase the rate of long term recession. High estimate sea level rise scenarios in line with the NSW Sea Level Rise Policy Statement, indicated a sea level rise from the 1990 sea level of 0.40 m by 2050, and 0.90 m by 2100 to maintain a conservative philosophy have been adopted. Estimates of resultant recession have been made using the Bruun Rule. It is possible that these estimates are conservative, as the Bruun analysis does not take the presence of underlying bedrock into account. However, where data were available to estimate the depth of underlying bedrock, this was taken into account when determining the nearshore equilibrium slope to use with the Bruun Rule calculations. Targeted geotechnical investigations to ascertain the depth of bedrock would allow an improved estimate of the long term shoreline recession due to projected sea level rise to be carried out for future studies.

Future changes to the estuary entrance dynamics at Smiths Lake are possible, as a result of climate change or changed estuary entrance management practices, leading to an increased potential for breakthrough of the entrance through the tombolo at Smiths Lake entrance.

Wave runup analysis for the design storm has indicated that runup levels may create some inundation hazard for the properties located behind One Mile Beach as the embankment height is lower than the runup level. The storm water culvert under Lakeside Crescent and the adjacent southern Elizabeth Beach car park as well as the Cape Hawke Surf Club might also suffer from inundation in the case of a significant storm. Kinka Road along Boat Beach will potentially be reached by the wave runup, including two properties behind the road.

Slope risk assessments at two sites in Seal Rocks have defined existing and potential slope failure mechanisms presenting slope instability to property and/or individual susceptibility arising from landslides at these sites. Qualitative assessments have been used to define the risk to property at each of the sites visited. Quantitative assessments have been used to define the risk to life at each of the sites visited.

The failure mechanism identified as most commonly occurring at these sites were debris slides ranging from 25 m^3 to 350 m^3. Land slips and rock falls are also a common type of failure where bed rock is under a cover of overburden soil and are generally constrained to overburden soils. Creeps or slow downslope movement of overburden material were also observed in places. Risk assessments were undertaken on those potential failures deemed significant in terms of potential to cause property damage or risk to life.

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FIGURES

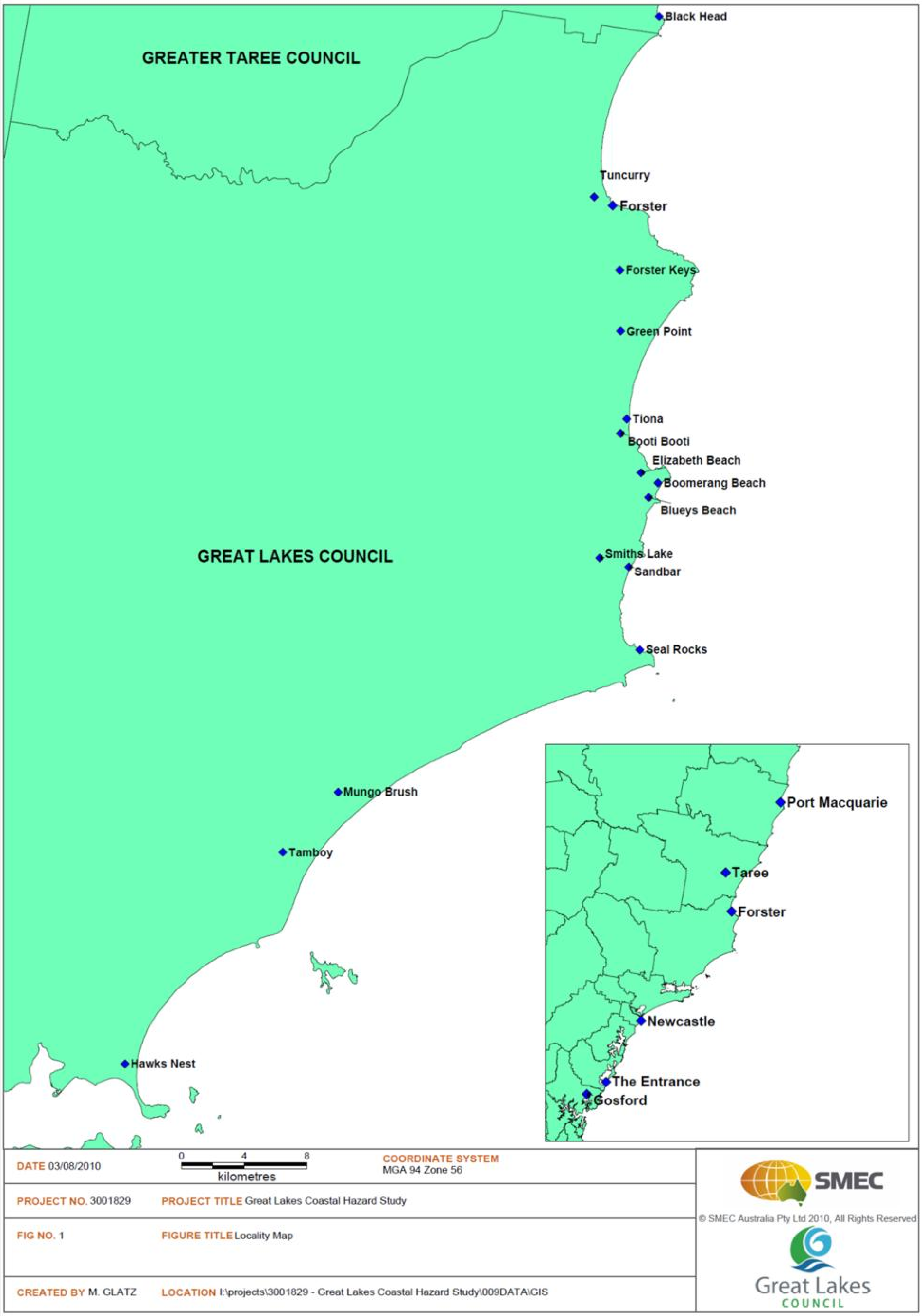

Figure 1: Locality Map

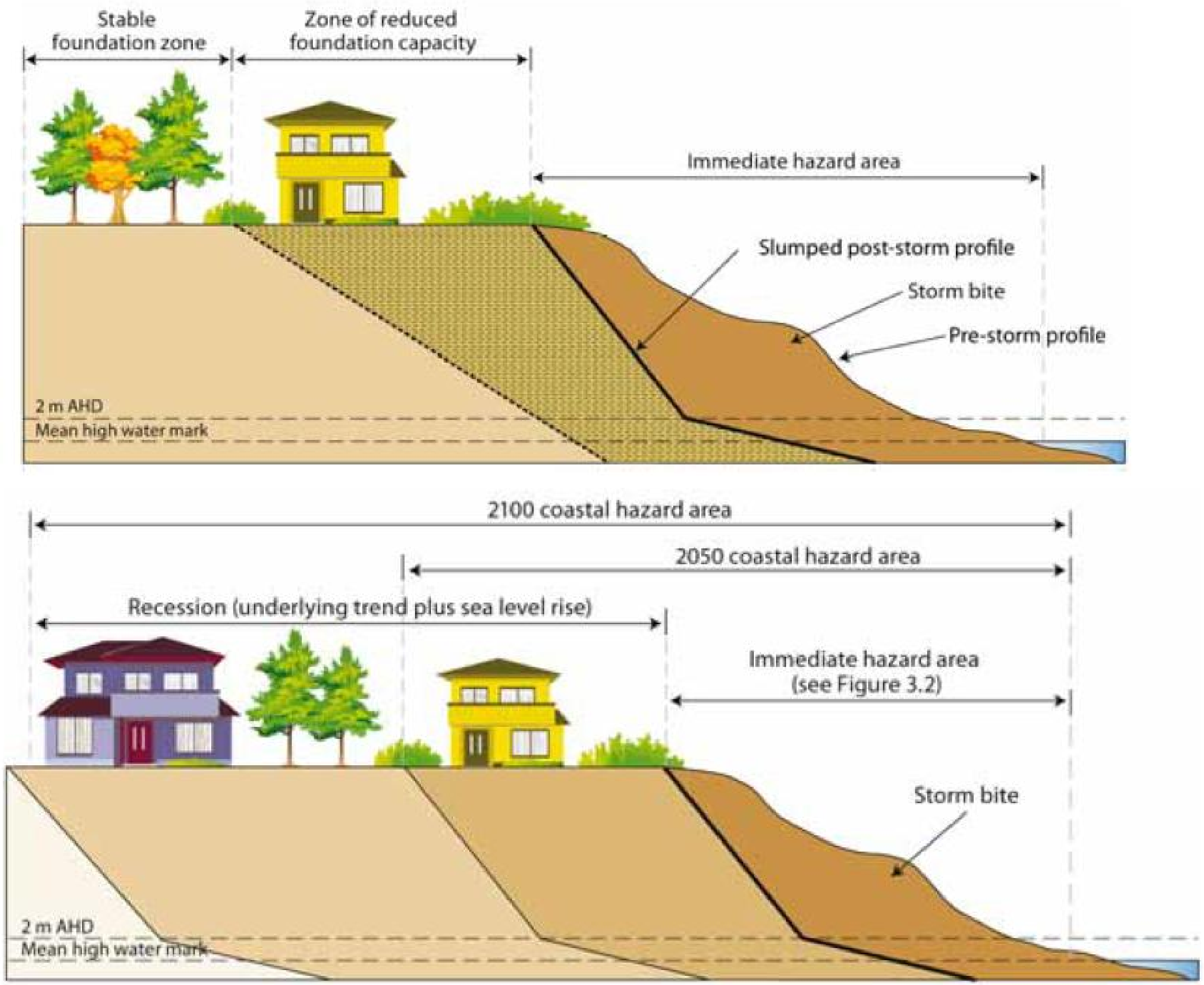

Figure 2: Top: Idealised schematic of a dune profile depicting hazard zone nomenclature (DECCW, 2010b)
Bottom: Idealised schematic of a dune profile depicting the high hazard zone, 2050 coastal hazard zone and 2100 coastal hazard zone (DECCW, 2010b)

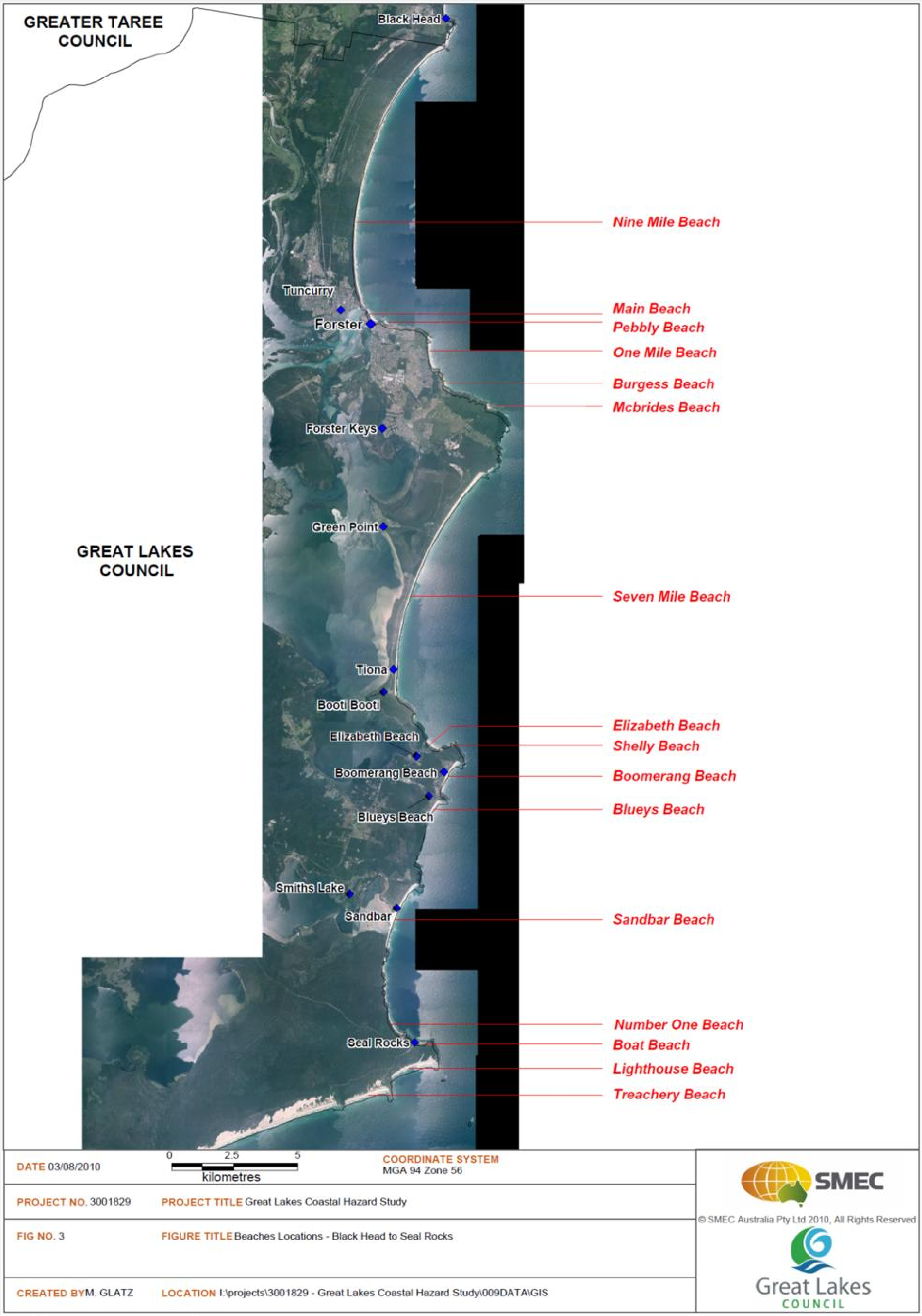

Figure 3: Beach locations – Black Head to Seal Rocks

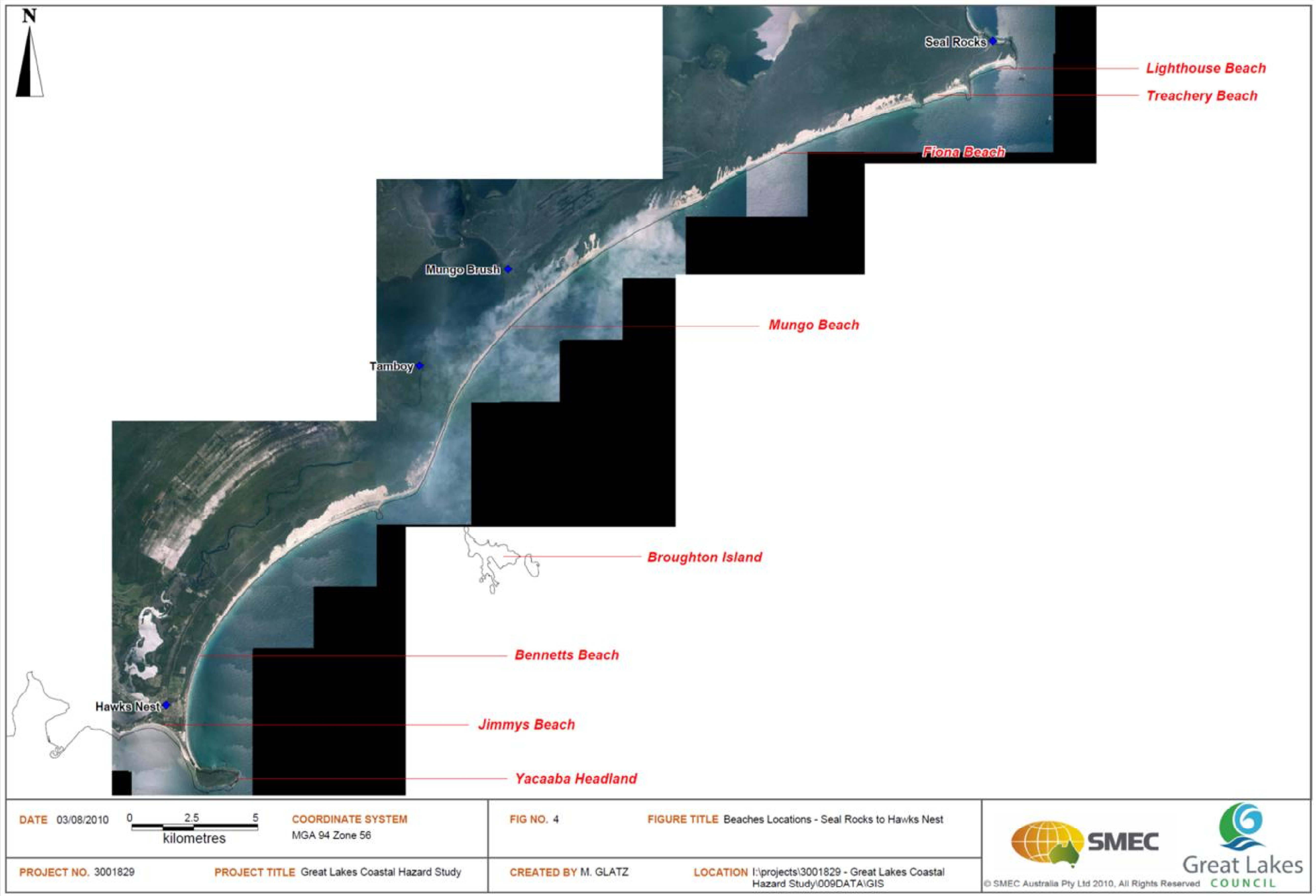

Figure 4: Beach locations – Seal Rocks to Hawks Nest

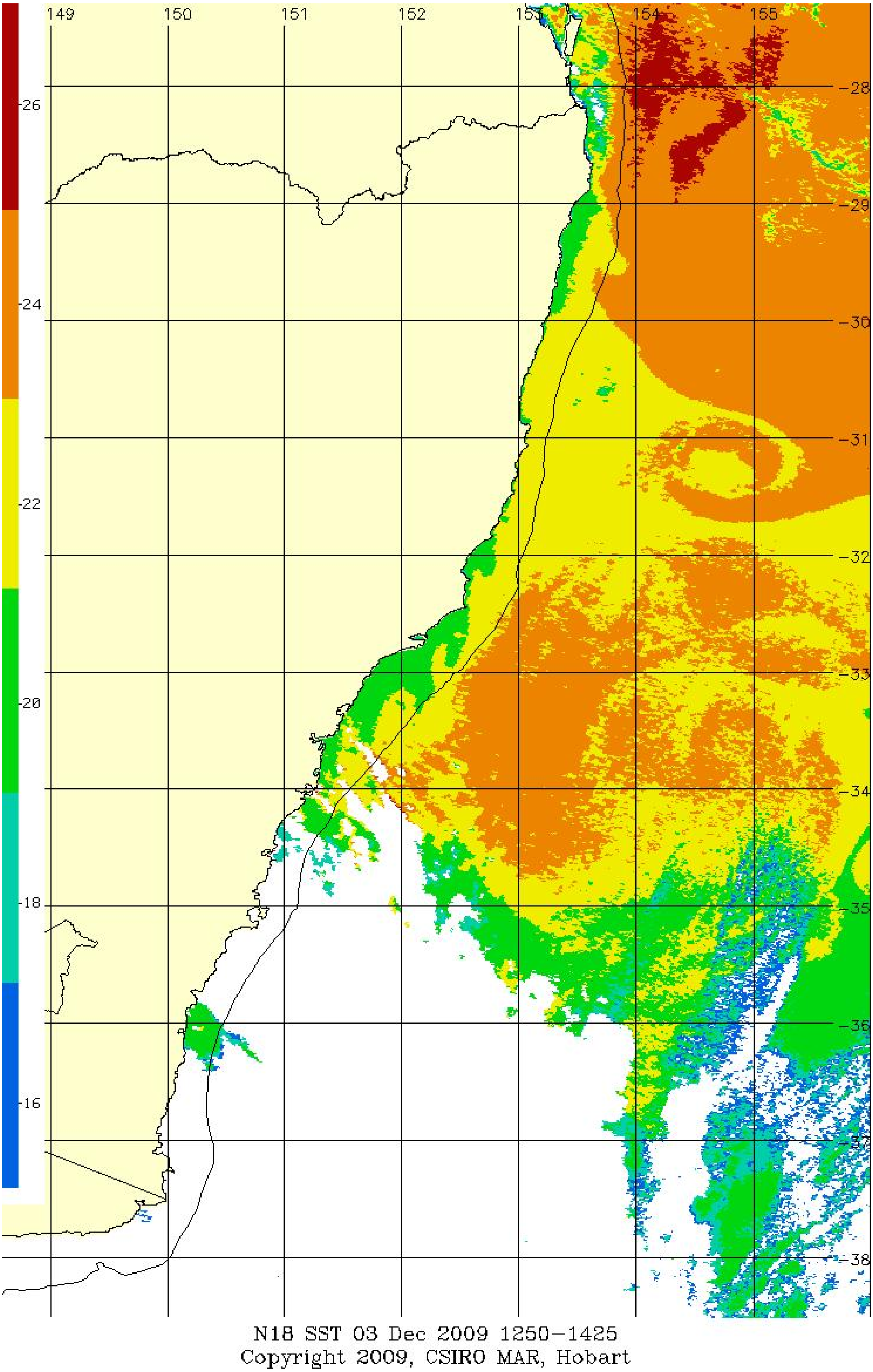

Figure 5: Map showing East Australia Current, December 2009

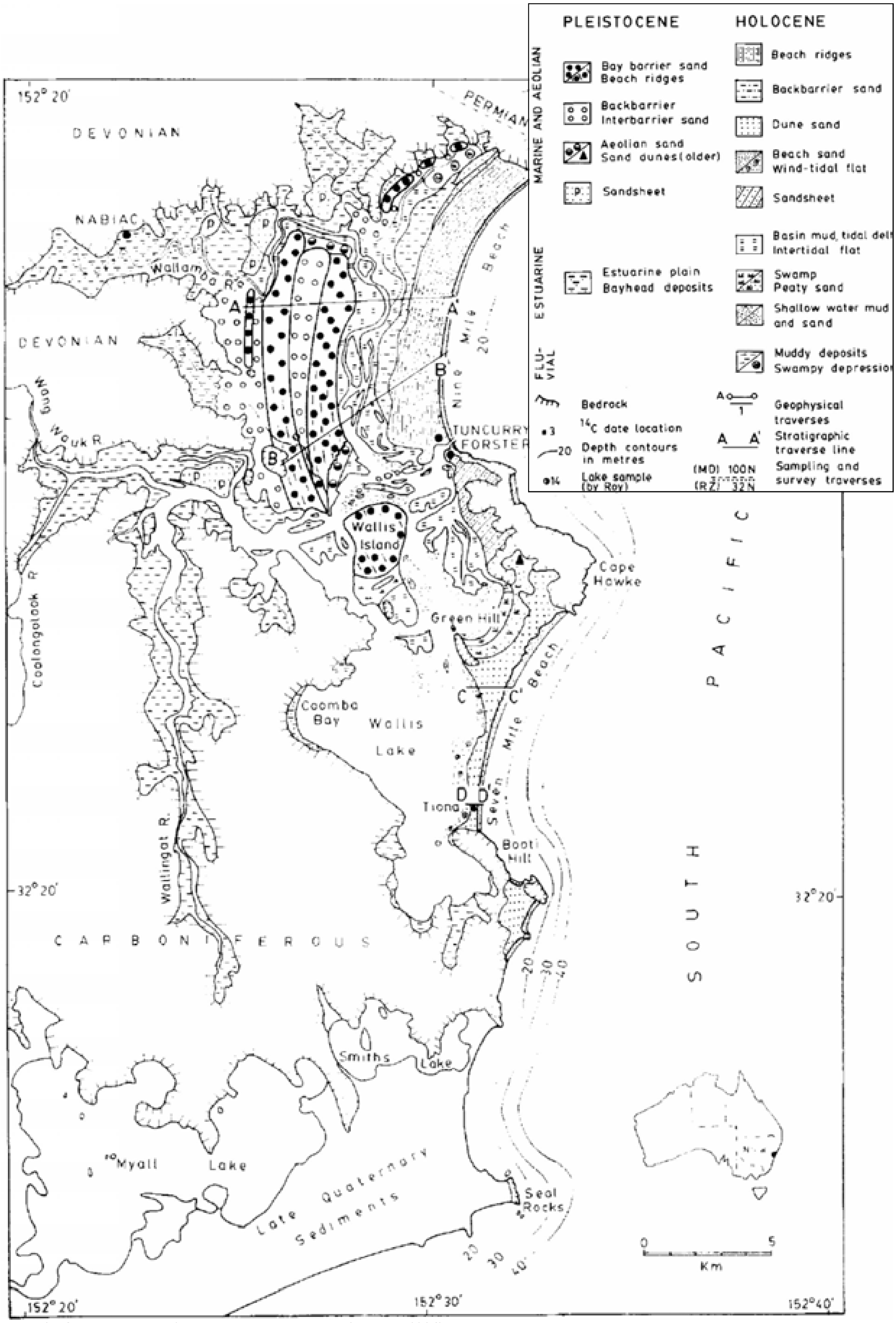

Figure 6: Geological map of the Forster-Tuncurry area (Melville, 1984)

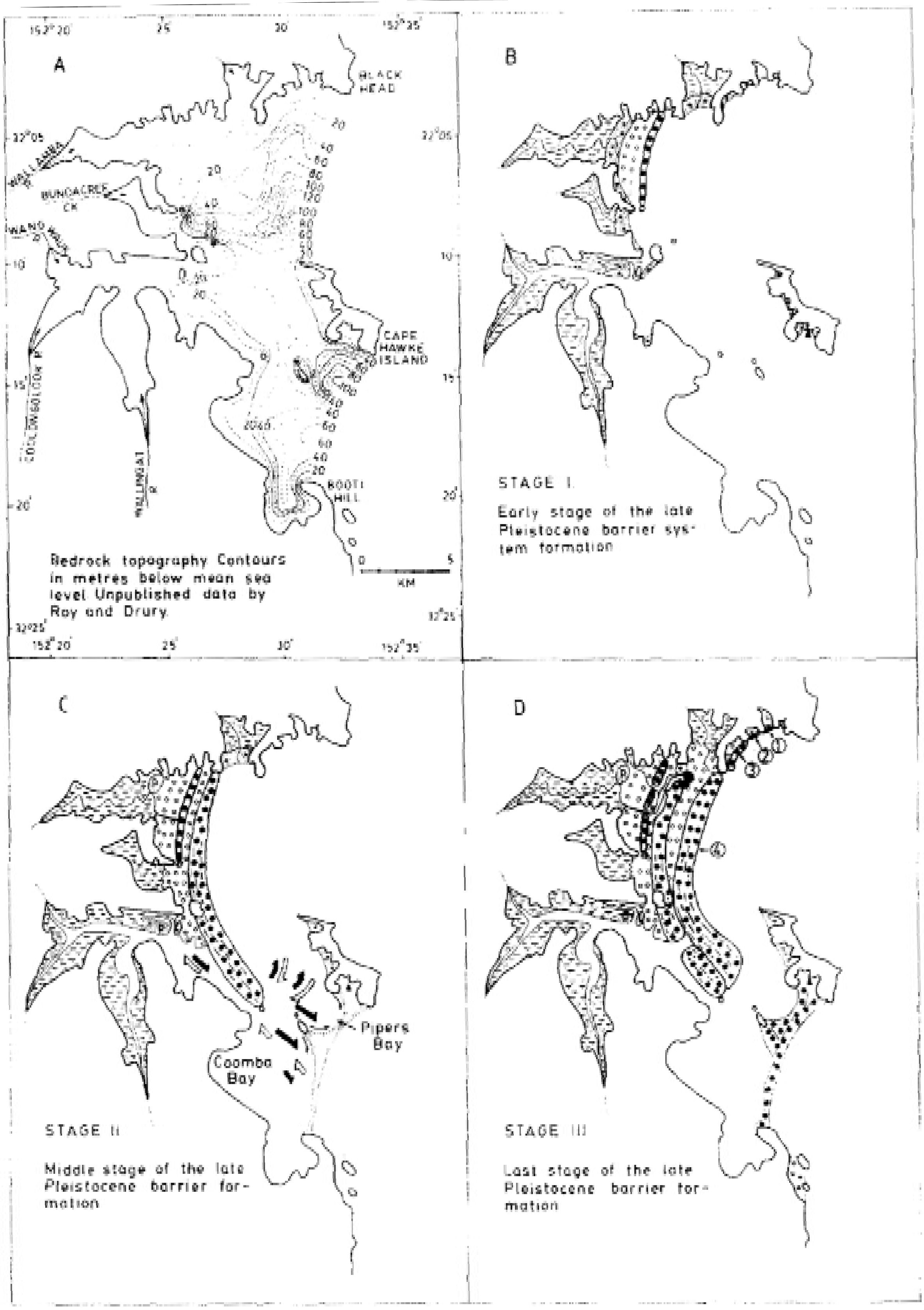

Figure 7a: Bedrock topography (A) and three first stages of the coastal evolution of the Forster-Tuncurry area (B-D) during the late Quaternary (Melville, 1984)

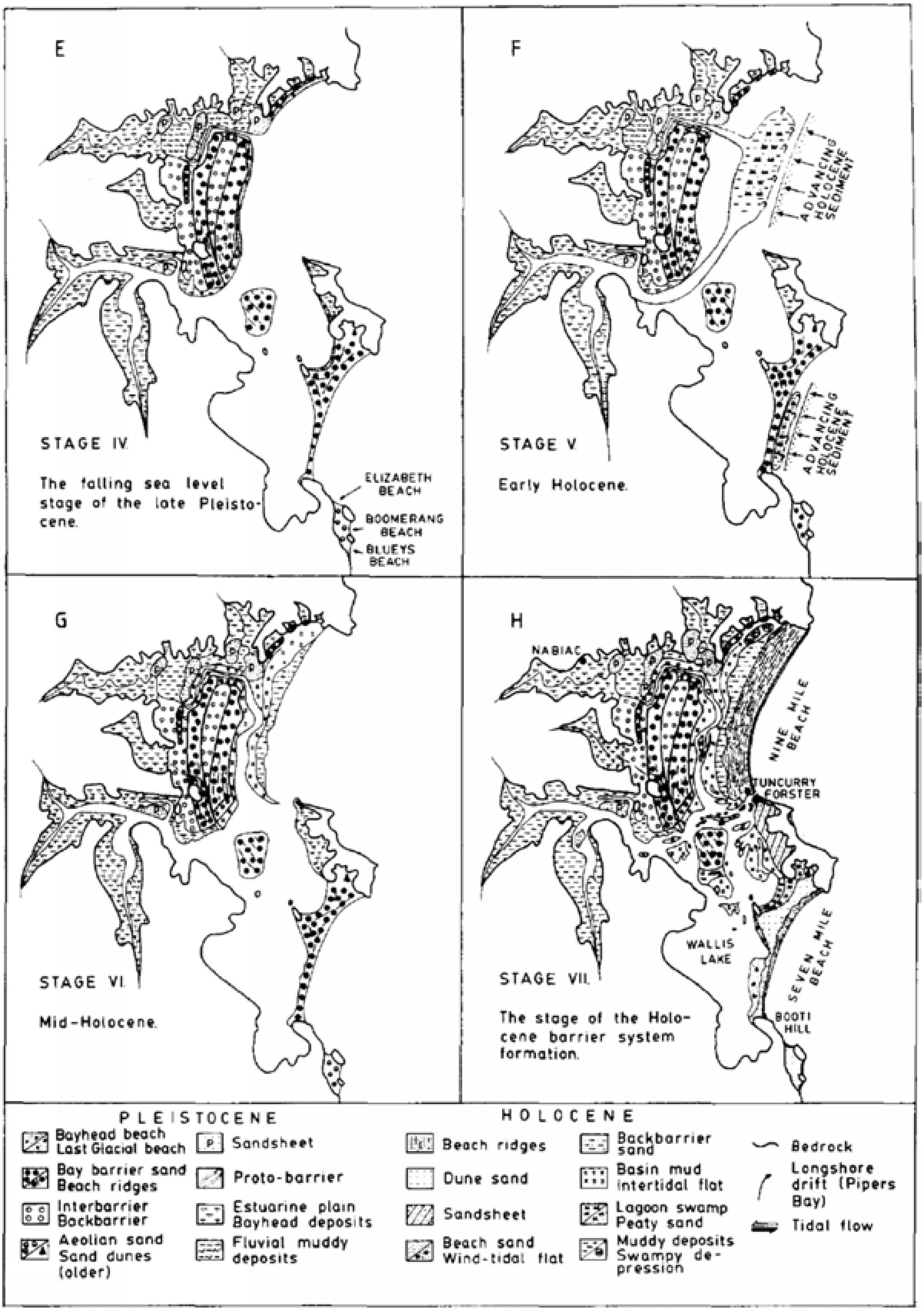

Figure 7b: Four last stages of the coastal evolution of the Forster-Tuncurry area during the late Quaternary (Melville, 1984)

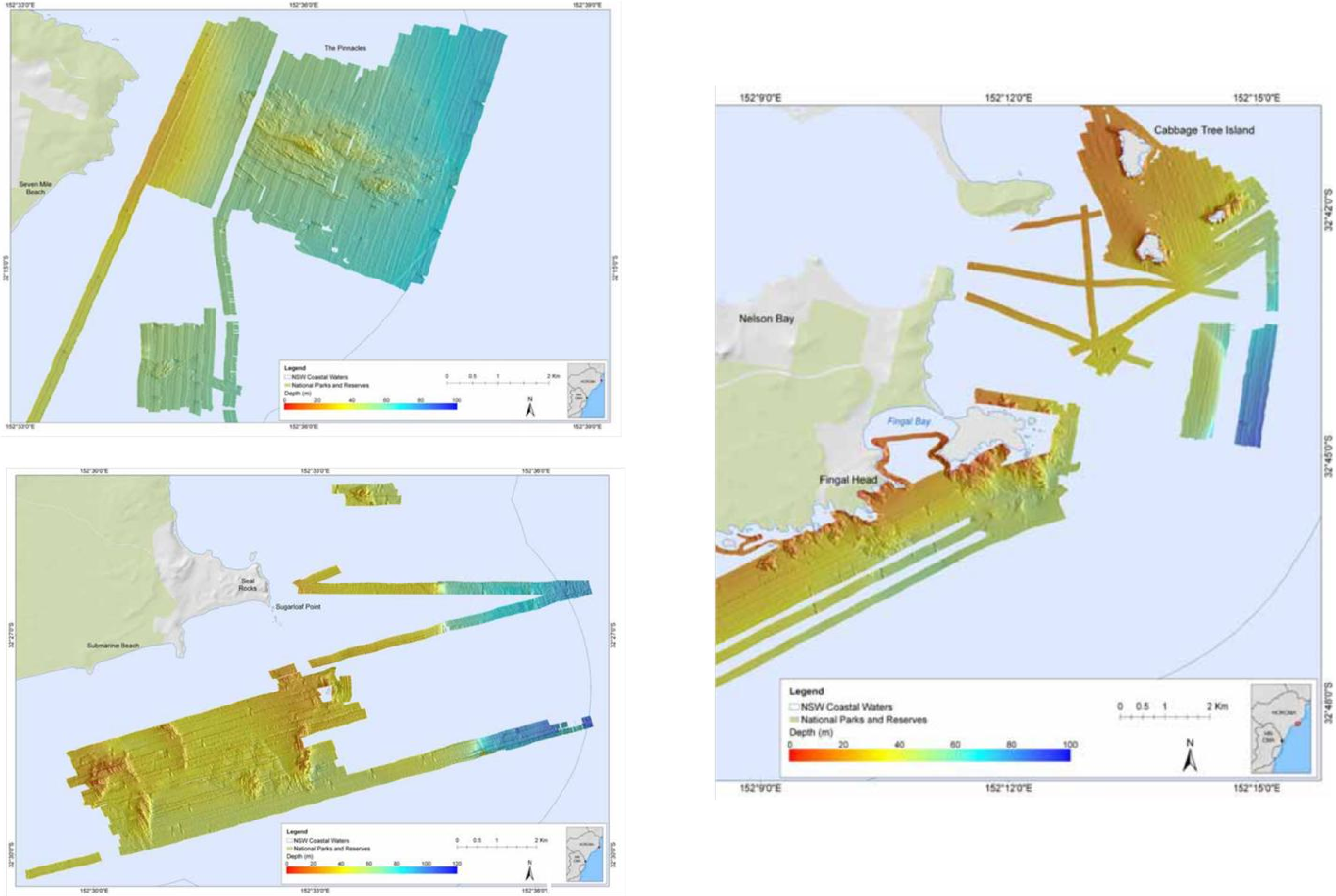

Figure 8: Nearshore bathymetric mapping offshore of Cape Hawke, Sugarloaf Point and Hawks Nest undertaken by DECCW (2009) indicating extent of nearshore rock reef

Figure 9: 4WD track on incipient dune at the northern end of Nine Mile Beach (July 2010)

Figure 10: Erosion escarpment at the northern end of Nine Mile Beach (July 2010)

Figure 11: Failed seawall at the southern end of Nine Mile Beach and area of the seawall possibly subject to overtopping issues (July 2010)

Figure 12: Seawall within Wallis Lake entrance (July 2010)

Figure 13: Wind protection for dune at southern end of Nine Mile Beach (July 2010)

Figure 14: Storm bite behind the fences at the southern end of Nine Mile Beach (July 2010)

Figure 15: Board and chain access at the southern end of Nine Mile Beach (July 2010)

Figure 16: Southern breakwater at Wallis Lake entrance (July 2010)

Figure 17: Erosion escarpment at the northern end of Main Beach (July 2010)

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Figure 24: Pebbly Beach (July 2010)

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Figure 27: Dune blow-out reaching the houses located behind the northern end of One Mile Beach (July 2010)

Figure 28: Fences partially covered with sand at the top of the coastal bluff at the northern end of One Mile Beach (July 2010)

Figure 29: Erosion escarpment along the northern half of One Mile Beach (July 2010)

Figure 30: Creek entrance at One Mile Beach and impact of the creek on the beach (right)

Figure 31: Damaged board and chain access to One Mile Beach (July 2010)

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Figure 38: Elizabeth Beach SLSC (July 2010)

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Figure 43: Closed entrance of Smiths Lake (July 2010)

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Figure 46: Landslip along Seal Rocks Road at Number One Beach (July 2010)

Figure 47: Dumped rocks to protect Seal Rocks Road at Number One Beach (July 2010)

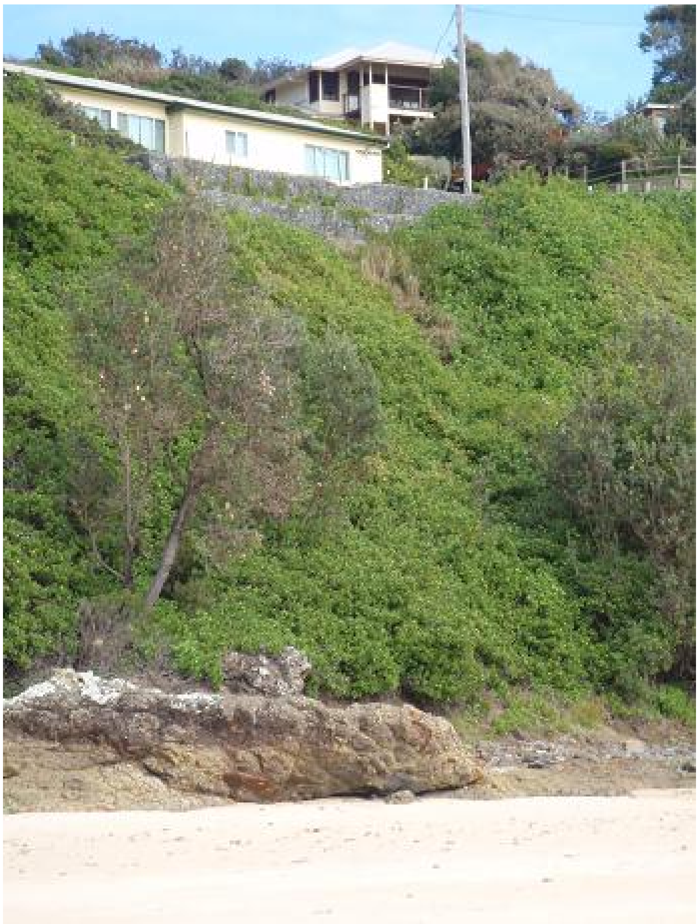

Figure 48: Gabions at the top of the coastal bluff along Kinka Road at the western end of Boat Beach

Figure 49: Erosion escarpment along Boat Beach (July 2010)

Figure 50: Erosion along Boat Beach and ad hoc protection (July 2010)

Figure 51: Damaged private boat ramp at Boat Beach (July 2010)

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Figure 53: Treachery Beach (July 2010)

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Figure 55: Remnant erosion escarpment visible along Bennetts Beach (July 2010)

Figure 56: Well-vegetated dune in front of Bennetts Beach SLSC (July 2010)

Figure 57: Damaged fences at the southern end of Bennetts Beach (July 2010)

Figure 58: Transgressive dune moving landward at the southern end of Bennetts Beach (July 2010)

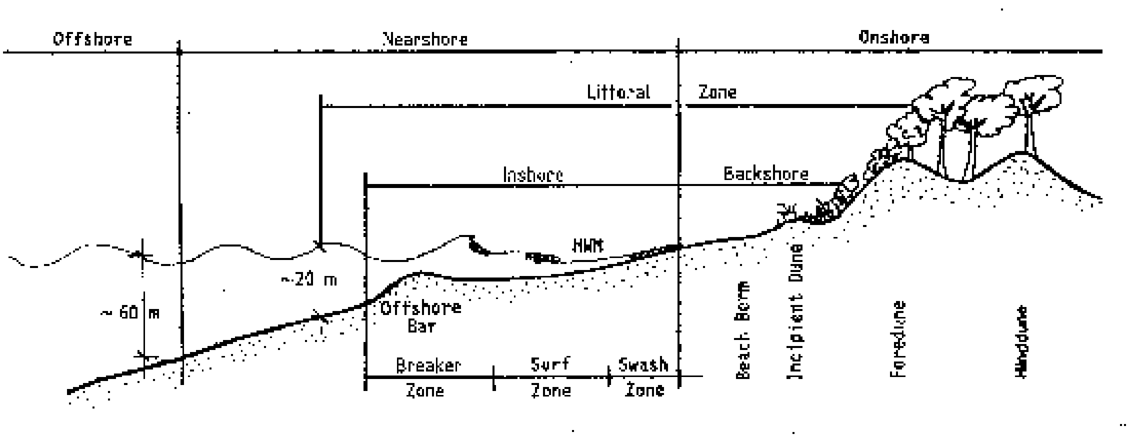

Figure 59: Beach definition sketch (open coast beaches)

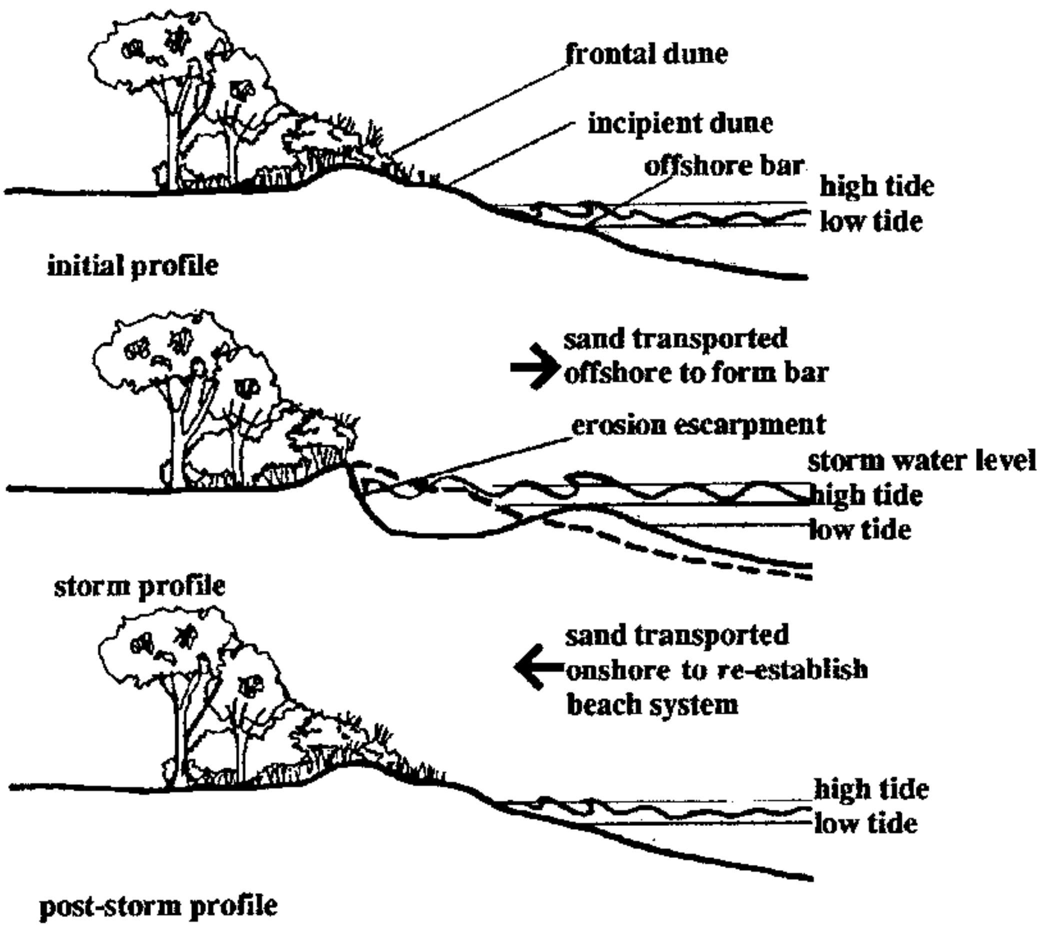

Figure 60: Beach storm erosion/accretion cycle

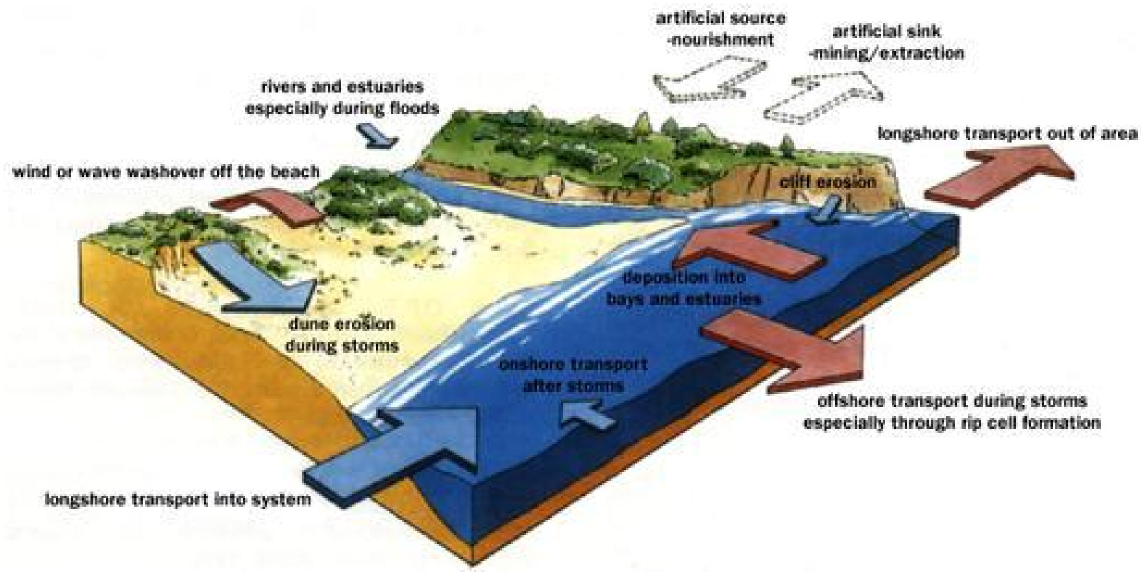

Figure 61: Sediment budget schema (NSW Government, 1990)

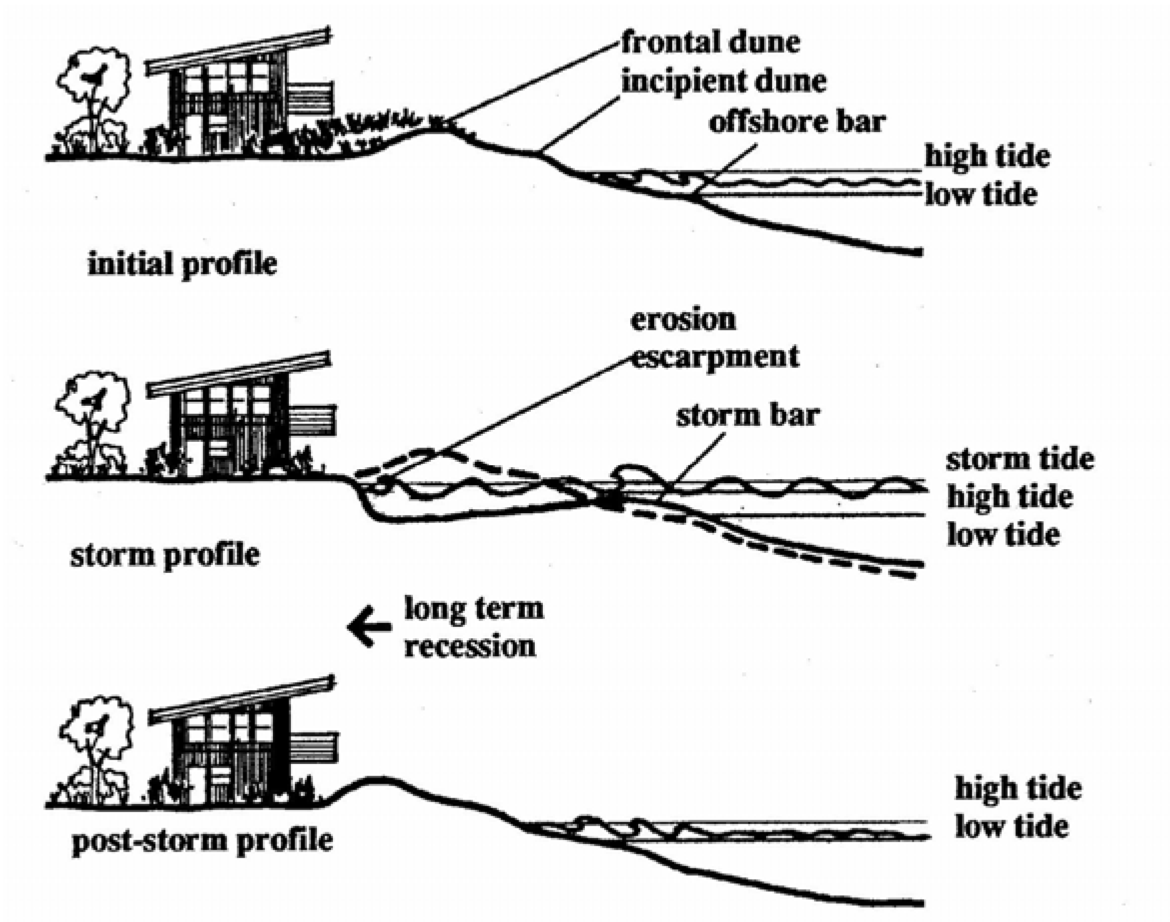

Figure 62: Long term erosion schema

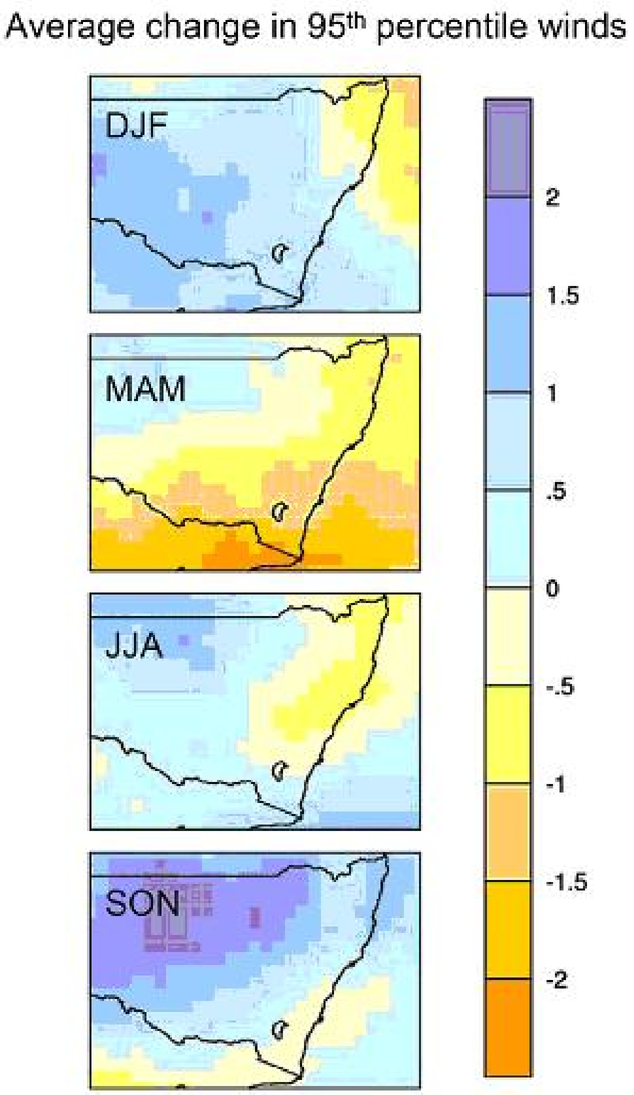

Figure S3: The change in extreme monthly wind speed derived by averaging the 12 models results. Units are % change per °C of global warming. DJF = summer, MAM = autumn, JJA = winter, SON = spring.

Figure 63: Change in extreme monthly wind speeds for NSW coast (Hennessy et al 2004)

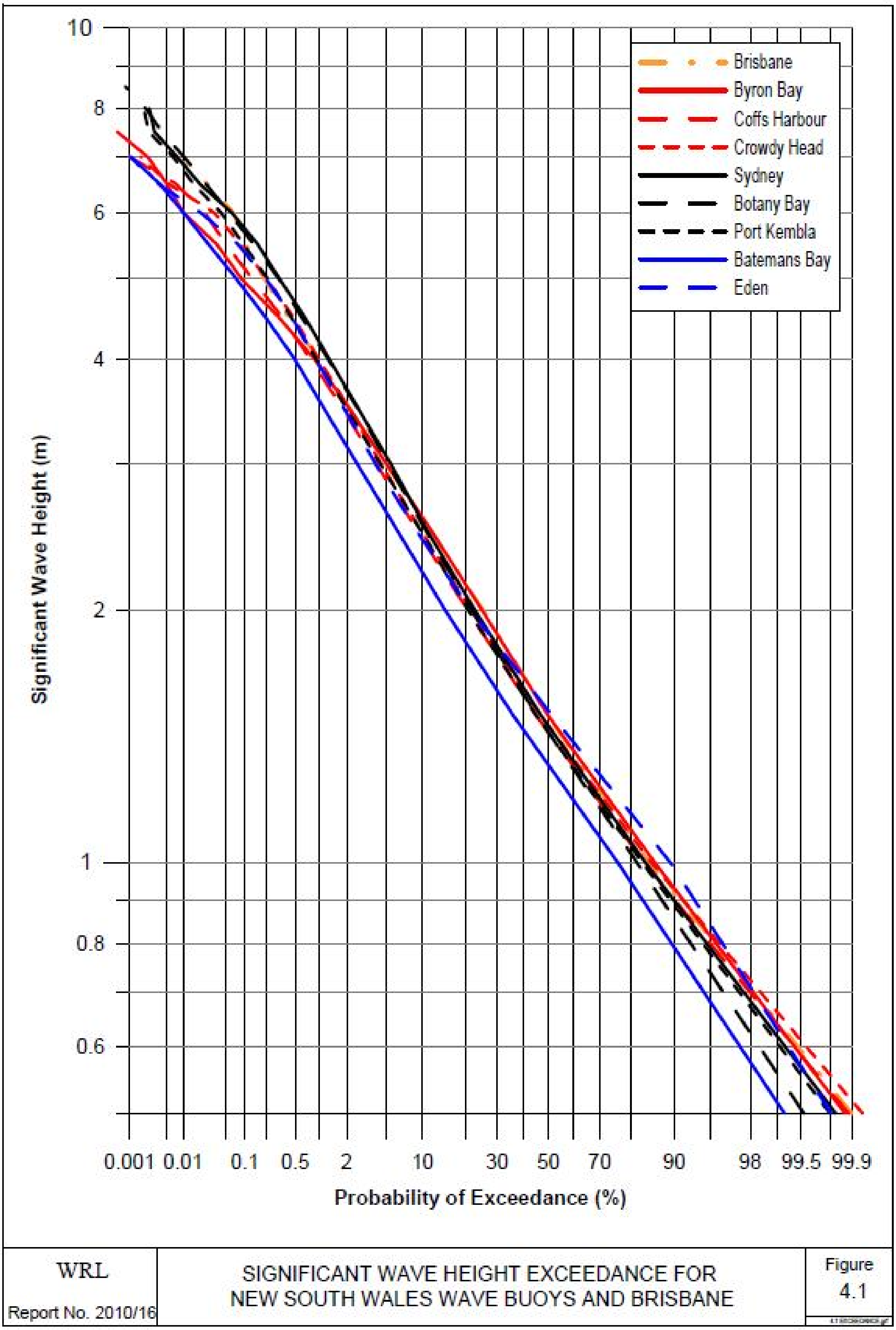

Figure 64: Significant wave height exceedance for NSW coast (Shand et al, 2010)

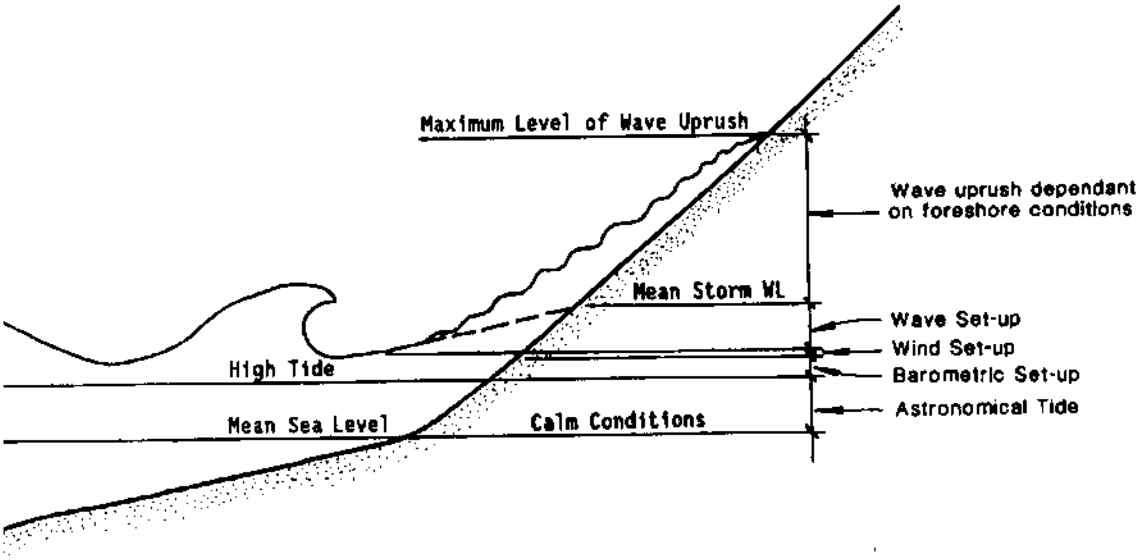

Figure 65: Components of elevated water levels on the coast (NSW Government, 1990)

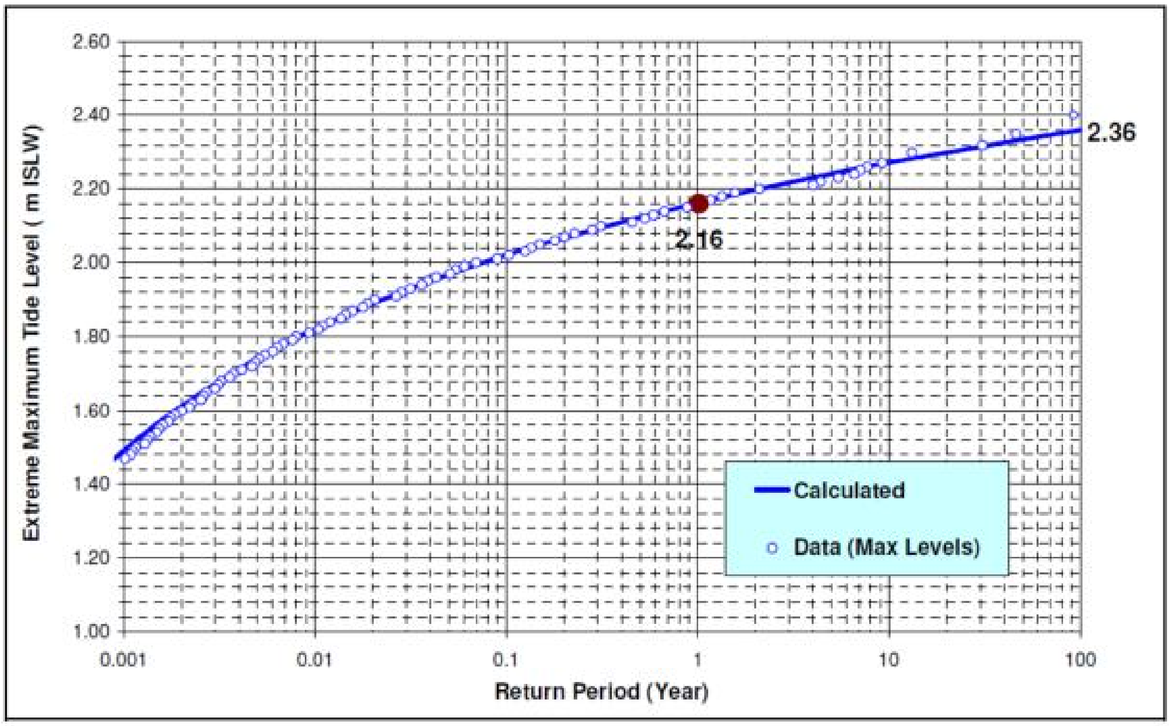

Figure 66: Sydney ocean level recurrence (Watson and Lord, 2008)

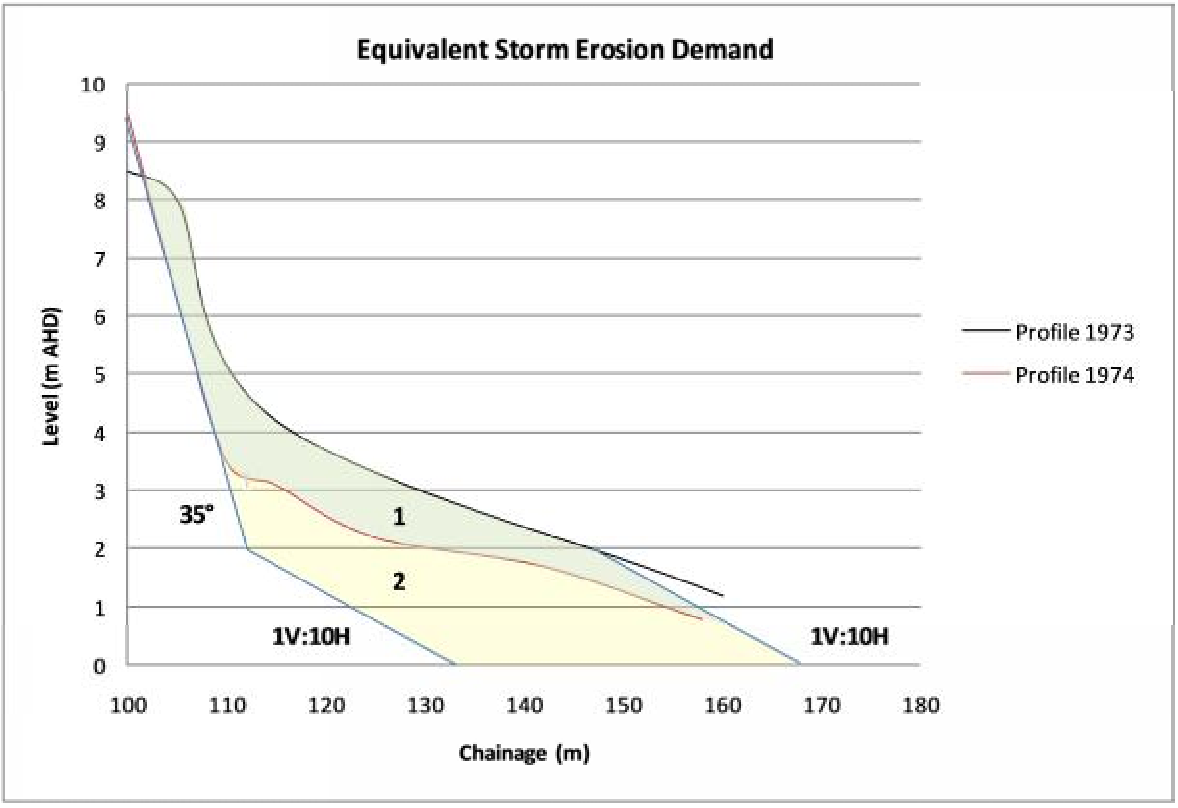

Figure 67: Dune stability schema (after Nielsen et al., 1992)

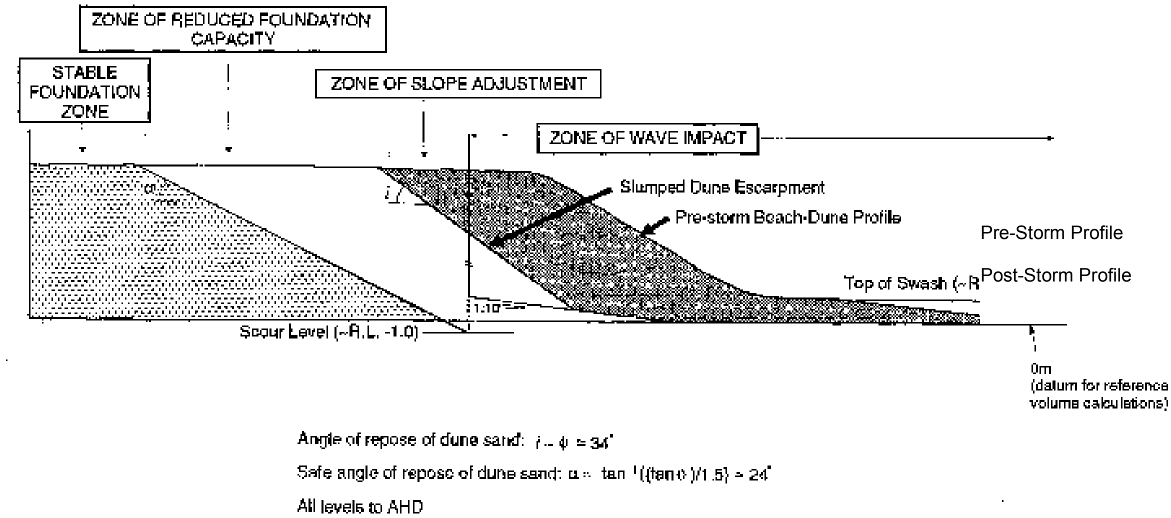

Figure 68: Determination of Equivalent storm erosion volumes

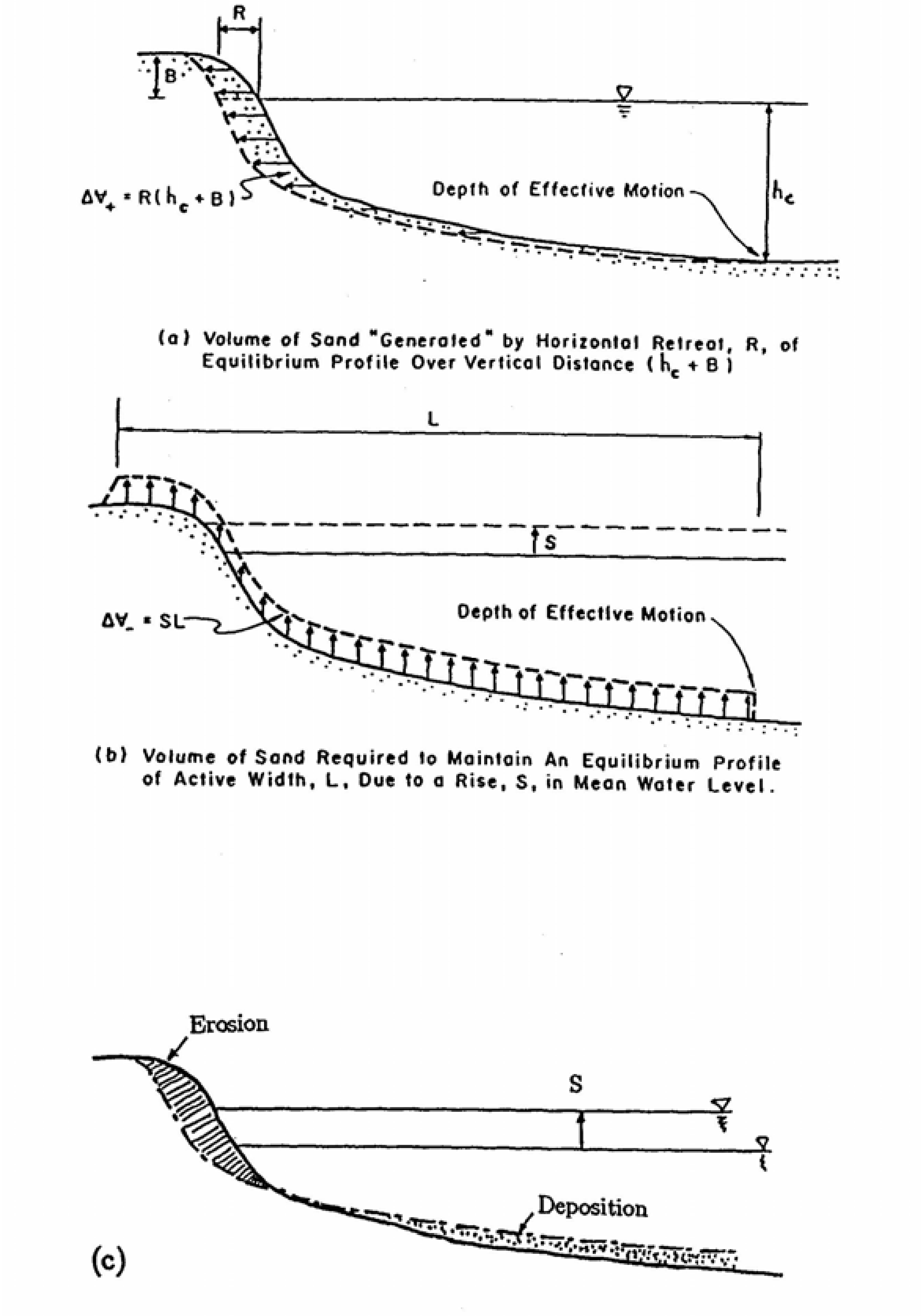

Figure 69: Concept of shoreline recession due to sea level rise