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Newcastle Coastal Zone Hazards Study

Final Report

January 2014

The City of Newcastle

Newcastle Coastal Zone Hazards Study
Final Report

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Title :	Newcastle Coastal Zone Hazards Study Final Report
Author :	Verity Rollason
Synopsis :	*The Newcastle Coastal Zone Hazards Study Report presents a summary of the coastal processes operating on the Newcastle coastline. The report then presents the methodology and outcomes for the definition of coastal hazards affecting the Newcastle study area coastline, and includes a summary of hazards defined for Stockton Beach from recent studies. The Study provides definition of the likelihood ('almost certain', 'unlikely' and 'rare') of coastal hazards, particularly beach erosion and recession, and coastal inundation and overtopping for the immediate, 2050 and 2100 timeframes.*

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EXECUTIVE SUMMARY

The Newcastle Coastal Zone Hazards Study provides a revision of coastal hazard extents defined for the Newcastle Local Government Area (LGA) coastal zone. City of Newcastle (CoN) resolved to revise the Newcastle Coastline Hazard Definition Study (WBM, 2000) (CHDS) in relation to:

- changes to the *Coastal Protection Act 1979* and new *Guidelines for Preparing Coastal Zone Management Plans* made by the NSW Government in 2010, which advocates a risk based approach to coastal hazards management;
- Section 733 of the *Local Government Act 1993*, under which CoN has a duty of care to inform its constituents of known risks, which includes coastal hazards and sea level rise ; and
- new and updated data on coastal processes and new analytical techniques for assessing coastal hazards.

The coastline under the jurisdiction of CoN extends from Glenrock Lagoon on Burwood Beach the Rifle Range at Fern Bay (Stockton Beach) in the north. For the purpose of this study, the study area extends from Hickson Street, Merewether in the south to the Rifle Range at Fern Bay. The study area includes Merewether, Dixon Park, Bar, Newcastle, Nobbys and Stockton Beaches, as well as the Port of Newcastle (Hunter River) entrance, and the rocky shorelines and headlands that separate the beaches. The beaches and coast are key focal points for a wider range of recreational and social activities, and are a key part of the community and social culture of Newcastle. Severe beach erosion and cliff slope instability has threatened development and assets in the past, and in some areas this is continuing. The response of the coastline to sea level rise may further threaten beach amenity as well as built assets into the future.

Coastal processes (natural and human influenced) are the principle source of risk in the coastal zone, and such processes can generate significant hazards to our use and development of coastal land and assets. The geologic framework of the coastline, waves and water levels interact to shape the morphology of beaches over various timescales, from days to many years. Coastal processes and their interactions that are outlined in this study include:

- **Regional Geology and Geomorphology**, which includes the headlands, reefs, seawalls, beach orientation, grain size, man-made structures such as the harbour breakwaters, beach states etc.;
- **Waves and Storms**, and variability in the wave climate from large scale climatological patterns such as El Nino- La Nina over seasonal, inter-annual and decadal time scales;
- **Elevated Water Levels**, which includes tides, storm surge, wave set up and wave run-up;
- **Currents**, such as longshore currents and rip currents;
- **Longshore and Cross-Shore Sediment Transport** driven by waves and currents;
- **Windborne Sediment Transport** and the capture of windblown sand by dune vegetation;
- **Coastal Entrances** and **Stormwater** drainage;
- **Projected Sea Level Rise and Climate Change Impacts** and their interaction and impacts upon all of the coastal processes described above.

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

- **Beach erosion**, relating to periods of enhanced storminess over seasons to years, and associated dune slope instability;
- **Long term recession**, relating to a long term sediment deficit (e.g. at Stockton Beach), and due to sea level rise in the future at all beaches;
- **Coastal inundation and wave overtopping,** during high tides combined with storms and sea level rise that may overtop coastal barriers and inundate low lying land connected through creeks or rivers to the ocean;
- **Cliff instability and geotechnical hazards**, which, depending upon the dominant processes causing cliff retreat, may be enhanced by sea level rise.

Other minor coastal hazards of interest in this study include sand drift, where windborne sediment may engulf back beach areas, and stormwater erosion at beach outlets.

Coastal Processes at Newcastle

To the south of the trained Hunter River entrance, the Newcastle coastline is characterised by sandy pocket beaches between rocky headlands and cliffs, with rock reef frequently exposed in the nearshore zone. This section of coast is aligned in a general south east facing direction and is fully exposed to open ocean wave conditions, which arrive dominantly from the south east.

Newcastle’s southern beaches, which include Merewether, Dixon Park, Bar, Susan Gilmore, Newcastle and Nobbys beaches, are also relatively developed, with promenades and other vertical walled structures found along the back beach areas. A significant engineered rock seawall is also located below dune sands between Dixon Park and Merewether Surf Clubs.

Nobbys Beach has formed immediately south of the Port of Newcastle (Hunter River) southern breakwater. The natural transport of sediment along the shoreline towards the north has been captured by the historic Macquarie Pier to Nobbys Head and along the southern breakwater, to form Nobbys Beach.

Stockton Beach is located north of the Port of Newcastle’s northern entrance breakwater. The portion of Stockton Beach that is in the Newcastle Local Government Area (LGA) is the southern-most part of a long continuous sandy beach known as Stockton Bight. Stockton Bight is characterised by a low sandy beach ridge in the south, extending to extensive dune ridges of heights up to 15 m to the north (outside of Newcastle LGA). The beach trends from north east in the south to facing nearly south at its far northern end.

Stockton Beach is known to be experiencing ongoing recession due to the interruption of northerly longshore sediment supply by the harbour breakwaters. At the far southern end of the beach, the breakwaters in fact shelter the beach from the dominant south easterly wave climate, and a slight accretionary trend has been observed. Moving northwards, the shoreline becomes increasingly exposed to swell waves, and without sediment supply from the south, this shoreline is experiencing ongoing recession, measured at rates of around 1 m per year.

Coastal Hazards at Newcastle

Newcastle's southern beaches are highly constrained by underlying bedrock, headlands and rock reefs, as well as man-made structures including formal seawalls (i.e. structures built to coastal engineering standards) and informal seawalls (i.e. structures not built to modern engineering standards, for example, vertical). The natural and formal structures limit the potential sand losses during beach erosion periods. Frequent storm events during the 1970s (and prior stormy periods during the 1940s and 1910s) have shown that virtually all of the sand reserves on the southern beaches can be eroded during such events. The beaches are at present average or slightly accreted, with sand held in dunes along Merewether to Bar Beach and Nobbys Beach, and more limited sand reserves at Newcastle. However, the dominant stormy periods of the past can almost certainly be expected to recur in the future.

In response to a rise in sea level, beaches and dunes will move upward and landward because the higher water level means waves will reach higher on the shoreline, shifting the sandy coastal barriers landward. However, Newcastle's southern beaches are limited in their ability to move landward by both bedrock and man-made structures. It may therefore be expected that the sandy reserves on these beaches will instead be eroded and bedrock or man-made structures will be exposed more frequently in the future with sea level rise. This response may have significant impacts upon beach amenity, which is a key component of Newcastle's cultural identity. At Nobbys Beach, the longshore drift which has accreted against the breakwater to form the beach will be reduced, however, the breakwaters will continue to impede the northerly transport of sediment. This may reduce the potential extent of recession due to sea level rise to some degree.

At Stockton Beach, ongoing recession due to the interruption of littoral drift by the harbour breakwaters is expected to continue, and this will be in addition to recession due to sea level rise. Stockton Beach is a sandy barrier, with the only constraint to recession being the formal seawall adjacent to Mitchell Street. Should the seawall be breached, recession extents would be considerably larger behind this section of shoreline. But as Stockton is a sandy barrier, the shoreline can move landward in response to sea level rise, therefore retaining a sandy beach.

Wave overtopping during storm events can be dangerous for pedestrians (should they venture out during a storm) and cause damage to both the barrier being overtopped and property behind the shoreline. With sea level rise, wave overtopping volumes can be expected to increase and overtopping events become more frequent in the future. There are known locations such as Shortland Esplanade between Nobbys and Newcastle Beaches where wave overtopping already occurs frequently. Both Merewether and Newcastle Ocean Baths are also currently overtopped at high tide. At other locations where wave overtopping is observed, such as the lower promenades at Merewether Beach, the shoreline behind the promenades slopes upward, thus limiting the potential impact on back beach areas. Modifications to structures will be required to reduce the extent of overtopping, which may otherwise pose a risk to the structures and development behind in the future.

Coastal hazards at Newcastle have been mapped using a risk-based approach that defines the likely extent of the hazards. An 'almost certain', 'likely', 'unlikely' and 'rare' extent of beach erosion and recession and coastal inundation has been determined for the immediate, 2050 and 2100 timeframes. Defining the likelihood of coastal hazards accounts for the uncertainty and limitations in estimating coastal processes and hazards, and the uncertainty in how coastal processes may be affected by climate change. The definition of coastal hazards at Newcastle is detailed in this report.

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GLOSSARY

Accreted Profile The profile (cross-section) of a sandy beach that develops in the "calm" periods between major storm events. During such periods, swell waves move sediment from the offshore bar beach onto the beach to rebuild the beach berm.

Astronomical Tide The ocean water level variations caused only by the gravitational effects of the earth, sun and moon, without any atmospheric influences.

Barometric Setup The increase in mean sea level caused by a drop in barometric pressure.

Bathymetry The measurement of depths of water, also information derived from such measurements.

Beach Berm That area of shoreline lying between the swash zone and the dune system.

Beach Erosion The offshore movement of sand from the sub-aerial beach during storms.

Beach Nourishment The supply of sediment by mechanical means to supplement sand on an existing beach or to build up an eroded beach.

Blowout The removal of sand from a dune by wind drift after protective dune vegetation has been lost. Unless repaired promptly, the area of blowout will increase in size and could lead to the development of a migrating sand dune and its associated problems.

Breaking Waves As waves increase in height through the shoaling process, the crest of the wave tends to speed up relative to the rest of the wave. Waves break when the speed of the crest exceeds the speed of advance of wave as a whole. Waves can break in three modes: spilling, surging and plunging.

Breakwater Structure protecting a shoreline, harbour, anchorage or basin from ocean waves.

Buffer Zone An appropriately managed and unalienated zone of unconsolidated land between beach and development, within which coastline fluctuations and hazards can be accommodated in order to minimise damage to the development.

Coastal Structures Those structures on the coastline designed to protect and rebuild the coastline and/or enhance coastal amenity and use.

Coastline Hazards Detrimental impacts of coastal processes on the use, capability and amenity of the coastline. The Coastline Management Manual identifies seven coastline hazards:

- Beach erosion
- Shoreline recession
- Entrance Instability
- Sand drift
- Coastal inundation
- Slope and cliff instability
- Stormwater erosion

Damage Potential	The susceptibility of coastline development to damage by coastline hazards.
Diffraction	The "spreading" of waves into the less of obstacles such as breakwaters by the transfer of wave energy along wave crests. Diffracted waves are lower in height than the incident waves.
Dune Field	The system of incipient dunes, foredunes and hind dunes that is formed on sandy beaches to the rear of the beach berm.
Dune Maintenance	The management technique by which dunes, dune vegetation and dune protective structures are kept in good "working order"; activities may include weed/pest/fire control, replanting, fertilising, repair of fences and access ways, and publicity.
Dune Management	The general term describing all activities associated with the restoration and/or maintenance of the role and values of beach dune systems; dune management activities and techniques include planning, dune reconstruction, revegetation, dune protection, dune maintenance, and community involvement.
Dune Protection	The management technique by which the dune system is protected from damage by recreational and development activities; dune protection activities generally include the use of fences, access ways and signposts to restrict and control access to dune systems.
Dynamic Equilibrium	The average condition about which the beach position and/or nearshore profile shape varies in the short term in response to varying wave and water level conditions and which remains essentially constant or only slowly changing over the longer term.
Dynamic Stability	The condition in which there is a non-changing long term average beach position despite short term variability in response to varying wave and water level conditions.
Erosion Hazard Extent	The extent of coastal land that is vulnerable to erosion within the immediate and/or future planning time-frame. It is assessed as 'best estimate' extents on the basis of available information, together with 'maximum' and 'minimum' extents which represent the range within which the erosion hazard is most likely to apply, as allowance for uncertainties inherent in the assessments.
Flood Tide	The inflow of coastal waters into bays and estuaries caused by the rising tide.
Foredune	The larger and more mature dune lying between the incipient dune and hinddune area. Foredune vegetation is characterised by grasses and shrubs. Foredunes provide an essential reserve of sand to meet erosion demand during storm conditions. During storm events, the foredune can be eroded back to produce a pronounced dune scarp.
Greenhouse Effect	A term used to describe the likely global warming predicted to accompany the increasing levels of carbon dioxide and other "greenhouse" gases in the atmosphere.
Groynes	Low walls build perpendicular to a shoreline to trap longshore sediment. Typically, sediment build up on the updrift side of a groyne is offset by erosion on the downdrift site.
Groyne Field	A system of regularly spaced groynes along a section of shoreline.

Hind dunes	Sand dunes located to the rear of the Foredune. Characterised by mature vegetation including trees and shrubs.
Incipient Dune	The most seaward and immature dune of the dune system. Vegetation characterised by grasses. On an accreting coastline, the incipient dune will develop into a Foredune.
Littoral Zone	Area of the coastline in which sediment movement by wave, current and wind action is prevalent. The littoral zone extends from the onshore dune system to the seaward limit of the offshore zone and possibly beyond.
Longshore Currents	Currents flowing parallel to the shore within the inshore and nearshore zones. Longshore currents are typically caused by waves approaching the beach at an angle. The "feeder" currents to rip cells are another example of longshore currents.
Mass Transport	The net shorewards current associated with the movement of waves through the nearshore and inshore zones. Sediment transport from the offshore bar by this current is responsible for the rebuilding of storm eroded beaches during inter-storm periods.
Mean High High Water	The average of the higher of the two high tide levels occurring during spring tide periods.
Nearshore Zone	Coastal waters between the offshore bar and the 60m depth contour. Swell waves in the nearshore zone are unbroken, but their behaviour is influenced by the presence of the seabed. (This definition is adopted for simplicity in the Coastline Management Manual and is based on wave motion considerations rather than sedimentology).
Offshore Bar	Also known as a longshore or nearshore bar. Submerged sandbar formed offshore by the processes of beach erosion and accretion. Typically, swell waves break on the offshore bar.
Offshore Zone	Coastal waters to the seaward of the nearshore zone. Swell waves in the offshore zone are unbroken and their behaviour is not influenced by the presence of the seabed. (See note to "Nearshore Zone").
Onshore/Offshore Transport	The process whereby sediment is moved onshore and offshore by wave, current and wind action.
Pocket Beaches	Small beach systems typically bounded by rocky headlands. Because of the presence of the headlands and the small size of these beaches, longshore currents are relatively insignificant in the overall sediment budget.
Reflected Wave	That part of an incident wave that is returned seaward when a wave impinges on a steep beach, barrier, or other reflecting surface.
Refraction	The tendency of wave crests to become parallel to bottom contours as waves move into shallower waters. This effect is caused by the shoaling processes which slow down waves in shallower waters.
Revetment	(Refer to Seawall)
Rip Currents	Concentrated currents flowing back to sea perpendicular to the shoreline. Rip currents are caused by wave action piling up water on the beach. Feeder currents running parallel to the shore (longshore currents) deliver water to the rip current.

Sand Bypassing	A procedure whereby sand deposited on the updrift side of a training wall or similar structure is mechanically delivered to the downdrift side. This facilitates the natural longshore movement of the sediment.
Sand Drift	The movement of sand by wind. In the context of coastlines, “sand drift” is generally used to describe sand movement resulting from natural or man-induced degradation of dune vegetation, resulting in either nuisance or major drift. Sand drift damage buildings, roads, railways and adjoining natural features such as littoral rainforest or wetlands; sand drift can be a major coastline hazard.
Sand Drift Control	The repair and maintenance of sand dunes to minimise sand drift. The protection and fostering of dune vegetation is an important element of such programs.
Sand Dunes	Mounds or hills of sand lying to landward of the beach berm. Sand dunes are usually classified as an incipient dune, a foredune or hind dunes. During storm conditions, incipient and foredunes may be severely eroded by waves. During the intervals between storms, dunes are rebuild by wave and wind effects. Dune vegetation is essential to prevent sand drift and associated problems.
Scarp	Also known as the Dune Scarp and Back-beach Erosion Escarpment. The landward limit of erosion in the dune system caused by storm waves. At the end of a storm the scarp may be nearly vertical; as it dries out, the scarp slumps to a typical slope of 1V:1.5H.
Seawalls	Walls build parallel to the shoreline to limit shoreline recession.
Sea Waves	Waves in coastal waters resulting from the interaction of different wave trains and locally generated wind waves. Typically, sea waves are of short wavelength and of disordered appearance.
Sediment Budget	An accounting of the rate of sediment supply from all sources (credits) and the rate of sediment loss to all sinks (debits) from an area of coastline to obtain the net sediment supply.
Sediment Sink	A mode of sediment loss from the coastline, including longshore transport out of area, dredging, deposition in estuaries, windblown sand, etc.
Sediment Source	A mode of sediment supply to the coastline, including longshore transport into the area, beach nourishment, fluvial sediments from rivers, etc.
Semi-Diurnal Tides	Tides with a period, or time interval between two successive high or low waters, of about 12.5 hours. Tides along the New South Wales coast are semi-diurnal.
Shoaling	The influence of the seabed on wave behaviour. Such effects only become significant in water depths of 60m or less. Manifested as a reduction in wave speed, a shortening in wave length and an increase in wave height.
Shoreline Recession	A net long term landward movement of the shoreline caused by a net loss in the sediment budget.
Shadow Area	Areas behind breakwaters and headlands in the less of incident waves. Waves move into shadow areas by the process of diffraction.

Significant Wave Height	The average height of the highest one third of waves recorded in a given monitoring period. Also referred to as $H_{1/3}$ or H_s.
Slope Readjustment	The slumping of a back beach erosion escarpment from its near vertical post-storm profile to a slope of about 1V:3H.
Southern Oscillation Index (SOI)	The SOI gives an indication of the development and intensity of El Niño or La Niña events in the Pacific Ocean. The SOI is calculated using the pressure differences between Tahiti and Darwin.
Storm Profile	The profile (cross-section) of a sandy beach that develops in response to storm wave attack. Considerable volumes of sediment from the beach berm, the incipient dune and the Foredune can be eroded and deposited offshore. The landward limit of the storm profile is typically defined by a back beach erosion escarpment (dune scarp).
Storm Surge	The increase in coastal water level caused by the effects of storms. Storm surge consists of two components: the increase in water level caused by the reduction in barometric pressure (barometric setup) and the increase in water level caused by the action of wind blowing over the sea surface (wind setup).
Storm Tide	The total ocean water level resulting from the combined effects of tide and storm surge.
Surf Zone	Coastal waters between the breaker zone and the swash zone characterised by broken swell waves moving shorewards in the form of bores.
Swash Zone	That area of the shoreline characterised by wave uprush and retreat.
Swell Waves	Wind waves remote from the area of generation (fetch) having a uniform and orderly appearance characterised by regularly spaced wave crests.
Swept Prism	The active area of the coastal system in which sediment may be mobilised by the forces of wind and wave action. On a sandy beach, it extends into the dune system and offshore to the limit of the nearshore zone.
Tidal Prism	The volume of water stored in an estuary or tidal lake between the high and low tide levels; the volume of water that moves into and out of the estuary over a tidal cycle.
Tides	The regular rise and fall of sea level in response to the gravitational attraction of the sun, moon and planets. Tides along the New South Wales coastline are semi-diurnal in nature, i.e. they have a period of about 12.5 hours.
Training Walls	Walls constructed at the entrances of estuaries and rivers to improve navigability.
Vegetation Degradation	The process by which coastal vegetation is "degraded" or damaged; this reduces the effectiveness of vegetation in protecting coastal landforms and increases the potential for erosion of underlying soil materials by wind (resulting in sand drift), water or waves.
Wave Height	The vertical distance between a wave trough and a wave crest.

Wave Hindcasting	The estimation of wave climate from meteorological data (barometric pressure, wind) as opposed to wave measurement.
Wave Length	The distance between consecutive wave crests or wave troughs.
Wave Period	The time taken for consecutive wave crests or wave troughs to pass a given point.
Wave Rider Buoy	A floating device used to measure water level variation caused by waves. It is approximately 0.9m in diameter and is moored to the sea floor.
Wave Runup	The vertical distance above mean water level reached by the uprush of water from waves across a beach or up a structure.
Wave Setup	The increase in water level within the surf zone above mean still water level caused by the breaking action of waves.
Wave Train	A series of waves originating from the same fetch with more or less the same wave characteristics.
Wind Setup	The increase in mean sea level caused by the "piling up" of water on the coastline by the wind.
Wind Waves	The waves initially formed by the action of wind blowing over the sea surface. Wind waves are characterised by a range of heights, periods and wavelengths. As they leave the area of generation (fetch), wind waves develop a more ordered and uniform appearance and are referred to as swell or swell waves.
Windborne Sediment Transport	Sand transport by the wind. Sand can be moved by the processes of suspension (fine grains incorporated in the atmosphere), saltation (medium grains "hopping" along the surface) and traction (large grains rolled along the surface).

1 INTRODUCTION

The City of Newcastle (CoN) is located on the mid-north coast of New South Wales, approximately 170km north of Sydney. The coastline under the jurisdiction of the City of Newcastle (CoN) extends approximately 13 kilometres from Glenrock Lagoon, Burwood Beach in the south to Stockton Beach (rifle range at Fern Bay) in the north. The study area for this project extends from Hickson Street, Merewether in the south to the Rifle Range at Fern Bay (see Figure 1-1).

The coastline to the south of the Hunter River is characterised by sandy pocket beaches between rocky headlands and cliffs. The cliffed and rocky nature of the coastline to the south of the Hunter River has resulted in narrow beach embayments with thin sand reserves overlying shallow rocky reefs and bedrock. To the north of the Hunter River is Stockton Beach, which is the southern-most part of a long continuous sandy beach known as the Stockton Bight. Stockton Beach is a low, sand beach dune barrier with little to no bedrock or rock reef.

This report identifies coastal processes and hazards that may impact upon the Newcastle coastline. It includes a revision of the previous Coastline Hazard Definition Study (WBM, 2000), providing an update of potential coastal hazards extents. Coastal processes and hazards assessments for Stockton Beach are based upon the Stockton Beach Coastal Processes Study (DHI, 2006) and the re-assessment of 2050 and 2100 hazard lines completed within the Stockton Beach Coastal Processes Study Addendum – Revised Coastal Erosion Hazard Lines (DHI, 2011).

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

- **Beach erosion**, relating to periods of enhanced storminess over seasons to years, and associated dune slope instability;
- **Long term recession**, relating to a long term sediment deficit (e.g. at Stockton Beach), and due to sea level rise in the future at all beaches;
- **Coastal inundation and wave overtopping,** during high tides combined with storms and sea level rise that may overtop coastal barriers and inundate low lying land connected through creeks or rivers to the ocean; **Cliff instability and geotechnical hazards**, which, depending upon the dominant processes causing cliff retreat, may be enhanced by sea level rise.
- Minor hazards such as sand drift and stormwater erosion are also noted as appropriate in the study.

The objectives for this Newcastle Coastal Zone Hazards Study are to:

- describe the coastal processes occurring in the study area to a level of detail sufficient to inform decision making;
- identify and map coastal erosion, inundation and cliff instability hazard areas;
- identify the potential impacts from coastal hazards on infrastructure and the environment; and

Title:
Study Area - Newcastle Coastline

Figure:
1-1

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0 1 2km

Approx. Scale

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- identify the public and private properties and assets likely to be affected by coastal hazards at the immediate, 2050 and 2100 timeframes (for use in assigning risk levels to these assets during the subsequent Newcastle Coastal Zone Management Study).

1.1 NSW Coastal Management Framework

Coastal management in New South Wales is guided by the:

- *NSW Coastal Protection Act 1979* and associated *Guidelines for Preparing Coastal Zone Management Plans* (OEH, 2013),
- NSW Coastal Policy 1997,
- *Local Government Act* 1993,
- *State Environment Planning Policy No. 71 – Coastal Protection*,
- *NSW Coastal Protection Regulation 2011*, and
- *Environmental Planning and Assessment Act 1979*.

Other guidance for land use planning in the coastal zone is given by the NSW Coastal Planning Guideline: Adapting to Sea Level Rise (DP, 2010), the Coastal Risk Management Guide – Incorporating sea level rise benchmarks in coastal hazards assessments (DECCW, 2010) and the Coastal Design Guidelines for NSW (DP, 2003).

The current requirements for the preparation of coastal zone management plans are outlined in the *Coastal Protection Act 1979* and associated *Guidelines for Preparing Coastal Zone Management Plans* (OEH, 2013) (the CZMP Guidelines).

Under Section 733 of the *Local Government Act 1993*, councils are taken to have acted in 'good faith' and thus receive an exemption from liability for land affected by coastal hazards where their actions substantially accord with the principles contained in the specified manual, in this case being the CZMP Guidelines. The Principles for Coastal Management outlined in the CZMP Guidelines are listed in Table 1-1. This study partly or wholly addresses Principles 1, 2, 3, 4 and 6.

The CZMP Guidelines replaced the former Coastline Management Manual (NSW Government, 1990). However, both the former NSW Coastline Management Manual (1990) and the CZMP Guidelines were used to prepare this study. The CZMP Guidelines (and supported by other recent NSW documents, as listed above) is the direction to adopt a risk-based approach to coastal management, which incorporates the uncertainty in hazards definition, and provides for prioritisation of management resources towards the greatest risks in the coastal zone.

Table 1-1 Coastal Management Principles addressed by the Newcastle Coastal Hazards and Management Studies

	Coastal Management Principles (OEH, 2013)
Principle 1	Consider the objectives of the Coastal Protection Act 1979 and the goals, objectives and principles of the NSW Coastal Policy 1997
Principle 2	Optimise links between plans relating to the management of the coastal zone
Principle 3	Involve the community in decision-making and make coastal information publicly available
Principle 4	Base decisions on the best available information and reasonable practise; acknowledge the interrelationship between catchment, estuarine and coastal processes; adopt a continuous improvement management approach
Principle 5	The priority for public expenditure is public benefit; public expenditure should cost effectively achieve the best practical long-term outcomes
Principle 6	Adopt a risk management approach to managing risks to public safety and assets; adopt a risk management hierarchy involving avoiding risk where feasible and mitigation where risks cannot be reasonably avoided; adopt interim actions to manage high risks while long-term options are implemented
Principle 7	Adopt an adaptive risk management approach if risks are expected to increase over time, or to accommodate uncertainty in risk predictions
Principle 8	Maintain the condition of high value coastal ecosystems; rehabilitate priority degraded coastal ecosystems
Principle 9	Maintain and improve safe public access to beaches and headlands consistent with the goals of the NSW Coastal Policy
Principle 10	Support recreational activities consistent with the goals of the NSW Coastal Policy

1.1.1 Revision of the Newcastle Coastline Management Plan

In 2003, CoN adopted the Newcastle Coastline Management Plan (Umwelt, 2003) (the NCMP), which was supported by the Newcastle Coastline Management Study (Umwelt, 2003) (the NCMS) and the Newcastle Coastline Hazard Definition Study (WBM, 2000) (the NCHDS). The NCMP was prepared in accordance with the former Coastline Management Manual (NSW Government, 1990) and provided the management framework for the Newcastle coastline.

In 2009, the NSW Government announced a coastal erosion reform package that included the release of the NSW Sea Level Rise Policy Statement (2009) (since repealed), and in 2010, amendments to the *Coastal Protection Act 1979* (as well as the *Environmental Planning and Assessment Act 1979*, the *Local Government Act 1993* and *SEPP Infrastructure 2007* to support the amendments), and new *Guidelines for Preparing Coastal Zone Management Plans* to replace the 1990 Coastline Management Manual.

The NSW Sea Level Rise Policy Statement (2009) set sea level rises of 0.4 m by 2050 and 0.9 m by 2100 above 1990 mean sea level, for use in coastal hazards assessments including CZMPs. The sea level rise benchmarks were based upon the latest projections specified by the IPCC (2007) and CSIRO (2007) for NSW, as detailed in the technical note accompanying the Policy Statement (see DECCW, 2009b).

In April 2011, CoN resolved to revise and update its NCMP to apply the latest guidance from the NSW Government contained within the CZMP Guidelines, and in particular, the sea level rise benchmarks. CoN also recognised that many of the actions of the NCMP had been implemented or amalgamated into other Council plans, which further supported a revision of the NCMP to reflect present day needs for coastal hazards management. In order to develop a revised Newcastle Coastal Zone Management Plan (CZMP), two preceding steps were required:

1. The Newcastle Coastal Zone Hazards Study (this report), to identify the likely extent of coastal risks that may affect the Newcastle coastline now and in the future (including sea level rise), which commenced in April 2011, and
2. The Newcastle Coastal Zone Management Study, to identify practical management options to address priority coastal risks, which was commenced in late 2011.

In late 2012, the NSW Government announced further changes to the NSW Coastal management process, including most importantly the repeal of the NSW Sea Level Rise Policy Statement (2009). As part of these Stage 1 Coastal Reforms, the NSW Government also further amended the *Coastal Protection Act 1979* in relation to "temporary" coastal protection works for coastal erosion hotspots. The NSW Government advised that Stage 2 Coastal Reforms are pending (and it is anticipated the reforms will accompany the reforms to NSW planning legislation currently underway).

In spite of the repeal of the NSW Sea Level Rise Policy Statement (2009), CoN has a duty of care under Section 733 of the *Local Government Act 1993* to inform its constituents of known risks, including sea level rise. Therefore, CoN has pursued completion of this Newcastle Coastal Zone Hazards Study as part of revising the Newcastle CZMP to include the latest projections for sea level rise. The sea level rises adopted for this study and their legal justification is detailed in Section 1.1.2.

The Newcastle CZMP, and the Newcastle Coastal Zone Hazards Study and Newcastle Coastal Zone Management Study upon which the Newcastle CZMP will be based are being prepared in accordance with the requirements of the *Coastal Protection Act, 1979* and associated *Guidelines for Preparing Coastal Zone Management Plans* (OEH, 2013), including the Stage 1 coastal reforms detailed by the NSW Government in 2012; and including the effects of sea level rise upon future coastal risks. The Newcastle CZMP will provide a framework for managing the risks from coastal hazards to existing and future development and community assets and values in Newcastle.

Community access and recreation are important considerations in the coastal zone and may be considered as part of a CZMP, in accordance with the *Guidelines for Preparing Coastal Zone Management Plans* (OEH, 2013). The Newcastle Coastal Zone Hazards Study and Newcastle Coastal Zone Management Study provide direction to managing recreational and community access where these aspects are affected by or affect the extent of coastal hazards. However, CoN is already managing community use of the coastline thoroughly through the Newcastle Coastal Revitalisation Strategy 2010 and its associated Plans of Management (POMs) and Public Domain Plans (e.g. at Merewether Beach) that have or are being prepared and implemented along the Newcastle coastline. Actions from the previous Newcastle Coastline Management Plan (2003) have already been incorporated into these other strategies and plans. Therefore, specific actions targeting community use have not been investigated, as these aspects are already being managed by CoN through other processes.

1.1.2 A Note on Sea Level Rise Benchmarks Adopted for this Study

The NSW Sea Level Rise Policy Statement 2009 was repealed in September 2012. This means that the previously prescribed state-wide sea level rise benchmarks no longer apply to coastal hazard assessments, such as this study. The NSW Government has indicated that local councils "have the flexibility to determine their own sea level rise projections to suit their local conditions" (NSW Environment and Heritage, 2012), although it is unclear if or how local councils may be equipped to do this. In lieu of prescriptive sea level rise benchmarks, the Office of Environment and Heritage (OEH) recommend that councils should adopt sea level rise projections that are "widely accepted by competent scientific opinion" (OEH, 2013, refer p 10).

Under Section 733 of the *Local Government Act 1993* (the LG Act), Council has a duty of care to inform its local constituents of known risks in order to receive an exemption from liability for acting in good faith with respect to known hazards (including coastal hazards). Under Section 733(4) of the LG Act, Council is considered to have acted in good faith where decisions are based substantially in accordance with the relevant manual for the hazard, in this case, the CZMP Guidelines.

CoN therefore has a legal imperative to consider sea level rise, as it is a known and measured risk that may impact coastal land. Furthermore, it is a requirement of the CZMP Guidelines upon which the good faith exemption is based for the impacts of sea level rise upon risks from coastal hazards to be investigated (refer p 10, OEH, 2013). Similarly, object (h) of the Coastal Protection Act 1979 is "to encourage and promote plans and strategies for adaptation to coastal climate change impacts, including projected sea level rise".

In this case, incorporation of projections for sea level rise based upon the best available information is a required component for the Newcastle CZMP and this study, with or without state prescribed sea level rise benchmarks.

The sea level rise projections that are 'widely accepted by competent scientific opinion' remain that given by the former Sea Level Rise Policy Statement (2009), being a rise of 0.4 m by 2050 and 0.9 m by 2100 above 1990 mean sea level. These projections are based upon the latest reports by both the IPCC (2007) and CSIRO (2007) combined. While the IPCC released further scientific projections in 2013, until regional NSW projections are available, the prior IPCC (2007) guidance remains relevant. The NSW Chief Scientist and Engineer (2012) assessed the former NSW Sea Level Rise Policy Statement levels and advised that the science informing the policy levels was adequate.

1.2 Study Area

The study area for this project extends from Hickson Street, Merewether in the south to the Rifle Range at Fern Bay (Stockton Beach) in the north. The study area, shown in Figure 1-1, includes the following areas:

- Merewether, Dixon Park and Bar Beaches, and associated rock platforms and headlands and ocean baths;
- Susan Gilmore Beach to Shortland Esplanade, including rock platforms and headlands within Shepherds Hill, Strezlecki Lookout and King Edward Park, and the Bogey Hole Baths;
- South Newcastle and Newcastle Beaches to the Newcastle Ocean Baths;

- Rock platforms and reef extending to Nobbys Beach (Flat Rock, the Cowrie Hole, the Groper);
- Nobbys Beach extending to the southern breakwater of the Port of Newcastle; and
- Stockton Beach from the northern breakwater northwards to the Rifle Range at Fern Bay.

The coastal zone is defined as three nautical miles seaward of the mainland and one kilometre landward of the open coast high water mark. For the purposes of this report, the investigations consider the ocean and landward components of the coastal zone where this affects the extent of coastal hazards and their management.

Burwood Beach from Hickson Street to Glenrock Lagoon is part of Newcastle LGA. This section of coastline has been excluded from the study area as it is part of the Glenrock State Conservation Area, which is managed by the NSW Office of Environment and Heritage National Parks and Wildlife Service (NPWS), and Burwood Wastewater Treatment Plant which is managed by Hunter Water Corporation.

The Hunter River has also been excluded from the study, as it is already managed through the Hunter River Estuary Management Plan and Floodplain Risk Management Plan, which incorporate relevant coastal and oceanic influences.

The coastal processes and hazards assessments for Stockton Beach documented herein comprise a summary of outcomes from recent assessments, particularly the *Stockton Beach Coastal Processes Study* (DHI, 2006) and the re-assessment of 2050 and 2100 hazard lines completed within the *Stockton Beach Coastal Processes Study Addendum – Revised Coastal Erosion Hazards Lines* (DHI, 2011).

1.3 Community Involvement in Preparing this Study

Consultation conducted for the preparation of the Newcastle Coastal Zone Hazards Study was largely facilitated through the Newcastle Coastal Technical Working Party (NCTWP). Members of the NCTWP represent a cross section from the state agencies and community. Additional stakeholders of relevance to the study such as Hunter Water Corporation, Hunter Surf Life Savings Australia and Ausgrid (formerly Energy Australia) were also consulted either directly (phone calls, letters, email) or through guest attendance at the NCTWP meetings.

It is noted that considerable community consultation was undertaken as part of the original CHDS (WBM, 2000), including a media release, a brochure for coastal residents and key community and stakeholders, and three community meetings (at Stockton, Nobbys and Merewether beaches). The purpose of these activities was largely to gather historical information for use in assessment of coastal processes and hazards. It is further noted that considerable effort was made gathering a wide range of historical information as part of the previous study. All relevant historical information sourced for the previous CHDS has been incorporated into this report.

Further workshops and community consultation will be conducted when preparing the Newcastle Coastal Zone Management Study and Plan.

1.4 Historical Data and Reports

The CHDS (WBM, 2000) utilised the following historical data and information sources during its preparation:

- Stockton Beach - Coastline Hazard Study (DLWC, 1995) and other related reports / updates for Stockton Beach;
- Newcastle Bight - Sand Drift Study (CALM, 1985);
- Photogrammetric data for Merewether, Bar Beach, Newcastle and Nobbys (the Southern Beaches), Stockton Beach and rock platforms at the Cowrie Hole, Susan Gilmore Beach and Shepherds Hill regions, from 1954, 1974 and 1996 (provided by then DLWC, now Office of Environment and Heritage (OEH));
- Beach surveys conducted by CoN between 1978 to 1987 at the southern beaches and to 1996 at Stockton Beach;
- Historical Aerial Photographs (1950s to 1996);
- Historical photographs, anecdotal and newspaper accounts, found through:
  - Searches of the Newcastle Regional Library, Hunter Photo Bank, the Newcastle Herald on Microfilm from 1960-1950, University of Newcastle Library; and
  - Discussions with the Newcastle Regional Museum, Newcastle District Historical Society, Newcastle Historical Reserve Trust, local Newcastle Papers and local residents;
- Wave time series data obtained from:
  - non-directional wave rider buoys at Newcastle Inshore (2 Wave rider buoys in 20m water depth 12/2/75 to 1998 and 19/5/83 to 1998) and Newcastle Offshore, Redhead (Wave rider in 80m water depth 12/2/75 to 12/5/82);
  - Sydney Wave rider buoy non-directional records from 17/7/87 to 1991 and directional records from 3/3/92 to 1998 and
  - Crowdy Head Wave rider buoy non-directional records from 10/10/85 to 1998;
- Wind data obtained from the Bureau of Meteorology's Nobbys weather station from 1957 to 1998.

1.5 Additional Information Used in this Study

Additional data and reports utilised to update and revise the understanding of coastal hazards at Newcastle has included:

- Photogrammetric data for 2001 for the southern beaches (provided by the OEH);
- 2007 Aerial Laser Survey topographic data (2007) (provided by CoN);
- 2008 Marine LiDAR bathymetric data for the Southern Beaches (provided by OEH);
- 2007 hydrographic survey data for Stockton Beach (provided by OEH);
- 2008 ortho-rectified aerial photography (provided by CoN);

- Wave statistics and time series data for the Sydney Directional Wave Rider buoy from 1992 to 2009 provided by Manly Hydraulics Laboratory (MHL) and funded by OEH; and
- *Stockton Beach Sand Scoping Study* (Worley Parsons, 2011).

It is noted that other resources pertaining to regional coastal processes generally were also utilised (refer References in Chapter 5). Current Geographical Information System (GIS) data sets for Newcastle LGA (including land zoning, assets, infrastructure, vegetation, etc.) were also utilised.

For Stockton Beach, a number of studies have been completed recently, including:

- *Shifting Sands at Stockton Beach* (Umwelt, 2002);
- *Stockton Beach Coastal Processes Study* (DHI 2006); and
- *Stockton Beach Coastal Processes Study Addendum – Revised Coastal Erosion Hazard Lines 2011* (DHI, 2011).

Findings from these studies (including outcomes of data analysis) at Stockton Beach has been summarised for this report.

Reports pertaining to climate change utilised in this study included:

- NSW Sea Level Rise Policy Statement (2009);
- *Hunter, Central and Lower North Coast Regional Climate Change Project* (HCCREMS 2009);
- *Projected Changes in Climatological Forcing for Coastal Erosion in NSW* (McInnes, K. L., Abbs, D.J., O'Farrell, S.P., Macadam, I., O'Grady, J. and R. Ranasinghe, 2007);
- *IPCC Fourth Assessment Report: Climate Change* (IPCC, 2007);and
- *Climate Change in Australia* (CSIRO, 2007).

Site inspections were also conducted for this study. The beach and cliff areas were inspected and key information collected with respect to the nature of the coastline and the associated processes. Inspections of seawall condition were conducted.

2 COASTAL PROCESSES AT NEWCASTLE

2.1 Introduction

Coastal processes (natural and human influenced) are the principle source of risk in the coastal zone, as such processes can generate significant hazards to human use and development of coastal land and assets. The geologic framework of the coastline and coastal processes interact to shape the morphology of beaches over various timescales, from hours and days to years and decades. Processes and interactions include:

- Regional geology and geomorphology;
- Waves;
- Water levels (from tides and during storms);
- Coastal entrances (of creeks, lagoons, lakes and estuaries);
- Waterborne sediment transport;
- Windborne sediment transport;
- Stormwater runoff; and
- Climate change, particularly sea level rise, which will affect all of the above coastal processes.

Coastal hazards formed by the interaction of coastal processes with human use of coastal land include:

- Beach erosion (during the short term storm event or events in close succession) and dune slope instability;
- Shoreline recession (relating to a long term sediment deficit at Stockton Beach, and due to sea level rise in the future at all beaches);
- Coastal inundation (during high tides combined with storms and sea level rise), which can manifest as wave overtopping of the open coastline, or inundation of land behind the open coastline via coastal creeks and estuaries and stormwater systems connecting to the ocean;
- Cliff instability and geotechnical hazards, which depending upon the dominant processes causing cliff retreat, may be enhanced by sea level rise;
- Coastal entrance instability around intermittently closed lagoons such as Glenrock Lagoon, which is outside of the study area;
- Erosion at stormwater outlets / drainage lines; and
- Sand drift, where windborne sediment transport may engulf back beach areas causing a minor to major nuisance to back beach development and beach use/users, and/or a loss of sediment from the sub-aerial beach.

2.2 Regional geology and geomorphology

2.2.1 Coastline Structure and Orientation

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

Broadly, the NSW coast is described as being controlled strongly by bedrock, which outcrops as headlands, rock platforms and cliffs. This is particularly the case for beaches south of the Hunter River, where the shoreline is characterised by sandy pocket beaches between rocky headlands and cliffs, with rock reef frequently exposed in the nearshore zone. Sandy dunes are limited to a short section between Merewether and Dixon Park and the central portion of Bar Beach. There is little to no evidence of the former sea level 5 m above present during the Pleistocene (~ 120, 000 years ago) on this section of coastline, as sandy beaches are limited by bedrock cliffs.

In contrast, Stockton Beach north of the Hunter River is characterised by a low sandy beach ridge in the south, extending to extensive beach ridges of heights up to 15 m to the north. This long continuous section of sandy shoreline extends 32 km to Birubi Point and is NSW's longest beach (Short, 2007). The Stockton Bight coastline shows evidence of the Pleistocene high sea level stand in the form of an inner beach ridge barrier particularly towards the north (indeed, sands in Stockton Bight provide evidence of older sea levels, up to 500,000 years old).

The shoreline south of the Hunter River faces south east (i.e. is oriented south-west to north east), and is fully exposed to the dominant south east wave climate. The cliffed and rocky nature of the coastline south of the Hunter River has tended to result in narrow beach embayments with thin sand reserves overlying shallow rocky reefs and bedrock.

Immediately north of the Hunter River entrance, the far southern end of Stockton Beach faces north east, with the entrance breakwaters providing protection from waves from the south to east south east. Further north along Stockton Beach, the shoreline curves around to face east south east at the northern end of the study area, and is much more exposed to waves. Beyond the study boundary, the coastal alignment continues to curve in a long arc, facing progressively more southwards to meet Birubi Point at its northern end. Birubi Point marks the southern boundary of the New England Fold Belt and the northern boundary of the Sydney Basin (Short, 2007).

2.2.1.1 Artificial Structures

The Newcastle coastline is characterised by several man-made structures, the most significant being the Newcastle Harbour (Hunter River) Entrance Breakwaters. Rubble mound seawalls have also been constructed between Merewether and Dixon Park (along John Parade) and for a length of 550 m in the central portion of Stockton Beach adjacent to Mitchell Street.

Numerous vertical revetments of varying height and construction are evident at Nobbys Beach, along Shortland Esplanade (Nobbys to Newcastle Baths), the entire length of Newcastle Beach, the northern end of Bar Beach and the southern end of Merewether Beach.

All of these structures have interacted with coastal processes affecting the shoreline to some degree. A review of the condition of seawalls is given in Section 3.4.3. Discussion of the impact of the Hunter River entrance breakwaters is given in Section 2.6.3.

2.2.2 Bathymetry and Sediments of the Nearshore and Continental Shelf

The section of beach that lies below water level has a dominant role in transposing waves and water levels, and thus controlling the shape and morphology of the coast. The width and slope of the continental shelf affects the dissipation and shoaling of waves as they move from deep water into the nearshore zone. At Newcastle, the continental shelf is very narrow and steep. The gradient of the shelf is relatively shallow out to the 40 m depth contour, before steepening to the 80 m contour around 11 km offshore in the study area, see Figure 2-1. A steeper continental shelf means there is less energy dissipation of deep water waves as they travel into the nearshore zone and onto the shoreline.

The type and extent of sediments in the nearshore and continental shelf and presence of rock reef is important in the availability of sediment to the upper beach face. The quartzose, rounded marine sediments that dominate beach sands today have been continuously reworked from the continental shelf as sea levels have risen and fallen through interglacial and glacial periods over hundreds of thousands of years (Roy, 2001).

An inner continental shelf sand unit extends from 20 to 60 m water depth along most of the NSW coast (and is recognisable for its iron-staining). This sand unit can be mobilised during large coastal storm events, however, net sediment movement is small, roughly estimated at 1 to 4 m^3/year onshore per metre length of beach in NSW (Roy, 2001). Over geologic timescales (thousands of years) these small net movements have contributed sediment into the nearshore zone where it has been reworked onto shore since sea levels stabilised 6,000 years ago (Roy, 2001).

The nearshore zone refers to the region extending from the beach dune barrier out to around 20 to 30 m water depth. Marked difference in sand types and bed morphology at the 20-30 water depth in NSW indicates the boundary between the inner continental shelf and nearshore zone sediments (Roy, 2001).

The nearshore zone is typically divided into three zones:

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

The Newcastle nearshore zone is dominated by rock reef, which is clearly visible in aerial photographs. The 2008 marine LiDAR data also indicates the region between the 20 to 30 m contour to be dominated by rock reef. This suggests that sand reserves are relatively depleted through this zone. Roy (2001) noted south of the Hunter River that the steep rocky nature of the shelf suggests there is a relatively limited supply of shelf sand, with coastal barriers typically stationary or receding over geological timescales (thousands of years). Cross shore sediment transport may be constricted by the presence of these reefs under lower wave conditions. Longshore sediment movements will occur across the surface of the reefs.

Title:

Digital Elevation Model - Newcastle Coast and Bathymetry

Figure: 2-1

Rev: A

N

0 2.5 5km

Approx. Scale

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North of the Hunter River, outcropping of rock reef is not evident in the surfzone, and Stockton Bight extends as a long, sandy embayment. The continental shelf is slightly wider through this region particularly out to the 40 m contour, which may have assisted in the onshore supply of sediment to the shoreline. Birubi Point forms a bedrock anchor that has repeatedly trapped northward littoral sediment transport to form Stockton Bight.

Fluvial sediments delivered to the coast from the Hunter River at the present day are unlikely to be contributing significantly to coastal sediment supply. The deep Hunter River entrance (up to 18 m depth) and Port areas are regularly dredged of sediment that is placed at an offshore disposal site, or offshore of Stockton Beach if clean marine sand . During floods, finer grained fluvial sediments tend to remain in suspension and become “diffused” seaward across the inner shelf, to be deposited in the mid shelf region (Roy and Stephens, 1980), beyond the present day nearshore zone.

2.2.3 Newcastle Beaches

The southernmost beach in the study area is the 1.5 km sandy beach that comprises Merewether in the south, Dixon Park at the centre (before a small rocky outcrop known as The Cliff) and Bar Beach at the northern end. The beach has rock reef at its north and south ends, and rock reef is fairly frequently exposed between Bar Beach and The Cliff. The beach morphology is typically a transverse to rhythmic sand bar, with rips spaced fairly frequently along the beach and adjacent to the bounding rock reefs at the north and south end of the beach.

Susan Gilmore Beach comprises a small pocket beach at the base of steep cliffs rising to Shepherds Hill. The beach essentially comprises a thin veneer of sand over a rocky shoreline, with protrusive rock platforms at both ends of the beach. During bigger storm events, this beach can be stripped entirely of sand.

Newcastle Beach is also a small pocket beach bounded by the Shepherds Hill cliffs to the south and rock reef platforms in the north, upon which Newcastle Baths have been built. The beach’s small size and rock reef constraints produce permanent (topographically constrained) rips particularly at the north and centre of the beach.

The shoreline from Newcastle Baths to Nobbys Beach is essentially exposed rock platforms and rock reef with vertical revetments walls at the landward fringe, above which Shortland Esplanade roadway is situated. Reefs along this region form popular surfing spots, particularly between the eroded dykes which provide deeper water sections adjacent to the reefs. The surfing reefs are known locally as Flat Rock (which extends behind the Newcastle Baths), the Cowrie Hole and the Grouper from south to north.

Nobbys Beach has formed from the accumulation of sand adjacent to the breakwater extending from the shoreline to beyond Nobbys Head (formerly Nobbys Island). The surfzone is also dominated by rock reefs (again, forming popular surfing spots), with a sandy section between that is heavily used by beach visitors. The rock reefs tend to dissipate incoming wave energy, resulting in a single attached sand bar at the shore and dumping waves onshore. Rip currents usually occur adjacent to the sections of reef.

Stockton Beach lies north of the Hunter River breakwaters. Unlike beaches to the south that are heavily constrained by cliffs, bedrock and rock reef outcrops, Stockton Beach is a low, sandy beach dune barrier with little to no bedrock and rock reef. Towards the northern end (outside the study area), the transverse dunes increase in height and width, forming the largest mobile sand mass in NSW. The section of Stockton Beach within the study area extends to the Rifle Range at Fern Bay.

Stockton Beach (within the study area) is mostly exposed to the dominant south easterly swells, except for the southern 5 km which is somewhat protected from the SSE waves by the Hunter River breakwaters. At its most southern end, the beach typically has a single attached sand bar due to lower waves and slightly coarser sand, which is cut by rips to the entrance breakwater. Moving northwards, a second outer sand bar develops under the influence of higher wave energy. The inner bar typically remains attached, with rips every 300-400 m. A wide trough separates the inner bar from the outer rhythmic bar, which is also cut by rips (Short, 2007).

2.3 Wave Climate

The regional wave climate is a dominant component of coastal processes. The deep water wave climate of the NSW coast comprises a highly variable wind wave climate superimposed on a persistent long period moderate to high energy south easterly swell.

2.3.1 Wave Generation Sources

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

The dominant wave generation sources include (Short and Trenaman, 1992; Short, 2007):

- <u>Tropical cyclones</u> (November to May), tracking towards the Tasman Sea (usually well offshore of the coast) may generate north easterly waves;
- <u>East coast cyclones</u> (typically May, June and July), said to generate the strongest winds, heaviest rainfall and largest waves experienced on the NSW Coast. These small intense storms may form anywhere along the coast, generating waves from south easterly to easterly directions;
- <u>Mid-latitude cyclones</u> (occur throughout the year particularly March to September) form in the Southern Ocean and Tasman Sea and generate the predominant south easterly swell experienced along the coast. Mid-latitude cyclones form closer to the southern Australian continent in winter than summer, thus typically forming higher waves in winter;
- The <u>subtropical anticyclone</u> produces fine, warm weather on the NSW coast, and particularly during summer, may generate weak north east to easterly swells.; and
- Onshore sea breezes forming in summer on hot days (as the land heats faster than the ocean, causing hot air to rise over the land and cooler air from the ocean to move in to replace it), which when persistent over days may generate weak north east to east wind waves.

2.3.2 Measured Regional Wave Climate

Wave data for Sydney was provided by MHL and funded by OEH from the directional wave rider buoy moored in around 85 m water depth around 10 km offshore. The record length for waves at Sydney (~150 km south) spans 17.8 years from March 1992 to December 2009.

Comparison of the time series data for Sydney and Crowdy Head (located approximately 200 km to the north) over a long period (10 years) showed that the differences in wave characteristics were generally minor, being most noticeable during short term storm events (WBM, 2000). Thus, use of the Sydney directional data was considered a good representation of the regional offshore wave climate at Newcastle.

The average offshore significant wave height (H_s) at Sydney is 1.62 m. Seasonally, wave heights are greatest from March to July with the highest measured wave of 8.43 m occurring in May at Sydney. This is consistent with the prevalence and seasonality of the main wave generation sources namely mid latitude cyclones and east coast low cyclones (see Section 2.3.1).

Analysis of wave direction statistics indicates that over 65% of waves arrive from the south east (SE) to south (S) sector (135 to 180° true north), with 30% of waves from south south east (SSE) alone. Likewise, the highest waves also arrive from this sector.

SE to S sector waves are dominant throughout the year, and again this reflects the dominance of mid latitude cyclones in generating the ocean swell experienced in NSW. In winter, wave directions are dominantly SE to S. Over summer, wave directions shift, arriving more frequently from the east north east (ENE) to east south east (ESE) sector. The shift in wave direction relates to the prevalence of north east wind swells and occasional tropical cyclone swells that may track southwards to NSW and the dominant mid latitude cyclones being generated further south from NSW in summer.

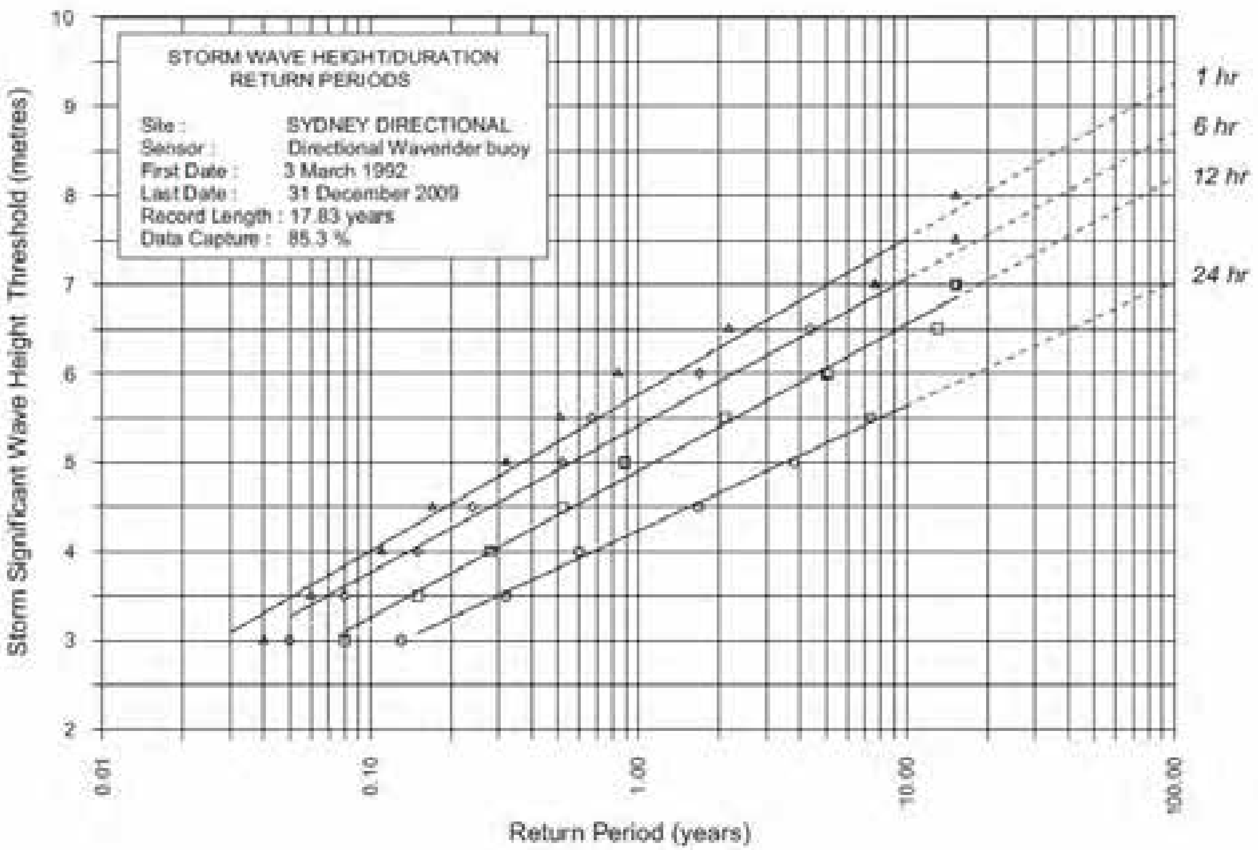


Figure 2-2 Storm Wave Height Duration Curve, Sydney

The MHL analysis of storm wave height/duration return periods at Sydney is illustrated in Figure 2-2. The MHL analysis indicates a 1 in 100 year average recurrence interval (ARI) H_s of 9.25 m for a 1 hour duration storm and 8.7 m for a 6 hour duration storm.

2.3.3 Nearshore Wave Analysis

Waves arriving in the nearshore zone have been transformed from offshore through refraction and diffraction at headlands and reefs and dissipated through friction as water depths decrease approaching the shore. Compared with other shorelines, there is little dissipation of wave energy until close to shore at Newcastle, due to the narrow relatively steep and deep continental shelf and nearshore zone.

In order to investigate wave transformation from offshore to nearshore for use in calculating wave run up and wave overtopping at the shoreline, the spectral wave modelling package Simulating Waves Nearshore (SWAN) was utilised. The model was used to propagate waves from 100 m water depth offshore into the study area shoreline. (In addition, it is noted that the Shoreline Evolution Model conducts wave transformation internally for use in calculating longshore and cross shore transport within the model).

2.3.3.1 The SWAN Wave Model

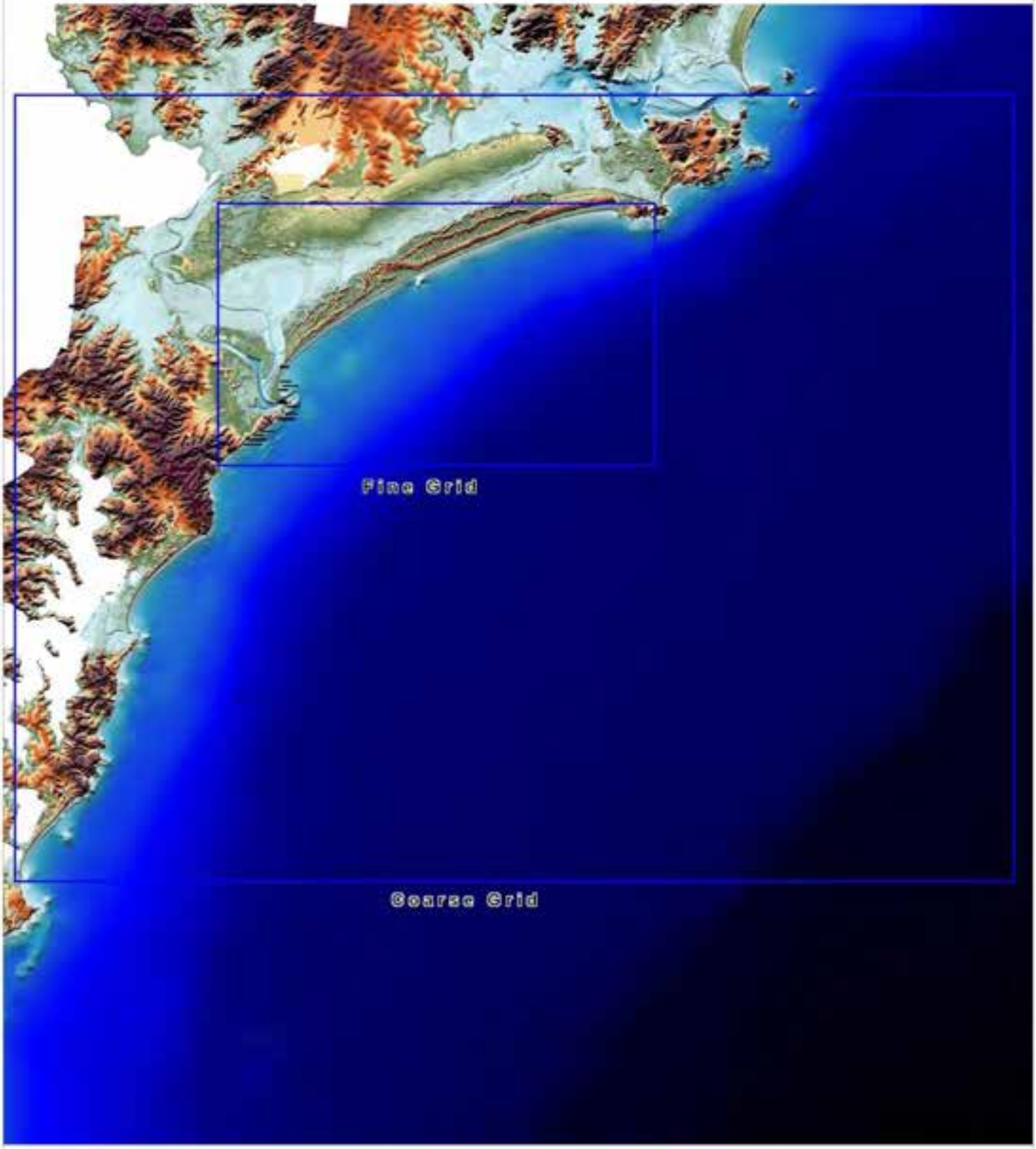
SWAN is a wave refraction model that is used to simulate the formation and propagation of waves in deep, intermediate and finite depths. The SWAN model is able to simulate the following physical phenomena of interest to this study (Delft, 2010):

- Wave propagation in time and space;
- Wave shoaling and refraction, due to depth, bottom friction and bathymetric features;
- Wave frequency shifting due to non-stationary depth;
- Nonlinear wave-to-wave interactions (quadruplets and triads);
- Depth-induced breaking; and
- Wave-induced set up.

While SWAN does not explicitly model diffraction, diffraction effects are simulated by applying directional spreading of the waves, typically taken to be 2 – 5 ° for swell waves, and 10 – 30 ° for wind waves.

Bathymetric data for the study area derived from the 2007 Stockton Beach Hydrosurvey (OEH), 2008 Marine LiDAR (OEH), 2007 LiDAR data (CoN) and Australian Hydrographic Chart AUS809 were combined to produce a digital elevation model (DEM) of 20 m grid cell size.

Two SWAN model grids were created from the DEM. A coarse grid with points spaced at 200 m intervals, covering an area of 80 x 63 km and extending from Port Stephens Entrance to Tuggerah Lakes Entrance in the south, then east to ~ 200 m water depth. A fine grid with points spaced at 50 m intervals was created from Birubi Point in the north to Redhead in the south, 35 x 21 km in size. The extent of the coarse and fine grid models and DEM are illustrated in Figure 2-3.



Title:
SWAN Grid Domains and Regional Digital Elevation Model

Drawing: 2-3

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N

0 10 20km

Approx. Scale

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The SWAN model was used to define the nearshore wave height and water depth for extreme wave and water level parameters for use in calculating wave overtopping rates, see Section 3.3.4. Model results also provide an indication of wave transformation at Newcastle. For the 100 year ARI 6 hour duration storm wave of 8.7 m from the SSE, the SWAN wave model indicated significant wave height (H_s) at the -10 m AHD contour to be:

- 65 - 70 % of the offshore H_s at Merewether to Bar Beach;
- ~ 70 % of the offshore H_s at Newcastle and Nobbys Beach;
- 35 % at Stockton SLSC; and
- 45 – 50% at Stockton seawall and adjacent dunes to the north.

These values increased minimally (1 -2 %) with sea level rise of 0.9 m by 2100.

It is evident that the majority of the Newcastle shoreline is highly exposed to offshore swell conditions. In contrast, waves are significantly reduced for the southern end of Stockton Beach, which is protected from incoming SSE swells by the harbour breakwaters.

A 6 m offshore H_s from the ENE was modelled to investigate potential H_s at the southern end of Stockton Beach as it is directly exposed to this wave direction (refer Section 3.3.4). A wave height of 6 m was selected as the highest likely wave from the ENE direction. The modelling indicated that the SSE wave condition (8.7 m) still produced the largest waves at the southern end of Stockton Beach.

2.3.4 Storms

Historical records and personal accounts provide information regarding the occurrence of storms prior to the formal recording of waves. The concurrence of high waves with high water levels is particularly important in the potential erosion from a storm. Reports and photographs from the Newcastle region indicate that highly damaging and erosive storms have been experienced in the past, notably in 1912 to 1914, the mid to late 1940s and again in the early 1950s.

Sources such as BBW (1985, 1986) also provide a history of storms. BBW indicated the years 1954, 1967, 1968, 1974 and 1978 experienced very severe storms on the region of the NSW coast including Newcastle. Of these, the May-June 1974 event was the largest. The event left the beaches south of the Hunter River virtually devoid of sand. The 1974 event is known locally as the *Sygna* storm due to the grounding of the bulk carrier *Sygna* onto Stockton Beach during the event (which remains as a wreck today).

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

- storms in February 1954, February 1974 and June 1967 (as noted above) which coincided with spring high tides (PBP, 2004);
- the May 1974 storm coincided with the highest water level recorded on the NSW coast, of 2.37 m (above ISLW) measured at Fort Denison (May 25, 1974), which included 0.24 m of unpredicted astronomical tide on top of 0.23 m of storm surge and 1.9 m of predicted tide (Foster *et al.,* 1975); and

- the May 1997 storm (peak H_s of 5.6 m) coincided with an elevated water level 0.7 m higher than the predicted tide. Water levels during the May 1997 storm were found to be 1.2 - 1.9 m higher than three other storms of greater wave height (e.g. August 1986, June 1989 and April 1989), and so, the storm was described as more damaging. When storm duration was also accounted for, this storm was considered the 7th largest between 1976 and 2001 (PBP, 2004).

More recently, an east coast low on 8th June 2007 resulted in an approximate 1 in 100 year flood event in parts of the City of Newcastle. Significant wave heights exceeded 6 m for much of June, however, the peak of the storm event occurred during a low tide. Erosion was evident, but not to extents of past events. The event is known locally as the *Pasha Bulker* storm, due to the grounding of the carrier *Pasha Bulker* at Nobbys Beach in the morning prior to the peak rainfall event.

2.3.5 Wave Climate Variability

Throughout the wave record, the predominant wave direction has remained south east along the NSW coast. However, there are likely to be subtle shifts in the wave climate (wave height, wave direction) between years and even decades that relates to the intensity and frequency of storms (affecting wave height) and storm generation sources (affecting wave direction). Such shifts in wave climate may manifest on the shoreline as a period of erosion or accretion, and variation in the direction and rate of longshore sediment transport, both within an embayment (manifesting as rotation) and through embayments.

Variability in the wave climate between years is observed in the NSW wave climate. There is found to be reasonable correlation between the south east Australian wave climate and the El Nino Southern Oscillation (ENSO). Generally, there is observed to be an increase in the occurrence of tropical cyclones and east coast low cyclones during the La Nina phase (Goodwin 2005; Phinn and Hastings, 1992; Hemer *et al.,* 2008, CSIRO, 2007). Relating to these wave generation sources, the La Nina phase has been associated with more northerly (easterly) wave directions (Short, *et al.,* 2000; Goodwin 2005; Ranasinghe *et al.,* 2004). Mean wave power has also been found to be higher during the La Nina phase, likely due to the greater frequency / intensity of tropical and east coast cyclones, which occur in addition to the predominant mid-latitude cyclones (e.g. refer Phinn and Hastings, 1992; Ranasinghe *et al.*, 2004; You and Lord, 2008). During the El Nino phase there are generally fewer tropical and east coast cyclones and mid-latitude cyclones remain dominant, resulting in a more southerly mean wave direction (Ranasinghe *et al.*, 2004; Goodwin, 2005).

Climate variability at decadal time scales (10-30 years) is also an intrinsic characteristic of the Australian regional climate (Power *et al.*, 1999). A period of dramatic erosion and shoreline retreat over the 1950s and 1970s is well documented, since which time a relatively calmer period of beach recovery and lower storminess persisted to around 2007 (WBM, 2003; Callaghan and Helman, 2008).

The high storm activity during the decade of the 1970s is typically associated with the greatest beach erosion extents in the historical record on NSW beaches (Forster, *et al.*, 1975; Thom and Hall, 1991; McLean and Shen, 2006). Photographic evidence provides a telling account of this period that caused the greatest erosion extents in living memory. The higher frequency of storms during this period suggests that the recovery of the beach between storms (or lack thereof) was also significant in the resulting extent of beach erosion, in addition to the impact of the individual storms (Short *et al.*, 2000; Ranasinghe *et al.*, 2004; McLean and Shen, 2006).

A notable component of the climate variability on decadal scales is found to be related to the Inter-decadal Pacific Oscillation (IPO) (Power *et al*., 1999; Salinger *et al*., 2001; Folland *et al*., 2002). The sea surface temperature anomaly associated with the negative (or cool) phase of the IPO produces an increased frequency of east coast low pressure systems, higher rainfall and associated flood activity (Rakich et al., 2008; Verdon et al., 2004). Verdon et al. (2004) demonstrated that the frequency of La Nina events (producing wetter, stormier conditions) is increased during the negative (La Nina-like) phase of the IPO. An increase in wave height and more frequent storms arriving from the east and east north east directions are expected during such periods, associated with such wave generation mechanisms.

Callaghan and Helman (2008) documented two centuries of weather records along the eastern Australian coastline and found that periods of extremes (storms and droughts) tend to occur in alternate phases that last for decades. Helman (2007) reported that major energy periods in the storm history of the east coast can be correlated with the negative (La Nina-like) phase of the IPO.

While there is good correlation between ENSO and IPO and the storms that produce high waves, these climatic indicators alone are not adequate to describe or predict the extent of variability observed in the wave climate (height and direction), nor the shoreline response. The interrelationships between IPO, ENSO and other climatic drivers (e.g. Southern Annular Mode and Indian Ocean Dipole) and how they affect wave climate is not yet fully understood. Therefore, it is not currently possible to use such climatic indicators to reliably hindcast or forecast the NSW wave climate.

The key message is that natural variability in the wave climate is observed to occur over longer periods (years and decades). Variability in wave height and direction that persists for years to decades will result in alternate cycles of erosion and accretion and rotation (longshore sediment movement) on the shoreline. A series of storms (and associated water levels) over months to years and even decades will have a cumulative effect upon the shoreline, which may result in greater erosion than a single severe storm alone. Periods of higher or lower storminess in the wave climate (and subsequent cycles of erosion and accretion) can be expected to continue in the future.

2.4 Water levels

In an open coastal situation, the components which contribute to elevated ocean water levels during storms include:

- astronomical tide;
- inverted barometric setup;
- wind setup;
- wave setup; and
- wave run-up.

Sea level rise will also contribute to elevated ocean water levels in the future, and must be considered in any assessment of inundation hazard.

2.4.1 Astronomical Tide

Forces caused by the gravitational attraction of the Moon, the Sun and the Earth result in the periodic level changes in large bodies of water. The vertical rise and fall resulting from these forces is called the astronomical tide.

Tides of the NSW coastline are classified as micro-tidal and semi diurnal with significant diurnal inequalities. This means that the tidal range is < 2.0 m, and there are two high tides and two low tides per day that are generally at different levels (i.e., the two high tide levels are different in any one day).

Astronomical tides are well understood and can be predicted many years in advance. The Australian National Tide Tables lists predicted tidal levels at standard ports, one of which includes the Port of Newcastle. Key tidal statistics are given for the Port of Newcastle in Table 2-1.

There is little difference between these statistics and that of Fort Denison in Sydney. Indeed, the ocean tidal regime is largely uniform along the entire NSW coast, with little variation between Sydney and Surfers Paradise (just beyond the NSW-QLD border). This uniformity means that shore-parallel tidal currents along the coastline are negligible. Near the larger estuary entrances such as the Hunter River, significant local currents may occur in the surf zone, driven by the tidal volume flowing through the entrance on the falling and rising tide.

Table 2-1 Tidal Statistics, Port of Newcastle (Australian National Tide Tables)

	m AHD
Highest Astronomical Tide (HAT)	1.1
Mean High Water Springs (MHWS)	0.6
Mean High Water Neaps (MHWN)	0.4
Mean Sea Level (MSL)	0.0
Mean Low Water Neaps (MLWN)	-0.4
Mean Low Water Springs (MLWS)	-0.6
Lowest Astronomical Tide (LAT)	-0.9

2.4.2 Wind Set Up

Winds blowing over the sea surface produce wind shear stress on the water surface resulting in surface currents. When wind induced currents moving landward from the ocean are impeded by the shoaling seabed, they result in elevated water levels or wind setup against the coast.

A peak wind gust of 165 km/hr was measured at Nobbys during the May 1974 event. The more recent *Pasha Bulker* storm of 2007 recorded a peak wind gust of 124 km/hr at Nobbys (BOM, 2011). The average wind speed (~ 130 km/hr) from the May 1974 event was used to estimate a wind setup increment on the open coast of 0.2 m (Lawson & Treloar, 1986).

Wind set up is included in the average recurrence interval elevated water levels described below.

2.4.3 Elevated Water Levels

DECCW (2010) has analysed the long still water level record from Fort Denison, Sydney to provide average recurrence interval (ARI) water levels for use in coastal assessments in NSW. Given the limited difference in tidal ranges on the open coast at Newcastle compared with Fort Denison (and along the NSW open coast generally), these elevated water level estimates provide the most accurate estimates for use in this study. The elevated water levels are given in Table 2-2.

Elevated water levels in Table 2-2 include contributions from astronomical tide, barometric pressure set up and wind set up (DECCW, 2010). For 2050 and 2100, the levels also include projected sea level rise at the NSW Government's benchmarks of 0.4 m and 0.9 m by 2050 and 2100 respectively. Note also that the levels in Table 2-2 account for the sea level rise of 0.06 m that has been recorded already between 1990 to 2010 (DECCW, 2010).

A small increase in storm surge heights (1 – 3 cm) associated with future climate change has been projected by McInnes *et al* (2007) (see Table 2-3). This has been incorporated into the assessment of still elevated ocean water levels for future time periods in the coastal inundation hazard (Section 3.4.1).

Table 2-2 Design Elevated Water Levels (DECCW, 2010)

ARI (years)	2010 (m AHD)	2050 (m AHD)	2100 (m AHD)
0.1	1.00	1.44	1.94
20	1.38	1.72	2.22
100	1.44	1.78	2.28

2.4.4 Wave Set Up

As waves approach a beach they cause changes in the mean water level which is associated with the radiation stress of the wave train (i.e., the pressure force in excess of hydrostatic pressure caused by the presence of waves). Near the point of wave breaking, the mean water level is lowered (due to the pressure of the unbroken waves just prior to breaking). Once waves have broken, kinetic energy is released and the mean water level is raised, sometimes substantially above the still water level. Maximum setup occurs at the beach face. The amount of setup depends on wave height, wave steepness and beach slope.

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

For this project, the contribution of wave set up to wave overtopping has been calculated within the SWAN wave model output for each relevant location along the coast. For wave run up equations (see below) wave set up is not explicitly added to the calculations as it is assumed to be part of the wave run up event.

For elevated still ocean levels assessed for the coastal inundation hazard (Section 3.3.4), a contribution from wave set up has been included as 15% of the offshore significant wave height. An estimated 10% increase in storm wave height based upon regional projections (refer Section 2.8) has been incorporated into the calculation of future wave set up levels for 2050 and 2100 and is discussed in relation to wave run up and overtopping rates in Section 3.4.1.

Although wave setup along the open coast shoreline is reasonably well understood there is growing evidence that wave setup at the entrance to an estuary can be much less. Measurements documented by Hanslow and Nielsen (1993) from the Brunswick River entrance (NSW north coast) indicated that even when waves were breaking across the entrance, measurements of mean water surface extending up-river for some 200 to 300m showed only a very small transfer of wave setup. The maximum wave setup within the entrance was found to be less than 3% of the offshore wave height (Hanslow and Nielsen, 1993).

However, wave setup contributions to high water levels in the ocean can affect estuaries by acting to block the outflow of water during a flood. That is, the hydraulic gradient between outflowing flood waters and the ocean is reduced where ocean levels are high, exacerbating flooding upstream in the estuary. As noted in Section 3.3.4, flood assessments for the Hunter River have included elevated ocean water levels including wave set up and sea level rise.

2.4.5 Wave Run-up

Wave run-up is the vertical distance on shore that the uprush of water from a breaking wave reaches above mean sea level. It is the wave run-up mechanism that governs the volume of water that overtops a coastal barrier, for example, dunes, seawalls and entrance berms.

Wave run-up is highly variable between storms and locations as it is dependent upon factors including wave height, wave period, elevated water level (still and wave set up), beach slope (with steeper slopes producing higher run-up), beach/dune shape and permeability, the roughness of the foreshore area and wave regularity. Run-up is more severe on steeper slopes and impervious materials which means that grouted rock seawalls will generate much higher run-up than beaches.

Wave run-up is also highly complex due to the irregular nature of waves. Run-up for random waves is not fixed and will have a Rayleigh statistical distribution which will vary from wave to wave.

For Newcastle, the rate of overtopping and frequency of overtopping is an important consideration when determining the effectiveness of protection offered by existing seawalls, particularly with future sea level rise.

Investigations of both wave run-up levels for a natural beach and wave overtopping rates for vertical and sloped seawalls were conducted, including sea level rise at 2050 and 2100, as reported in Section 3.3.4.

2.5 Sediment Transport

2.5.1 Longshore Sediment Transport

Waves approaching the shoreline from an oblique angle generate a current alongshore which transports sediment. Depending on the prevailing wave direction, the longshore sediment transport may be directed either north or south along the coast. On NSW beaches, including at Newcastle, net longshore sediment transport is directed to the north, due to the predominant south east wave climate relative to the general north to south orientation of the coastline.

Longshore sediment transport (also commonly referred to as littoral drift) occurs predominantly in the mid to outer surfzone (or inner nearshore zone), diminishing in strength with distance offshore into deeper water. Winds and tides may contribute to longshore currents (and may dominate the currents outside of the surfzone).

The net regional longshore transport rate will be greater or lower than the average rate in any one year, or over years to decades depending upon the wave climate conditions (refer Section 2.3.5). Wave climate may enhance or reduce the longshore transport rate due to slight shifts in wave direction and may affect the bypassing of sediment past headlands and reefs, which typically occurs during higher waves or even storm conditions. This may result in natural accretion and erosion on a beach over extended periods of time.

Where more sand is transported out of a beach area than is being brought in over an extended period of time, the beach will erode. The erosion will occur initially in the surfzone where sediment transport is greatest, and manifest as beach retreat following onshore/offshore readjustment of the nearshore profile. Correspondingly, beach accretion may occur where longshore transport brings in more sand than is taken away. Shifts in transport direction can also result in a shift in sand from one end of the beach compartment to the other and a corresponding slight change in beach alignment between the controlling headlands.

2.5.1.1 Regional Longshore Sediment Transport Rate

The beaches to the south of the Hunter River are essentially pocket beaches in between headlands and reef where longshore transport processes are not so critical. However, there is evidence of longshore transport in deeper water past the rocky headlands, and a small rate of regional transport has been determined.

Sediment transport calculations from both the WBM (2000) and DHI (2006) studies indicate a northwards net littoral transport under the predominant south easterly waves at beaches south of the Harbour.

WBM (2000) determined a regional transport rate of 30,000 m^3/yr south of the Hunter River (not accounting for reefs or groyne effects at headlands). This was estimated using the analytical formulation derived by the United States Coastal Engineering Research Centre (CERC) with input of forty years of directional wave data for the Newcastle region (which was hindcast for the WBM study). The calculations also indicated variability in the yearly rate, which is as expected due to wave climate variability. For example, during years when storm waves from the southern sector have a greater influence than those from the east and northeast sector, a net longshore transport rate towards the north occurs. The reverse applies when there is a dominant influence from the east and northeast sectors.

Umwelt (2002) determined volumetric changes in the area off Stockton Beach by comparing volumes calculated from recent and historic hydrosurvey information from 1816 to 2000. The difference calculations suggested an average of:

- 41,500 m^3/yr loss between 1816 to 2000 (although the study noted data prior to 1866 is more likely to be inaccurate);
- 26,700 m^3/yr loss between 1866 to 2000; and
- 32,300 m^3/yr loss between 1921 to 2000.

If it is assumed no sediment bypassing occurs across the harbour breakwaters to enter the Stockton area, these volumetric losses are equivalent to the regional net longshore sediment transport rate.

Detailed sediment transport modelling was conducted by DHI (2006), which aimed to determine longshore sediment transport rates under the action of wave driven currents and the potential influence of tidal currents through the Newcastle Harbour entrance. The rate of transport along Nobbys Beach was estimated at 33,000 m^3/yr (DHI, 2006). This is in agreement with values of 30,000 m^3/yr calculated by WBM (2000) and Umwelt (2002). DHI (2006) also noted their modelling exhibited varying rates (and directions) of transport in any one year under varying wave conditions.

Based upon the previous investigations, it can be reasonably assumed that the average yearly regional longshore sediment transport rate is approximately 30,000 m^3/yr. In any one year this rate may vary naturally, depending upon wave height and direction over that year.

2.6 Cross-shore Sediment Transport

During storms, increased wave heights and elevated water levels cause sand to be eroded from the upper beach/dune system (often termed 'storm bite') and transported in an offshore direction, typically forming one or more shore-parallel sand bars in the nearshore zone. As the sand bars build up, wave energy dissipation within the surfzone increases and wave attack at the beach face reduces. During calmer weather, sand slowly moves onshore from the nearshore bars to the beach forming a wave-built berm under the action of swell waves. From the berm, wind blows sand to form incipient dunes and foredunes.

The severity of wave attack at the dune is dependent on wave height, elevated water level (the combination of tide, storm surge and wave setup) and preceding beach condition (i.e. if the beach is accreted or eroded prior to the storm). In addition, depending upon the orientation of the coastline relative to the direction of the incoming storm, the beach may either experience unimpeded wave power and severe erosion, or may be shadowed and protected from incoming wave energy.

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

At Newcastle’s southern beaches, the most extreme example of storm erosion and recovery is evident by comparing the beach state after storms of the 1970s with beach state experienced in 1998 (shown in the CHDS, WBM (2000)) and the present conditions. While it has taken many years, the beaches have recovered and demonstrate ample beach sand reserves following the severe erosion that occurred in the 1970s (see Chapter 4 for historical and recent photographic evidence).

2.6.1.1 Rip Currents

The main cross shore current of interest within the surf zone are rip currents (other cross shore currents tend to be small in comparison). Rip currents facilitate the offshore flow of water from the surf zone, which has been delivered by onshore breaking waves. Rip currents are dominant upon high energy single to double barred beaches, such as occurs at Newcastle.

The spacing of rips is dependent upon the wave energy conditions, such that during large waves, fewer rips will form at greater distance apart, however, the currents are wider and stronger. Feeder currents and troughs into the rips will also increase in width and strength during high waves.

Rip currents contribute to the extent of beach erosion during severe storms both in terms of erosion of the upper beach face at the landward end of the current, as well as transporting offshore the sand mobilised by wave breaking.

Topographically constrained rip currents form at headlands or along reefs, to facilitate the offshore flow of water from breaking waves at the headland constraint. Topographic rips at headlands assist in the bypassing of sediment around headlands, delivering sediment beyond the headland during high waves. These rips are common in Newcastle, such as along the reefs at the ends of Newcastle, Bar and Merewether Beaches and Nobbys reef.

Between the headland / reef constraints on the open beach, rips may also form at any location along the beach. Their formation at any potential location needs to be considered when planning set backs for the beach erosion hazard.

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

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

While the average net longshore flow of sand may bypass a headland or reef over a period of years, thus maintaining beach stability, in the short term there is potential for short term erosion / accretion effects upon the shoreline. For example, there could be erosion upon the downdrift beach due to the short term unbalance in the sediment budget, as potentially large quantities of sand moved away by longshore transport during the storm are not immediately replaced by sand bypassing of the updrift headland. Erosion upon the beach may be further exacerbated if the downdrift beach has also lost sand via bypassing to its adjacent downdrift beach. The short term starvation of sediment from the beach in this instance may have short term erosive impacts upon the shoreline.

Newcastle's highly structured southern coastline is likely to be dependent on such bypassing events around and across the shoreline reef platforms at the headlands to enter adjacent beaches. However, for cross-shore supply, the reefs may impede transport over the short term. For example, onshore transport under swell waves may build up sand at the base of the reef before this can be transported across the reef surface onto the beach. In contrast, storms will erode sand off the beach and offshore, where again, it must build up before being transported across the reef onto the beach.

There are numerous seawalls along the Newcastle shoreline. The majority of these are historic promenade-type vertical structures that are unlikely to have been built to coastal engineering standards as protection structures. The Merewether to Dixon Park seawall and Mitchell St Seawall at Stockton Beach are the only two engineered seawall structures that may offer reliable shoreline protection. Given that the Macquarie Pier was constructed under conditions of exposure to wave forces on a daily basis, this structure is also considered to provide adequate erosion protection (should it be exposed). All of the seawalls are located at the back beach beyond the limit of typical wave conditions, except the seawall at Stockton Beach. Seawalls can interact with longshore and cross shore sediment transport to exacerbate erosion as follows.

- Vertical walls tend to reflect wave energy and as such, enhance erosion of sediment at the base of the wall; and
- Erosion may be exacerbated at the ends of the seawall, either because the wall is unnaturally holding the shoreline in a more seaward position (for example, the Mitchell St seawall) than would otherwise occur, or by transferring storm demand to adjacent areas during a storm, enhancing erosion of adjacent soft sediments.

2.6.2.1 Beach Rotation

Changes in the dominant wave direction that generates longshore transport may lead to the shifting of sand from one end of the beach to the other, causing a change in beach width and alignment at opposite ends of the beach. This increase in beach width at one end while the opposing end experiences a decrease in width is termed beach rotation.

Beach rotation is a response to shifts in wave direction and height over seasons and years (Short *et al.*, 2000; Ranasinghe *et al.* 2004). It is particularly notable on pocket beaches where headlands constrain the longshore transport within the beach compartment.

The phenomenon of beach rotation forms a component of the observed extent of "erosion" on beaches. WBM (2000) estimated the contribution of beach rotation to erosion to be of the order of 5 - 10 m movement in beach position.

The approach applied in estimating the beach erosion hazard for this study incorporates the phenomenon of beach rotation (refer Section 3.2).

2.6.3 Interaction of Port of Newcastle Breakwaters with Sediment Transport

2.6.3.1 History of Construction of the Port Entrance

Construction of breakwaters and dredging activities that have formed the Port of Newcastle entrance are as follows (Umwelt, 2002; DHI, 2006):

- Between 1812 and 1846, the Macquarie Pier was constructed between Newcastle mainland and Nobbys Island (now Nobbys Head);
- Dredging of the Newcastle Harbour entrance commenced in 1859, as the entrance was still hazardous for ships;
- In 1875 the extension of the southern breakwater from Nobbys commenced, and following several storms, was completed in 1891;
- Between 1898 and 1912, the northern breakwater was constructed, measuring nearly 1140 m;
- In 1961, depths across the harbour entrance were around -8 m. To enable safer passage, the harbour entrance was deepened to -11 m between 1962 and 1967;
- A further channel deepening project commenced between 1967 to 1976, to increase depths through the channel to -12.8 m;
- Channel deepening continued between 1977 and 1983 to further deepen the entrance in line with Port expansion activities that continue to the present; and
- At the present time, the navigation channel is maintained at a depth of -18 m, with dredged material typically placed at an offshore disposal site.

Approximately 130,000 m^3 of sand was dredged from the entrance in August 2009 and placed off Stockton Beach. The placement event was generally agreed to be a success and represents the first documented nourishment event for Stockton Beach. Over more recent years, some small volumes of suitable dredged material (~5,000 m^3 per episode) have been placed at Stockton Beach by the Port's maintenance dredger. Suitable sediment sources for use on Stockton Beach are the subject of a recent Stockton Beach Sand Scoping and Funding Feasibility Study (WorleyParsons, 2011).

2.6.3.2 Past and Present Impacts upon Sediment Transport Processes

Construction of the Port of Newcastle entrance has considerably changed the adjacent shorelines over the period from construction (spanning 100 years) to present. Most notably, Nobbys Beach has formed as the accumulation and capture of net northwards littoral drift against the Macquarie Pier and southern breakwater to Nobbys Island. The beach is now among Newcastle's most valued coastal assets.

The interruption of littoral transport past Nobbys Head has also affected Stockton Beach, located north of the northern breakwater.

It appears that by at least 1966, sediment bypassing of the southern breakwater was occurring. WBM (2000) cited a joint NSW Public Works Department and Australian Atomic Energy Commission tracer study in 1966 that concluded there was significant sediment transport towards the entrance past the southern breakwater. As noted above, however, channel deepening events involving dredging of the harbour entrance had commenced by 1966, so it is unclear to what extent sediment bypassing into Stockton may have occurred before this time. In any case, the channel deepening works would have precluded any sediment bypassing into Stockton after that time.

Extensive modelling investigations of sediment transport processes at Stockton Beach have recently been completed by DHI (2006) for the Stockton Beach Coastal Processes Study. DHI (2006) model results indicated that sediment transport past Nobbys Head and the southern breakwater was occurring, some of which may be entering the Port entrance and some of which is being directed north east (into deeper water). However, DHI (2006) noted clearly that due to ongoing dredging of the entrance channel (and the deep nature of the port entrance), it can be assumed that no sediment is traversing the entrance channel to enter the Stockton area.

The report suggested that a bypassing mechanism may be developing (shown as an area of slight accretion north of the entrance in model results), however, the depths of the channel at the entrance (-18 m) are such that there is limited capacity for sediment transport under tidal or wave driven currents. That is, should bypassing to this area be occurring, transport shoreward under swell action would occur very slowly (likely slower than the rate of erosion at the shoreline under the same wave action, should these volumes not be removed through dredging first). Some of the bypassing sediment appeared to be accumulating along the southern edge of the entrance channel inside the Port and migrating landward to eventually reach Horseshoe Beach (DHI, 2006). The frequency of entrance channel dredging was reported to support the occurrence of sediment bypassing into the southern side of the channel (DHI, 2006).

North of the Hunter River at Stockton Beach, longshore sediment transport processes are more complex. Investigations by DHI (2006) have indicated a southwards directed current from Mitchell St Seawall towards the breakwater, reducing from 13,500 m^3/yr to 1,800 m^3/yr at the most southern end, with a weak seaward flowing current along the breakwater (in fact, rip currents would readily form along the breakwater). DHI (2006) noted that the sheltering effect of the breakwaters acted to reduce currents and therefore transport under the dominant south easterly waves. As reported in the DHI (2006), WBM (2000) and PWD (1985) studies, the low rates of transport into the far southern end of Stockton Beach adjacent to the breakwater under both southerly and easterly wave conditions has resulted in minor accretion at this location.

North of the seawall, sediment transport is directed to the north, beginning at low rates (4,500 m^3/yr) increasing to 30,000 m^3/yr at the sewage treatment ponds on Stockton Beach (DHI, 2006). Currents increase towards the north as the sheltering effect of the harbour breakwaters diminishes (DHI, 2006). Thus, a nodal point was identified by DHI (2006) immediately north of the Mitchell St Seawall, northwards of which sediment transport increases. Along this stretch, erosion occurs as more sediment is being transported north than is being supplied into the area from the south. The DHI (2006), PWD (1985), WBM (1998) and Umwelt (2003) studies all indicated a slight recessionary trend between Hereford St and the Stockton sewage treatment ponds.

Transport rates of more than 50,000 m^3/yr were estimated further northwards (DHI, 2006). An increasing longshore transport along Stockton beach is reasonably expected as there is no interruption by reefs or headlands along the embayment, the shoreline experiences the full effects of the oblique dominant south easterly waves, and there is a greater sediment supply in the nearshore zone (compared with south of the harbour).

Investigations by DHI (2006) found that tidal currents through the Port of Newcastle entrance did not contribute significantly to sediment transport characteristics at the adjacent beaches (Stockton, Nobbys). Wave driven currents were found to be the dominant process in the nearshore zone. DHI (2006) model results indicated sediment deposition at the NE end of the northern breakwater that is in part due to returning flows through the entrance in addition to wave driven currents.

2.6.4 Sea Level Rise and Headlands & Coastal Structures

Sea level rise tends to exacerbate the interruption of littoral drift by natural headlands and man-made structures (breakwaters). As sea level rises, the water depth offshore of the headlands or breakwaters becomes deeper, thus bypassing of sediment is substantially reduced or ceases as water depths are (initially) too deep for the transport of sediment under the existing wave conditions. However longshore transport continues to be generated within the embayment. This results in sediment being transported from south to north along the beach. Without supply from other beaches to the south, the southern end of the beach erodes as the northern end accretes against the headland, breakwater or other structural feature. Bypassing of the headland will essentially recommence when the nearshore profile has accreted (shallowed) to a depth where transport under existing wave conditions can occur. However, as sea level rise is likely to continue the profile may not be able to accrete fast enough to match the rise in sea level, resulting in ongoing cessation of bypassing and enhanced erosion at the southern ends of beaches with sea level rise.

Seawalls, which form hard structures on the shoreline, are likely to act similarly to headlands as sea level rises. Where a seawall is separated from the ends of the beach, such as at Stockton, the wall may form a headland and compartment the beach. Where a seawall is attached to bedrock constraints such as between Merewether and Dixon Park beaches, the wall will constrain recession, becoming exposed on the shoreline, as the limited sediment reserves are eroded under the action of waves at higher water levels.

At reefs in the nearshore zone, sea level rise will result in impacts at the shoreline in lee of the reefs. The wave dissipation and refraction at the reefs would be lessened due to the greater water depths over the reef with sea level rise. The result is enhanced wave activity at the shoreline and subsequent erosion of tombolos, salients and sand lobes that had formed previously in lee of the reef. Given the extensive reef in the nearshore zone of Newcastle, the impact upon the shoreline alignment in the lee of nearshore reef will be important.

The impacts of seawalls, headlands, reefs and other features with sea level rise have been investigated for the long term recession hazard in Section 3.3.

2.6.5 Wave Climate Variability and Transport

Erosion is a response not only to short term storm events, but to medium term changes in wave climate that will affect longshore and cross-shore sediment transport. Where a coastline is stable and longshore and cross shore transport rates are on average roughly equal, the longer term wave climate periods may promote accretion or erosion, through both cross-shore and longshore transport. The variability in longshore and cross-shore transport due to natural wave climate variability has been noted in discussions above, as it is an important consideration when determining setbacks for natural coastal processes.

The historical beach response given in the photogrammetry demonstrates the effect of longer periods of wave climate variation, which produce enhanced periods of accretion, erosion or stability.

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

The 1970s period of enhanced storminess resulted in the greatest erosion extents typically observed on the NSW coast, including Newcastle. The resulting erosion was in part due to offshore transport and also longshore transport both within and between embayments, driven by the oblique angle of attack from the various storms in this period. From the end of the 1970s to 2007, significant accretion on beaches has been observed as a response to the relatively calmer, more persistently south east wave climate over this period. Such periods drive beach accretion through both longshore and cross shore transport.

For coastal planning purposes it is important to consider that a period of wave climate producing enhanced erosion on beaches such as occurred during the 1970s is likely to occur again in the future. Thus, the aim is not to measure the sediment transport during a single storm, but to understand the potential envelope of beach movement in response to periods of enhanced storminess. This is discussed in greater detail as part of the beach erosion hazard (Section 3.2).

2.7 Aeolian (Windborne) Sediment transport

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

Aeolian transport is the key builder of foredunes particularly where vegetation enables the windblown sediment to be captured and stabilised. The sediment is thus stored within the beach system, rather than transported further landward where it is essentially removed from the active beach system. Thus, windborne transport typically contributes positively to the growth of incipient foredunes and storage of sediment in vegetated foredunes, providing protection during periods of beach erosion.

Active dunes refer typically to unvegetated dune fields where vegetation is sparse or minimal, and sediment is blown freely landward in large sheet like patterns perpendicular to shore. Such windblown sediment transport or sand drift can present a hazard where back beach development is being inundated by dune sands.

Loss or damage to vegetation on sand dunes (e.g. the creation of informal tracks by walkers or four-wheel drive vehicles, and weeds such as Bitou Bush) may initiate sand blowouts and subsequent destabilisation of the dune system. This may have consequences for the retention of sediment within foredunes and therefore, the protection available to beaches during periods of erosion by waves and high water levels. Discussion of the sand drift hazard is given in Section 3.6.2

2.8 Climate Change Projections Relevant to Coastal Processes

Scientific understanding of the impacts of climate change relevant to coastal assessments now include wave height and direction, storm surge and wind speed and direction (as described in McInnes *et al.,* 2007; Macadam *et al.,* 2007; CSIRO, 2007) and sea level rise, as given in Table 2-3.

These climate change parameters will affect each of the individual coastal processes that generate coastal hazards.

Rather than defining a separate ‘climate change hazard’ (as per the CMM 1990), the assessment of climate change has been integrated into the analysis of each coastal hazard for the 2050 and 2100 extents, where possible. This is because climate change will affect coastal processes and therefore hazards.

Projections of potential climate change impacts were identified for the Hunter, Central and Lower North Coast region of New South Wales as an initiative of the Hunter & Central Coast Regional Environmental Management Strategy (HCCREMS). The Regional Climate Change Project completed in 2009, provides regional scale projections of climate change by establishing relationships (i.e. shifts and changes) between key synoptic types (based on projected monthly sea-level pressure field output from the CSIRO Mk3.5 Global Climate Model (GCM)) and regionally specific climate data measured by the Bureau of Meteorology (BoM). The projections for key climate variables are presented by HCCREMS (2009) in terms of three regional climate zones, namely the Western Zone, Central Zone and Coastal Zone. For the present study, key climate change impacts relevant to coastal hazards for the Newcastle coastline are based on downscaled predictions obtained for the Coastal Zone.

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

A summary of the climate change parameters that are relevant to this coastal hazard assessment is given herein.

2.8.1 Sea Level Rise

The former NSW Government’s Sea Level Rise Policy Statement recommended that an increase in mean sea level above 1990 levels of 0.4 m by 2050 and 0.9 m by 2100 be used in all coastal assessments in NSW. The NSW Government has since repealed this policy, and recommended that local councils “have the flexibility determine their own sea level rise projections to suit their local conditions” (NSW Environment and Heritage, 2012). The Office of Environment and Heritage (OEH) has recommended that councils consider sea level rise projections that are ‘widely accepted by competent scientific opinion’, or indeed consider a range of probable projections (OEH, 2013).

The NSW Government’s former sea level rise policy benchmarks were based upon IPCC (2007) and CSIRO (2007) reports (see DECCW, 2009). These reports are effectively the most current projections that are ‘widely accepted by competent scientific opinion’. The former sea level rise benchmarks were calculated as the addition of the upper range of projections from:

- the IPCC (2007) projections for sea level rise (ranging from 0.18 – 0.59 m by 2090-99),

- the IPCC's (2007) assumed linear trend in global ice melt (that was recommended to cause 0.1-0.2 m sea level rise by 2100); plus
- the CSIRO (2007) projections for regional sea level rise by 2100 associated with the East Australian Current on the NSW Coast (of 0.08 to 0.14 m).

The projections for 2100 were compared with the sea level rise trend projections to derive a 2050 sea level rise estimate of 0.4 m (DECCW, 2009b). While it is noted that the IPCC has released another global assessment report in 2013, the IPCC (2007) values remain valid until such time as the CSIRO also releases projections for NSW to accompany the 2013 IPCC projections (as the CSIRO contributes modelling to the global IPCC projections).

HCCREMS (2009) note that while sea level rise estimates adopted by the NSW Government are applicable for the study area, regional impacts of sea level rise also depend on relative movement of the land to the ocean, caused by sedimentation, land subsidence, tectonism and millennial scale geodynamics. The summary of climate change projections provides regionally specific sea level rise estimates of +0.37 m (by 2050) and +0.845 m (by 2100) based on draft sea level rise estimates and consideration of the regional impacts noted above.

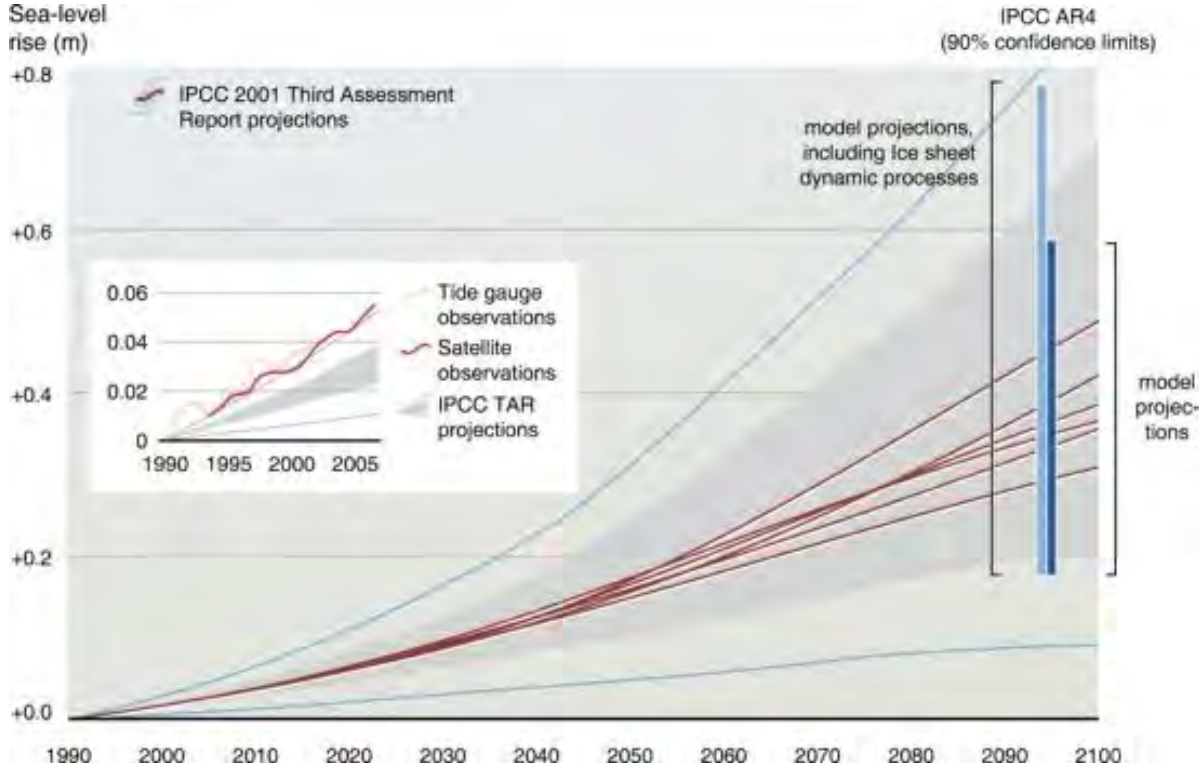
Figure 2-4 provides a summary of the global measurements and projections for sea level rise since 1990. The rate sea level rise measured over the last century was 1.7 mm/year (Church et al., 2010). The rate of global sea level rise since 1992 to date is around 3.1 ± 0.4 mm/year (CSIRO/ARECRC, 2012).

Figure 2-4 shows that global sea level rise measurements are tracking with the highest sea level rise projections (i.e. 90th percentile projection plus poorly defined ice-sheet contribution). Similarly, the HCCREMS projections are very similar to the NSW Government policy levels. This indicates that the upper range levels used to derive the former NSW sea level rise policy benchmarks are likely to occur by 2100 and provide the best estimate projection for this coastal hazard assessment.

Therefore, sea level rise benchmarks of 0.4 m by 2050 and 0.9 m by 2100 above 1990 mean sea level have been adopted for this study.

From a risk perspective, it is important to consider changes beyond that given within the current predictions. Thus, in addition to the adopted best estimate sea level rise levels, the impact from a higher than predicted sea level rise of 1.4 m by 2100 (i.e. 0.5 m higher rise than the prescribed NSW Government levels) and 0.7 m by 2050, (assuming a linear rate of increase to 2100) has also been analysed. The higher than predicted sea level rise provides for investigation of impacts where sea level rise occurs faster than predicted. Investigation of higher than predicted sea level rise provides a sensitivity test for an extreme or very unlikely (rare) scenario impact.

The use of sea level rise scenarios in estimating the shoreline recession hazard and the coastal inundation hazard are discussed in detail in Section 3.3 and Section 3.3.4 respectively.



**UNEP/GRID-Arendal (2012) explain for this figure: "the projected range of global averaged sea-level rise from the IPCC 2001 Assessment Report for the period 1990 to 2100 is shown by the lines and shading [grey]. The updated AR4 IPCC [2007] projections made are shown by the bars plotted at 2095, the dark blue bar is the range of model projections (90% confidence limits) and the light blue bar has the upper range extended to allow for the potential but poorly quantified additional contribution from a dynamic response of the Greenland and Antarctic ice sheets to global warming".*

Figure 2-4 Projected and Measured Sea Level Rise to 2100 (source: UNEP/GRID-Arendal*, 2012)

2.8.2 Wave Climate

Theoretically, an increase in storm intensity or wave height means that beaches may experience greater erosion of sand during individual storms, while increased storm frequency means that beaches have less time to recover and accrete sand upon the upper beachface before the next storm occurs. Any increase in storm intensity or frequency due to climate change will be coupled with a rise in sea level, further intensifying potential storm erosion. Further, a sustained shift in the wave direction (even if not combined with a change in wave height) may impact upon coastlines, because it is the wave direction relative to the orientation of the shoreline that is a key determinant for longshore sediment transport rates.

Projections for future wave climate given in McInnes *et al*. (2007) and discussion given by HCCREMS (2009) that are relevant to this study provide potentially contradictory results.

HCCREMS (2009) estimates based upon the observed IPO -ve and IPO +ve periods (1948 to1976 and 1977 to 2007 respectively) determined that average significant wave height during summer is projected to increase marginally for the period leading up to 2040, and decrease thereafter. For autumn and winter months, average significant wave height is predicted to decrease. No significant trends were found for the spring wave climate or mean wave directions occurring year-round.

However, storm frequency during autumn and winter is predicted to increase in the Coastal Zone of the Hunter, Lower North Coast and Central Coast Region (HCCREMS, 2009). the analysis of the frequency of synoptic types showed a 4% increase in the frequency of mean circulation patterns during autumn and winter. HCCREMS (2009) suggested the probability of an east coast low forming during autumn and winter would be expected to increase along the NSW east coast based on the frequency of weather patterns responsible for these events also increasing. This would imply increases in storm wave heights (and therefore average significant wave height) in autumn and winter in relation to such events. This contradicts the findings above.

McInnes *et al.* (2007) investigated future wave heights (average and storm waves) and future wave directions due to climate change for Batemans Bay and Wooli Wooli Estuary. Newcastle is approximately half way between both sites.

For Batemans Bay, McInnes *et al.* (2007) suggested a potential increase in storm wave heights of 32%, or decrease by 6% by 2070. Batemans Bay is relatively closer to Mid-latitude cyclones, which generate the dominant swell and storm waves in NSW. Therefore, use of the Batemans Bay projections at Newcastle is likely to give an over estimate of future storm waves. Projections for Wooli are inconclusive, with a potential decrease (-15%) or increase (+9%) by 2070. Projections for changes to swell wave height from the dominant SSE direction were similar for Batemans Bay and Wooli, but inconclusive (-8 to +8 %).

Projections for changes to swell wave direction given by McInnes *et al.* (2007) suggested a shift of up to 3.3° more easterly at Wooli, and 3.8° more southerly at Batemans Bay. Such shifts in wave direction to the east or south are within the variability of the existing wave climate.

The historical shifts in wave climate that occur naturally are greater in range than the predicted shifts in the future wave climate given by both studies. Indeed, both bodies of work suggest that the historical variability of wave climate over the past 60 years most likely reflects the range of possible conditions over the next century. The resolution of the climate change models (CCM2 and CCM3) used to derive the predictions for both studies is not sufficiently fine scaled to replicate all of the climatic systems important to the NSW coast. Most notably, the models cannot fully simulate the occurrence of east coast low weather systems that are responsible for extreme waves in NSW (see Section 2.3.1).

From a risk perspective, an increase in storm wave heights or shift in average wave direction to a more easterly wave direction is still a valid consideration for future hazard extents at 2050 and 2100. Wave height and directional change during storms has largely been encapsulated by the approach taken to determining beach erosion hazard extents (Section 3.2).

Sensitivity testing of a 5° shift in wave direction to the east by 2100 to determine impacts upon regional longshore sediment transport rates and future shoreline recession has been assessed with the Shoreline Evolution Model, as part of defining the shoreline recession hazard (Section 3.3). A wave direction shift to the east was selected as this replicates an increase in La Nina-like wave conditions, which are associated with erosion and beach rotation (see Section 2.3.5).

In lieu of conclusive projections, an increase in storm wave height of 10% has been considered as part of elevated water level assessments under a worst case or ‘rare’ scenario for the coastal inundation hazard (Section 3.3.4).

2.8.3 Storm Surge

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

Although regionally specific information relating to storm surge is not specifically addressed by HCCREMS (2009), the analysis of the frequency of synoptic types shows a 4% increase in the frequency of mean circulation patterns during autumn and winter. For the Newcastle region, storm systems responsible for elevated sea levels and storm surge conditions include East Coast Lows, cut-off lows and southward-moving tropical cyclones. As such, storm frequency during autumn and winter is predicted to increase in the Coastal Zone of the Hunter, Lower North Coast and Central Coast Region (HCCREMS, 2009).

In the absence of regionally specific information, predictions for the likely change in storm surge due to climate change provided by McInnes *et al.* (2007) given in Table 2-3 have been used in assessing future elevated water level events under a worst case or 'rare' scenario, in addition to projected sea level rise and wave set up change due to climate change impacts on wave height (as given above), for the coastal inundation hazard (Section 3.3.4).

2.8.4 Rainfall

HCCREMS (2009) explain that while there is no overall (annual) increase in rainfall beyond the bounds of natural variability for the period 2020 to 2080, sustained wet periods (similar to those experienced during La Nina conditions) is projected for the region. For the coastal zone, seasonal shifts (relative to the inter-decadal period 1948-1976) in rainfall include a predicted decrease of ~13% in winter, increase of ~15% in spring, decrease of ~9% in autumn and ~2% decrease in summer.

There may be minor effects upon erosion occurring at stormwater outlets on beaches due to increased flow velocities (from larger rainfall events) that may cause increased scour at outlets. However, the projections suggest conditions overall in the future will be similar to the existing case.

2.8.5 Wind

Future changes in wind speeds or directions may have an effect on windborne (aeolian) sand transport from the beach and dune systems. While the volume of aeolian sediment transport is controlled by grain size, the number of days during which appropriate wind conditions occur may modify future volumes of sediment transported.

No change to average annual windspeed as a consequence of climate change is predicted for the Hunter region (HCCREMS, 2009). Seasonal shifts to average windspeed are predicted for autumn (increase of 1.5 km/hr) and spring (decreased of 1.4 km/hr). Minor changes to average windspeed are noted for summer and winter. Overall, windspeed projections for the coastal zone lie within the bounds of natural variability (based on wind data available between1970 and 1996). The magnitude of wind gusts during winter is predicted to decrease as a consequence of the decreased frequency of westerly winds in the region, which is unlikely to have any significant impact on coastal hazards. Onshore (easterly) winds in the coastal region are predicted to increase in summer, which can affect windborne (Aeolian) sand transport from the beach into dune systems as well as swell and wind waves approaching the coastline.

The current projections for the Hunter region therefore suggest that windborne sediment transport processes will be similar to the present at 2050 and 2100. While there may be impacts to the generation of wind waves from onshore breezes in summer that do contribute to average conditions, such waves are not dominant in coastal hazard events.

Table 2-3 Climate Change Parameters for Coastal Hazards Assessment

Prediction	2050	2100	Reference
Sea Level Rise	+0.34 m	+0.84 m	NSW Government (2009) inc. +0.06 m rise to 2010
Change in Storm wave Height	+5%	+10%	Based on HCCREMS (2009) and McInnes *et al.* 2007
Change in Mean Wave Direction	-2.5 ^{o}	-5 ^{o}	Based on projections from McInnes *et al.* 2007 of Max 3.5

3 COASTAL HAZARDS METHODS & ASSESSMENT

3.1 Hazard Probability / Likelihood Zones

The definition of coastal hazards inherently involves uncertainty relating not only to coastal processes but also to the uncertainties involved with climate change. There are uncertainties surrounding climate change projections, the timeframes over which this change may occur, as well as how climate change may affect the environment. Irrespective of climate change, the episodic nature and unpredictability of coastal hazards have always presented a challenge to planners and managers. There is generally limited data on coastal processes (e.g. historical shoreline change, wave climate, water levels and response to these variables, etc.) and there are many different ways to assess the extent of hazards, which add to the uncertainty in estimating coastal hazards.

The uncertainty and natural variability in coastal processes, particularly at Stockton Beach, was recognised previously by WBM (2000). It was noted that adopting a purely best estimate (single line) approach inherently incorporates a risk that the limit of erosion will extend beyond the projected line or in fact will never reach it.

The approach adopted by WBM (2000) was to provide a band of possible erosion extents, in order to illustrate the variable probability associated with erosion reaching certain limits within each planning period. The upper (landward) limits of the band represented an erosion extent that had a low probability of being reached. Conversely the seaward boundary of the band represented the minimum distance considered appropriate and by definition, erosion has a relatively high probability of reaching this line within the specific planning period. WBM (2000) noted that future coastal management planning should consider the risk and consequences of erosion reaching certain limits in deciding appropriate management strategies. To assist coastal management decisions where a preferred line is required, a best estimate within that band was provided for planning purposes.

For this study, WBM's earlier pioneering concept of a band of likely erosion extents has been extended and a formal Risk Management approach has been applied to assessing coastal hazards and management. The use of the risk assessment framework for managing coastal hazards is prescribed in the CZMP Guidelines, as well as the *NSW Coastal Planning Guideline: Adapting to Sea Level Rise*. The accepted process for identifying and managing risks is outlined in the Australian Standard Risk Management Principles and Guidelines (AS/NZS ISO 31000:2009), and is the process applied to this study.

A risk assessment approach is a powerful methodology for dealing with uncertainty in processes and information. Rather than attempting to provide a single answer with absolute and potentially unfounded accuracy, the risk assessment approach allows us to consider a range of events, their likelihood, consequence and thus the overall level of risk.

A risk is considered to be the probability of an event occurring and the consequential impact of the event upon the asset or value. Under the Australian Standard, risks are analysed in terms of their 'likelihood' and their 'consequence'. Coastal hazards are considered to be the event that is to be analysed through risk management, therefore both 'likelihood' and 'consequence' of the hazards needs to be analysed.

The hazards definition phase of the NSW coastal management process is suited to defining the 'likelihood' or probability of occurrence of coastal hazards, through the analysis of coastal processes and historical beach responses, and to account for uncertainty in both the occurrence of hazards and shoreline response to sea level rise.

As prescribed by the Australian Standard (AS/NZS ISO 31000:2009) and its companion document (HB 436:2004), risk criteria should be developed specifically for the risk assessment being conducted (that is, there is not a "standard" matrix or scale given in the Australian Standard, rather, the scales should be developed specifically for each risk assessment in order to address the context and objectives of that assessment). A scale of 'likelihood' of occurrence for a coastal hazard impact that aligns with guidance in Australian Standard (AS/NZS ISO 31000:2009) and its companion document (HB 436:2004)is given in Table 3-1. This likelihood scale has been developed over the course of the many other coastal zone hazards and management studies that BMT WBM have conducted in NSW. The timeframes over which coastal hazards probability has been assessed is defined in Table 3-2, namely the immediate (~2013), 2050 and 2100 planning horizons.

The scale in Table 3-1 is tailored to both the long timeframes for coastal planning (up to 100 years) and the potential for relatively infrequent, but damaging events that can occur within that timeframe (e.g. 1 in 100 year storm erosion events). A likelihood has been ascribed to the coastal hazards from this scale, based upon a technical review of the analysis used to define the hazards (see below).

Presenting a likelihood to the hazard estimates provides transparency regarding the uncertainties, limitations and assumptions used to assess hazards. Establishing a likelihood for coastal hazards can also educate coastal planners and the wider community that hazard lines are estimates only and not precise predictions of future shoreline response. As recognised by WBM (2000), the consequence and overall risk can then be considered when determining a suitable management response.

Table 3-1 Risk Likelihood / Probability

Probability	Description
Almost Certain	There is a high possibility the event will occur as there is a history of frequent occurrence.
Likely	It is likely the event will occur as there is a history of casual occurrence.
Unlikely	There is a low possibility that the event will occur, however, there is a history of infrequent or isolated occurrence.
Rare	It is highly unlikely that the event will occur, except in extreme / exceptional circumstances, which have not been recorded historically.

Table 3-2 Timeframes for Coastal Planning

Timeframe	
Immediate	Present day conditions (e.g. 2013)
2050	Expected conditions by circa 2050
2100	Expected conditions by circa 2100

Historical beach response and other data are generally not comprehensive or detailed enough to differentiate between the five likelihood categories given in Table 3-1 at all timeframes. Rationalisation of these categories has thus been made, with focus given to 'almost certain', 'unlikely' and 'rare' probabilities for the immediate, 2050 and 2100 planning horizons. It has been presumed that these categories will provide a sufficient level of detail for coastal planning purposes.

Our understanding of coastal processes and climate change and the potential for hazards impacts will continue to improve, allowing for improvements in determination of likelihood or probabilities in the future. CoN is encouraged to continue to expand their data collection (e.g. beach surveys following consequential storms), in order to have ongoing datasets with which to refine the coastal risk assessment into the future.

The consequences of coastal hazards will be analysed as part of the Newcastle Coastal Zone Management Study and will relate to the type of coastal hazard impact and the assets and values of coastal land affected. For example, the consequence of 'almost certain' beach erosion at one beach may involve the loss of one or many houses, but at another beach it may be the loss of national park lands or foreshore reserves. The resulting 'risk' is different based on the value or asset exposed to the hazards (i.e. 'consequence'), not just the extent of the hazard (i.e. 'likelihood'). During the coastal management stage, consequence and likelihood are combined to give the level of risk from coastal hazards at various locations along the coastline. Management responses may then be developed and targeted towards areas at highest risk.

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

3.2 Beach Erosion

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

- Offshore, with sand eroded from the beach face and transported to the seabed to form a sand bar roughly parallel to the shoreline; and
- Alongshore (i.e., along the beach) either upcoast or downcoast depending on wave direction.

The result is erosion on the beach face that may pose a hazard to back beach land and assets. The short term storm related cross shore sand transport and longshore drift occur simultaneously. Their effects are additive, although the beach itself (above mean sea level) will be observed to erode predominantly during storm events.

On average, however, stable beaches exhibit a form of dynamic equilibrium. Following periods of large-scale short term erosion, the beach will tend to restore itself over time to an average state, and during favourable wave climate periods, an accreted beach state.

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

- the presence / location and strength of rip current cells, which promote seaward transport of sediment, and which may allow larger waves access to the beach face resulting in further localised beach erosion;

- the state of the beach (eroded or accreted, both on land and underwater) prior to a storm(s); and
- adjacent headlands or coastal structures that can modify local wave conditions and the supply of sediment during the storm event. Any differentials in longshore transport rates can therefore contribute to the short term erosion by more sand being carried out of an area than is being brought in during the storm.

If a beach is backed by a seawall or natural rocky outcrops, such as the southern beaches in Newcastle, the storm demand may exceed the volume of sand available thereby effectively removing all the sand from the upper beach profile. There is evidence of such events at Newcastle, such as during 1974 (refer Figure 4-1 to Figure 4-4, Chapter 4).

The sand that is transported offshore during a storm event is generally not lost from the overall beach system. It is gradually transported back onshore following the storm by lower swell waves forming a beach berm. As the beach builds up again, the sand above high tide becomes dry and may be blown landward by the prevailing onshore winds. Native dune grasses and shrubs adapted to the harsh coastal environment trap the sand and rebuild the dune. The onshore transport of sand is typically slow and where a beach is backed by a seawall or natural rock, the foreshore may be left devoid of sand for some time.

On the southern beaches which are in long term 'dynamic equilibrium', the amount of sand which returns to the beach is equal to the amount eroded during the storm . That is, the beach maintains a stable long term alignment on which the short term fluctuation are superimposed. However, Stockton Beach is experiencing long term recession, thus not all the sand eroded may be returned, and so the erosion escarpment will move landward on average over time.

3.2.1 Photogrammetric and Historical Data Coverage and Quality

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

Photogrammetric and other data utilised in the assessment of Newcastle's southern beaches includes:

- Photogrammetric data for 1954, 1974, 1996 and 2001 for Merewether to Bar Beach, Newcastle Beach, the Cowrie Hole and Nobbys Beach (and Burwood Beach, outside of the study area);
- 2007 LiDAR data processed along the existing photogrammetric profiles for Merewether to Bar Beach, Newcastle Beach, the Cowrie Hole and Nobbys Beach (and Burwood Beach, outside of the study area);
- Historical photographs following the 1974 storms at Newcastle and Merewether to Bar Beaches.

For the CHDS (WBM, 2000), newspaper reports that provided insight into previous erosion during storm events and beach survey with traditional levelling were also processed for Newcastle's southern beaches, and was reviewed against findings for this study.

While inaccuracies can be common in older dates of photogrammetric data, all dates of photogrammetry were found to be accurate for analyses in this study. Photogrammetry and LiDAR provides data on changes above mean sea level, therefore consideration of longer term trends is based primarily on movements of the upper beach/dune system.

Photogrammetric data can be processed to calculate volumes along a profile cross section (in m^3/m), cumulative volumes (in m^3) of a set of profiles (a block) and to measure the horizontal distance to a particular elevation or contour position. Review of photogrammetric processing methods by Hanslow (2007) concluded that both the horizontal movement of a selected dune contour position and the sub-aerial beach volume calculation have statistical significance to be appropriate for use in hazard assessments. Both of these methods have advantages and disadvantages, therefore, both the sub-aerial beach volume data (cumulative block volumes, individual profile volumes) and dune contour position movement were used to assess beach erosion and historical long term recession.

The 4 m AHD contour position is often used as this elevation is within the area of active surfzone processes during storms, but not regular (daily) beach changes which may obscure the assessment of erosion events. The 4 m AHD elevation is also typically the region of active contemporary dune building processes during beach recovery, and was therefore considered an appropriate benchmark to assess storm based fluctuations of the beach position, and long term recession, where this is present.

For this assessment, the 2 m AHD contour was also investigated for the beaches south of Newcastle Harbour. This is because the beaches are relatively narrow and mostly backed by bedrock or seawalls, which constrains both the development of foredunes and erosion events to the structures. In this case, the 2 m AHD contour was also considered useful for understanding beach profile changes over time.

Individual profile volumetric data (m^3/m) was also considered in determining the probable beach erosion extents. To enable a broad comparison with the analysis of dune position change, the volumetric data was converted to a movement of the shoreline position. The dune (4 m, 2 m AHD) contour calculations and profile volume calculations were compared with the photogrammetry profile cross sections in order to ensure the calculations were representative of actual changes in beach morphology over time.

Digital elevation models (DEMs) of the photogrammetric data were compiled to derive contour plots for the 4 m and 2 m AHD contour at the southern beaches (shown in Figure 4-5 to Figure 4-19 of Chapter 4). The plots demonstrate the oscillating beach position over time in response to erosion (storms) and accretion phases, and evidence of long term recession, where this exists.

3.2.1.1 Calculations used to Define the Beach Erosion Hazard

A common approach to estimating the beach erosion hazard involves estimating potential erosion ('storm bite' or 'storm demand') occurring during a single 'design' storm. The 'design' storm typically comprises a worst case wave height and water level, e.g. the 100 yr ARI water level and wave height (of 1 hour duration). However, there are disadvantages to this approach particularly for planning purposes, as follows.

- The 'design' storm conditions specified and subsequent calculation of 'storm bite' is not necessarily representative of the most eroded beach condition, which is of key interest to planners and managers in utilising areas behind the beach. As noted above, beach erosion is influenced by many variables, including wave height, wave direction, water levels, storm duration, sediment grain size, beach geomorphology, beach state prior to the storm, and series of closely spaced storms, which prevent the definition of ‘design’ storm criteria (and further, there is often insufficient data to parameterise these variables).

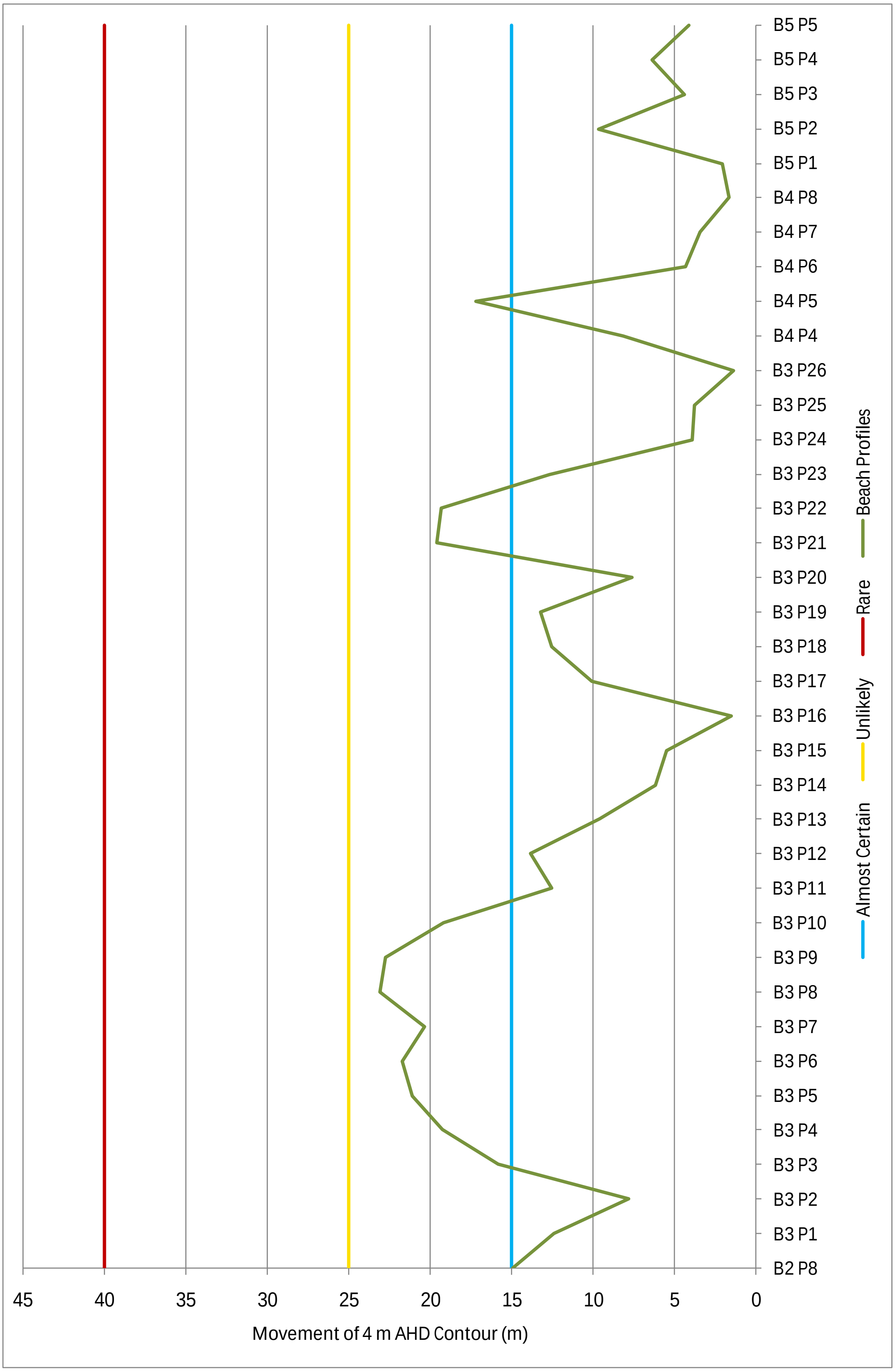
- Longshore transport differentials can be important to the extent of short term erosion both during the event and through their longer term influence on the nearshore beach profile and the demand for sand from the upper beach. An understanding of these processes is necessary in assessing erosion potential.
- There are limitations to the use of photogrammetric data to define the extent of erosion during a single storm event, or ‘storm demand’. The timing of consecutive dates of photogrammetry relative to the occurrence of storms is usually too great to reliably calculate the extent of sediment eroded from the upper beach and dune during a single storm. Similarly, where ‘design’ wave height and water level have been set, the photogrammetry data is not suitable for estimating erosion during the design conditions.
- There are inherent issues with the design storm approach for planning purposes, in that the ‘design’ storm does not account for the full extent of potential beach erosion or ‘storm demand’ that may occur under particular circumstances (e.g. consecutive storms over months, such has occurred in recent years).

The most definitive way of determining the actual effect of processes on the coastal zone is to physically measure the changes, using land survey and hydrographic survey where available.

For this study, rather than attempting to define the erosive capacity of one ‘design’ storm, the adopted approach was to use the historical data to determine the potential envelope of beach change that has occurred in the past, and so, can be expected to recur in the future. This approach accounts for the occurrence of rip currents and the beach rotation phenomenon, and extended periods of wave climate that promote erosion (or accretion).The approach is particularly suitable for planning purposes where the historical extent of erosion needs to be accounted for when deriving zones within which beach erosion may occur and be a hazard to back beach development and assets.

For each photogrammetric profile along the southern beaches, the most eroded (landward) position of the 4 m AHD contour was measured compared with the 2007 position, as shown in Figure 3-1. Data was processed relative to the 2007 position because this is the date for which aerial laser survey data is available and from which hazard extents will be measured and mapped. Beach erosion calculations from this date therefore account for the beach state upon which lines will be measured, to ensure the values adopted do not overestimate potential erosion extents. Profiles in areas known to be limited by bedrock (and therefore where dune contour movement is limited) were ignored to ensure the analysis gave estimates for potential sediment movement.

The subtraction between most eroded and 2007 dates was repeated for the profile volume data (m^3/m), and after subtraction, the volumetric data was converted to a horizontal movement (m) based upon the dune height of the profile. These calculations were used to cross-check the values derived from the dune contour position analysis.



Note: "B2 P8" nomenclature refers to the block (B) and profile (P) of the photogrammetric data. Profiles are drawn from the back beach to the shoreline. Profiles drawn along the same orientation are arranged in blocks.

The graph represents the maximum landward position of the 4 m contour measured at each photogrammetric profile, relative to the 2007 position. The graph is not a representation of a single profile changing over time.

Figure 3-1 Dune Position Change and Beach Erosion Likelihoods

In accordance with the risk-based approach being applied to this study, the qualitative likelihood of an extent of beach erosion has been considered. The calculations for dune contour movement have been variously used to define erosion extents of various likelihoods. This is outlined in detail in Section 3.3.3 for the immediate timeframe and in combination with shoreline recession for future time periods (2050, 2100).

Stockton Beach

For Stockton Beach, the short term and medium term erosion calculations provided by DHI (2006) have been used to define zones of beach erosion likelihood, as explained in Section 3.3.3.

Potential short term erosion for Stockton Beach was analysed by DHI (2006) using a dune erosion model and application of storm conditions from May & June 1974, as well as June 1999 that arrived from the E to ESE and so more directly impact the southern end of Stockton Beach. While the design storm approach can be problematic, Stockton Beach is experiencing long term recession, and therefore it is difficult to separate short term events from the long term recession signal in beach survey and photogrammetric data. The maximum erosion estimates adopted by DHI (2006) ranged from 5 m at Stockton Tourist Park to 17 m at Meredith Street, and 24.5 m at the LGA Boundary. DHI (2006) noted that additional erosion impacts in relation to the breakwater structure, as well as the occurrence of rip currents may add to the erosion estimates, and a further 5 m of erosion was added for the southern end of the beach due to this process.

Analysis was also undertaken to determine the impact of ongoing deepening of the nearshore off Stockton Beach upon potential erosion extents at the dune face. DHI (2006) estimated that a further deepening of the nearshore zone by 1 m would increase erosion rates by another 5%.

Using the photogrammetric data, DHI (2006) also estimated erosion relating to medium term wave climate variability, such as enhanced storminess or more easterly wave direction over a sustained period. From their analysis, DHI (2006) provided a best estimate of 20 m shoreline movement along the shoreline south of the Mitchell St seawall, and 18 m north of the seawall as the medium term erosion estimate.

Even after the *Pasha Bulker* storms of 2007 and long term recession at Stockton, Stockton Beach is currently quite accreted. The Mitchell Street seawall is relatively well covered with a sandy beach at its base, as is the dune and upper beach around Stockton SLSC. This reflects the addition of some 130,000 m^3 of sand into the surfzone in 2009, but also, the relatively calm wave conditions that have enabled this sand to be reworked onto the beach face, rather than directly transported northwards under unfavourable storm conditions. In part, this demonstrates the influence of wave climate variability even at locations known to be experiencing long term recession.

3.2.1.2 Discussion of Photogrammetric Data for the Southern Beaches

Historical photographs of the southern beaches of Newcastle following the 1974 storms provide an excellent graphical portrayal of the potential extent of erosion. The beaches were eroded back to the bedrock level at Newcastle and the northern end of Bar Beach to Cooks Hill SLSC (refer to Figure 4-11 and Figure 4-4 of Chapter 4). The potential landward extent of erosion in 1974 appears to have been limited to the roadway of John Parade and Scenic Drive at Bar Beach. These areas have limited bedrock extent and the back beach area is dune sand. In 1979, a seawall was constructed along

Merewether to Dixon Park roughly along the alignment of the 1974 erosion escarpment. The seawall now effectively limits the potential extent of erosion to the wall alignment.

Earlier photographs and newspaper reports indicate that such conditions had been experienced before, particularly around 1912-1914, the mid to late 40's and early 1950's (WBM, 2000). The southern beaches have recovered following these storm events, for example there is no evidence of the 1974 storms at present. Dune revegetation works since 1988 will have assisted in the growth of dunes, adding to the currently observed accreted state.

Volumetric changes at Merewether to Bar Beach for individual profiles comparing the most accreted with most eroded position of the past (typically the 1974 position) indicate an average volume change of 115 m^3/m of beach and maximum of 200 m^3/m. At Newcastle, average volume change between the most eroded and most accreted position is 90 m^3/m and a maximum of 190 m^3/m. These values are in good agreement with WBM (2000), which assessed a storm erosion potential of 200 m^3/m or to the limit of bedrock or seawalls, whichever occurs first. The smaller average volumes are a reflection of the erosion demand exceeding the available sand, That is, during major storm events, the available sand in the upper beach is less than that required to achieve a storm profile and effectively all of the sand is removed from the upper beach system.

3.3 Long Term Recession

Beaches can be subject to longer term trends of erosion or accretion associated with the gradual net removal or addition of sand to the active nearshore profile. Long term recession is frequently associated with a longshore sediment transport differential, where the supply of sediment into the system is less than the sediment losses from the system. Such differentials are typically related to prominent structural features of the shoreline, particularly man-made structures such as river entrance breakwaters that, when introduced to the coastline, interrupt the average longshore transport of sediment along an embayment(s). This interruption of transport can also result in long term accretion of the shoreline updrift of the structure.

Beaches experiencing long term recession over the past to present are characterised by a prominent back beach escarpment which moves landward over time following storm events (rather than recovering fully to the pre-storm position). The active beach system extends from the dune seaward to water depths of at least 10-15 metres. Longshore sand losses create an overall *net* depletion of the active profile, initially concentrated in the surfzone and subsequently redistributed across the entire active profile.

Recession of the shoreline is also expected to occur in response to sea level rise. In this case, there is an upward and landward translation of the entire beach and dune position as the shoreline reaches a new equilibrium with the new sea level position. This two-dimensional concept is demonstrated by the Bruun Rule, in Figure 3-2. As the sea level rises, wave, tide and wind processes are occurring at a higher position at the beach face, with the beach and dune evolving to a more landward position to return to equilibrium with the new sea level.

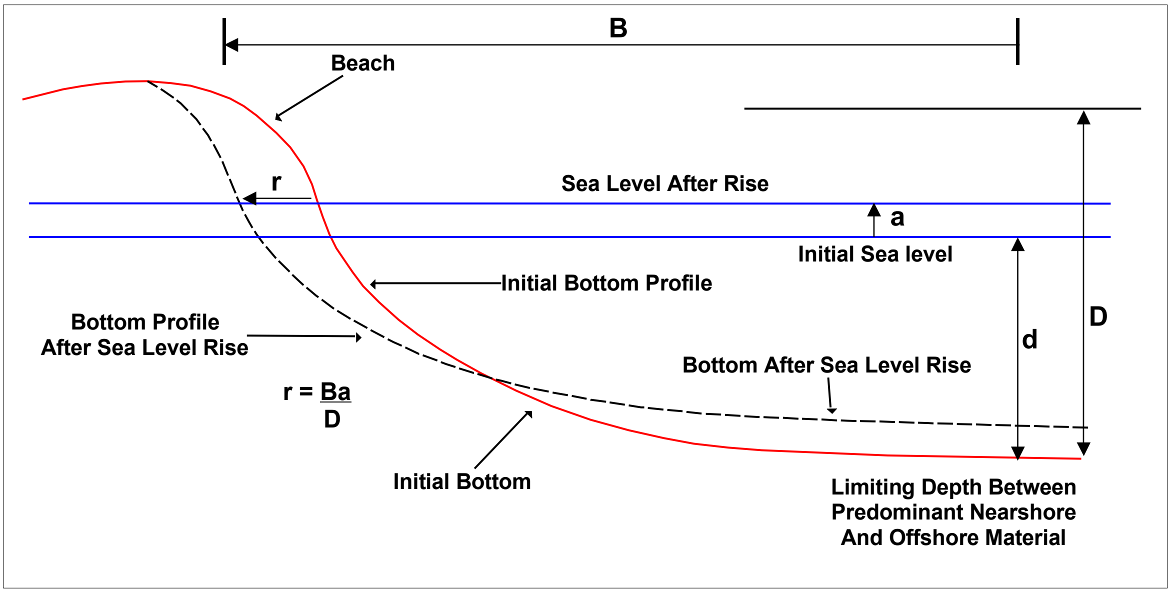


Figure 3-2 Bruun (1962) Concept of Recession due to Sea Level Rise

3.3.1 Historical Recession

Beaches experiencing recession are characterised by a prominent back beach escarpment which moves landward over time. The nearshore area has been depleted of sand progressively by longshore sand losses, hence the storm cut into the beach and dune will be unusually high as a result of the combined losses. In such a case, the beach will not recover to its former state.

Longshore sand losses create an overall net depletion of the active beach profile evident as retreat of the duneface, beach and nearshore profile down to a depth of about 5 metres, progressively reducing in extent across the nearshore zone seaward from the 5 metre depth out to zero at about 10- 15 metres. Thus, for a profile with dune height of 5 metres, only approximately one-third of the total volumetric sand loss occurs above mean sea level. This is an important factor in interpreting photogrammetric and survey data that only covers the upper beach/dune area.

Merewether to Bar Beach and Newcastle Beach are found to be stable on average over time. That is, there are natural fluctuations in beach condition over seasonal to decadal time scales relating to wave climate variability, however, the net change overall is roughly zero. This is demonstrated in the plots for the 4 m and 2 m AHD contour at the southern beaches (Figure 4-5 to Figure 4-19 of Chapter 4). The plots demonstrate the oscillating beach position over time in response to erosion (storms) and accretion phases, however, trends for long term progradation or recession are not evident at Merewether to Bar Beach and Newcastle Beach.

Shoreline retreat and advance at opposing ends of the beach associated with a shifting of sand from one end to the other of the individual beach units, typically called ‘beach rotation’, is a response to wave climate variability at inter annual to decadal timescales (refer Section 2.3.5). Such medium term cycles of beach change relating to wave climate variability are captured within the beach erosion hazard estimate in Section 3.2.1.1. WBM (2000) suggested that such variations may be of the order of 5 to 10 metres shift in beach position at opposing ends of a beach unit.

The photogrammetric data and contour plots for Nobbys Beach (Figure 4-17 to Figure 4-19 of Chapter 4) demonstrate a signature of accretion in the past, which has slowed and stabilised to the present position. Nobbys Beach is essentially formed from the accretion of littoral drift sediment against the southern breakwater. The construction of the Hunter River entrance breakwaters commenced with a land bridge out to Nobbys Island completed in 1846, then the extension of the southern breakwater from Nobbys Island completed in 1912. Historical paintings of Nobbys (Figure 4-15, Chapter 4) at the time of construction clearly illustrate waves breaking up onto the breakwater initially after its construction.

At some point, the accumulation of sediment both above and below MSL has filled the available space at Nobbys and sediment will have then began to be transported past the southern breakwater. DHI (2006) model results indicate that bypassing of the southern breakwater is occurring, although much of this sediment is likely to accumulate within the navigation channel before being removed by periodic maintenance dredging works.

Sand has also accumulated in Horseshoe Beach adjacent to the southern breakwater within the entrance channel, behind Nobbys Beach, as evident from historical photographs. Much of this sand is likely to have been blown over the southern breakwater and transported by wave/current action into Horseshoe Beach. DHI (2006) have also suggested a bypassing mechanism whereby sediment passes the southern breakwater and is transported along the entrance channel and eventually onto Horseshoe Beach.

Detailed studies of coastal processes at Stockton Beach conducted by DHI (2006) indicated that the beach is experiencing ongoing recession due to the cessation of littoral drift into the compartment from the southern beaches past the entrance breakwaters. DHI (2006) results found that the southern end of Stockton Beach is in fact stable, while the northern end from the end of the Mitchell St seawall is receding. While bypassing of the southern breakwater is very likely to be occurring, the sediment is either removed through entrance maintenance dredging, or is in water depths too great for significant wave driven currents to form to transport the sediment back onto Stockton Beach (DHI, 2006).

The northern breakwater acts to shadow the southern end of Stockton Beach, from south easterly swells, and a complex pattern of transport is generated towards the south and then captured against the northern breakwater (DHI, 2006). Both the WBM (2000) and Umwelt (2002) studies also identified a slight accretionary trend at the southern end of Stockton Beach.

A nodal point where the transport changes direction is reported at the northern end of the seawall. Here, the transport changes from a net southerly drift to a net northerly drift, starting at low rates (~ 4,500 m^3/yr) and increasing to the regional rate of 30,000 m^3/yr at the sewage treatment ponds along Stockton Beach. However, because this section of coast is no longer supplied by littoral drift from the south, the shoreline is continuing to erode. DHI (2006, 2011) used model results to determine best estimates of shoreline retreat along Stockton Beach, which are reproduced in Table 3-3. These rates were found to be in good agreement with historical recession rates of 1 – 1.3 m/yr along this stretch of beach (DHI, 2006).

Historical long term recession rates must be incorporated into the assessment of long term recession in the future in combination with recession due to sea level rise, as described in Section 3.3.3.

Table 3-3 Best Estimate Ongoing Recession Rate at Stockton Beach from DHI (2011)

Location	Best Estimate (m/year)
Stockton Tourist Park	0
Stockton Surf Club	0
South Seawall / Hereford Street	0
Child Care Centre	-1.0
Meredith Street	-1.24
Sewage Ponds	-1.3
Fort Stockton	-1.05
Fort Wallace / Stockton Centre	-0.8
Council Boundary	-0.8

3.3.2 Future Long Term Recession

3.3.2.1 The Shoreline Evolution Model

BMT WBM's Dean Patterson has developed a Shoreline Evolution Model as part of his PhD studies. The model is the first of its kind able to predict shoreline evolution in response to large scale changes in sea level (e.g. 0 to 100 m) and changes in shoreline structure, e.g. due to the installation of harbour breakwaters that may affect longshore sediment transport. The model includes regional longshore transport, onshore transport, and internally calculates both longshore and cross shore sediment transport driven by wave time series. The model includes the effects of coastal structures such as headlands, reefs, groynes and seawalls where they are present in the natural coastline. This model is particularly effective at a regional scale as it is able to model multiple beach units along long coastlines. A schematic of the two-dimensional model domain is given in Figure 3-3 and Figure 3-4 (Patterson, 2010).

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

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

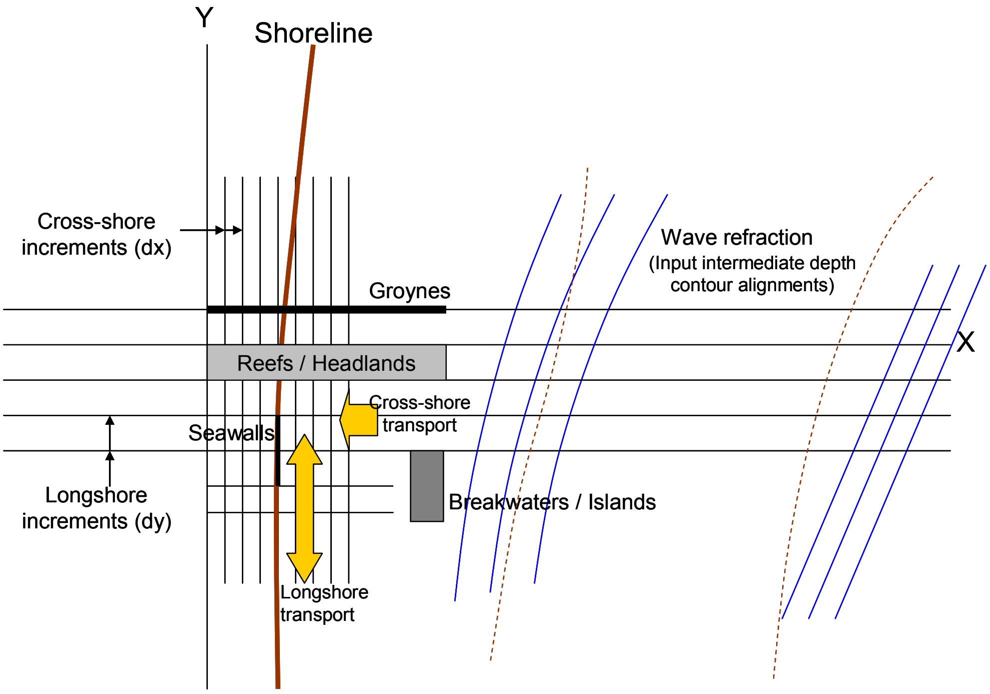


Figure 3-3 Plan View Schematisation of SEM Domain (Patterson, 2010)

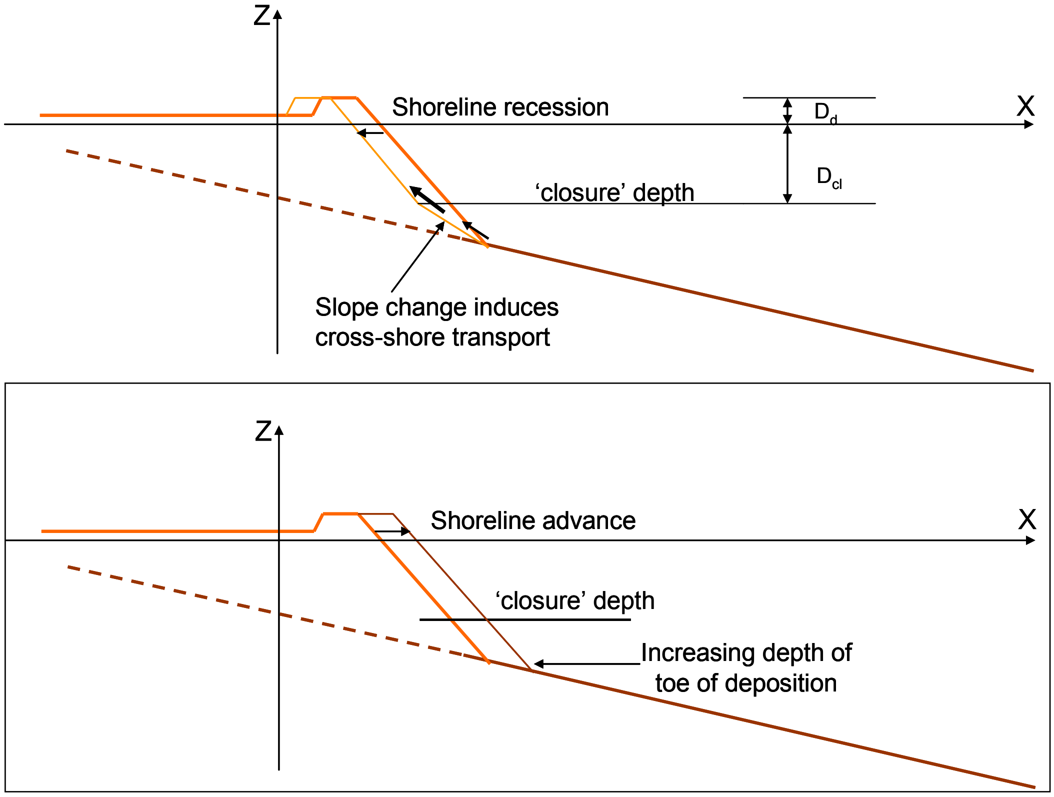


Figure 3-4 Cross shore schematisation of upper profile change for receding (top) and advancing (bottom) shoreline (Patterson, 2010)

3.3.2.2 Application of the Shoreline Evolution Model to Newcastle

The assessment of shoreline response to sea level rise for the southern beaches of Newcastle utilised this modelling tool, with verification against available historical data. The model is capable of accounting for ongoing accretion at Nobbys Beach in estimating response to sea level rise. The model was also applied to Stockton Beach, north of the harbour breakwaters, to provide sensitivity testing, as a form of verification of the recession estimates compiled for Stockton by DHI (2006, 2011) (noting that the results of DHI were used to define hazards in this report). The following procedure and model simulations were conducted.

- Two separate models were created, extending from south of Burwood Beach to the southern breakwater; and from the southern breakwater to the northern end of Stockton Beach. The shoreline was separated for modelling to enable better representation of the known impact on longshore transport into Stockton Beach.
- Modelling of a 'base' case shoreline without sea level rise, but including all natural features such as headlands, emerging reefs, offshore reefs acting as breakwaters, and bedrock horizons further landward of the shoreline where known to occur from historical and topographic data. The 'base' case was simulated for a period of 5000 years (at zero sea level rise) to stabilise the regional longshore transport into, along and out of the Newcastle coastline. This is done to verify the model's applicability, prior to introducing sea level rise and other modifications to the shoreline.
- A verification process was undertaken to compare model results with the existing shoreline, to determine if results were consistent with observed shoreline and reefs in the nearshore zone. This included consideration of the shoreline north and south of the harbour entrance evident in historical accounts prior to harbour breakwater construction and dredging. Modification to the structural representation of the shoreline within the model was conducted as required, then the 'base' case remodelled, until good consistency between the modelled shoreline and the actual shoreline was achieved.
- Modelling of a 'breakwater' case, simulated for 250 years from 1890 to 2140 including the southern and northern breakwaters. Changes to the shoreline from 1890 to 2140 were again verified against historical data (e.g. accretion and erosion rates at Nobbys and Stockton respectively) and the present shoreline position.
- Modelling of a 'sea level rise' case, simulated for 200 years from 1910 to 2110, and including the Newcastle Breakwaters. As per the sea level rise benchmarks adopted for this study, sea level rise was kept constant until the year 1990, after which a rise of 0.06 m to 2010 occurs, then a linear rise to 0.4 m by 2050 and then to 0.9 m by 2100 was simulated. Accounting of the sea level rise between 1990 and 2010 of 0.06 m is prescribed by DECCW (2010).
- Modelling of a second theoretical 'sea level rise' case, to investigate the impact of a 0.5 m greater than predicted rise in sea level by 2100. Again, the simulation was run for 200 years from 1910 to 2110, with a sea level rise of 0.06 m to 2010, then rising linearly to 0.7 m by 2050 then 1.4 m by 2100. This theoretical sea level rise case enables consideration of a faster than predicted rise in sea level, under a 'rare' or worst case scenario.
- Modelling of a 'wave climate change with sea level rise' case, simulated for 200 years from 1910 to 2110, using the sea level rise benchmarks adopted for this study and an average 5° more easterly wave climate. The case included the Newcastle Breakwaters. Sea level rise was kept

constant until the year 1990, after which a rise of 0.06 m to 2010 occurs, then a linear rise to 0.4 m by 2050 and then to 0.9 m by 2100 was simulated.

- The model results were adopted within the ‘likely’, ‘unlikely’ and ‘rare’ cases, with rounding to account for uncertainty, as explained in Section 3.3.3.

3.3.2.3 Discussion of Future Recession Response

Southern Beaches

Results from the shoreline evolution model for the southern beaches replicate the current shoreline position at Nobbys Beach by 2010. The model results suggest accretion at Nobbys Beach progressed swiftly to 1950, then slows by 2010, with some sediment bypassing of the southern breakwater commencing by this time. This is consistent with historical observations and photogrammetric data for accretion on Nobbys Beach and recent findings by DHI (2006) regarding bypassing of the southern breakwater. Beyond 2010 *without sea level rise*, the model results suggest little if any further accretion of Nobbys Beach will occur (refer Figure 3-5).

The outcomes of the shoreline modelling for the southern beaches without sea level rise are consistent with the existing shoreline evident at present and historical changes, particularly at Nobbys Beach, as described by the photogrammetry for the beaches. Thus, there is confidence in the use of modelling results to predict the response of the southern beaches to projected sea level rise and the harbour impact (i.e., for Nobbys Beach) in the future.

For the southern beaches of Newcastle except Nobbys Beach, the model results with sea level rise indicate that the structure of the coastline produces perturbations in the extent of recession along the embayments, unlike a typical Bruun Rule approach (refer Figure 3-6). This relates to the interaction between headlands, reefs and combined longshore and cross shore sediment transport that is not accounted for in the Bruun Rule (1962).

The modelling results demonstrate that the extent of recession due to sea level rise is greater at the southern end of the beach, while the northern end of the beach experiences minimal recession. The south easterly wave climate generates a northerly longshore sediment transport. As sea level rises, headlands act to interrupt sediment transport from beach to beach due to the increased water depths at the headland. The northerly transport within an embayment acts to supply sediment to the northern end of the beach, mitigating recession to some degree. However, the southern end of the beach is the source of this supply and, without supply from beaches to the south into the compartment, there is enhanced recession at the southern ends of beaches due to sea level rise.

At Nobbys Beach, the supply of sediment into the embayment initially limits recession due to sea level rise, such that recession is not evident by 2050. However as sea level rise progresses, transport into the embayment is reduced due to the bounding headlands and rock reefs to the south of the beach. Longshore transport from the south to the northern end of the embayment progresses, and as such the southern end of the beach experiences enhanced recession by 2100 (refer Figure 3-7).

The model results suggest Newcastle Beach may experience enhanced recession due to sea level rise compared with nearby beaches. The occurrence of bedrock at shallow depth at the shoreline limits sediment supply in the surfzone, and thus recession of the overlying back beach barrier is enhanced. The extents of recession at Newcastle Beach assume that, while there is bedrock at depth, there may not be bedrock at height within the central portion of the beach that would limit recession. If bedrock is present at height, this would limit the recession estimates given by the model.

As a sensitivity test within a worst case or ‘rare’ scenario, the possible impact of a shift in mean wave direction to 5° more easterly on average to 2100 was investigated with the model. For both the southern beaches and Stockton, the results suggest that up to 20 m variation in the shoreline position (accretion or erosion) may occur by 2100 under this scenario, as shown in Figure 3-8. A more easterly wave climate in combination with sea level rise would tend to enhance recession at the northern end of the beach and reduce recession at the southern end of the beach, compared with sea level rise under the existing wave climate. This is because sediment transport rates to the north are reduced. For example, at the southern end of Nobbys Beach, the more easterly wave direction reduces sediment transport rates to the north, reducing the potential extent of erosion.

Given that current climate change projections are inconclusive regarding wave direction and storminess (wave height), it is unknown whether such impacts may manifest. At the current time, the existing variability of the wave climate may produce similar shifts in wave direction, and this has been incorporated into the approach used to define the beach erosion hazard (refer Section 3.2.1.1).

Stockton Beach

It is important to note that modelling of Stockton Beach conducted in this study was performed as a verification exercise, and was not intended to replace the assessments documented by DHI (2006, 2011) for erosion and recession at Stockton Beach. The DHI (2006, 2011) findings have been used to define the hazard zones provided in this study.

The shoreline evolution model for Stockton was not able to fully replicate the extent of erosion observed historically along this shoreline. However, the model did replicate the general trend of accretion (or stability) at the far southern end of Stockton in lee of the breakwaters and recession commencing immediately to the north before decreasing to zero beyond the CoN boundary. It was necessary to use separate models for the southern beaches and Stockton Beach in order to correctly apply the complete cessation of littoral transport into Stockton since the harbour entrance construction. That is, typically the coastal system would equilibrate to the impact of the breakwaters and bypassing would recommence (which would occur in the model). However, this has not been able to occur at Stockton due to deepening of the Port entrance for ships and ongoing maintenance dredging. As such, the construction of the breakwaters has resulted in complete cessation of sediment supply from the southern beaches into Stockton Beach.

The shoreline evolution model for Stockton Beach was extended for the full length of Stockton Bight to Birubi Point. The “warm up” simulations (run for 5000 years) produced interesting results for this embayment that provide confidence in the model’s performance. Model results showed a decreasing longshore transport rate along the embayment, while accretion of the shoreline, particularly at the central portion of the embayment occurred. This is in fact sensible, as longshore sediment transport is highest when the angle between wave approach and the shoreline is at or near 45°. Along Stockton Bight, the shoreline faces increasingly more towards the south, and thus the angle between waves and the shoreline approaches 90°. The longshore transport rate should therefore be expected to decrease. However, the central and northern part of the embayment continues to accrete because longshore transport into the central and northern sections is higher than the rate of transport through the section. It is likely that the orientation of Birubi Point compared with the orientation of Fort

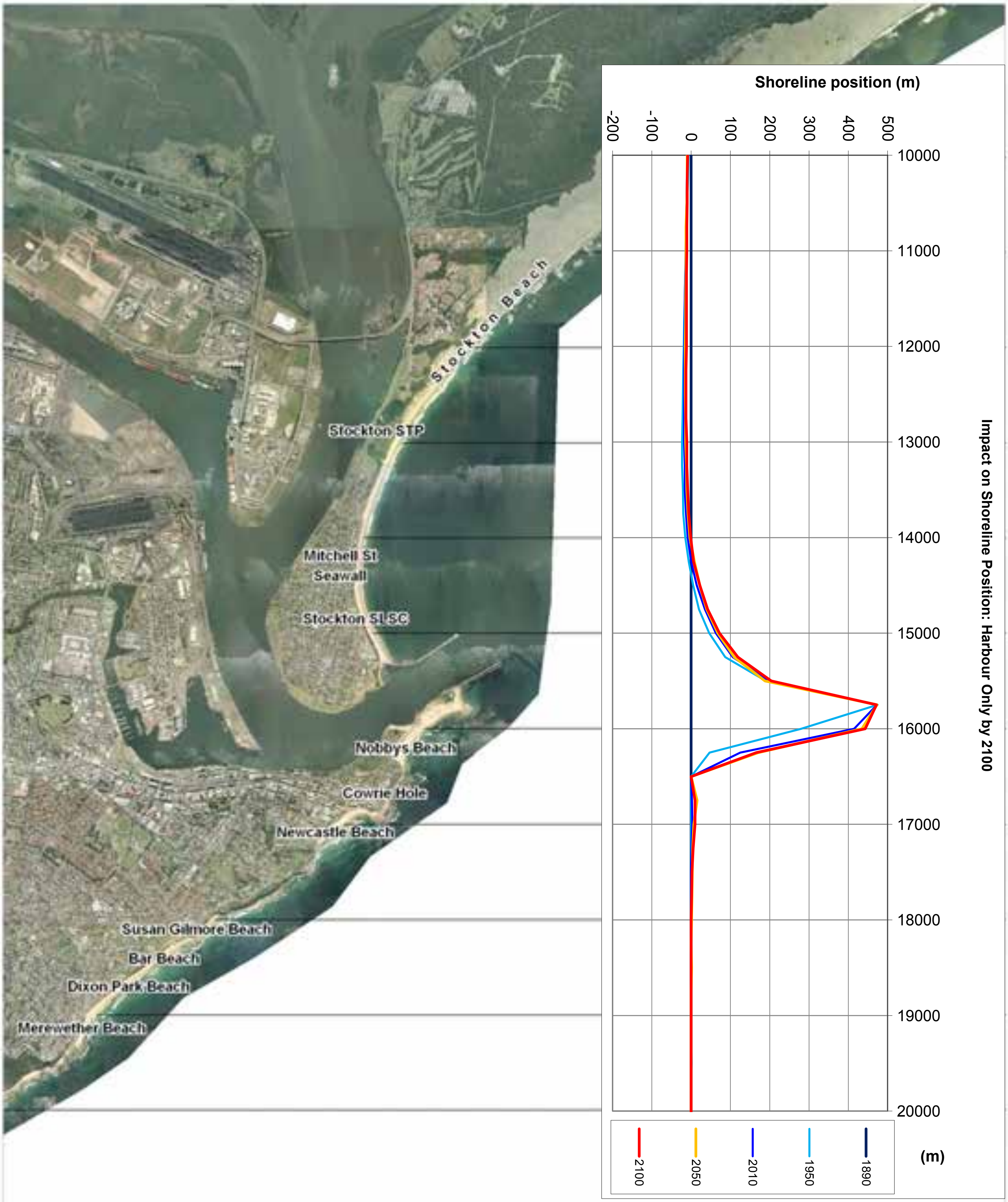
Scratchley has formed an embayment that faces increasingly towards the south, contributing to the processes that have resulted in accretion in this embayment through successive sea level transgressions over the last 500,000 years.

While the shoreline evolution model for Stockton did not fully replicate erosion extents due to harbour construction, the results for sea level rise scenarios are still considered useful in understanding potential impacts at this embayment.

Long sandy shorelines can reasonably be expected to respond in the manner described by the Bruun Rule (1962), because the impact of headlands and reefs on longshore sediment transport is not present. The model results for sea level rise impacts on Stockton Beach demonstrate this response, with a uniform recession extent along the entire embayment at 2050 and 2100. At the southern end of Stockton where the harbour structure exists, the uniformity of the recession extent appears to relate to the cessation of longshore sediment transport by the harbour breakwaters that occurred prior to sea level rise. The longshore sediment supply that may have been affected by sea level rise has already been completely interrupted by the harbour. In this case, sea level rise cannot further reduce longshore transport past the harbour breakwaters. Thus, the Bruun Rule two dimensional concept applies, as the impact of structures on longshore sediment transport has already occurred at Stockton Beach, prior to sea level rise.

As described above for the southern beaches, a shift in mean wave direction to 5° more easterly tends to enhance recession around the central portion of Stockton Beach and reduce recession in lee of the harbour breakwaters, as longshore transport directions shift in response to the more easterly wave approach, altering transport into and out of the central portion of Stockton Bight.

The rate of recession indicated by the shoreline evolution model for Stockton Beach is slightly lower at around 45-50 m compared with 68 m estimated by DHI (2011) by 2100 with 0.9 m sea level rise. The lower rates of recession relate to the slope of the nearshore zone adopted in the model, and which may differ from estimates used by DHI. The nearshore zone and continental shelf of Newcastle's southern beaches and Stockton is relatively steep compared with other parts of NSW. The shoreline evolution model utilises the slope of the nearshore zone as measured from bathymetric data, which for Newcastle includes both marine LiDAR (2008) and hydrosurvey (2007) out to 30 to 40 m water depth. It is thus expected to be very reliable. The rates of recession due to sea level rise across Newcastle are thus likely to be lower than elsewhere in NSW, in relation to the steeper nearshore slope (that is, as per the Bruun Rule concept, it is the slope of the active profile that governs the future shoreline position, see Figure 3-2, such that shallower slopes result in greater recession than steeper shoreline slopes).



Title:

Modelled Change in Shoreline Position due to Harbour Construction Only

Drawing: 3-5

Rev: A

N

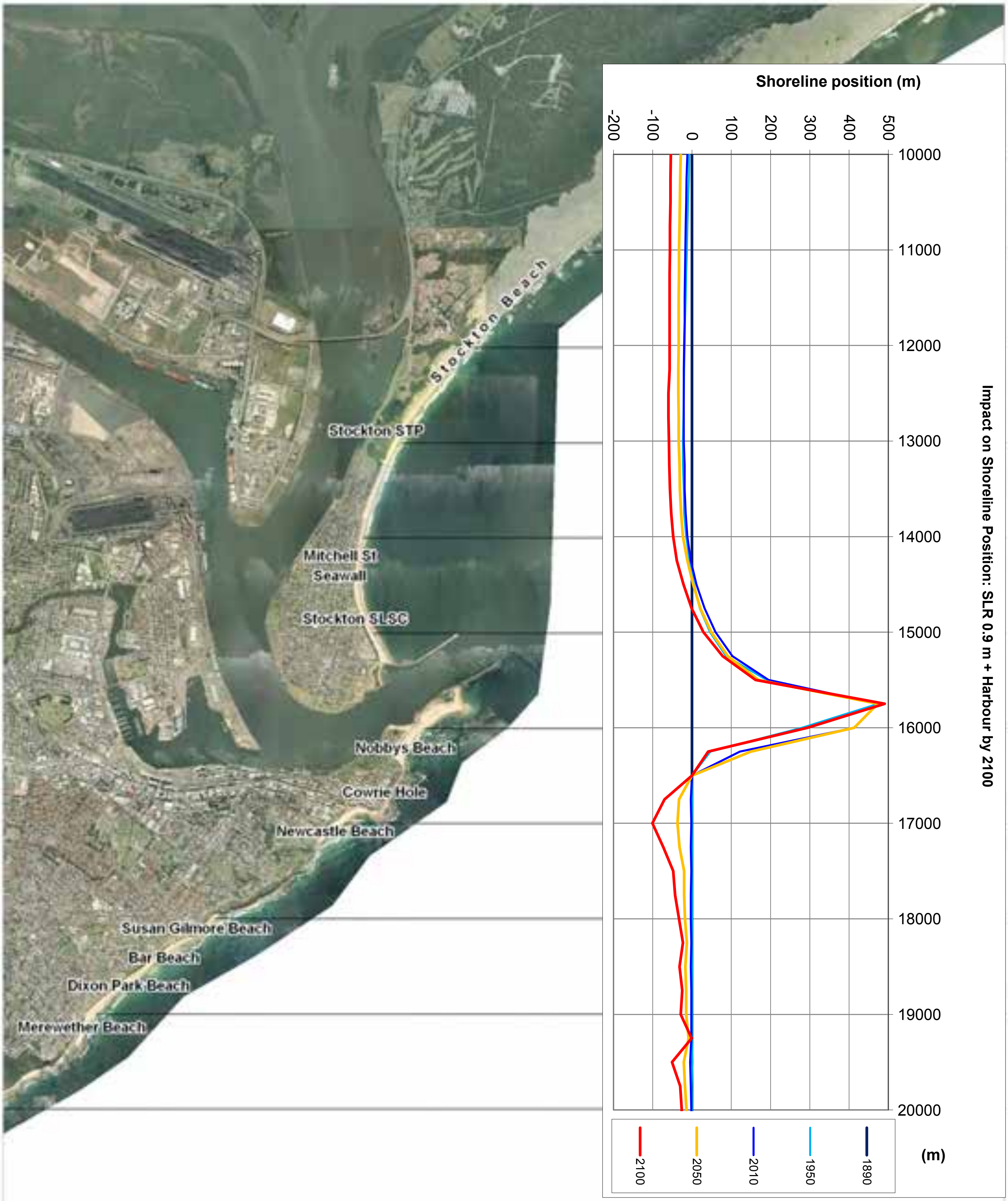
0 1 2km

Approx. Scale

BMT WBM

www.wbmpl.com.au

Filepath : K:\N2051_NewcastleCoastalHazards&Management\MI\Workspaces\DRG_019_111107_Modelled_Harbour_Construction.WOR



Title:

Modelled Change in Shoreline Position due to Harbour Construction and 0.9m Sea Level Rise

Drawing: 3-6

Rev: A

N

0 1 2km

Approx. Scale

BMT WBM

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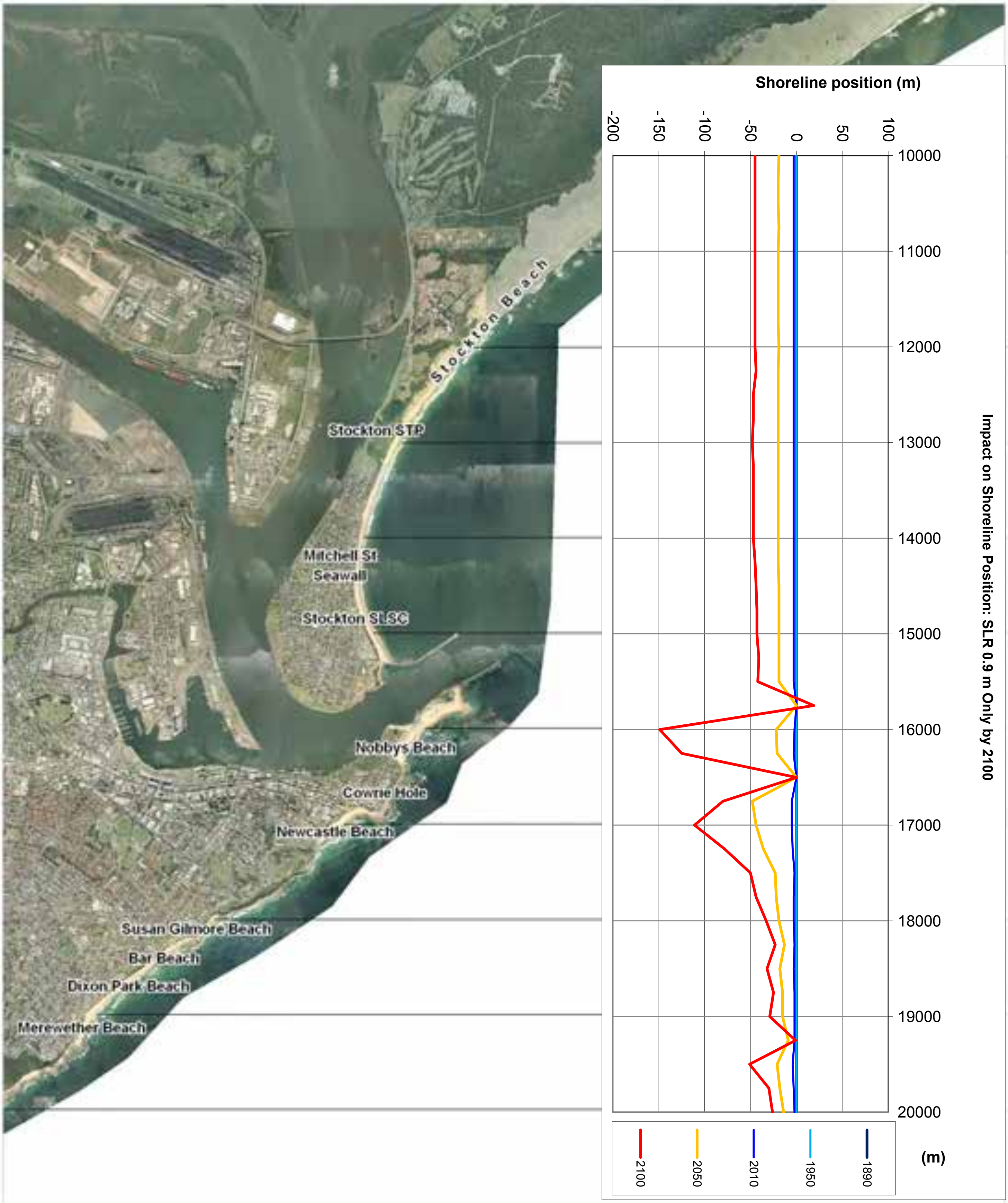
Filepath : K:\N2051_NewcastleCoastalHazards&Management\MI\Workspaces\DRG_020_111107_Modelled_Harbour_Construction_SLR.WOR



Title:

Modelled Change in Shoreline Position due to 0.9m Sea Level Rise Only

Drawing: 3-7

Rev: A

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

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0 1 2km

Approx. Scale

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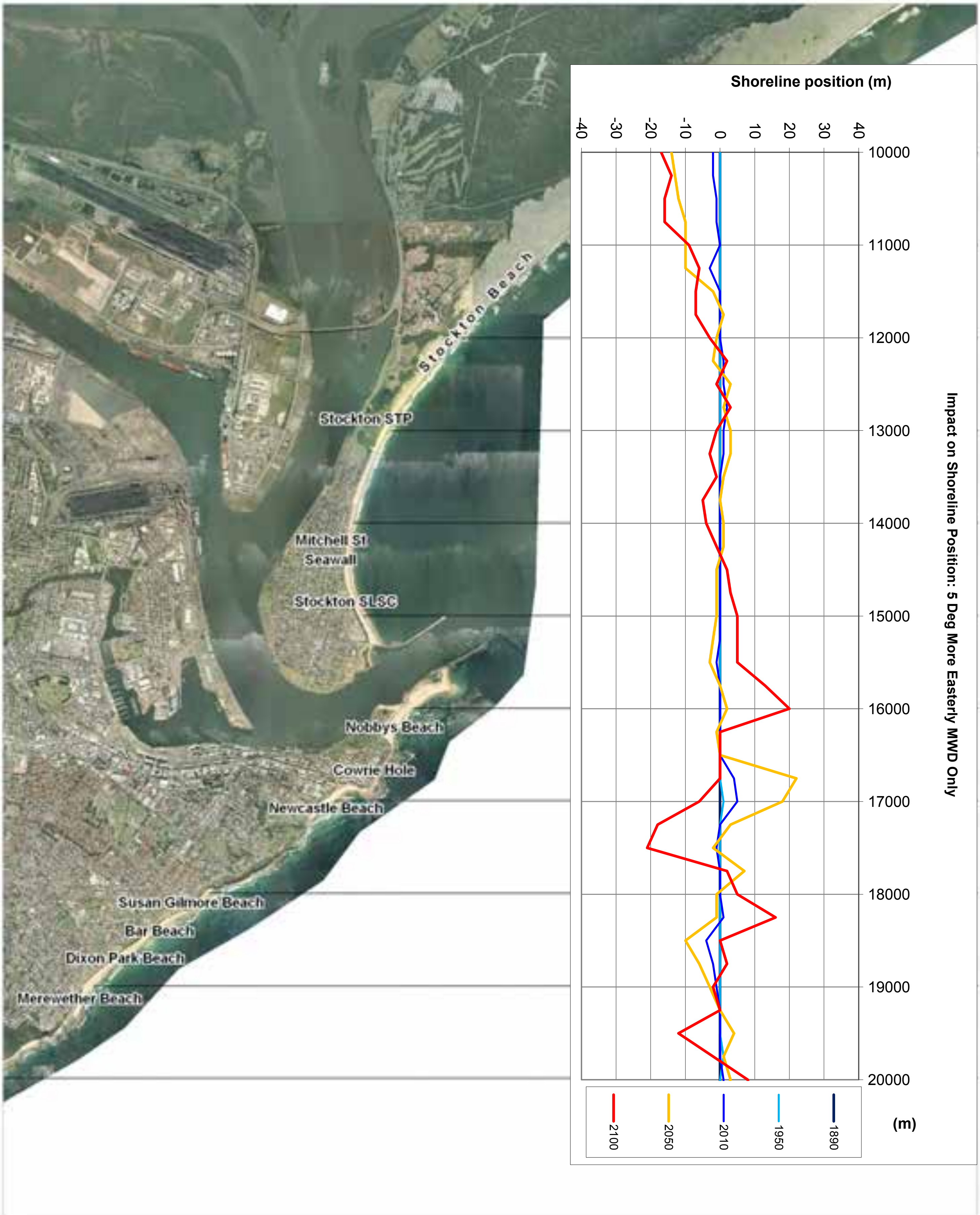

Title:

Modelled Change in Shoreline Position due to 5 Degree Easterly Shift in Mean Wave Direction Only

Drawing: **3-8**

Rev: **A**

N

0 1 2km

Approx. Scale

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www.wbmpl.com.au

Filepath : K:\N2051_NewcastleCoastalHazards&Management\MI\Workspaces\DRG_022_111107_Modelled_Wave_Direction.WOR

3.3.3 Hazard Definition for Erosion and Recession

The methodology adopted for qualitatively assigning likelihoods to beach erosion extents; and combining future long term recession and beach erosion hazard extents to derive the 2050 and 2100 hazard likelihood zones is summarised in Table 3-4 and explained below.

The approach to defining the extents of potential beach erosion was to consider the most eroded beach and dune position given in the photogrammetric data, rather than attempt to define the erosive capacity of one 'design' storm. This is particularly suitable for planning purposes where the historical extent of erosion needs to be accounted for when deriving zones within which beach erosion may occur and be a hazard to back beach development and assets.

The 'immediate' beach erosion hazard extents are carried forward to 2050 and 2100 as there is currently no reliable or reasonable data that would justify assuming a different extent of erosion in the future. Indeed, events of the past have indicated that erosion is constrained by bedrock along key sections of the shoreline of the southern beaches. Combining the long term recession due to sea level rise (as derived from model results) at 2050 and 2100 with the immediate beach erosion hazards ensures that both wave climate variability and long term permanent change are captured within the hazard mapping.

The risk approach also enabled definition of erosion setbacks both with and without the seawalls and promenades. Informal structures (promenades, seawalls not built to engineering standards) were assumed to provide limited protection; engineered seawalls (i.e. Merewether, Stockton, Macquarie Pier) that can be assumed to provide a high level of protection; and failure of the properly engineered structures was investigated as a worst case or rare scenario. Bedrock at suitable height, where it was confidently known to occur was assumed to constrain erosion in all cases.

An important consideration regarding the southern beaches of Newcastle are the constraints on future beach position and alignment caused by underlying bedrock and existing seawalls. That is, while the hazard lines may not demonstrate significant impact to back beach development, there will be significant impact to beach amenity, such as at Newcastle Beach and locations along Merewether Beach. The beach state of the 1970s that comprised a lack of sand on the beach face is likely to become far more common, such that by 2100, there are likely to be areas of beach that predominantly comprise exposed rock or seawalls. This outcome may not be evident immediately based on the position of the hazard lines, but is a very important consideration when determining management actions. At locations such as Bar Beach where a section of sandy back beach substrate can enable the beach to recede (and so, a sandy beach to be retained), preservation of beach amenity through retreat may far outweigh the values of assets behind (e.g., Memorial Drive, Empire Park and the Skate Park). The same issues regarding beach amenity will also need to be taken into consideration for the beach between Merewether and Dixon Park when considering options to retain (and thus maintain) or remove the existing seawall at this location.

Issues surrounding beach amenity will be investigated as part of the Newcastle Coastal Zone Management Study, however, it is important to recognise this aspect of the recession hazard, particularly as the exposure of underlying bedrock (or other constraints) may not be immediately apparent from hazard maps alone.

The erosion hazard extents for the immediate timeframe for the southern beaches are provided in Table 3-5, and the erosion hazard extents for the immediate, 2050 and 2100 timeframes for Stockton Beach are provided in Table 3-6, Table 3-7, and Table 3-8 respectively. Detailed description of the derivation of the hazard likelihood zones is provided in the following sections.

Table 3-4 Erosion and Recession Hazard Likelihood Zones

Probability	Immediate	2050	2100
Almost Certain	'average' beach erosion[1], to limit of all structures	Immediate 'average' beach erosion + harbour impacts (Stockton), to limit of all structures	Immediate 'average' beach erosion + harbour impacts (Stockton), to limit of all structures
Likely	Not Mapped [2]	Immediate 'average' beach erosion + 0.4 m SLR recession + harbour impacts (Nobbys, Stockton), to limit of all structures	Immediate 'average' beach erosion + 0.9 m SLR recession + harbour impacts (Nobbys, Stockton), to limit of all structures
Unlikely	'maximum' beach erosion[3], to limit of engineered seawalls and known bedrock	Immediate 'maximum' beach erosion + 0.4 m SLR recession + harbour impacts (Nobbys, Stockton), to limit of engineered seawalls and known bedrock	Immediate 'maximum' beach erosion + 0.9 m SLR recession + harbour impacts (Nobbys, Stockton), to limit of engineered seawalls and known bedrock
Rare	'extreme' beach erosion [4] and engineered seawalls fail or are removed / absent	**Worst Case of either**: Immediate 'maximum' beach erosion + 0.7 m SLR recession **OR** Immediate 'extreme' beach erosion + 0.4 m SLR recession **OR** Immediate 'maximum' beach erosion + structural impacts + 0.4 m SLR + 5 ° more easterly wave climate **AND** Engineered seawalls fail or are removed / absent	**Worst Case of either**: Immediate 'maximum' beach erosion + 1.4 m SLR recession **OR** Immediate 'extreme' beach erosion + 0.9 m SLR recession **OR** Immediate 'maximum' beach erosion + structural impacts + 0.9 m SLR + 5 ° more easterly wave climate **AND** Engineered seawalls fail or are removed / absent

[1] The average of the most eroded position for all photogrammetric profiles, see Table 3-5.
[2] Not Mapped due to inadequate data to differentiate likelihoods between 'almost certain' and 'unlikely'.
[3] The maximum of the most eroded position measured for any and all photogrammetric profiles, see Table 3-5 and Figure 3-1.
[4] Assumed to be the addition of the 'almost certain' and 'maximum' erosion extents, in lieu of better data.

Table 3-5 Immediate Erosion Hazard Likelihoods, Southern Beaches

Immediate Beach Erosion Hazard*	**Almost Certain**	**Unlikely**	**Rare**
Newcastle Beach Merewether – Bar Beach Nobbys Beach	15 m	25 m or limit of bedrock /seawall	40 m or limit of bedrock

** Erosion extents are measured from the 4 m AHD contour in 2007.*

Table 3-6 Immediate Erosion Hazard Likelihoods, Stockton Beach (adapted from DHI, 2006)

Location	**Almost certain (m)**	**Unlikely (m)**	**Rare (m)**
North of Breakwater	10	30	40
Stockton Tourist Park	10	30	40
Stockton Surf Club	17	37	54
Hereford Street	8.6	28.6	37.2
Child Care Centre	12.1	30.1	42.2
Meredith Street	17	35	52
Sewage Treatment Ponds	17.9	35.9	53.8
Fort Stockton	21.9	39.9	61.8
Fort Wallace	22.4	40.4	62.8
Stockton Centre	23.8	41.8	65.6
CoN Boundary	24.5	42.5	67

** Erosion extents are measured from the 4 m AHD contour in 2007.*

Table 3-7 2050 Erosion & Recession Hazard Likelihoods, Stockton Beach

Location	**Almost certain (m)**	**Likely (m)**	**Unlikely (m)**	**Rare (m)**
North of Breakwater	10.0	38.2	58.2	68.2
Stockton Tourist Park	10.0	38.2	58.2	68.2
Stockton Surf Club	17.0	45.2	65.2	82.2
Hereford Street	8.6	36.8	56.8	65.4
Child Care Centre	56.1	84.3	102.3	114.4
Meredith Street	71.6	99.7	117.7	134.7
Sewage Treatment Ponds	75.1	103.3	121.3	139.2
Fort Stockton	68.1	96.3	114.3	136.2
Fort Wallace	57.6	85.8	103.8	126.2
Stockton Centre	59.0	87.2	105.2	129.0
CoN Boundary	59.7	87.9	105.9	130.4

** Erosion extents are measured from the 4 m AHD contour in 2007.*

Table 3-8 2100 Erosion & Recession Hazard Likelihoods, Stockton Beach

Location	Almost certain (m)	Likely (m)	Unlikely (m)	Rare (m)
North of Breakwater	10.0	78.2	98.2	108.2
Stockton Tourist Park	10.0	78.2	98.2	108.2
Stockton Surf Club	17.0	85.2	105.2	122.2
Hereford Street	8.6	76.8	96.8	105.4
Child Care Centre	106.1	174.3	192.3	204.4
Meredith Street	133.6	201.7	219.7	236.7
Sewage Treatment Ponds	140.1	208.3	226.3	244.2
Fort Stockton	120.6	188.8	206.8	228.7
Fort Wallace	97.6	165.8	183.8	206.2
Stockton Centre	99.0	167.2	185.2	209.0
CoN Boundary	99.7	167.9	185.9	210.4

** Erosion extents are measured from the 4 m AHD contour in 2007.*

3.3.3.1 Almost Certain Hazard

The average of the most eroded landward distances measured for all of the photogrammetric profiles (in m movement of the 4 m AHD contour) was adopted as the 'almost certain' beach erosion extent, as given in Table 3-5. Given that the erosion extents are derived from historical data, it is very likely that the conditions which produced such extents in the past will occur again in the future.

As shown in Table 3-5, equal setbacks for beach erosion have been applied across the southern beaches. While there are small differences between the adjacent beaches, they are equally exposed to ocean conditions, so it is reasonable to assume the same beach erosion extents could potentially occur at any of the southern beaches. Indeed, the analysis of beach erosion at Nobbys Beach is obscured by the long term accretion occurring on this beach, requiring application of results from adjacent beaches.

For Stockton Beach, DHI (2006) provided a short term erosion estimate as separate to the erosion that could be expected due to medium term wave climate variability. The short term erosion values provided by DHI (2006) is considered appropriate as the 'almost certain' immediate erosion as these values would be expected to occur over the short term. The values as adopted from DHI (2006), includes additional effects associated with the breakwater at the southern end of the beach, are listed for various locations along Stockton Beach in Table 3-6.

The 'almost certain' hazard for 2050 and 2100 includes:

- 'almost certain' beach erosion determined for the immediate timeframe,
- Historical long term recession (i.e. at Stockton Beach); and
- no allowance for recession due to sea level rise.

The advice given by the NSW Government (DP, 2010) is that the seaward boundary of coastal risk planning areas should be based on the immediate hazard line, which is effectively a scenario without sea level rise. This is equivalent to the 'almost certain' hazard line. While many would argue that sea level rise is very likely to occur, the 'almost certain' zone provides a planning benchmark irrespective of uncertainty associated with future climate change.

For the southern beaches, the 2050 and 2100 'almost certain' line is consistent across all timeframes as there is no evidence of recession at these beaches to date. Nobbys Beach has exhibited a trend of long term accretion, although this has slowed in recent years as the beach compartment has filled to a point where bypassing of the southern breakwater is occurring. It is therefore conservative to assume Nobbys Beach is also stable (i.e. no long term accretion or recession), for deriving the future 'almost certain' hazard extent.

Ongoing recession has been determined at rates of 1 to 1.3 m/year along Stockton Beach north of the Mitchell St seawall relating to the cessation of littoral transport across the harbour entrance (DHI, 2006). The 'almost certain' hazard at Stockton Beach therefore combines the 'almost certain' erosion estimates with the continuing recession rates detailed by DHI (2006) in Table 3-3 , forecasted to 2050 and 2100, as given in Table 3-7 and Table 3-8.

The 'almost certain' hazard extents at all timeframes have been assumed to be constrained by both seawalls of suitable engineering design and walls and promenades along the back beach area. While most of the walls and promenades along Newcastle's beaches have not been designed as formal coastal engineering structures, most of them have survived infrequent exposure to wave action in the past.

Similarly, bedrock is known to occur (exposed in photographs) at the back of the beach at Newcastle and the ends of Merewether and Bar Beaches. The existence of bedrock at sufficient height (i.e. above AHD) constrains the extent of potential erosion and this has also been accounted for in mapping erosion setbacks.

The 'almost certain' hazard zones for Newcastle's beaches for the immediate, 2050 and 2100 timeframes are shown Drawings A1 to C9 in the Drawings Section at the end of this report.

3.3.3.2 Likely Hazards

A 'likely' hazard extent was not provided for the immediate timeframe, as there is insufficient historical beach data to determine a reliable estimate.

The 'likely' hazard zone for 2050 and 2100 is the addition of:

- future long term recession due to predicted sea level rise of 0.4 m and 0.9 m by 2050 and 2100;
- 'almost certain' beach erosion (as determined for the immediate timeframe); and
- historical recession or accretion, where relevant (i.e. Stockton Beach, Nobbys Beach).

The 'likely' hazard probability zone aims to clearly implicate the process of sea level rise (and its subsequent shoreline impacts) as a likely phenomenon. The addition of 'almost certain' erosion extents is additionally very certain. The 'likely' hazard zone does not provide for an enhanced erosion event in combination with sea level rise. The 'likely' hazard extent may provide a suitable planning benchmark where it is required to clearly identify recession due to sea level rise in combination with the beach erosion extent that will almost certainly occur over a typical 20-30 year planning period.

The recession due to sea level rise applied in the hazard lines for the southern beaches is adopted from the shoreline evolution model results (with rounding to the nearest 5 m to account for the considerable uncertainty in both sea level rise impacts and all modelling techniques). The hazard extents in metres have not been tabulated, as the values vary along the shoreline in response to the combination of waves, sea level rise and sediment transport (as discussed in detail in Section 3.3.2.3). Instead, the reader is referred to the ‘likely’ hazard zones for Newcastle’s beaches for the immediate, 2050 and 2100 timeframes shown Drawings B1 to C9 in the Drawings Section at the end of this report.

For Stockton Beach, DHI (2011) estimated 28 m by 2050 and 68 m by 2100 additional recession along Stockton Beach due to sea level rise, using a Bruun Rule approach with sea level rise projections of 0.4 m and 0.9 m by 2050 and 2100 respectively. These values have been added to derive the ‘likely’ recession hazard at 2050 and 2100 in Table 3-7 and Table 3-8.

3.3.3.3 Unlikely Hazards

The maximum of the most eroded landward distances measured for all of the photogrammetric profiles (in m movement of the 4 m AHD contour) was adopted as the ‘unlikely’ beach erosion extent, as given in Table 3-5. Figure 3-1 depicts the maximum extent of erosion recorded at each of the photogrammetric profiles.

The maximum erosion value was adopted across the entire length of beach, to encompass the possibility that rips (and their associated erosion scarps) may form at any location along a beach, and that waves may arrive from any direction to impact any area of the beach. Indeed, as shown in Table 3-5, equal setbacks for beach erosion have been applied across all of the southern beaches, as they are equally exposed to ocean conditions. For Nobbys Beach, the analysis of beach erosion obscured by the long term accretion that has occurred, requiring application of results from adjacent beaches.

The approach of adopting a maximum extent of beach erosion encompasses both short term events and medium term variability (as captured by the photogrammetric data). For Stockton Beach then, the ‘unlikely’ immediate erosion hazard has been adopted as the addition of short term erosion and medium term variability as defined by DHI (2006), as listed in Table 3-6. Discussion of the short term and medium term erosion analyses conducted by DHI was provided in Section 3.2.1.1.

The ‘unlikely’ hazard for 2050 and 2100 was the addition of:

- future long term recession due to predicted sea level rise of 0.4 m and 0.9 m by 2050 and 2100 respectively; and
- ‘unlikely’ beach erosion (as determined for the immediate timeframe outline d above); and
- Historical long term recession (i.e. at Stockton Beach relating to the Newcastle Breakwaters).

While future sea level rise is probable, the combination of both recession due to sea level rise and the ‘unlikely’ beach erosion setback provides a conservative estimate of erosion impact that should be considered ‘unlikely’. In particular, the mapping of the ‘unlikely’ hazard lines at any timeframe should not be considered to the be position of the entire shoreline at that timeframe, but rather, the position that a section of the shoreline may be eroded to, under the combination of potential conditions (i.e. a series of storms of varying wave direction, beach rotation, shoreline recession, rip currents etc.).

Except for the Merewether (John Parade); Stockton (Mitchell Street) and Nobbys (Macquarie Pier and the Cowrie Hole) seawalls, the remaining promenades and walled structures backing Newcastle's beaches are not designed to coastal engineering standards. The 'unlikely' hazard has been drawn assuming that the remaining structures of inadequate coastal design fail completely (or are otherwise removed). The informal structures have survived infrequent exposure to wave action in the past, however with sea level rise, such impacts would be expected to become more frequent in the future. Therefore, the 'unlikely' erosion hazard accounts for partial or complete failure of these structures. Properly engineered structures have been assumed to remain intact in estimating the 'unlikely' erosion extent.

The recession due to sea level rise applied in the hazard lines for the southern beaches is adopted from the shoreline evolution model results (with rounding to the nearest 5 m to account for the considerable uncertainty in both sea level rise impacts and all modelling techniques). The hazard extents in metres have not been tabulated, as the values vary along the shoreline in response to the combination of waves, sea level rise and sediment transport (as discussed in detail in Section 3.3.2.3).

The 'unlikely' hazard zones for Newcastle's beaches for immediate, 2050 and 2100 timeframes are shown in Drawings A1 to C9 in the Drawings Section of this report.

The shoreline evolution model provides improved prediction of shoreline response to sea level rise as it incorporates natural structural constraints such as headlands and reefs and man-made structural features such as the seawalls at Merewether and the harbour breakwaters at Nobbys. The natural and built structures interact with sediment transport as sea level rises, resulting in alongshore variation in response to sea level rise. The model thus provides improved prediction of sea level rise impacts that cannot be accounted for using the uniform two dimensional Bruun Rule approach.

For Stockton Beach, the 'unlikely' recession hazard accounts for the long term recession estimate as well as recession due to sea level rise, plus the 'unlikely' extent of beach erosion (as in Table 3-6). DHI (2011) estimated 28 m by 2050 and 68 m by 2100 additional recession along Stockton Beach due to sea level rise, using a Bruun Rule approach with sea level rise projections of 0.4 m and 0.9 m by 2050 and 2100 respectively. These values have been added to derive the 'unlikely' recession hazard at 2050 and 2100 in Table 3-7 and Table 3-8. The 'unlikely' hazard at 2050 and 2100 is equivalent to the 'best estimate' provided by DHI (2011) for these timeframes.

The shoreline evolution model results for Stockton Beach provide a sensitivity test for the results of DHI (2011) for recession due to sea level rise, as DHI utilised the standard Bruun Rule approach. The model results indicate that the recession estimates given by DHI (2011) using a Bruun Rule approach are appropriate for Stockton Beach as follows.

- The shoreline evolution model results suggested a slightly lower extent of recession due to sea level rise of 20 m by 2050 and 45-50 m by 2100 with projected sea level rise, compared with recession of 28 m and 68 m recommended by DHI (2011) for 2050 and 2100 respectively. It is likely that the slope of the nearshore zone applied in the shoreline evolution model is slightly steeper than that applied in DHI (2011). It is unclear if DHI (2011) utilised measured nearshore data or commonly applied equations (e.g. Hallermeier) to estimate the nearshore slope, which they adopted as 0.0125. As the approach taken by DHI (2011) in applying the Bruun Rule was valid, it is considered reasonable to adopt the values they specified.

- The shoreline evolution model results demonstrated that Stockton Beach is likely to respond to sea level rise in a uniform manner, as would be projected using the Bruun Rule concept. Unlike the southern beaches of Newcastle which are highly structured with headlands, reefs and seawalls, Stockton Beach is a long, continuous sandy embayment with only one notable structure, being the Newcastle Breakwaters. Because there has already been a complete cessation of littoral transport past the breakwaters into Stockton Beach, there is no additional impact on longshore transport past this structure due to sea level rise. Without a change in longshore supply into Stockton Beach with sea level rise, recession due to sea level rise follows a two-dimensional cross-shore impact, equivalent to the Bruun Rule.

3.3.3.4 Rare Hazards

There are limitations in the extent, coverage and accuracy of historical data that must be acknowledged and managed. It is reasonable to assume that not all beach erosion events have been recorded at every beach because there are relatively few dates of photogrammetric and other data. The ‘likelihood’ approach enables estimates of beach erosion that have not been captured in the historical record, where the beach is not constrained by bedrock.

A ‘rare’ erosion hazard has been derived to provide further information for both landuse planners and the general public about extreme coastal processes that may be worse or more extensive than has been recorded in the data or observed historically. This approach also encapsulates the potential for an increase in wave height or shift in wave direction for storms due to climate change, for which predictions are presently unclear (see Section 2.8). The average beach erosion extent was added to the maximum erosion extent to form the ‘rare’ beach erosion scenario as in Table and Figure 3-1. This is an arbitrary calculation made in lieu of more comprehensive data, to represents more extensive storms than have been captured in the data.

In accordance with the risk approach applied at the southern beaches, the ‘rare’ immediate erosion extent forms the addition of the ‘almost certain’ and ‘unlikely’ values, and this is given as the recommended ‘rare’ erosion extent for the immediate timeframe at the various locations on Stockton Beach in Table 3-6.

In keeping with the risk approach, it is important to consider the potential impact to back beach development along Merewether to Dixon Park beach assuming the seawall is removed or fails; and to the Nobbys area assuming the breakwater comprising Macquarie Pier is exposed and fails. This provides information for CoN and community as to the protection offered by the seawall, or alternatively, the beach position should planned retreat be applied. In this case, the ‘rare’ erosion hazard extent has been applied assuming the seawalls are not present.

The ‘rare’ hazard probability zone was derived as the maximum extent of recession due to <u>either</u>:

- future long term recession due to a higher than predicted sea rise of 1.4 m by 2100 plus the immediate ‘unlikely’ (maximum) beach erosion extent; or
- future long term recession due to projected sea level rise of 0.9 m by 2100 plus the ‘rare’ beach erosion extent; or

- future long term recession due to projected sea rise of 0.9 m and a shift in mean wave direction to 5° more easterly by 2100 (2.5 ° by 2050), plus the immediate 'unlikely' (maximum) beach erosion extent.

As with the risk approach applied for the immediate 'rare' hazard, the erosion estimates were applied assuming the existing seawalls of suitable engineering design are removed or fail (i.e., the seawalls at Merewether to Dixon Park and Mitchell St, and Macquarie Pier backing Nobbys Beach). Again, this provides greater clarity as to the protective capacity of the walls as well as the potential shoreline position should a planned retreat management approach be applied.

For Stockton Beach, the 'rare' hazard estimates additionally incorporated the long term recession given for the various locations by DHI (2006). The recommended 'rare' hazard extent for Stockton following the rationale above plus ongoing recession for 2050 and 2100 are given in Table 3-7 and Table 3-8 below.

From a risk perspective, it is important to consider the impact of a higher rise in sea level than that currently projected. As such, the impact of an additional 0.5 m sea level rise by 2100 (equating to 0.7 m rise in sea level by 2050 and 1.4 m by 2100) was modelled (refer Section 3.3.2.2). This also accounts for sea level rise occurring faster than predicted.

At the present time the existing wave climate remains predominantly south-easterly in direction, even during phases of enhanced storminess and/or varied average wave direction. Projections are currently inconclusive regarding any likely shifts in wave direction or height due to climate change, and range within the existing variability of the wave climate (refer Section 2.8). Indeed, other modelling studies have demonstrated that sea level rise is far more dominant in generating shoreline recession compared with the changes to wave climate predicted by McInnes *et al.* (2007). From a risk perspective, however, it is important to consider a permanent climate change induced shift to a more easterly wave direction. A sustained shift to a more easterly wave climate would modify longshore sediment transport rates and so, affect how recession in response to sea level rise may manifest upon the shoreline. In lieu of more reliable projections, a shift in the mean wave direction to 5 ° more easterly by 2100 was investigated as a 'rare' scenario using the Shoreline Evolution Model. .

The 'rare' hazard zones for Newcastle Beaches for immediate, 2050 and 2100 timeframes are shown in Drawings A1 to C9 in the Drawings Section of this report.

Results from the Shoreline Evolution Model suggest a 5° more easterly mean wave climate in combination with sea level rise (of 0.9 m AHD by 2100) may increase or decrease recession by up to 20 m in some locations. For most shorelines in Newcastle, however, the model suggested a shoreline shift of 1 -2 m more seaward at the southern end and 1 -2 m more landward at the northern end of the beach. This response is far less significant than the effects of greater than predicted sea level rise (to 1.4 m by 2100) or the addition of 'rare' beach erosion extents. While the shoreline is sensitive to shifts in wave climate, this is not a dominant factor in the potential shoreline recession due to climate change.

For the 'rare' hazard likelihood zones, it was typically found that a higher than projected sea level rise caused the greatest potential for recession, and thus this was the main scenario adopted as defining the 'rare' hazard.

3.3.3.5 Assumptions and Limitations

For all scenarios, the results of the shoreline modelling have been used with caution. Model results have not been adopted exactly, as this implies a level of certainty and accuracy that is not appropriate. The shoreline model is considered to be a tool, used to assist the derivation of recession hazard zones. The values have typically been rounded to reflect the uncertainty involved in using model results. The model results for sea level rise have been applied at locations along the beach and adjusted to reflect the actual response of the beach evident in the historical data.

All hazard lines are measured from the 4 m AHD contour taken from the 2007 aerial laser survey data. To ensure that beach erosion calculations accounted for the beach state in 2007 , photogrammetric data was processed relative to the 2007 position. It is noted that the DHI (2006, 2011) were drawn from a designated 'reference line' surveyed by CoN, which is said to be located approximately between 3 and 4 m AHD. The use of the 4 m AHD position in 2007 is considered to be similar to the original reference line, such that the differences in the exact position of the hazard lines would be negligible (and indiscernible in the hazard maps).

The values adopted for the beach erosion probabilities on the southern beaches were rounded from the average and maximum values (to the nearest 5 m). This aims to clearly recognise the uncertainty and assumptions used in determining the estimates. That is, using exact numbers implies a level of accuracy in the assessment that is not consistent with the reliability of photogrammetric data coverage and quality.

Each of the beach erosion probabilities ('almost certain', 'unlikely' and 'rare') have been adopted across the length of the beach embayment and /or to the limit of bedrock where it is known to occur. Newcastle's beaches are highly exposed to the offshore wave climate, thus all locations along the beaches have the potential to be affected depending upon the wave height, direction and water level of storms. This approach also accounts for longshore transport variations as sediment bypassing events, and the potential formation of rip currents at any location along the beach, as well as adjacent to headlands.

In mapping hazard extents, areas of known or "assumed" bedrock and suitably designed seawalls that would constrain erosion and recession extents have been identified as best as possible, and utilised in modelling and mapping as follows:

- Areas of high elevation (12 m AHD) were assumed to be bedrock where bedrock was exposed in aerial photography, historical photography or field observations (e.g. above headlands, rock outcrops on the beach);
- Seawalls known to be of appropriate coastal engineering design (through provided engineering design drawings or similar, e.g. at Merewether Beach) were also identified for inclusion as a constraint in modelling and mapping scenarios;
- Where the hazard lines intersect with the assumed bedrock zones (e.g. headlands), the hazard lines have been clipped to the boundary of the assumed bedrock, as beach erosion or shoreline recession processes will not significantly recede bedrock within the 100 year planning timeframe;
- Likewise, the hazard lines have been clipped to the identified seawalls, except for the 'rare' scenario hazard where it is assumed all structural protections fail or have been removed; and

- Where the areas of high elevation were suggested in historical or aerial photographs to be sediment (e.g. between The Cliff carpark and the northern end of Bar Beach), or where information regarding the depth to bedrock is unknown (e.g. the central portion of Newcastle Beach) , it has been assumed that these areas may be affected by beach erosion and shoreline recession hazards.

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

Where protection by seawalls exists, their stability under the design wave conditions is a consideration affecting the potential extent of erosion. The seawall condition assessment is important to identify the protection offered by the walls in their current condition, for the immediate to 2100 timeframe. Presumably, this condition assessment will influence a suitable maintenance program to be implemented over time, within the subsequent Newcastle Coastal Zone Management Study.

3.3.4 Dune Stability and Reduced Foundation Capacity

Immediately following storm erosion events on sand beaches, a near vertical erosion escarpment of substantial height can be left in the dune or beach ridge. A zone of reduced foundation capacity can exist on the landward side of such dune escarpments. This can impact on structures founded on sand within this landward zone, as the sand escarpments pose a hazard of sudden collapse. Following such storm events, inspection of sand escarpments should be undertaken to assess the need for restricting public access and the impact on structures.

Over time the near vertical erosion scarp will slump through a zone of slope adjustment to the natural angle of repose of the sand (approx. 1.5 Horizontal to 1.0 Vertical). Nielsen *et al.* (1992) outlined the zones within and behind the erosion escarpment on a dune face that are expected to slump or become unstable following a storm erosion event (see Figure 3-9), namely:

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

Amongst other factors, the width of the zone of reduced foundation capacity behind the crest of an erosion escarpment is dependent upon the angle of repose of the dune sand and the height of the dune above mean sea level (refer Figure 3-9). Table 3-9 provides an indicative guide to the width of the zone of reduced foundation capacity that is measured landward from the crest (or top) of the erosion escarpment for various dune heights.

The allowances in Table 3-9 are provided for indicative planning purposes only, and have not been included in hazard definition maps due to the extensive presence of bedrock particularly along the southern beaches that will modify the extent of both the zone of slope adjustment and zone of reduced foundation capacity, as explained below. The allowances in Table 3-9 assume a dunal system made up entirely of homogeneous sands (with an assumed angle of repose of 35 degrees) and makes no allowance for the presence of more structurally competent stratums, for example indurated sands and bedrock that exist within the study area. Nor do these allowances take account of water table gradients that may be present within the dunal system.

Expert geotechnical engineering assessment is recommended to establish the structural stability of foundations located (or likely to be located) within the zone of reduced bearing capacity on a case by case basis. For indicative planning purposes only, both zones can be added to the immediate, 2050 and 2100 year beach erosion hazard (i.e. taken to occur in a landward direction from the edge of the beach erosion extent). Climate change is not expected to modify soil stability, and thus the hazard extents remain relevant at the 2050 and 2100 year planning period.

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

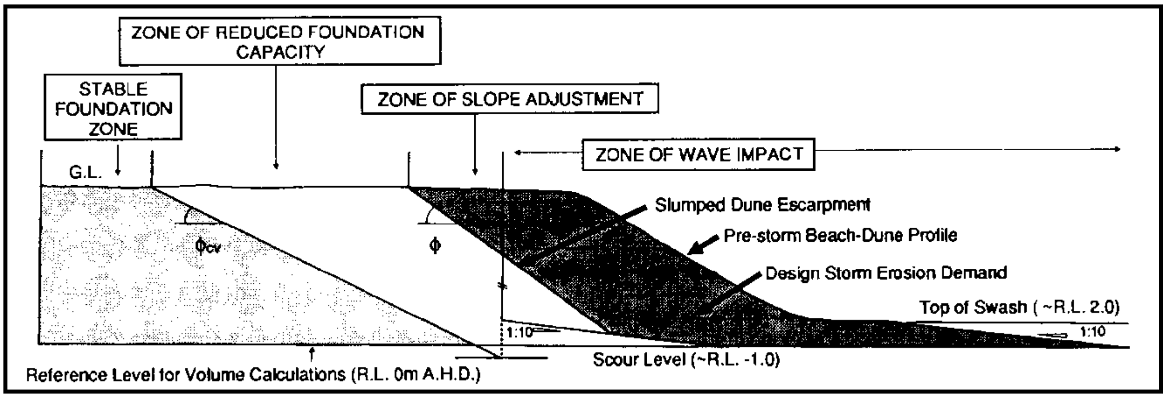

Figure 3-9 Design Profile and zones of instability for Storm Erosion (From Nielsen *et al.*, (1992)

Table 3-9 Indicative Widths of Zone of Reduced Foundation Capacity

RL of Dunal System (m AHD) [1]	Zone of Slope Adjustment (m) [2]	Zone of Reduced Foundation Capacity (m) [3]	Total for both Zones (m) [2]
4	1.4	9.3	10.7
5	2.1	10.7	12.9
6	2.9	12.2	15.0
7	3.6	13.6	17.1
8	4.3	15.0	19.3
9	5.0	16.4	21.4
10	5.7	17.9	23.6

1 *Assumed that surface of dunal system is approximately level (see Figure 3-9).*
2 *Distance measured landward from the top of the erosion escarpment (see Figure 3-9).*
3 *Distance measured landward from the top of the erosion escarpment following slope readjustment (see Figure 3-9).*

3.4 Coastal Inundation and Wave Overtopping

The coastal inundation hazard comprises the overtopping of coastal barriers, such as dunes and seawalls, by oceanic waters and waves, and the inundation of estuary foreshores, lake and lagoon foreshores (closed or open) and low lying back beach areas hydraulically connected to the ocean due to elevated ocean water levels during a storm. Sea level rise will also contribute to elevated ocean water levels in the future, and must be considered in any assessment of inundation hazard.

Coastal inundation is characterised by two processes:

- a "quasi-static" component, which includes the effects of elevated water levels due to astronomical tide, inverted barometric setup and wind setup (storm surge) and wave setup; and
- a "dynamic" component, which includes the effects of wave run-up and wave overtopping caused by the direct impact of waves on coastal dunes, cliffs and structures.

The components comprising elevated water levels (i.e., astronomical tide, inverted barometric setup and wind setup (storm surge), wave setup and wave run-up) were detailed in Section 2.4.

In determining the hazards associated with elevated ocean water levels, there are two key aspects to consider.

- The wave run-up water level may not present a hazard unless the run-up is overtopping coastal barriers at a rate or volume that would cause a significant impact to pedestrians or land and assets behind. For this reason, a wave overtopping rate was considered in addition to a discrete wave run up level.
- Elevated ocean levels may cause inundation by either directly inundating low lying assets, such as low lying promenades, by propagating into estuary and creek entrances or by acting as a tailwater level precluding outflow from the creeks and so elevating the water levels within the rivers / creeks /lagoons. Storm surge may have a duration of many hours to days while the peak astronomical tide level occurs with a low rate of rise and fall for a half hour either side of the peak of the high tide. Thus, elevated water levels may exist at or near their peak levels for a maximum duration of about 1 hour around the high tide. For this study, the coastal creeks, lagoons and the Hunter River entrance are specifically excluded from assessment. Notwithstanding, it is considered that any future coastal inundation of Glenrock Lagoon and Murdering Gully (outside of the study area) is unlikely to pose a significant risk to land or assets, including impacts to Hunter Water's Burwood Sewage Treatment Plant, while the Hunter River (and its tributaries) have been the subject of a detailed Flood Study and Floodplain Risk Management Plan assessment that has included elevated ocean water levels (including sea level rise) in the calculation of potential flood levels.

3.4.1 Elevated Ocean Levels

Potential elevated water levels *excluding* wave run-up (i.e. the "quasi-static" component of coastal inundation) provide the starting point for analysis of coastal inundation impacts. The design ocean water levels given previously in Table 2-2 include all of the "quasi-static" components except wave set up, namely: barometric pressure set up and wind set up (storm surge); and astronomical tide plus tidal anomalies.

Wave set up may be estimated at 15% of the offshore significant wave height. The wave set up values during 1 in 20 year and 1 in 100 year 6 hour storms are included in the design ocean water levels given in Table 3-10. As discussed previously, wave heights associated with the 6 hour storm duration are used as this is reasonably likely to coincide with a high tide.

Future elevated water levels for 2050 and 2100 (as given in Table 3-11 and Table 3-12) include the projected increase in sea level, as well as projected (minor) increases in storm surge (from McInnes *et al*, 2007 as detailed Section 2.8).

In considering risk, it is important to consider factors that may induce greater water levels than are predicted. Components that may contribute to higher water levels that have been considered in this study under an extreme or 'rare' scenario are as follows:

- A higher than projected sea level rise, which has been adopted as 1.4 m by 2100, representing 0.5 m greater than the predicted (0.9 m) sea level rise (and an equivalent 0.7 m rise by 2050);
- Storm surge levels greater than predicted from the historical data, as a result of extreme climatic conditions (e.g. a tropical cyclone tracking further southwards or more intense east coast low, see below). Given the relatively short record of measured weather data in Australia, there is the potential for storms of greater intensity to occur under the existing climate; and
- Increase in storm wave heights by 10% by 2100 due to climate change (as determined in Section 2.8), which would increase wave set up and therefore still water levels at the shoreline.

These components are included in predicted ocean water levels in Table 3-11 and Table 3-12.

In deriving a sensible estimate for potential extreme climate conditions that would produce greater than predicted storm surge, cyclone storm surge values from south-east Queensland were reviewed. For sites in southern Queensland (Rainbow Beach, Scarborough, Surfers Paradise) that have a similar highest astronomical tide to Newcastle (1.06 – 1.24 m AHD) the difference in surge level between a 1 in 100 year event and a 1 in 1000 year event was 0.2 to 0.3 m. Thus, to represent the possibility of an extreme climatic condition, an additional 0.2 m above the 1 in 100 year water level has been adopted, as given in Table 3-10 to Table 3-12.

The adopted likelihood of various water levels and resultant coastal inundation is discussed in Section 3.4.4.

Table 3-10 Immediate Elevated Ocean Levels (exc. Wave Run-Up)

Recurrence Interval (years)	Still Water Level (Fort Denison) (m AHD)	6 hr duration wave height (m)	Wave Set up (m) (15% of wave ht)	Extreme Water Levels (m AHD)	Adopted Likelihood
20	1.38	7.6	1.14	**2.5**	**Almost Certain**
100	1.44	8.7	1.31	**2.7**	**Unlikely**
100 (extreme storm conditions)	1.64	8.7	1.31	**2.9**	**Rare**

Table 3-11 2050 Elevated Ocean Levels (exc. Wave Run-Up)

Recurrence Interval (years)	Still Water Level (Fort Denison) (m AHD)	Predicted increase in storm surge due to CC (m AHD)	6 hr duration wave height (m)	Wave Set up (m) (15% of wave ht)	Sea Level Rise	Extreme Water Levels (m AHD)	Adopted Likelihood
100	1.44	0.01	8.7	1.31	0.34	**3.1**	**Unlikely**
100 (extreme storm conditions)	1.64	0.01	`	1.37	0.34	**3.4**	**Rare**
100 (extra SLR)	1.44		8.7	1.31	0.64	**3.4**	**Rare**

Table 3-12 2100 Elevated Ocean Levels (exc. Wave Run-Up)

Recurrence Interval (years)	Still Water Level (Fort Denison) (m AHD)	Predicted increase in storm surge due to CC (m AHD)	6 hr duration wave height (m)	Wave Set up (m) (15% of wave ht)	Sea Level Rise	Extreme Water Levels (m AHD)	Adopted Likelihood
100	1.44	0.03	8.7	1.31	0.84	**3.6**	**Unlikely**
100 (extreme storm conditions)	1.64	0.03	9.6	1.44	0.84	**3.9**	**Not used**
100 (extra SLR)	1.44		8.7	1.31	1.34	**4.1**	**Rare**

3.4.2 Wave Run-up and Overtopping Assessment

3.4.2.1 Methodology

The "dynamic" component of coastal inundation results from the combination of waves at the shoreline on top of any "quasi static" elevated ocean water level. This is generally referred to as wave run-up. Where the crest height of a shoreline structure or dune is less than the wave run-up level, waves will overtop the shoreline and cause inundation.

For a coastal protection structure, wave run-up and subsequent overtopping depends, amongst other things, on:

- hydraulic parameters such as: ocean water level, wave height, wave period, wave direction, water depth; and
- structural parameters such as: the seawall roughness and porosity (random rock armour or smooth concrete surface); slope (sloping, composite, vertical, stepped); and crest levels.

This study has investigated exposure to wave overtopping through a conservative application of current engineering design methods. The results are expected to be indicative of those values that would typically be obtained through a design assessment.

Results provided are suitable for planning purposes and highlight impacts that would arise from changes in sea level. The values should not be adopted for the detailed design of individual foreshore structures. For detailed design, more rigorous advice from a suitably experienced coastal engineer should be sought.

The present standard for engineering practice is provided by *EurOtop Wave Overtopping of Sea Defences and Related Structures: Assessment Manual* (Pullen *et al,.* 2007) ('the Eurotop Manual'). Methods in the Eurotop Manual require input of the "spectral significant wave height" at the toe of a structure (H_{m0}) to calculate overtopping rates.

The calculation of overtopping rates follows the stages below:

1. Selection of appropriate water level conditions;
2. Selection of an appropriate wave condition, and propagation of that wave into a location offshore of wave breaking, accounting for refraction and shoaling as appropriate;
3. Transformation of that wave through the breaker zone to the toe of the structure; and
4. Use of appropriate equations to calculate design overtopping rates.

Each of these steps is described below.

Step 1 – Selection of Water Level Conditions

The design water level at the toe structure was based on a number of factors:

- Peak design water level (refer Section 2.4.3);
- An allowance for sea level rise at 2050 and 2100 (0.4 m and 0.9 m respectively – refer Section 2.4.3); and
- An allowance for wave set-up, which was determined using the SWAN wave model.

Both 5% and 1% peak design water levels were considered. It was found that the nearshore wave height difference between the two conditions varied minimally. However, the difference in water levels (6 cm) could result in significant changes to the calculated overtopping rates. Conservatively, the 1% peak design water level was adopted. This is a conservative approach as it assumes that the storm from which barometric pressure set up is associated makes landfall, and therefore the pressure effects occur at the shoreline.

Step 2 – Selection and Propagation of Offshore Waves

The 1% Annual Exceedance Probability (AEP) wave height was adopted for assessment purposes. Analysis obtained from Manly Hydraulics Laboratory indicates an offshore H_s of 8.7 m would be exceeded for 6 hours, on average, once every 100 years (i.e. 1% chance in any given year) (refer

Figure 2-2). This wave condition was assumed to approach from a typical storm wave direction of SSE (refer Section 2.3.2). The six hour window makes it likely that the wave will coincide with a high tide.

In addition, a 6 m wave approaching from ENE was also considered to investigate waves from a different direction, which may result in additional exposure to the southern end of embayed beaches (most notably, Stockton). A 6 m wave corresponds to the highest wave on record approaching from this wave direction.

The SWAN wave model was used to propagate waves into the nearshore area and to calculate wave set up at all 16 locations considered. The scenarios simulated in SWAN are summarised in Table 3-13.

It was generally found that the difference in nearshore significant wave heights for both offshore wave conditions was less than 10%. To simplify the comparative assessment only the results from the SSE direction were considered, noting that this condition was more rigorously derived as a 1% AEP value. Further, this condition was found to produce the highest waves at the shoreline at all locations, including Stockton SLSC.

Table 3-13 Summary of Parameters Simulated in the SWAN Wave Model

Timeframe	Water Level (m AHD)	Wave Height (Hs) (m)	Wave Period (Tp) (s)	Wave Direction (TN)
Existing	1.44	8.7	8 10 12	SSE
2050	1.78	8.7	8 10 12	SSE
2100	2.28	8.7	8 10 12	SSE
Existing	1.44	6	8 10 12	ENE
2050	1.78	6	8 10 12	ENE
2100	2.28	6	8 10 12	ENE

Each condition was run for peak spectral wave periods (T_p) of 8, 10 and 12 seconds. Preliminary analysis of the results showed that nearshore waves were typically larger for the 12 second simulations but only by a small amount (<10%). Results from the 8 and 10 second simulations were therefore not considered further.

The SWAN simulations indicated that the Newcastle shoreline is relatively exposed to incoming waves at all locations except the far southern end of Stockton Beach. Thus , the protective effects of headlands at any of the locations have not been considered.

Step 3 – Transformation of Waves Through the Breaker Zone

Engineering design typically requires consideration of the largest wave capable of breaking at the toe of the foreshore. As a 'spectrum' of waves (noting that waves on a beach over a short time period comprise a mixture of heights and periods) propagates across the surf zone, the larger waves in the spectrum break, reduce in height, reform, re-break and so on. Therefore the distribution of wave heights offshore of the breaker zone is diminished before it reaches the toe of the structure, with the larger waves breaking further offshore.

A variety of methods are available to represent and assess this process. The Eurotop manual recommends use of a graphical method utilising charts derived from the findings of van der Meer (1990), which has subsequently been adopted for this study.

Step 4 – Equations for Design Overtopping Rate and Wave Run Up

A number of relationships for run-up and overtopping have been applied, depending on the nature of the coastline at the location of interest, as outlined below.

Type 1: Overtopping Rate for a Rock Armoured or Stepped Slope

The mean overtopping discharge is calculated from the relationship provided in Chapter 6 of the Eurotop manual (Pullen *et al.*, 2007).

$$\frac{q}{\sqrt{g \times H_{m0}^3}} = 0.2 \times e^{-2.3 \times \frac{R_c}{H_{m0} \times \gamma_f \times \gamma_\beta}}$$

Where

$q =$ mean overtopping discharge rate (l/s);

$H_{m0} =$ Depth limited spectral significant wave height (m)

$R_c =$ distance of freeboard crest above still water level (m);

$\gamma_f =$ factor for effect of roughness elements (set to 0.60);

$\gamma_\beta =$ factor for effect of roughness elements (set to 1.00, assuming orthogonal wave approach)

Type 2: Overtopping of a Vertical Seawall

For a vertical seawall, the first step involves determining whether wave conditions at the toe are impulsive or non-impulsive.

$$h_* = 1.35 \times \frac{h_s}{H_{m0}} \times \frac{2 \times \pi \times h_s}{g \times T_{m-1,0}^2}$$

Where
$h_s =$ depth at structure toe;
$H_{m0} =$ Depth limited spectral significant wave height (m)
$T_{m-1,0} =$ Spectral Wave Period (s) ;

If the wave is non-impulsive, h_* > 0.3 and

$$\frac{q}{\sqrt{g \times H_{m0}^3}} = 0.04 \times e^{-1.8 \times \frac{R_c}{H_{m0}}}$$

If the wave is impulsive, h_* < 0.3, and there are two options:

$$\frac{q}{{h_*}^2 \sqrt{g \times {h_s}^3}} = 2.8 \times 10^{-4} \times \left(h_* \times \frac{R_c}{H_{m0}}\right)^{-3.1} ; where\ 0.02 < h_* \times \frac{R_c}{H_{m0}} < 1.0$$

and

$$\frac{q}{{h_*}^2 \sqrt{g \times {h_s}^3}} = 3.8 \times 10^{-4} \times \left(h_* \times \frac{R_c}{H_{m0}}\right)^{-2.7} ; where\ h_* \times \frac{R_c}{H_{m0}} < 0.02$$

Type 3: Run-up on a Sandy Beach

The 2% run-up level ($R_{2\%}$) has been derived based on the findings of Nielsen and Hanslow (1991), who indicate:

$$R_{2\%} = 0.58 \times \tan\beta \times \sqrt{H_{0_{RMS}} \times L_{0_{TZ}}} \times \sqrt{ln(50)}$$

Where
$\beta =$ slope of the beach face (assumed to be 0.10);
$H_{0_{RMS}} =$ deepwater RMS wave height $\approx \mathrm{H}_s/\sqrt{2}$;
$L_{0_{TZ}} =$ deepwater wavelength corresponding to zero crossing wave period;
$x =$ exceedence level

The run-up level derived from the above equation is added to the still water level.

Discussion of Other Variables Applied in Calculations

The local water surface elevation was applied as described above (i.e. 1% AEP water level at existing, 2050 and 2100 + set up calculated in SWAN at each location). Commensurate with a typical design erosion profile for NSW (Nielsen *et al.*, 1992), the bed elevation fronting the toe of the structure has been adopted as -1.0 m AHD (current conditions). The slope fronting the structure for wave transformation is based on nearshore slopes measured from LiDAR data. Where necessary, local conditions have been considered to further adjust the bed elevation, for example the depth of bedrock is known to be above -1.0 m AHD.

The Bruun (1962) concept for sea level rise assumes that the dune elevation and surfzone will rise vertically (as well as move landward) in response to sea level rise (with the sand sourced from the nearshore zone worked onshore to form the higher, more landward dunes). This would imply that the bed elevation at the base of the dunes will rise commensurately with sea level rise. However, it is unknown how the bed elevation at the toe of hard structures (seawalls or bedrock) will respond as sea level rises. Thus, for this assessment we have considered both the situation where the bed elevation rises equally with the sea level rise and the situation where it remains stationary despite sea level rise.

For run-up equations on a natural beach, shifts in the bed elevation at the toe of the dune with sea level rise do not reduce the run-up level. This is because the run up level equation is dependent upon the beach face slope, rather than bed elevation, as well as wave height and water surface elevation.

Overtopping calculations are dependent upon bed elevations further offshore, as the bed elevation governs the wave height that can reach the structure, and therefore overtopping rate. In this case, overtopping rates are reduced where the bed elevation rises in concert with sea level rise.

Potential increase or decrease in storm wave heights in the future due to climate change was discussed in Section 2.8. In the absence of more detailed guideline, projections for change to storm wave height have simply adopted a 10% increase in storm wave height by 2100. Investigation of the impact upon wave height at the shoreline (using the wave transformation method of van der Meer (1990) described above) and subsequent overtopping rates found that such increases in wave height may increase overtopping rates in the future, generally by small amounts. Absolute run-up levels may also increase by 0.1 – 0.3 m by 2100.

3.4.2.2 Discussion of Results

Sixteen discrete locations were adopted along the Newcastle coastline for analysis, as shown in Figure 3-10. A summary of overtopping rates calculated for the immediate, 2050 and 2100 time periods at the 16 locations of interest is given in Table 3-14. The computed volumes and levels represent an infrequent event of comparatively short duration. Run-up values estimated for use in defining the immediate, 2050 and 2100 coastal inundation hazard are presented in Section 3.4.4.

The performance of the various seawalls (informal and formal protection structures) in relation to the calculated overtopping rates is discussed in Section 3.4.3 below. For comparison with the rates in Table 3-14, guidelines as to acceptable limits on wave overtopping discharge and volumes taken from the Eurotop (2007) Manual are summarised in Table 3-15, and discussed in more detail in Section 3.4.3.2.

In all cases, the overtopping rates and run-up values identified must be considered with caution. The overtopping rates do not account for how the water is dispersed between successive waves, so may misrepresent the actual volumes that pond in back beach areas, or where such flows may be directed. Wave run-up events are not continuous, and the calculations do not account for water draining directly back into the ocean, into the local stormwater system or elsewhere that would reduce the severity of inundation experienced. As such, inundation depths associated with overtopping are difficult to estimate. Furthermore, from a risk management perspective, low levels of overtopping (above guideline limits, see Table 3-15) may be tolerated for structures, depending on the structure type, location and purpose, as the values represent a low recurrence storm scenario of relatively short duration.

Title:
Locations for Run-up and Overtopping Analyses

Drawing: 3-10

Rev: A

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

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Approx. Scale

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Table 3-14 Summary of Overtopping Rate Calculations

Site #	Overtopping Rate [3]	Crest (mAHD)	Immediate (l/s/m)	2050 (l/s/m)	2100 (l/s/m)
1	Stockton Dunes North of Seawall	5	23.1	63.2	203.7
2	Stockton Seawall	5	1.2	6.0	37.1
3	Stockton SLSC	4.5	38.0	101.6	315.7
4	Nobbys Beach (south end)	5.8	62.5	140.7	367.1
5	Nobbys Beach in front of SLSC	4	107.8	240.5	846.3
6	Cowrie Hole	3	180.9	740.1	10,859.5
7	Newcastle Beach north end [1]	3.8	176.6	405.5	1,649.6
8	Newcastle Beach near south end [1]	4.1	117.8	257.8	831.9
9	Newcastle Beach south end [1]	3	468.4	1,487.9	16,132.4
10	Cooks Hill / Bar Beach Kiosk [1]	3.9	124.3	275.4	1,009.5
11	Bar Beach Dunes	9.5	1.9	6.2	24.2
12	Dixon Park Boat Ramp	6.6	25.1	60.9	173.4
13	John Parade (Coane Street) [2]	7.5	13.3	41.4	161.4
14	John Parade (near Stormwater outlet) [2]	8.5	15.5	47.1	176.4
15	Merewether SLSC [1]	3.8	389.0	256.5	1,005.9
16	Merewether Surfhouse [1]	3	425.0	1,329.5	14,576.1

[1] Overtopping is calculated for the lowest promenade / walled structure at the site

[2] Overtopping is calculated for the seawall crest (5 m AHD), does not account for height to adjacent roadway

[3] Overtopping rate is calculated for the 1 in 100 year ARI 6 hour duration wave height (8.7 m from SSE) and 1 in 100 year ocean water level, plus sea level rise of 0.4 m at 2050 and 0.9 m at 2100, since 1990.

Table 3-15 Average wave overtopping volume limits resulting in damage (Eurotop, 2007)

At Risk	Average permissible overtopping (l/s/m)
Pedestrian[1]	0.10 to 10
Motor vehicles[2]	0.01 to 50
Damage to paving (landward of the crest)	200
Damage to grasses/turf (landward of the crest)	50
Seawall structure (crest)[3]	200
Buildings and assets[4]	1

Notes:

[1] Assumes that pedestrians have a clear view of the sea and able to tolerate getting wet through to trained staff expecting to get wet. All limits assume non violent, low velocity overtopping.

[2] Lower limits apply to high speed vehicles while upper limits apply to low speed vehicles, pulsating flows at low depths.

[3] Limit for no damage to a well protected crest

[4] Limit for damage, discharge measured at the building or asset

3.4.3 Seawall Performance with Overtopping

3.4.3.1 Purpose of a seawall

Seawalls are generally constructed to provide protection to land, assets or people on their landward side. On a sandy ocean beach where the sole objective is the protection of existing or proposed development and the maintenance of the sandy beach amenity for community use is also highly important, a range of other options are available that should be considered first. Seawalls should therefore not be seen as the only appropriate solution to an erosion problem. The use of a seawall is generally the solution of last resort, effectively drawing a line beyond which the ocean cannot be allowed to proceed, protecting the land behind the seawall, often at the expense of the sandy beach.

Where the decision to construct a seawall has been made previously, this has usually been in response to some coastal erosion activity or to address a perceived threat prior to it occurring. Often the community perception is that a seawall causes erosion and loss of the beach, an incorrect correlation being drawn between the pre-existing storm damage and the apparent reduction in the beach width and level once a seawall is constructed. On a receding beach or where a seawall is located too far seaward, the wall will be regularly impacted directly by storm waves and this will result in substantial wave reflection, overtopping and increased scour of sand adjacent to the wall. Appropriately designed sloping seawalls with a rough surface and porosity can absorb wave energy reducing wave reflections and wave run-up levels below those that would exist on a natural, saturated sandy beach or a wave cut vertical erosion escarpment in dune sands. If sited sufficiently landward on a stable beach, a seawall will only be exposed during extreme erosion events, and so may remain buried and vegetated for much of the time (e.g. Merewether to Dixon Park seawall). However, recession due to sea level rise will result in seawalls being more frequently exposed in the future (with associated effects noted above), as the stable shoreline becomes a receding shoreline, moving landward over time.

The primary design objectives of a seawall for protection are:

- to limit the landward excursion of waves during a storm event and thus protect the assets located landward of the structure;
- to limit the volume and extent of wave overtopping during storms, which would otherwise result in flooding or damage to assets located landward of the structure;
- to retain and stabilise the land behind the wall so that it can be used;
- to minimise the adverse impacts from the seawall either along the beach or immediately seaward of the seawall; and
- to minimise the damage to the structure and hence minimise maintenance requirements over the design life.

3.4.3.2 Discussion of Performance of Seawalls with Overtopping

During storm events, waves may impact seawalls at times of peak ocean water levels and/or when the sand buffer on the beach has been eroded. Overtopping rates given in Table 3-14 have been used to assess seawall condition and performance now and into the future at Newcastle's beaches. Where seawalls are subjected to wave overtopping during storms there are four main outcomes that must be carefully considered (Eurotop, 2007):

- risk of injury or death to persons immediately behind the structure;
- damage to property, infrastructure and economic impact on activities behind the structure;
- damage to the structure itself, possibly resulting in increased overtopping or failure; and
- minor flooding risk from overtopping volumes landward of the structure.

Guidelines as to acceptable limits on wave overtopping discharge and volumes are incorporated in the Eurotop (2007) Manual. These conditions are summarised in Table 3-15 (as derived from Eurotop Manual (2007) Table 3.2, 3.3, 3.4, 3.5). More detailed information may be obtained from the Eurotop manual directly.

Overtopping of the crests occurs most commonly from broken wave water and spray that travels over the crest as a result of the wave momentum and local winds, or in more extreme cases, in the form of bores of water which propagate landward as each wave breaks against the face of the wall and over the crest (green water). In extreme cases, overtopping may cause structural damage to the seawall crest and to development or assets immediately behind the structure.

The overtopping is presented as the rate of water discharge across the seawall crest at the peak of the storm surge and for the highest 2% of waves occurring. This computed overtopping rate is expressed as an average rate in litres per second per metre of seawall (l/s/m). For example, an average overtopping rate of 10 l/s/m would equate to an overtopping volume from each wave with a 10 second wave period of 100 litres per metre of seawall.

In considering the computed overtopping rates it should be noted that the volumes presented are indicative only, based on a range of assumptions (typical or worst case) and for a single location and for a low probability storm condition along each section of seawall or dune. Of greater relevance are the relative rates that give an idea of the scale of likely overtopping at different locations and the way in which that hazard will change at any single location with future sea level rise.

The calculation procedure used does not take into account any increase in overtopping rates associated with winds. At the peak of a severe storm, there are likely to be high wind velocities and these are likely to be directed towards the shoreline, increasing the volumes of overtopping and particularly the movement of spray across the seawall. This may in particular pose a hazard to vehicular traffic (for example along Shortland Esplanade) as visibility is suddenly lost. While the impact of onshore winds is minimal on volumes computed for significant wave overtopping situations (green water), it can increase the computed volume of overtopping by a factor of up to 4 times for discharge rates less than 1.0 l/s/m (Eurotop, 2007).

From a risk management perspective, low levels of overtopping (above guideline limits) may be tolerated for structures, depending on the structure type, location and purpose. This is because the values represent a low recurrence storm scenario of relatively short duration.

Many of the lower level promenades at the beaches in Newcastle can be expected to be overtopped at the present time, increasing to potentially full inundation by the ocean during storms in the future. However, at most of these locations the hind dune area continues to rise in elevation, typically as a series of additional vertical walls and promenades, to heights of 8 – 10 m or greater. This would constrain the impact of wave overtopping to back beach areas.

At the engineered seawall at Merewether to Dixon Park, the substrate above the seawall crest is sediment that could be dislodged by the overtopping mechanism. However assuming the sediment acts as a slope for waves, overtopping onto John Parade is likely to be minimal.

Overtopping along Shortland Esplanade at the Cowrie Hole is likely to pose the greatest risk, as although the overtopping rates are smaller than at Newcastle Beach, there are properties along the roadway behind the promenade that are of low elevation and could potentially be inundated.

Detailed review of the structures at each beach is provided in Chapter 4 as part of the individual beach assessment.

3.4.3.3 Deterioration, Maintenance and Monitoring

Seawalls are high value assets, constructed to protect people and property. They are built in a high risk and extremely hostile environment, required to withstand extreme, unpredictable wind and wave loadings at irregular intervals. Modern structures are designed with a certain amount of redundant capacity (factor of safety). This is not necessarily the case for older structures that have been constructed often by trial and error, awaiting the next significant storm event to be tested.

Importantly, seawalls need to be well maintained and regularly monitored to identify faults and degradation, allowing repairs prior to an event that could result in damage or failure occurring. The review and maintenance of seawalls should form an integral part of the CoN asset register. This would assist prioritisation of maintenance works and appropriate planning for replacement of those structures that have reached the end of their serviceable life.

The adequate recording of the condition of seawalls and the associated monitoring of changes to the beach conditions are even more crucial within a framework of climate change. The impact of sea level rise alone will be the landward movement of the beach with a loss of protective sand volumes seaward of the seawalls. Coupled with this is the increase in ocean storm water levels. These two factors will result in an increase in the frequency at which existing seawalls are exposed to wave attack, an increase in the wave forces on the structures during extreme events and an increase over time in the magnitude and frequency of wave overtopping.

In undertaking the review for this report, information on the seawalls, their condition and composition relied on a review of the information available within the CoN filing system and a site inspection of the whole coastline by the consultants. No detailed field assessment to determine the key parameters of these walls was undertaken (e.g. drilling, excavation etc.) as this was beyond the scope of this study.

The existing walls at Newcastle's beaches are of varying construction and age (Figure 3-11). They include:

- Vertical seawalls constructed of stone or concrete (generally older structures dating from 1800s to 1960s, or repairs to these structures);
- Sloping rock armoured revetments (1970s and 1980s); and
- Sloping revetments of geotextile sand filled containers (1996 to present).

Title:

Location and Type of Seawalls in Newcastle LGA

Figure: 3-11

Rev: A

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

N

0 1 2km

Approx. Scale

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The majority of the older works are of unknown construction (toe levels, wall thickness etc.). At most locations the back of the seawall is not accessible for this assessment and the toe also is buried on the beach. Many have been repaired, rendered or paved over since they were originally built. Limited information can be found within the CoN files. In a few cases design plans are on the files but generally no “work as executed” drawings for the works exist.

Many of the structures along the Newcastle coast are very old, dating back to the early period of the development of the city (e.g., 1900s at Newcastle Beach), and are likely to have heritage value.

In the major access areas (particularly Merewether, Bar Beach, Newcastle Beach and Nobbys Beach) the construction of the works has continued over the period of settlement, with the works constructed at different times and for different purposes. They are interlinked with existing beach facilities (such as the ocean baths), stormwater drainage and sewer lines. The resulting protection is provided by a patchwork of different structures, materials and seawall types. Visible elements of many of these works are in poor condition.

Many of the higher level walls above the immediate beachfront concourse are built as retaining structures (many of brick or block) not designed to be exposed to wave forces. At each of these locations there is an immediate need to undertake an inventory of the protection works, ascertaining the fabric of the seawall components, their construction details, crest and toe levels, bedrock levels etc. Where they are found to be inadequate for future higher sea level conditions, planning should be put in place for their upgrading or replacement.

At present, in most areas existing protection works appear to be performing satisfactorily, with maintenance undertaken as localised failures occur. However, there is clear evidence of degradation in many of the older structures.

Significantly, the review of the CoN files did not provide much reliable information, particularly on the older structures, that was of assistance in assessing their current condition or providing evidence of their ability to withstand significant storm events. While this is understandable given their age and the recent technological changes in record keeping, it should be addressed going forward. A regular and systematic monitoring system needs to be put in place with condition reports forming part of the ongoing asset register.

3.4.4 Hazard Definition for Coastal Inundation

A risk approach has once again been applied in defining the inundation hazard including run up. Hazard extents have been ascribed likelihoods of ‘almost certain’, ‘unlikely’ and ‘rare’ using the rationale outlined in Table 3-16.

While still ocean water levels during a storm are relatively straightforward in terms of a defined hazard area, the highly complex phenomenon of run up is less clear. Indicative mapping only of run up and overtopping areas has been completed, and should be used with caution. The absolute run up level occurs for 2% of wave conditions and may not cause damage or considerable water volumes overtopping an area. Further, overtopping volume calculations do not account for water draining away between wave run up events, which would reduce the severity / extent of inundation. Mapping of such volumes would therefore be misleading.

The approach adopted to map elevated still ocean level areas and indicative overtopping areas at the immediate, 2050 and 2100 timeframes, is explained below. Inundation levels adopted are summarised in Table 3-17.

Table 3-16 Coastal Inundation Likelihood Summary

Probability	Immediate	2050	2100
Almost Certain	1 in 20 yr storm surge and wave set up	As per immediate	As per immediate
Likely	NM[1]	NM	NM
Unlikely	1 in 100 yr storm surge and wave set up **AND** Wave run up and overtopping[2]	1 in 100 yr storm surge and wave set up + 0.4 m SLR and change in storm surge **AND** Indicative areas of potential overtopping[2] including 0.4 m SLR	1 in 100 yr storm surge and wave set up + 0.9 m SLR and change in storm surge **AND** Indicative areas of potential overtopping[2] including 0.9 m SLR
Rare	1 in 100 yr storm surge and wave set up + extreme climatic conditions (e.g. tropical cyclone, 1 in 1000 year east coast low)	**Worst Case of either:** 1 in 100 yr storm surge and wave set up + extreme climatic conditions + 0.4 m SLR and climate change impacts[3] **OR** 1 in 100 yr storm surge and wave set up + 0.7 m SLR and climate change impacts	**Worst Case of either:** 1 in 100 yr storm surge and wave set up + extreme climatic conditions + 0.9 m SLR and climate change impacts[3] **OR** 1 in 100 yr storm surge and wave set up + 1.4 m SLR and climate change impacts

[1] *NM = Not Mapped*

[2] *Only applies at open coast barriers (not within lagoons, estuaries etc.). Wave run up and overtopping are calculated using 1 in 100 yr storm surge + 1 in 100 yr 6 hr duration H_s.*

[3] *Includes increase in set up levels associated with a 5 % and 10 % increase in storm wave heights by 2050 and 2100 respectively, refer Section 2.8.*

Table 3-17 Adopted Inundation Levels

Adopted Inundation Levels [1]	Immediate (m AHD)	2050 (m AHD)	2100 (m AHD)
Almost Certain	2.5	2.5	2.5
Unlikely	2.7	3.1	3.6
Rare	2.9	3.4	4.1
Unlikely Wave run up [2]			
Stockton	5.5	*5.8*	*6.3*
Nobbys	5.6	*5.9*	*6.4*
Newcastle	5.7	*6.0*	*6.5*
Merewether to Bar Beach	5.6	*5.9*	*6.4*

[1] *Refer to Table 3-10, Table 3-11 and Table 3-12 for derivation of inundation levels.*

[2] *Run up height for the 1 in 100 year 6 hour storm wave height of 8.7 m.*

3.4.4.1 Almost Certain Inundation Hazard

At all timeframes the 'almost certain' likelihood is considered equivalent to the existing 1 in 20 return interval event (waves and water levels), without run up or sea level rise, as shown in Table 3-17. As for the beach erosion hazard, this provides a planning benchmark irrespective of the uncertainty associated with climate change.

Run up has not been included in the mapping of the 'almost certain' hazard, due to the complications of mapping run up described above. An indicative runup level has been provided for the 'unlikely' scenario only for hazard definition purposes.

3.4.4.2 Unlikely Inundation Hazard

The 'unlikely' coastal inundation hazard is considered equivalent to the 1 in 100 year event (waves and water levels), and for future time periods (2050, 2100) also includes sea level rise at the projection adopted for this study plus the minor increase in storm surge predicted with climate change, as given in Table 3-17.

Under the 'unlikely' scenario, an indicative run up level and area of potential overtopping associated with the 1 in 100 year event has been mapped for the immediate timeframe.

At 2050 and 2100, areas of potential overtopping under the 'unlikely' scenario wave and water level conditions have also been mapped, however a run up level has not.

For future time periods (2050, 2100), mapping of run up and overtopping is problematic. This is because it is unknown where the shoreline position will be and at what height dunes or seawalls will be behind the shoreline by 2050 and 2100. The erosion and recession extents at 2050 and 2100 provide the best indication of potential coastal processes at those future time periods including run up.

In this case, only areas of potential overtopping where low dune or seawall levels exist at present have been indicated within the 'unlikely' inundation extent for 2050 and 2100. The areas have been determined based upon the run up and overtopping calculations at 2050 and 2100, given in Table 3-14. Run up levels predicted for 2050 and 2100 under the 'unlikely' scenario are shown in Table 3-17.

It is not known if sediment will accumulate (and if so, how much) at the base of structures or on rock platforms as sea level rises. Overtopping calculations indicated volumes would be reduced if bed elevation at the toe of the structure rises (accretes) with sea level rise. This is because the wave height at the toe of the structure is reduced across the shallower bed elevation prior to reaching the structure. For the purpose of this assessment, it was considered appropriate to adopt the conservative overtopping estimates associated with bed elevations remaining the same with sea level rise, under the 'unlikely' scenario.

3.4.4.3 Rare Inundation Hazard

The 'rare' hazard at the immediate timeframe accounts for a greater than 1 in 100 year event, such as resulting from an extreme climatic condition. For example, the extreme event may represent a tropical cyclone tracking further southwards along the NSW coast or extreme east coast low cyclone, and estimated to add 0.2 m to the 1 in 100 year water level (refer Section 3.4.1). Given the potential for tropical cyclones to track further southwards due to climate change or more extreme storms due to climate change or natural variability over the immediate to 2100 period, it is reasonable to plan for greater than expected water levels.

For the 2050 and 2100 planning periods, the 'rare' scenario adopted was either: a 1 in 100 yr event plus 0.5 m greater than projected sea level rise by 2100; or the combination of an extreme climatic condition (e.g. a 1 in 1000 year still water level event, excluding wave set up), sea level rise projections of 0.4 m by 2050 and 0.9 m by 2100, increased wave set up associated with increased wave heights and increased storm surge due to climate change, whichever was the higher, see Table 3-17.

Under a 'rare' scenario sea level rise, run up levels would be 0.2 to 0.5 m higher. However given the limitations of the run up and overtopping calculations and problems associated with mapping such levels for future time periods, mapping of 'rare' scenario run up was not considered to provide additional meaningful information of the risk associated with wave run up and overtopping.

3.5 Geotechnical Hazard Summary

Newcastle's LGA shoreline includes significant sections of rocky coast comprised of coastal cliffs, coastal bluffs and slopes, and rocky shore platforms, which have formed within the Newcastle Coal Measures. These rocky shores are known to have a number of cliff and slope instability hazards. A geotechnical assessment of coastal hazards associated with the rocky coastline was carried out by RCA Australia as a component of the current study, and is detailed in the *Geotechnical Assessment of Newcastle Coastal Cliffs/Slopes: Newcastle LGA Coastal Zone Draft Report* (RCA, 2013) (Appendix B). The geotechnical assessment specifically addressed geotechnical hazards along the Newcastle LGA Coastline in accordance with the '*Practice Note Guidelines for Landslide Risk Management*', formulated by the Australian Geomechanics Society Landslide Practice Note Working Group and published in the Australian Geomechanics, Volume 42 No 1 March 2007, herein referred to as AGS LRM 2007.

The geotechnical assessment conducted by RCA (2013) was based on a desktop review of existing geotechnical data for the Newcastle coastal zone obtained from previous coastal studies and recent field mapping of identifiable geotechnical hazards. The impact of projected sea level rise of 0.4 m by 2050 and 0.9 m by 2100 on existing hazards and risk to life was included in the assessment. Likely changes to current cliff / slope recession rates as a consequence of projected sea level rise are provided.

For current and projected sea level rise conditions, RCA (2013) performed an assessment of risks posed by the identified geotechnical hazards to people, property, services, community facilities, access, transport services and the environment. The identified coastal cliff and slope hazards along the study area coastline were ranked in order of landslide risk and maintenance / risk mitigation priority. A qualitative assessment of the stability of cliff/slope areas and their suitability for development (both existing and future), pedestrian access and vehicular movements was provided. Risk mitigation, maintenance options and future investigations are proposed for the identified coastal cliff / slope geo-hazards.

Key findings from the assessment of geotechnical hazards are summarised below in the following sections.

3.5.1 Cliff Line Recession Rates

Cliff line recession rates are affected by rock mass properties, sub-aerial weathering processes and exposure to direct wave action (RCA, 2013), and were previously estimated for the CHDS (WBM, 2000). The rates of recession (assessed using various methods and/or data sources) were found to be highly variable. Cliff line recession rates estimated for the Newcastle coastline range between 1 mm/yr and +75 mm/yr, with the greatest rate of recession occurring at Lloyd Street due to the effect of mine subsidence and Nobbies Headland due to wave erosion (WBM, 2000). An additional rock platform analysis by RCA (2013) estimated typical cliff recession rates of between 10 mm/yr and 30 mm/yr for locations including Newcastle East, Strzelecki to Shepherds Hill and at Merewether Baths. The smallest cliff recession rate (less than 5 mm/yr) was estimated along the cliffs at South Newcastle, in the vicinity of the King Edward Park and the Bogie Hole (RCA, 2013).

3.5.2 Qualitative Assessment of Risk to Property

A qualitative assessment of the identified coastal cliff/slope hazards causing damage to property is reproduced in Table 3-18. Risk levels were assessed by RCA (2013) based on the likelihood and consequence of geo-hazards for present and future mean sea level conditions. The implication of risk ranged between tolerable (a very low risk) to unacceptable (a high risk). The majority of geo-hazards were assessed to be of a low to moderate risk. Higher risk was assessed at present for Shortland Esplanade - Bogie Hole, Bar Beach Car Park and the East End of Hickson Street at Merewether. Sites found to have relative increasing level risk due to rising sea levels include Shared Walkway - South Newcastle, Shortland Esplanade - King Edward Park, Cliff above Bogie Hole Pool, Shepherds Hill Cliff Top, Susan Gilmore Cliff, Bar Beach Car Park and Bar Beach the Bar Beach Car Park, however the future risk levels for each of these sites were not estimated.

Table 3-18 Summary of Assessed Risk to Property (RCA, 2013)

Coastal Geo-Hazard Site	Location	Assessed Risk at Present M.S.L.	Assessed Risk at 2050 M.S.L.	Assessed Risk at 2100 M.S.L
1	Nobbys Headland, Breakwater Pathway	Low	No change	No change
2	Nobbys Headland, N Beach	Low	No change	No change
3	Nobbys Headland, Signal Station	Moderate	No change	No change
4	Fort Scratchley Hill - NE	Low	No change	No change
5	Fort Scratchley Hill - E	Moderate	No change	No change
6	Shared Walkway, Newcastle Beach	Low	No change	No change
7	Shortland Esplanade, Newcastle Beach Skate Park	Low	No change	No change
8	Cliff above shared Walkway, South Newcastle	Very Low	No change	No change
9	Shared Walkway, South Newcastle	Low	Likely to increase	Likely to increase
10	Shortland Esplanade, King Edward Park	Low	Likely to increase	Likely to increase

Coastal Geo-Hazard Site	Location	Assessed Risk at Present M.S.L.	Assessed Risk at 2050 M.S.L.	Assessed Risk at 2100 M.S.L
11	Shortland Esplanade, Bogie Hole	High	No change	No change
12a	Cliff above Bogie Hole Viewing Area	Moderate	No change	No change
12b	Cliff above Bogie Hole Pool	Moderate	Likely to increase	Likely to increase
13	Cliff Top Walk, Strzelecki to Shepherds Hill	Low	No change	No change
14a	Shepherds Hill Cliff Top	Low	Likely to increase	Likely to increase
14b	Susan Gilmore Cliff	Moderate	Likely to increase	Likely to increase
15	Susan Gilmore Beach	Low	No change	No change
16a	Bar Beach Car Park (BBCP)	Moderate to High	Likely to increase	Likely to increase
16b	Bar Beach, below BBCP	Low	Likely to increase	Likely to increase
17	'The Cliff', North Dixon	Low	No change	No change
18	Baths & Beach below Lloyd St, Merewether	Moderate	No change	No change
19a	East end of Hickson St., Merewether	Moderate to High	No change	No change
19b	Rock Platform, below Hickson St Cliff	Low	No change	No change
20-21	Obelisk Hill – N & W rock faces	Low	No change	No change
22	Obelisk Hill – S rock face	Low	No change	No change

3.5.3 Quantitative Assessment of Risk to Life

The results of a quantitative assessment of the identified coastal cliff/ slope hazards causing risk to life (expressed as an annual probability of loss of life of an individual) are reproduced in Table 3-19. The assessed risk to life was calculated using indicative probabilities associated with the likelihood of geo-hazards occurring by incorporating the:

- annual probability of the landslide;
- probability of spatial impact on the landslide impacting a building taking into account the travel distance and travel direction given the event;
- temporal spatial probability (e.g. of the building or location being occupied by the individual) given the spatial impact and allowing for the possibility of evacuation given there is warning of the landslide occurrence; and
- vulnerability of the individual (probability of loss of life of the individual given the impact).

The risk to life is presented for present and future mean sea level conditions. The annual risk to life ranges between 1 in one million million to 1 in 10,000. The risk to life for persons most at risk is ~1 in 10,000, which is considered tolerable for existing slopes and development based on guideline values published by AGS LRM (2007).

The risk to life for all the geo-hazards, bar North Nobbies Beach (Hazard #2) were estimated to be less than 1 in 10,000, which corresponds to the suggested tolerable risk for existing slopes and developments. Change to the annual risk to life between present and future sea level conditions were estimated for the Cliff above Bogie Hole Pool (Hazard #12b), Cliff Top Walk - Strzelecki to Shepherds Hill (Hazard #13), Shepherds Hill cliff top (Hazard #14a), Rock Platform below Shepherds Hill Cliff (Hazard #14b), Bathers way - Bar Beach Car Park (Hazard #16a), Beach below Bar Beach Car Park (Hazard #16b) and Lloyd St Cliff – Merewether (Hazard #18).

Table 3-19 Summary of Assessed Risk to Life (RCA, 2013)

Coastal Geo-Hazard Site	Persons Most at Risk	Present Day Risk	Total Risk 2050	Total Risk 2100
1	Person(s) on breakwater footpath in the 20 m long rock fall risk zone hit by rock fall	2×10^{-5}	Not likely to be affected	Not likely to be affected
2	Person(s) within 16 m of cliff/slope toe	4.5×10^{-4}	Not likely to be affected	Not likely to be affected
3	Person(s) in building or behind brick fence when cliff top failure occurs	3.7×10^{-9}	Not likely to be affected	Not likely to be affected
4a	Person(s) in vehicle that impacts rock fall	8×10^{-6}	Not likely to be affected	Not likely to be affected
4b	Person(s) in vehicle that impacts rock fall	3×10^{-7}	Not likely to be affected	Not likely to be affected
5	Person(s) in vehicle that impacts failure debris	3.6×10^{-6}	Not likely to be affected	Not likely to be affected
6	Person(s) in impacted by block fall from wall	6×10^{-5}	Not likely to be affected	Not likely to be affected
7	Maintenance personnel and/or vehicles working under cliff/slope	1.6×10^{-5}	Not likely to be affected	Not likely to be affected
8	Person(s) using walkway protected by rock fall barrier fence	8.9×10^{-12}	Not likely to be affected	Not likely to be affected
9	Person(s) using walkway	2.2×10^{-7}	Not likely to be affected	Not likely to be affected
10	Person(s) using walkway	8.9×10^{-8}	Not likely to be affected	Not likely to be affected
11	Person(s) using walkway	3.6×10^{-5}	Not likely to be affected	Not likely to be affected
12a	Person(s) using viewing area, steps to pool	3.4×10^{-5}	Not likely to be affected	Not likely to be affected
12b	Person(s) within 16 m of cliff/slope toe	3.4×10^{-5}	Likely to increase	Likely to increase

Coastal Geo-Hazard Site	Persons Most at Risk	Present Day Risk	Total Risk 2050	Total Risk 2100
13	Person(s) using walkway	5.8×10^{-8}	Not likely to be affected	Likely to increase
14a	Person(s) standing at cliff top barrier	1.5×10^{-8}	Not likely to be affected	Likely to increase
14b	Person(s) crossing 'notch' in rock platform	3×10^{-4}	Likely to increase	Likely to increase
15	Person(s) within 16 m of cliff/slope toe	5×10^{-5}	Not likely to be affected	Not likely to be affected
16a	Person(s) walking or leaning against cliff top barrier	2.9×10^{-5}	Likely to increase	Likely to increase
16b	Person(s) within 16 m of cliff/slope toe	5×10^{-5}	Likely to increase	Likely to increase
17	Person(s) within 16 m of cliff/slope toe	5×10^{-5}	Not likely to be affected	Not likely to be affected
18	Person(s) within 16 m of cliff/slope toe	6×10^{-6}	Likely to increase	Likely to increase
19a	Person(s) in residence or cliff top backyard	2.7×10^{-5}	Not likely to be affected	Not likely to be affected
19b	Person(s) within 16 m of cliff/slope toe	5×10^{-5}	Not likely to be affected	Not likely to be affected
20	Person(s) within 3 m of rock face	7.2×10^{-5}	Not likely to be affected	Not likely to be affected
21	Person(s) within 3m of rock face	6×10^{-5}	Not likely to be affected	Not likely to be affected
22	Person(s) on tennis court nearest to rock face	6.7×10^{-9}	Not likely to be affected	Not likely to be affected

3.5.4 Public Amenities and Sea Level Rise

In addition to risks associated with identified geotechnical hazards (i.e. coastal cliff or slope), several public amenities were identified as being at risk from projected sea level rise. The amenities assessed included:

- Fort Scratchley Seawall;
- Newcastle Baths;
- Bogie Hole Pool;
- Rock platform between Bar Beach and Susan Gilmore Beach;

- Susan Gilmore Beach;
- Merewether Baths; and
- Hunter Water Sewer, South Merewether, Burwood Beach.

A summary of the possible impacts of projected sea level rise on each the above amenities are provided in Table 3-20.

Table 3-20 Summary of Projected Sea Level Rise Impacts on Public Amenities

Public Amenity	Projected Sea Level Rise	
	Consequences	**Impacts**
Fort Scratchley Sea Wall	• Mean sea level residing at the base of the sea wall • Increased wave action • Increased wave spray extent during storm and large swell periods	• Higher maintenance costs • Increased deterioration rate of amenities • Hazard for car and pedestrian traffic along Shortland esplanade • Reduced access to bathers walk footpath
Newcastle Baths	• Increased frequency of inundation • Increased wave action	• Reduced access to the Newcastle Baths • Higher maintenance costs associated with increased deterioration rate of amenities
Bogie Hole Pool	• Increased frequency of inundation	• Reduced access to the Bogie Hole • Higher maintenance costs associated with increased deterioration rate of amenities
Rock platform	• Increased frequency of inundation	• Reduced access to rock platform
Susan Gilmore Beach	• Increased frequency of inundation	• Reduced access to beach
Merewether Baths	• Increased frequency of inundation • Increased wave action	• Reduced access to the Merewether Baths • Higher maintenance costs associated with increased deterioration rate of amenities
Hunter Water Sewer	• Increased frequency of inundation	• Flood damage to sewer pipeline

3.5.5 Risk Mitigation and Maintenance

Risks associated with geo-hazards identified along the Newcastle coastline can be managed with a combination of mitigation measures and/or maintenance. In general, the report prepared by RCA (2013) recommends:

- Adoption of development guidelines to ensure:
  - Any proposed developments within the Newcastle coastal landslide assessment zone (as identified in the study, including lands on a slope or in proximity to a cliff), is subject to an AGS LRM 2007 landslide risk assessment
  - All proposed development located in the Newcastle coastal landslide assessment zone (i.e. on a slope or in proximity to a cliff) is carried out in accordance with good hillside practice; and

- Establishment and maintenance of vegetation cover on slopes comprised of soil and/or extremely low to low strength rock;
- Removal and/or poisoning of vegetation growing from competent rock faces where appropriate to minimise 'root jacking' and subsequent rock falls; and
- Ongoing geotechnical assessments of landslide risks along the Newcastle coastline every 10 years or as required by slope failures or by proposed development guidelines.

Site specific mitigation options and maintenance tasks recommended for each geo-hazard are reproduced in Table 3-21.

Table 3-21 Risk Mitigation/Management for Geo-hazards (RCA, 2013)

Risk Ranking	Hazard #	Location	Risk Mitigation / Management
1	11	Shortland Esplanade, Bogie Hole	Specific geotechnical investigation, including installation of inclinometers to determine depth & rate of existing failure and stabilisation strategy for cliff top fill embankment.
2	16a	Bar Beach Car Park (BBCP)	April 2012 CoN removed cliff top row of car spaces. RCA recommends CoN immediately: Re-instate barricades 2m from fence to keep BBCP pathway users out of at risk area; At risk section of BBCP is protected by a retaining structure founded below base of landslide; and Specific geotechnical investigation to determine overall stabilisation strategy for vulnerable cliff top. Large or long reach excavator working from BBCP to confirm base of slide prior to wall construction.
3	19a	Hickson St. Cliff top, Merewether	Specific geotechnical investigation to determine stabilisation strategy for ragged soil/EW rock face 3-6 m from Lloyd Street residential properties No.34a – 38a.
4	12	Cliff above Bogie Hole Pool	Slope 'groomed' after rock fall in 2003. Re-assessment of rock fall hazard at least once every 10 years.
5	18	Lloyd Street Cliff	Remove remaining spoil on slope above Merewether Bath's picnic tables & benches; and Re-assessment of landslide hazard at least once every 10 years.
6	5	Fort Scratchley Hill - East	Structural engineer to assess condition of the existing concrete revetments and retaining walls; and Specific geotechnical investigation to determine risk more accurately.
7	2	Nobbys headland	Flatten the debris fan along the beach side of cliff to 'catch' rock falls rather than promote 'run out'.
8	14b	Rock Platform below Shepherds Hill Cliff	Post Warning Signs 'Beware Falling Rocks' on rock platform both sides of hazard.
9	20	Obelisk cliff above Wolfe St. Footpath	Remove & poison vegetation growing in rock face defects and remove or support unstable blocks as needed.

Risk Ranking	Hazard #	Location	Risk Mitigation / Management
10	21	Obelisk Hill – North face	Remove & poison vegetation growing in rock face defects and remove or support unstable blocks as needed.
11	6	Newcastle beach	At meeting on 23/3/2012 CoN indicated crumbling wall to be demolished and slopes regraded. RCA recommends: soils battered at ≤ 2H: 1V, weathered rock cut at ≤ 1.5H: 1V, fresh competent rock cut at ≤ 0.75H: 1V; or Support steeper slopes with engineer designed retaining wall(s).
12	19b	Rock Platform below Hickson St Cliff	Post Warning Signs 'Beware Falling Rocks' on rock platform 16m offset from base of slope.
13	15	Susan Gilmore Cliff	Susan Gilmore footpath to remain closed to public; and Re-locate stormwater outlets to base of slope.
14	17	The Cliff, Kilgour Avenue, Dixon Park	CoN to monitor cliff/slope condition on an annual basis and/or after rainfall events ≥ 1 in 100yr; and CoN to commission a detailed Landslide Risk Assessment if cliff top assets come under threat.
15	16b	Beach –rock platform below Bar Beach Car Park Cliff	CoN to monitor slope stability on an annual basis and/or after rainfall events ≥ 1 in 100yr; and CoN to commission a detailed Landslide Risk Assessment if cliff top assets come under threat.
16	1	Nobbys headland	Install 21 m of concrete jersey kerb to protect people using the breakwater walkway from rock fall hazard.
17	7	South Newcastle Cliff, above Skate Park	Cliff/slope to be inspected for rock fall/landslide risks prior to any work being undertaken behind fence.
18	4a	Shortland Esp., Fort Scratchley Hill - NE	Remove loose and/or detached blocks from exposed rock faces, remove & poison vegetation growing in rock defects.
19	4b	Fort Dr., Fort Scratchley Hill - NE	Install 'No stopping rock fall hazard signs'; and Prevent car parking along toe of slope, revetments and retaining walls.
20	9	Shared Walkway, South Newcastle	CoN to re-seal pavement crack to prevent ingress of water into fill behind sea wall and monitor pavement crack development; Conduct geotechnical re-assessment of hazard at least once every 10 years; and Replace existing cracked retaining wall to support Shortland Esplanade.

Risk Ranking	Hazard #	Location	Risk Mitigation / Management
21	10	Shortland Esp., King Edward Park	Recommend CoN: 1. Remove broken footpath and cracked asphalt 2. Re-grade and compact upper metre of fill 3. Re-instate asphalt seal and concrete kerb & gutter (and) 4. Re-instate concrete footpath (optional). Also, Conduct specific geotechnical investigation to determine stabilisation strategy for Shortland Esp. cliff top fill embankment & retaining wall; or Construct new retaining wall to support Shortland Esplanade.
22	13	Cliff Top Walk, Strzelecki to Shepherds Hill	Conduct specific geotechnical investigation for proposed hill top walk bridges and viewing platforms. Likely outcomes: 1. Found supports for cliff top walkway 600mm below G.L. 2. Found supports for footbridges below the base of the 'friable' cliff top conglomerate unit, typically 7-10m thick.
23	14a	Shepherds Hill cliff top	Specific landslide risk assessment for proposed barrier fence.
24	22	Obelisk Hill – South face	Remove & poison vegetation growing in rock face defects and remove or support unstable blocks as needed.
25	3	Nobbys headland	Relevant authority to monitor cliff top retreat; Conduct AGS LRM landslide risk assessment at least once every 10 years; and/or Upgrade existing brick wall to protect buildings from cliff retreat.
26	8	South Newcastle Cliff	Maintain existing rock barrier fence and inspect cliff/slope rock fall/landslide risks prior to work being undertaken behind barrier fence; and Conduct 5 yearly AGS LRA reviews.

3.6 Other Coastal Hazards

3.6.1 Stormwater Erosion

It is generally accepted that the contribution of stormwater outlets to overall erosion volumes on the beach during storm events is minor compared with the impact of waves and water levels. However, stormwater discharge across the beach can result in a number of impacts posing a minor hazard on the coast, including:

- localised erosion around unstabilised outlets, which can result in the formation of a steep unstable eroded bank along the path of the flow from the outlet to the ocean, with some potential for collapse of these banks;
- increased access of large waves to the back beach region.

Stormwater discharges can also result in high velocity flows across the beach following significant rainfall events, and poor water quality discharge including gross pollutants (such as litter) as well as sediment, nutrients and heavy metals. There is also a visual impact of discharge.

At the present time, the two major stormwater outlets at Merewether and Bar Beach that have demonstrated erosion in the past are stabilised with rock rip rap around the outlet, limiting the potential for erosion of surrounding sand dunes during discharges. There are other stormwater outlets along the coast, however, the site inspection did not note any major erosion episodes around these outlets at the present time. Indeed, should erosion become an issue in the future, then treatment with rock rip rap would be an acceptable solution, especially in view of the already highly modified and structured shoreline of Newcastle.

Concerns have been raised over the impact of stormwater discharges and erosion upon surfing conditions at Nobbys Beach. Again, the contribution of stormwater discharges to erosion compared with natural beach fluctuations driven by waves and water levels is minor.

Stormwater outlets along the Newcastle coastline are listed in Table 3-22. These outlets have been included within the register of assets affected by hazards, in Section 3.7.

There are also stormwater outlets at cliff regions in King Edward Park, as well as the recently stabilised area of Shortland Esplanade into the Park. However, as these sites are not located on the beach where they may be affected by wave processes and erosion, they have not been listed in Table 3-22.

Table 3-22 Coastline Stormwater Discharge Points

Outlet Location	Approx. Size Catchment	Condition
Merewether Beach, John Pde	23 ha, Merewether urban area	Stabilised with rock rip rap. Concrete covered outlet. Water treatment unknown
Dixon Park, adjacent to boat ramp	6 ha including some urban area and Dixon car parks	Stabilised with rock rip rap and concrete. Water treatment unknown
Bar Beach, Scenic Drive	4 ha (possibly greater) draining urban areas and Empire Park	Stabilised with rock rip rap, water treatment unknown
Bar Beach, far north end	Unknown, drains small area of Bar Beach car park	Concrete covered channel and concrete toe to beach. Section of pipe out to ocean along rocks appears to no longer be used. Water treatment unknown, grate at beach outlet for public safety.
Newcastle Beach, south end	Royal Mirvac Development, Courthouse and adjacent park	Pipe and culvert believed to be over 100 years old. Pipe located on bedrock.
Newcastle Beach, middle	Unknown, drains large area of Newcastle east, including SLSC	Concrete pipe outlet at edge of promenade, grated for public safety. Water outflow uncontrolled, although outlet size is small and only minor erosion currently evident. Water treatment unknown.
Cowrie Hole, adjacent to Newcastle Baths	Unknown, drains small residential area of Newcastle east	Pipe outlet from vertical revetment wall, discharge point has been stabilised with concrete, likely due to erosion in the past. Discharge points have some oil/litter pit controls.

Outlet Location	Approx. Size Catchment	Condition
Nobbys Beach, south end	Unknown, drains small area of roadway and car park adjacent to beach. Foreshore Park drains to sand filter behind Horseshoe Beach	Pipe outlet from older section of vertical revetment wall, near to exposed rock platform. Water treatment unknown. Sand filter at Horseshoe Beach.
Stockton Beach, south end adjacent to breakwater	Unknown, drains fields, caravan park and area around Stockton SLSC.	Concrete-lined swale drain discharging onto beach. Water treatment unknown.
Stockton Beach, within seawall	Unknown.	The pipe outlet is concrete previously housed in gabion baskets which are now degraded (falling apart). This outlet is not shown in CoN's GIS system, it is unknown what catchment area drains to this pipe. Water treatment unknown.

3.6.2 Sand Drift

Sand drift is a hazard associated with windborne sediment transport. All sandy beaches experience sand drift to a certain extent, however, sand drift may present a notable hazard where coastal developments are being overwhelmed by windborne sediment, or significant volumes of sediment are being lost from the active beach system. Dune systems act as reservoirs to supply sand to the active beach during periods of erosion. If sand is lost inland through windborne transport, the volume of sand available to supply the erosion demand is less and therefore the erosion extent will be greater.

Windblown sand can affect coastal developments, the main concern being burial of roadways, fences, land or property and ecosystems and blockage of street gutters and stormwater drains. Windblown sand can also cause abrasion of buildings, motor vehicles, vegetation etc. and structural damage to buildings caused by the forces of the imposed sand.

Dune vegetation plays an important role in minimising the detrimental effects of sand drift by acting to trap windblown sand, helping to build up the dune and keep the sand within the active beach system. Sand drift can be initiated by the degeneration or destruction of dune vegetation. Once initiated, this can lead to the irreversible generation of blowouts which concentrate the wind velocities and cause more sand to drift. A common cause of dune vegetation destruction is uncontrolled pedestrian and vehicular traffic.

Sand drift has posed an issue at Newcastle's beaches in the past, particularly where unvegetated dunal regions allowed for sand to ingress into coastal development. For example, a curved deflector fence was constructed along John Parade in an attempt to minimise the wind blown sand being carried onto and across the road. Spinifex was planted after 1988 and other native vegetation continues to be cultivated along the dunes.

The dune vegetation works along Merewether to Dixon Park have been highly effective in trapping windblown sediments, and at the present time, a substantial sediment buffer has accumulated within the dunes and incipient dune region.

The remaining sites of nuisance sand drift (aside from occasional issues along footpaths etc. during very severe winds) are listed below:

- At Dixon Park south of the boat ramp sand is often blown onto the footpath as the curved barrier is lower and dunal vegetation is less extensive around the ramp;
- The Cliff carpark is regularly ingressed with windblown sand. At the present time, small blowouts are evident within the dunes and some dune fencing has been exposed. The current management practice is to remove the sand from the carpark, although it is not clear if this sand is placed back on the beach;
- Adjacent to the concrete ramp on the southern side of Cooks Hill SLSC frequently experiences sand drift, with sand blowing across Memorial Drive into Empire Park. At times the sand accumulation is quite deep and must be removed by excavator. Dune vegetation is nearly non-existent adjacent to the concrete ramp and pedestrian access is uncontrolled. Various tracks from the ramp to the beach are typically evident;
- At the southern end of Nobbys Beach sand drifts occasionally accumulate across the roadway against the wall of the Nobbys Surf Club equipment shed. Some of this sand continues across into the river channel and is then reworked into Horseshoe Bay. (Horseshoe Bay was known in Newcastle as the ‘sand trap’ around the 1940s and 50s. Small scale enterprises would collect sand from the ‘sand trap’ to sell to local builders).

Bitou Bush has largely been removed from the sandy dune regions of the southern beaches. However, there is extensive Bitou Bush across the cliff regions, such as at The Cliff between Dixon Park and Bar Beach, and from Bar Beach along the top of Shepherds Hill. This vegetation has not yet been replaced due to concerns over cliff stability should it be removed. The impact to cliff stability from the removal or retention of vegetation at various sites has been investigated by RCA (2013).

At the present time, projections for changes to wind speeds are considered within the natural variability of the existing climate (see Section 2.8). However, while ever dunes are vegetated, windblown sediment is more likely to be captured and retained within the beach system.

3.6.3 Coastal Entrance Instability

The only natural entrances within the Newcastle LGA are Glenrock Lagoon (draining Flaggy Creek) and Murdering Gully, both of which cross Burwood Beach at the southern and middle sections of the beach respectively. Both creeks are relatively small and the entrances exhibit typical characteristics of small intermittently closed and open lakes and lagoons (ICOLLs).

The entrances are predominantly closed, as the influences of wave and tide driven longshore transport is dominant compared with catchment inputs. The catchments are relatively small and therefore catchment flows are insufficient to keep the entrances permanently open.

During periods of heavy rainfall, the entrances will breakout and scour to allow the discharge of water. The entrance may then stay open for a period of time and migrate northwards along the coast under the influence of the prevailing waves and longshore transport, until these coastal processes once again allow for closure of the entrance.

Interpretation of historical aerial photography has indicated entrance breakout and migration occurs over a relatively short distance. Furthermore, the undeveloped status of the area is such that creek entrance processes do not create any significant hazards.

The entrance to the Hunter River has been trained to provide safe navigational access to the Port of Newcastle. The breakwaters have been subject to storm wave attack and damage necessitating periodic maintenance. However, the entrance itself has been quite stable.

As Burwood Beach and the Hunter River are both excluded from this study, no further hazards assessments are required relating to entrance instabilities.

3.7 Register of Public and Private Assets affected by Hazards

A variety of coastal “assets” representing various land uses, facilities and features (including environmental features) of the Newcastle coastal zone were identified based upon Geographical Information Systems (GIS) processing of:

- spatial mapping of land zoning, land tenure, cadastre and aerial photography;
- mapping of stormwater assets, wastewater and water supply assets, heritage items, parks, public buildings, cycleways, roads, etc.;
- information regarding assets (social, cultural, recreational, economic) from various reports; and
- details provided on assets through the Newcastle Coastal Technical Working Party.

The variety of assets identified across the Newcastle coastal zone are listed in Table 3-23. A series of maps of coastal assets in Newcastle were generated.

The asset maps also provide the blueprint for determining the values associated with coastal land and assets and therefore the overall consequence of hazards, should they occur.

Within a risk assessment approach, risk is defined as *likelihood X consequence*. The hazard likelihood lines were intersected with the asset maps to identify the assets that may be affected by coastal hazards at the various timeframes. Defining the consequence of coastal hazards forms the next key part of the risk assessment process, which shall be outlined and documented in the subsequent Newcastle Coastal Zone Management Study.

The assessment of public structures and their construction details has been extracted from the CHDS (2000) with updating of information where relevant for 2011 (e.g. most notably regarding the Merewether Surfhouse structure). The details of public assets, including construction details are provided in Appendix A. Based upon site inspections in 2011, various minor repair works were observed at all structures. However, comments regarding the processes causing conditions requiring maintenance from 1998 remain relevant, and have been retained in the summary given in the Appendix.

Table 3-23 Coastal Asset Categories and Items

Coastal Assets Categories and Asset items	
Parks, Beaches and open space	***Transport & Other Infrastructure***
Beaches	Major (arterial) roads, bridges
Parks, Public open space / reserves	Local Roads, (including car parks)
Private recreational land (e.g. golf courses, football grounds, bowls clubs, tennis courts)	Railway systems
Wetlands / Forests / Other Habitats (including estuary entrances)	Harbour breakwaters
Coastal Dune Systems	Engineered Seawalls
Community Infrastructure	Vertical walls and promenades
Surf Clubs	***Water and sewage infrastructure***
Caravan Parks	Stormwater outlets and pipes
Heritage / Historic Sites and Significant Aboriginal Sites	Sewage Treatment Plants, sewage pumping stations, water supply networks
Cycleway / Shared Pathway	***Residential Development***
Ocean Pools	Existing Residences
Community halls, libraries, other public buildings	***Institutional Infrastructure***
Amenities blocks, sheds, etc. (CoN facilities / assets)	Hospitals, Hospices
Lifeguard towers	Schools, child care facilities
Commercial and Industrial Development including hotels, cafes, restaurants etc.	Aged care facilities

4 INDIVIDUAL BEACH ASSESSMENT

4.1 Merewether, Dixon Park and Bar Beaches

4.1.1 Beach Description

Merewether Beach, Dixon Park Beach and Bar Beach form one beach unit extending between the rocky headlands at Merewether in the south and Shepherds Hill in the north (Figure 1-1). Around the centre of the beach is a small hill and rocky cliff section (locally known as The Cliff). The entire beach unit is backed variously by concrete promenades, sandy dunes, and a continuous seawall from Merewether Surf Club to Dixon Park Surf Club. The natural land level immediately behind the beach is typically elevated well above Mean Sea Level along the entire beach unit, ranging from around 8 m AHD at John Parade, to 7 m AHD at Dixon Park and 9.5 m AHD at Bar Beach. While a sandy beach currently is present, storm erosion in the past has periodically removed this sand leaving underlying bedrock exposed along much of the foreshore.

At the southern end (Merewether Beach), the Merewether Ocean Baths have been constructed on top of the rock platform with associated pavilions, seawalls and promenades extending to the Merewether Surf Life Saving Club on the edge of the sandy beach.

Photographic evidence (Figure 4-1) suggests that the area of John Parade at Merewether comprises deep dune sands, with little to no bedrock constraint. The roadway of John Parade is effectively constructed along the crest of what would previously have been the frontal dune. Residential development lies immediately behind John Parade. Likewise, the car park at Dixon Park is also situated on top of the frontal dune. However, at Dixon Park, residential properties are set behind parkland adjacent to the beach. Following severe erosion in the 1970s, a rock seawall was constructed along the beach between Merewether Surf Club and Dixon Park (approximately to the base of the Cliff) in 1976/77. The Dixon Park Surf Life Saving Club House is constructed on high ground some 60m back from the beach face.

At the northern end of the beach unit (Bar Beach), the Cooks Hill Surf Life Saving Club and associated pavilions, promenades and seawalls have been constructed at the base of the hill immediately adjacent to the beach. While there is certainly reef and bedrock across the entire surf zone between the Cliff and Bar Beach, the beach above this is likely to be dunal sands with bedrock at depth, and thus erodible (Figure 4-3) Bedrock below Cooks Hill Surf Club and the northern end of the beach has been uncovered by erosion in the past (Figure 4-4), and is a constraint to potential storm erosion.

Dune vegetation was established after 1988, and dune works have progressed to the present (particularly to replace non-native weeds such as bitou bush with native, low lying species). At the current time, a well developed, typically vegetated frontal and incipient dune exists along the entire beach unit, and has completely covered the rock seawall between Dixon Park and Merewether (Figure 4-2).

Figure 4-1 Merewether to Dixon Park Beach Erosion Following Severe Storms circa 1974

Figure 4-2 Merewether to Dixon Park (2011) – Well developed dunes now overlay seawall (right)

Figure 4-3 Bar Beach (centre) Erosion Extents Following Severe Storms circa 1974

Figure 4-4 Bar Beach (north) Erosion Extents Following Severe Storms circa 1974

4.1.1.1 *Shepherds Hill Area*

The Shepherds Hill Area extends from Bar Beach around to Newcastle Beach. It is characterised by high cliffs with a rock platform below. A veneer of sand is present at the base of the cliffs forming Susan Gilmore Beach. This shoreline section is mainly public reserve. There are various lookouts and car parks and a swimming hole in the rocky platform known as the Bogey Hole. The cliffs are up to 70m in height and mostly in a natural state with limited fencing. The crests of the cliffs are often abrupt with loose erodible materials and as such, pose a hazard to persons venturing close to the edge. The Shepherds Hill area was assessed within the Cliff Stability Assessment (Section 4.1.2.5).

4.1.2 Hazards Definition

Coastal hazards defined for Merewether to Bar Beaches are summarised in Table 4-1 to Table 4-4 below (excluding geo-hazards, see Section 4.1.2.5), and discussed in detail in the following section.

Table 4-1 Immediate Timeframe Hazards, Merewether to Bar Beach

Likelihood	Erosion	Inundation	Wave Run up
Almost Certain	15 m	2.5 mAHD	N/A
Unlikely	25 m or limit of bedrock / seawall	2.7 mAHD	5.6 mAHD
Rare	40 m or limit of bedrock	2.9 mAHD	N/A

Table 4-2 2050 Hazards, Merewether to Bar Beach

Likelihood	Erosion	Inundation	Wave Run up
Almost Certain		2.5 mAHD	N/A
Unlikely	Variable, see Hazard Map, Figures B-8 and B-9	3.1 mAHD	5.9 mAHD
Rare		3.4 mAHD	N/A

Table 4-3 2100 Hazards, Merewether to Bar Beach

Likelihood	Erosion	Inundation	Wave Run up
Almost Certain		2.5 mAHD	N/A
Unlikely	Variable, see Hazard Map, Figures C-8 and C-9	3.6 mAHD	6.4 mAHD
Rare		4.1 mAHD	N/A

Table 4-4 Extreme Wave Overtopping Rates (l/s/m), Merewether to Bar Beach

Location[1]	Immediate	2050	2100
Merewether Surfhouse	425.0	1,329.5	14,576.1
Merewether SLSC	389.0	256.5	1,005.9
John Parade (near Stormwater outlet)	15.5	47.1	176.4

Location[1]	Immediate	2050	2100
John Parade (Coane Street)	13.3	41.4	161.4
Dixon Park Boat Ramp	25.1	60.9	173.4
Bar Beach Dunes	1.9	6.2	24.2
Cooks Hill / Bar Beach Kiosk	124.3	275.4	1,009.5

[1] See Table 3-14 for details.

4.1.2.1 Beach Erosion and Recession

At the current time, the beaches are generally well accreted, with well developed dunes and incipient dunes along the beach, except fronting the surf clubs and associated promenades at Merewether and Bar Beaches.

Historical photographs of erosion following storm events in the 1970s provide an excellent portrayal of potential impacts of storms in the future at Merewether, Dixon Park, Bar Beach and Cooks Hill surf club, as given in Figure 4-1 to Figure 4-4. The beach is shown to be virtually devoid of sand, and bedrock reefs are exposed such as below Cooks Hill Surf Club. A period of wave climate producing similar erosion extents has been reported at other times in the past (WBM, 2000), and so, similar extents of erosion can be expected to recur in the future.

Contour plots of the 2 m and 4 m AHD contours derived from photogrammetric profiles demonstrate the naturally oscillating position of the beach and dunes in relation to storms and the variable wave climate, in Figure 4-5 to Figure 4-8. The beach erosion hazard is estimated for the immediate timeframe at Merewether to Bar Beach in Table 4-1. The methodology applied in deriving this hazard estimate is given in Section 3.2.

For future time periods, of particular note is the impact to beach amenity where shoreline retreat and storm erosion is limited by bedrock along the beach and / or the seawall at Merewether to Dixon Park. At those locations (assuming the seawall remains in place to 2100), it can be expected that complete removal of sediment from the upper beach will occur more frequently into the future as sea levels rise and wave action occurs at a higher position on the beach. There may be sections of the beach that are commonly exposed rock (or seawall) by 2100 or even 2050. The back beach area between The Cliff and Bar Beach comprises dunal sands, and therefore is able to retreat landward. However, this would require relocation of the roadway, and Skate Park and sacrifice of sections of Empire Park.

The seawall at Merewether to Dixon Park Beaches will be frequently exposed in the future, if it is maintained to withstand such impacts. However, this has ramifications for beach amenity, as the beach will have a limited sand width (or perhaps exposed rock) at the base of an exposed rocky seawall. These aspects must be considered by community and land managers in determining management responses to future sea level rise impacts. The long term recession hazard due to sea level rise is added to the beach erosion estimates as explained in Section 3.3, and illustrated in the Drawings Section at the end of this report.

Title:

Position of the 2 m AHD Contour Over Time, Merewether to Dixon Park Beach

Drawing: **4-5**

Rev: **A**

N

0 100 200m

Approx. Scale

BMT WBM

www.wbmpl.com.au

Filepath : K:\N2051_NewcastleCoastalHazards&Management\MI\Workspaces\JS_Working\DRG_015_111031_Drawing_4-5.WOR

Title:

Position of the 2 m AHD Contour Over Time, Dixon Park to Bar Beach

Drawing: **4-6**

Rev: **A**

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

N

0 100 200m

Approx. Scale

BMT WBM

www.wbmpl.com.au

Filepath : K:\N2051_NewcastleCoastalHazards&Management\MI\Workspaces\DRG_018_111031_Drawing_4-6.WOR

Title:
Position of the 4 m AHD Contour Over Time, Merewether to Dixon Park Beach

Drawing: 4-7

Rev: A

N

0 100 200m
Approx. Scale

BMT WBM
www.wbmpl.com.au

Filepath : K:\N2051_NewcastleCoastalHazards&Management\MI\Workspaces\JS_Working\DRG_011_111028_Drawing_4-7.WOR

Title:

Position of the 4 m AHD Contour Over Time, Dixon Park to Bar Beach

Drawing: 4-8

Rev: A

N

0 100 200m

Approx. Scale

BMT WBM

www.wbmpl.com.au

Filepath : K:\N2051_NewcastleCoastalHazards&Management\MI\Workspaces\JS_Working\DRG_012_111028_Drawing_4-8.WOR

4.1.2.2 Coastal Inundation and Wave Overtopping

The coastal inundation and wave overtopping assessment outlined in Section 3.3.4 determined that the lower promenades at Merewether and Bar Beach below the surf clubs and other infrastructure experience overtopping at present, and this is likely to become more frequent and at greater volumes in the future with sea level rise, as discussed in Section 4.1.2.3 below. However, the back beach areas behind Merewether to Bar Beach are at higher elevation (8 – 10 m AHD), therefore overtopping and run-up is not expected to affect back beach areas at the present time, and there may be minimal overtopping (if at all) in the future with sea level rise. This assessment is based upon the back beach area being of similar height in the future as at present, and this would be expected given elevations landward of the beach at present.

The area of the boat ramp at Dixon Park may experience some overtopping during an infrequent storm event at present, however this is considered manageable at present. However, the site will experience enhanced wave run-up and overtopping in the future. The water volumes would be expected to be mostly contained within the car park, and, as ground elevations generally slope towards the ocean at this location, water delivered by wave run-up would be expected to recede back into the ocean between waves. However, the rates of overtopping by 2050 and 2100 are considered to impact upon the serviceability and condition of the structure, as outlined in Section 4.1.2.3, and will require management.

The elevated ocean water level analysis illustrates that Merewether Baths would be fully engulfed by ocean water during a severe storm at the present time. Due to sea level rise, the frequency of overtopping of the Baths will increase. Management of the condition of the Baths accounting for sea level rise is likely to be an important issue for the community.

Likewise, the lower promenades at Cooks Hill surf club and Bar Beach are likely to be overtopped at present. The rates and frequency of overtopping is likely to increase substantially in the future with sea level rise. There are community facilities along this lower promenade. As the frequency of overtopping increases, the current format of facilities will become unworkable. A re-design of the facilities and structures in this region will be required in the future.

Elevated ocean water levels, and areas that may be subject to wave run up and overtopping at the immediate, 2050 and 2100 timeframes are given in the Drawings Section at the end of this report.

Detailed discussion of the stability and performance of the shoreline structures (seawalls) is provided below.

4.1.2.3 Seawall Condition and Performance

Merewether Beach

The southern end of Merewether Beach (south of Merewether Surfhouse) is founded on a bedrock shelf which is exposed at the surface. The rock shelf extends north as far as the Surf Club and is exposed in the surf zone and offshore at a lower level. This area contains the Merewether Ocean Baths and the bathing pavilion. The seaward wall of the ocean pool provides the primary wave protection at present. Landward of the pool, the alignment of the old colliery railway can be seen along the beach and this forms the present day low level walkway landward of the baths, below Merewether Surfhouse and seaward of the Merewether Surf Life Saving Club (SLSC) to the north.

The back beach area (between the bathing pavilion and the baths) comprises a patchwork of old and repaired/replaced seawalls, retaining walls and paving in various states of disrepair. Much of the structure is old and weathered. Many of the higher retaining wall sections are not designed as seawalls and would not withstand future wave action following sea level rise. The lower level walls along the walkways will be inundated by 2100. A review of CoN files shows little information is available on the construction of the various seawall and retaining wall sections. Much of the structures are not readily visible for inspection.

Plate 2.1 New Surf House at Merewether under construction. A mixture of high level and low level walls are constructed on the lower beach. The front pathway appears to follow the alignment of the old railway. Sections of the retaining structures, paving and fittings are in poor condition. **Photo:** Coastal Environment 30/04/2011

Plate 2.2. Stairs leading from the walkway to the beach. Construction details are not known. The front seawall of vertical concrete construction is exposed to wave action and has rotated seaward at the top with cracking extending through the structure. **Photo Source:** Coastal Environment 30/04/2011

The Merewether Reserves Plan of Management (NCC, 2009) describes the protection structures and promenade as follows "*The promenades are prominent features of the study area and also act as a seawall, protecting the landward assets and property. The upper promenade, beginning at the Merewether Baths and extending north along John Parade to Dixon Park and beyond, forms a strong link between the Baths, Merewether Beach Pavilion (Surf House) and the SLSC. The lower beach promenade sits just above beach level and also begins at the Baths and extends north to the SLSC and beach*." On the condition of these promenades NCC, (2009) advises that "*Upper promenade – in need of repair, uneven and narrow in sections. Lower promenade – in need of minor repairs*"

While the condition of the existing seawall and paving is serviceable, there is little available documentation showing the construction of the seawall components and their suitability to withstand substantial wave erosion. Some visible element of the structures are degraded (plates 2.3, 2.4) and in need of maintenance or replacement.

Plate 2.3 Walkway between Surf House and the SLSC, following the route of the old colliery railway line. There is a low vertical wall on the seaward side of unknown construction which is regularly overtopped by storm waves at present. This section of the beach appears to be shallowly underlain by bedrock. **Photo:** Coastal Environment 30/04/2011

Plate 2.4. Low retaining /seawall seaward of the shelter sheds. The original wall is of stone blocks with mortar that is eroding. Concrete paving has been poured over this and is cracking. Much of this structure is in poor condition and could be further damaged under wave action. **Photo:** Coastal Environment 30/04/2011

Overtopping calculations were undertaken at two sites for this assessment (sites 15, 16, Figure 3-10) Site 15 is on the seaward edge of the lower promenade near the Merewether SLSC while site 16 is located on the lower promenade near the Merewether Surfhouse.

At both locations there is a vertical wall of unknown construction fronting the promenades with the crest level at 3.8m AHD near Merewether SLSC and approximately 3.0m AHD seaward of Surf House. The toe level is not known, but it is possible the structures are founded on bedrock. At both locations the promenade is regularly overtopped during high tides and large seas at present. The overtopping computations at both locations show inundation rates around 400 l/s/m at present posing unacceptable risks to pedestrian safety during storms and likely to cause damage to seawalls, paving and buildings. These rates will increase substantially with sea level rise. The overtopping and risk to pedestrians will increase to 2050 and by 2100 may be in excess of 1,005.9 l/s/m at the SLSC while the promenade at the Surf House would be inundated with the ocean water level only 0.4 m below the existing seawall crest.

The future use of the Merewether Ocean Baths, the promenade and the existing facilities and buildings will require review in the light of sea level rise. The existing condition of the structures and the lack of detailed knowledge of their construction and therefore condition warrant a detailed assessment of all existing seawalls and structures likely to be subject to future wave inundation, to determine their likely performance in providing protection.

Dixon Park

From the boat ramp north of the Merewether SLSC to the northern side of the Dixon Park SLSC, there is a substantial rock armoured revetment, which is currently covered with dune sand and dune vegetation. CoN files (50/00509/00000/15) show the structure was built in two sections. The first section was constructed by CoN from the Merewether SLSC ramp to the intersection of Berner Street and John Parade. This was completed in 1975/76. The second section extended the wall from this intersection to the north side of the Dixon Park SLSC where it abuts a natural rock outcrop. This section was completed under a state Government Beach Improvement Program grant and completed in 1976. Both sections of wall are now buried under the vegetated dune face and no longer visible. The wall does not extend to the crest of the embankment and occasional rocks are visible along the crest. A separate concave concrete deflector wall is constructed along John Parade at ground level. This was placed to control windblown sand movement from the beach, which was a problem for back beach footpaths, roadway and development prior to dune revegetation works following the construction. Sections of this deflector fence have been recently replaced (1999) with flat fibre cement sheeting.

The revetment face is at a slope of 1V to 2H with a crest level at approximately 5m AHD and a toe level at approximately -1m AHD. The revetment face comprises two layers of primary armour (2 tonne to 5 tonne) with two layers of secondary armour and a gravel filter over the sand slope. Where existing dumped rock protection existed this has been integrated into the wall. There is no work as executed drawings for the seawall as constructed. However, the design drawings on CoN files show the wall to be comparable with current design practice. The structure and height of the wall should be assessed and surveyed when it is next exposed.

Plate 2.5. A sloping rock armoured revetment extends from the boat ramp at Merewether SLSC to the northern extent of the Dixon Park SLSC. This wall, constructed in the 1970s is buried beneath the existing dune. **Photo:** Coastal Environment 30/04/2011

Plate 2.6. Stormwater outlet north of Watkins Street. Rock has been placed to protect the outlet structure which intersects the buried seawall
Photo: Coastal Environment 30/04/2011

Overtopping modelling was undertaken at three locations between the Dixon Park SLSC and Merewether (Site 12, 13, 14, Figure 3-10). Site 12 is at the Dixon Park boat ramp at the southern end of the car park, approximately 125 m south of the SLSC. Site 13 is on John Parade near Coane Street. Site 14 is near the stormwater outlet north of Watkins Street (Plate 2.6).

The boat ramp (Site 12) is a concrete ramp constructed above the surface of the seawall at a slope of approximately 1V to 8H and with a crest level at 6.6m AHD. The overtopping assessment shows significant overtopping of the ramp may occur during storms at present (25.1 l/s/m) which would pose a risk to pedestrians on or at the crest of the ramp. It would also make the ramp inoperable in those conditions. By 2050 the rate of overtopping could increase to around 60.9 l/s/m and by 2100 to 173.4 l/s/m. The overtopping rates are considered manageable at present and present little risk to the ramp itself or the paved carpark behind. However over time, and certainly by 2100, the operation of the ramp may be compromised. This could readily be addressed in the future by either removing the ramp or elevating the landward end above the current level.

At locations 13 and 14, the overtopping computations are undertaken on the buried seawall. The face of the revetment was assumed at a slope of 1V to 1.5H (slightly steeper than the actual structure) with a crest level around 5m AHD. It should be noted that the dune covering the seawall extends several metres above this crest level and is vegetated. Similarly, this section of John Parade is at a level several metres above the constructed seawall crest. Under the current conditions the computed storm overtopping of the seawall crest is approximately 15 l/s/m at both locations. There is no development behind the crest and pedestrians do not walk along the crest, using the footpath to John Parade which is elevated and further landward. This overtopping rate would increase by 2050 to approximately 45 l/s/m and by 2100 could be around 160 - 175 l/s/m. As the sea level increases and the run-up heights on the wall increase, this could be addressed through appropriate armouring of the upper slope to the John Parade seaward edge. While the future overtopping discharges may appear an issue at the present crest level, this can be readily managed provided the seawall crest is able to be raised.

Bar Beach

From The Cliff northwards there are no protection works constructed behind the beach to the north, until the Cooks Hill SLSC at Bar Beach, a distance of approximately 600 m. This section of beach is backed by an elevated bluff area along Kilgour Avenue to the car park at the end of Memorial Drive and then a natural, vegetated dune system along Memorial Drive to Bar Beach (Plate 2.7). The area is underlain by bedrock with rock outcrops evident in the surf at isolated locations. Bar beach is facing south east and exposed to the predominant swell direction.

Plate 2.7. North of Dixon Park SLSC there is no seawall protecting the back beach north to the Cooks Hill SLSC at Bar Beach. **Photo:** Coastal Environment 30/04/2011.

At Bar Beach, there are a group of buildings (Cooks Hill SLSC, Lifeguard tower and kiosk) located on the sloping dune behind the beach on the seaward side of Memorial Drive. Along the front of this developed strip there is a promenade at a low level fronted by a low seawall and the sandy beach. It extends approximately 200 m south from Bar Beach carpark on the headland. This section of beach is underlain by bedrock extending from the headland and clearly visible in the surf zone seaward of the buildings.

The protection structures include the seawall, paving and retaining walls up the slope behind the buildings and to the headland carpark. These walls are of early construction and appear, in the main, to be stone block walls with little or no mortar remaining. They have been intersected by access works and drainage with repairs and patched at many locations. The stormwater drainage is intermingled with the protection walls and there also appears to be redundant pipe outlets still in place. Many sections of the seawalls appear to be in poor condition, some sections at the end of their useful design life and in need of repair/replacement (Plate 2.9).

Plate 2.8. View north along the Bar Beach foreshore. The low level promenade is at the left. The lifeguard tower is in the background and the Cooks Hill Surf Club beyond. **Photo:** Coastal Environment 30/04/2011.

Plate 2.9. There are a variety of retaining structures along Bar Beach, of unknown construction. The walls behind the promenade and up the slope to the road above are unlikely to be designed for any sort of wave loadings. **Photo:** Coastal Environment 30/04/2011.

A selection of seawalls and retaining structures up the slope to the Bar Beach carpark on the headland above Susan Gilmore Beach were evident at the time of the site inspection. These walls are of unknown construction and generally are in poor condition, and a variety of materials and repairs have been used over many years. It is noted that since the site inspection, CoN has commenced restabilisation works along the cliff below Bar Beach carpark.

Overtopping modelling was undertaken for the low level promenade at the southern end of Bar Beach, in front of the Cooks Hill SLSC, Lifeguard tower and kiosk (Site 10, Figure 3-10). The seawall along the seaward side of the promenade is of unknown construction. The crest level is at 3.9m AHD and the southern buildings and the shelter sheds at the north end are within a few metres of the seawall crest.

The overtopping assessment shows the potential for peak overtopping at present to rates of approximately 124.3 l/s/m which is well outside the safe allowance for pedestrians. This overtopping rate will increase by a factor of 3 by 2050 and may be in excess of 1,009.5 l/s/m by 2100. With sea level rise, inundation events at lower levels effectively become more frequent. The frequency of overtopping and the extent would make the lower promenade levels unusable on frequent occasions and could cause damage to the seawall, paving and buildings during storms.

The use of the lower promenade and the location of the current buildings may need to be rethought as sea level rises. A thorough survey and assessment of the existing protection structures, paving, buildings and stormwater drainage is needed.

4.1.2.4 Sand Drift

Sand drift has posed an issue at Newcastle's beaches in the past, particularly where unvegetated dunal regions allowed for sand to ingress into coastal development. Dune revegetation works, commencing in 1988 and continuing to present, have been very effective in capturing sediment within the dunes and incipient dunes, promoting the accretion evident on the beaches at present. A curved deflector fence was constructed along John Parade in an attempt to minimise the wind blown sand being carried onto and across the road.

There are three remaining sites of sand drift that pose an issue, requiring management.

- At Dixon Park south of the boat ramp sand is often blown onto the footpath as the curved barrier is lower and dunal vegetation is less extensive around the ramp;
- The Cliff carpark is regularly ingressed with windblown sand. At the present time, small blowouts are evident within the dunes and some dune fencing has been exposed. The current management practice is to remove the sand from the carpark, although it is not clear if this sand is placed back on the beach;
- Adjacent to the concrete ramp on the southern side of Cooks Hill SLSC frequently experiences sand drift, with sand blowing across Memorial Drive into Empire Park. At times the sand accumulation is quite deep and must be removed by excavator. Dune vegetation is nearly non-existent adjacent to the concrete ramp and pedestrian access is uncontrolled. Various tracks from the ramp to the beach are typically evident.

4.1.2.5 Cliff and Slope Stability Hazards: Merewether to Shepherds Hill

Cliff and slope stability hazards were identified along this segment of coastline at the locations identified in Table 4-5 and Table 4-6. The assessed risk to property and life from these geo-hazards are summarised below.

Refer to *Geotechnical Assessment of Newcastle Coastal Cliffs/Slopes* by RCA (2013) in Appendix B for further details regarding the scope of these hazards.

Table 4-5 Geo-Hazard Risk to Property, Merewether to Shepherd Hill (RCA, 2013)

Coastal Geo-Hazard Site	Location	Assessed Risk at Present M.S.L.	Assessed Risk at 2050 M.S.L.	Assessed Risk at 2100 M.S.L
13	Cliff Top Walk, Strzelecki to Shepherds Hill	Low	No change	No change
14a	Shepherds Hill Cliff Top	Low	Likely to increase	Likely to increase
14b	Susan Gilmore Cliff	Moderate	Likely to increase	Likely to increase
15	Susan Gilmore Beach	Low	No change	No change
16a	Bar Beach Car Park (BBCP)	Moderate to High	Likely to increase	Likely to increase
16b	Bar Beach, below BBCP	Low	Likely to increase	Likely to increase
17	'The Cliff', North Dixon	Low	No change	No change
18	Baths & Beach below Lloyd St, Merewether	Moderate	No change	No change
19a	East end of Hickson St., Merewether	Moderate to High	No change	No change
19b	Rock Platform, below Hickson St Cliff	Low	No change	No change

Table 4-6 Geo-Hazard Risk to Life, Merewether to Shepherd Hill (RCA, 2013)

Coastal Geo-Hazard Site	Persons Most at Risk	Present Day Risk	Total Risk 2050	Total Risk 2100
13	Person(s) using walkway	2×10^{-5}	Not likely to be affected	Likely to increase
14a	Person(s) standing at cliff top barrier	4.5×10^{-4}	Not likely to be affected	Likely to increase
14b	Person(s) crossing 'notch' in rock platform	3.7×10^{-9}	Likely to increase	Likely to increase
15	Person(s) within 16 m of cliff/slope toe	8×10^{-6}	Not likely to be affected	Not likely to be affected
16a	Person(s) walking or leaning against cliff top barrier	3×10^{-7}	Likely to increase	Likely to increase
16b	Person(s) within 16 m of cliff/slope toe	3.6×10^{-6}	Likely to increase	Likely to increase
17	Person(s) within 16 m of cliff/slope toe	6×10^{-5}	Not likely to be affected	Not likely to be affected
18	Person(s) within 16 m of cliff/slope toe	1.6×10^{-5}	Likely to increase	Likely to increase
19a	Person(s) in residence or cliff top backyard	8.9×10^{-12}	Not likely to be affected	Not likely to be affected
19b	Person(s) within 16 m of cliff/slope toe	2.2×10^{-7}	Not likely to be affected	Likely to increase

4.2 Newcastle Beach

4.2.1 Beach Description

Newcastle Beach is a small pocket beach between the rocky headlands of Strezlecki Lookout to the south and Fort Scratchley headland to the north (Figure 1-1). The Newcastle Ocean Baths and associated pavilions have been constructed on the rocky platform at the northern end of the beach.

The beach has effectively no dune system with seawalls, pavilions, Newcastle Beach surf club, a skate park and promenades constructed along the entire back beach area (Figure 4-9). At the southern end, the beach is backed by a steep cliff. Shortland Esplanade has been constructed at the base of this cliff adjacent to the beach. It is now closed to vehicular traffic and substantial stability works have been undertaken to mitigate rock falls. The roadway is open to pedestrian and cycle traffic. Discussion of the geotechnical stability of this roadway has been provided by RCA Australia (2011).

Figure 4-9 Newcastle Beach (2011) - Promenades and Walls Back the Entire Beach

Shortland Esplanade continues from Newcastle around the base of Fort Scratchley to Nobbys Beach. The roadway is supported by an old revetment wall comprising a mix of mass concrete and mortared stone construction along its length, (see Section 4.2.2.3). Some repairs are apparent in places together with the addition of newer toe sections to repair apparent toe scour and prevent further scour. A short section of wall in the vicinity of the Cowrie Hole has been replaced with a modem reinforced concrete wall. Residential properties located behind the wall (on the opposite side of the Shortland Esplanade roadway) are relatively low lying and are subject to inundation during periods of elevated water levels and large waves. Indeed, wave overtopping onto the footpath adjacent to the roadway is observed frequently at high tide.

4.2.2 Hazards Definition

Coastal hazards defined for Newcastle Beach are summarised in Table 4-7 to Table 4-10 Extreme Wave Overtopping Rates (l/s/m), Newcastle Beach, below (excluding geo-hazards, see Section 4.2.2.4), and discussed in detail in the following section.

Table 4-7 Immediate Timeframe Hazards, Newcastle Beach

Likelihood	Erosion	Inundation	Wave Run up
Almost Certain	15 m	2.5 mAHD	N/A
Unlikely	25 m or limit of bedrock / seawall	2.7 mAHD	5.7 mAHD
Rare	40 m or limit of bedrock	2.9 mAHD	N/A

Table 4-8 2050 Hazards, Newcastle Beach

Likelihood	Erosion	Inundation	Wave Run up
Almost Certain	Variable, see Hazard Map, Figures B-6	2.5 mAHD	N/A
Unlikely		3.1 mAHD	6.0 mAHD
Rare		3.4 mAHD	N/A

Table 4-9 2100 Hazards, Newcastle Beach

Likelihood	Erosion	Inundation	Wave Run up
Almost Certain	Variable, see Hazard Map, Figures C-6	2.5 mAHD	N/A
Unlikely		3.6 mAHD	6.5 mAHD
Rare		4.1 mAHD	N/A

Table 4-10 Extreme Wave Overtopping Rates (l/s/m), Newcastle Beach

Location[1]	Immediate	2050	2100
Cowrie Hole	180.9	740.1	10,859.5
Newcastle Beach north end	176.6	405.5	1,649.6
Newcastle Beach near south end	117.8	257.8	831.9
Newcastle Beach south end	468.4	1,487.9	16,132.4

[1] See Table 3-14 for details.

4.2.2.1 Beach Erosion and Recession

Newcastle Beach presently has a relatively wide expanse of sand. However, during storms in the past (e.g. 1974), effectively all of this sand has been removed exposing underlying bedrock and causing damage to promenades and other structures. This is demonstrated clearly in Figure 4-10 and Figure 4-11.

Wave climate periods producing similar erosion extents have been reported at other times in the past (WBM, 2000), and so, similar extents of erosion can be expected to recur in the future.

Figure 4-10 South Newcastle Beach Erosion Extents Following Severe Storms circa 1974

Figure 4-11 Newcastle Beach Erosion Extents Following Severe Storms circa 1974

Contour plots of the 2 m and 4 m AHD contours derived from photogrammetric profiles demonstrate the naturally oscillating position of the beach in relation to storms and the variable wave climate, in Figure 4-12 and Figure 4-13. The beach erosion hazard is estimated for the immediate timeframe at Newcastle Beach in Table 4-7. Given the high exposure of all of the southern beaches to wave energy, the same extent of potential erosion was applied to all of the beaches. The methodology applied in deriving this hazard estimate is given in Section 3.2.

For future time periods, of particular note is the impact to beach amenity as shoreline retreat and storm erosion is limited by bedrock along the entire beach. It can be expected that complete removal of sediment from the upper beach will occur more frequently into the future as sea levels rise and wave action occurs at a higher position on the beach. Sections of the beach may comprise exposed bedrock for the majority of the time by 2100, or even as early as 2050. The impact to beach amenity is a key consideration for community and land managers in determining management responses to future sea level rise impacts.

The long term recession hazard due to sea level rise is added to the beach erosion estimates as explained in Section 3.3 and illustrated in the Figures Section at the end of this report.

4.2.2.2 Coastal Inundation and Wave Overtopping

The Newcastle Beach Surf Life Savings Club was replaced after the 1970s storms, however, it is still a low lying structure that could be expected to experience wave impacts during elevated ocean levels and storm conditions. Figure 4-14 demonstrates wave uprush during an erosion event of the 1970s.

The coastal inundation and wave overtopping assessment outlined in Section 3.3.4 determined that the lower promenades along the entire Newcastle Beach should be expected to be overtopped at present. Overtopping would be expected to affect the surf club and adjacent kiosk during such events at the present time. The volumes and frequency of overtopping is expected to increase in the future with sea level rise, in fact elevated ocean levels could engulf the promenades completely. The back beach area to the roadway and cliffs behind Newcastle Beach rises steeply (> 9 m AHD), and so is not expected to be affected by overtopping now or in the future with sea level rise. Overtopping of the lower promenades is largely contained by the higher back beach elevation, except for the walkway under the road within Newcastle Surf Club Pavilion. Discussion of the impact of overtopping to the condition and community use of the structures now and in the future is outlined in Section 4.2.2.3.

The elevated ocean water level analysis illustrates that Newcastle Baths and adjacent pools would be fully engulfed by ocean water during a severe storm at the present time. Due to sea level rise, the frequency of overtopping of the Baths will increase. Management of the condition of the Baths accounting for sea level rise is likely to be an important issue for the community.

Elevated ocean water levels, and areas that may be subject to wave run-up and overtopping at the immediate, 2050 and 2100 timeframes are given in the Figures Section at the end of this report.

Title:

Position of the 2 m AHD Contour Over Time, Newcastle Beach

Drawing: **4-12**

Rev: **A**

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

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0 100 200m

Approx. Scale

BMT WBM

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Title:

Position of the 4 m AHD Contour Over Time, Newcastle Beach

Drawing: **4-13**

Rev: **A**

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Approx. Scale

BMT WBM

www.wbmpl.com.au

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Figure 4-14 Wave Uprush onto Promenades and Former Surf Club, Newcastle circa 1974

4.2.2.3 Seawall Condition and Performance

The entire back beach area of Newcastle Beach is comprised of vertical seawalls and promenades, constructed at various times (as early as 1903) and of various materials. From Newcastle Beach to the Cowrie Hole, there is an exposed rock shelf on which the heritage Newcastle Ocean Baths are constructed. This complex incorporates a range of seawall structures, paved areas and the seaward walls of the baths and canoe pool themselves. The baths are regularly inundated by wave overtopping at high tides and need to be closed at present during storm events for safety reasons, raising issues for the future use of this area, as the inundation of the baths increases over time with sea level rise. The heritage Art Deco façade of the baths fronting Shortland Esplanade has been recently restored.

Overtopping calculations were undertaken at four sea wall sections along Newcastle Beach and the Cowrie Hole to the north of the baths (Sites 6, 7, 8 and 9, Figure 3-10). Site 6 is landward of the Cowrie Hole and adjacent to the residential development on the western side of Shortland Esplanade (Plate 2.14). Site 7 is towards the northern end of Newcastle Beach, between the Canoe Pool and dressing sheds (Plate 2.13). Site 8 is around the centre of the beach at the bottom of Church Street. Site 9 is at the southern end of the beach adjacent to the closed section of Shortland Esplanade below Ordnance Street (Plate 2.10).

At sites 7, 8 and 9 along the low esplanade fronting Newcastle Beach from south of the skate park to the canoe pool, the inundation computations have been carried out at the front of the apron where a low vertical concrete seawall separates the sand from the paved back beach area. The construction details for this seaward wall are unknown but bedrock is likely to shallowly underlie the beach and is exposed along the surf zone and offshore. The crest level along this promenade is very low, at 3.8 m AHD towards the northern end, 4.1 m at site 8 and 3 m AHD in the south (estimated from the 2007 LiDAR survey). The lower sections and toe of the wall are not visible and the level of the toe is not known. Newcastle Beach is oriented to the south east and exposed to the dominant south east swell direction. While there is an accumulation of sand in front of the wall, limiting direct wave attack at most times, this can be quickly eroded during storms exposing the underlying rock reef and subjecting the wall to direct wave action and overtopping across the promenade. There are retaining walls and other structures located along and behind the promenade that have not been designed to withstand wave action. The overtopping assessment shows the seawall and promenade can be substantially overtopped at present with rates varying from 117.8 l/s/m around the centre where the seawall crest is slightly higher, to 176.6 l/s/m at the northern end and 468.4 l/s/m at the southern end where the crest is lowest. The current overtopping rates along the promenade at present suggest it is unsuitable for pedestrian access during storms.

These overtopping volumes will more than double by 2050 and will increase by a factor of 4 to 8 along the central (Plate 2.12) and northern sections (Plate 2.13) by 2100. At the southern end where the crest level is lowest (Plate 2.10) the oceans storm level will be only a half metre below the promenade level by 2100. Storm waves will break across the promenade, possibly impacting the newly stabilised bluff slope 10m to 15m landward of the seawall crest. By 2100, the promenade will be unusable on many high tides and the extensive overtopping during storms may damage the seawall, paving and facilities on the promenade.

Similar to Merewether and Bar Beach, an assessment of the future use of the low beachfront area and the ocean baths and associated buildings is required for future planning. The existing protection structures are not well described and more detailed information is required to assess their suitability as future foreshore protection.

Plate 2.10. South Newcastle beach, old vertical rendered stone revetment protects the now closed section of Shortland Esplanade immediately behind the beach. **Photo:** Coastal Environment 30/04/2011.

Plate 2.11 Parts of the seawall (at least) are constructed on the rock shelf. Reclaimed tank traps have been placed at the base of the wall on the underlying rock at this most exposed location. The stone block construction can be inferred through the render, (similar to plate 2.15). Repairs to the upper section of the wall are clearly visible. **Photo:** Coastal Environment 30/04/2011.

Plate 2.12. A low level promenade runs around the foreshore from south end of Newcastle Beach to the Canoe Pool. A vertical seawall faces the promenade with low crest level. Structures and retaining walls are located landward of this seawall, at the base of the slope up to Shortland Esplanade above. **Photo:** Coastal Environment 30/04/2011.

Plate 2.13. At Newcastle Beach there are a range of protection structures at a low level separating the walkways, change sheds and paved areas from the sandy beach. These are of variable quality and largely undocumented construct. Stormwater services are intertwined with the protection works. **Photo:** Coastal Environment 30/04/2011.

At the Cowrie Hole (Site 6) the seawall is facing east south east. There is little sand on the beach with the rock shelf exposed at the base of the beach at low to mid tide. Shortland Esplanade is immediately behind the seawall and at the closest position the residential properties on the western side of Shortland Esplanade are less than 15 metres from the seawall crest. The seawall is of early construction and with a near vertical, concrete face. It is continuous and of similar section from the Newcastle Ocean Baths to Nobbys Beach. The wall is of unknown construction. (Plate 2.14). The crest level of the near vertical seawall at the Cowrie Hole is 3.0 m AHD (estimated from the 2007 LiDAR data) and the level of the toe is around 0 m AHD on the exposed rock shelf. This area of the wall is very low and is known to overtop under spring tides and moderate wave conditions several times per year when the debris line and sand deposition can be seen on the western side of Shortland Esplanade. The overtopping assessment shows the potential for peak overtopping at present to rates of 180.9 l/s/m which is unacceptable for pedestrian traffic and for motor vehicles during storms. This overtopping rate will continue to increase by a factor of 4 by 2050. By 2100, the design elevated ocean level will be only 0.4 m below the seawall crest and roadway, allowing the waves to directly impact the seawall crest and residential properties on the western side of Shortland Esplanade, with the roadway itself impassable. It is likely that damage to the seawall and/or the roadway would have occurred due to the more frequent overtopping in the future.

Plate 2.14. North of Newcastle baths, the old near vertical seawall continues along the shoreline to Nobbys Head. Again this seawall appears to be constructed on the rock shelf along Shortland Esplanade. Construction and foundation details are unknown. **Photo:** Coastal Environment 30/04/2011.

4.2.2.4 Cliff and Slope Stability Hazards: Shepherds Hill to Fort Scratchley Hill

Cliff and slope stability hazards were identified along this segment of coastline at the locations identified in Table 4-11 and Table 4-12. The assessed risk to property and life from these geo-hazards are summarised below.

Refer to *Geotechnical Assessment of Newcastle Coastal Cliffs/Slopes* by RCA (2013) in Appendix B for further details regarding the scope of these hazards.

Table 4-11 Geo-Hazard Risk to Property, Newcastle Beach (RCA, 2013)

Coastal Geo-Hazard Site	Location	Assessed Risk at Present M.S.L.	Assessed Risk at 2050 M.S.L.	Assessed Risk at 2100 M.S.L
4	Fort Scratchley Hill - NE	Low	No change	No change
5	Fort Scratchley Hill - E	Moderate	No change	No change
6	Shared Walkway, Newcastle Beach	Low	No change	No change
7	Shortland Esplanade, Newcastle Beach Skate Park	Low	No change	No change
8	Cliff above shared Walkway, South Newcastle	Very Low	No change	No change
9	Shared Walkway, South Newcastle	Low	Likely to increase	Likely to increase
10	Shortland Esplanade, King Edward Park	Low	Likely to increase	Likely to increase
11	Shortland Esplanade, Bogie Hole	High	No change	No change
12a	Cliff above Bogie Hole Viewing Area	Moderate	No change	No change
12b	Cliff above Bogie Hole Pool	Moderate	Likely to increase	Likely to increase

Table 4-12 Geo-Hazard Risk to Life, Newcastle Beach (RCA, 2013)

Coastal Geo-Hazard Site	Persons Most at Risk	Present Day Risk	Total Risk 2050	Total Risk 2100
4a	Person(s) in vehicle that impacts rock fall	8×10^{-6}	Not likely to be affected	Not likely to be affected
4b	Person(s) in vehicle that impacts rock fall	3×10^{-7}	Not likely to be affected	Not likely to be affected
5	Person(s) in vehicle that impacts failure debris	3.6×10^{-6}	Not likely to be affected	Not likely to be affected
6	Person(s) in impacted by block fall from wall	6×10^{-5}	Not likely to be affected	Not likely to be affected
7	Maintenance personnel and/or vehicles working under cliff/slope	1.6×10^{-5}	Not likely to be affected	Not likely to be affected
8	Person(s) using walkway protected by rock fall barrier fence	8.9×10^{-12}	Not likely to be affected	Not likely to be affected
9	Person(s) using walkway	2.2×10^{-7}	Not likely to be affected	Not likely to be affected
10	Person(s) using walkway	8.9×10^{-8}	Not likely to be affected	Not likely to be affected
11	Person(s) using walkway	3.6×10^{-5}	Not likely to be affected	Not likely to be affected
12a	Person(s) using viewing area, steps to pool	3.4×10^{-5}	Not likely to be affected	Not likely to be affected
12b	Person(s) within 16 m of cliff/slope toe	3.4×10^{-5}	Likely to increase	Likely to increase

4.2.2.5 Sand Drift

Newcastle Beach currently does not have a vegetated dune or incipient dune. As noted above, the beach is backed by a series of concrete promenades. The promenades in front of Newcastle Surf Club are frequently partially or fully covered with sand. The sand ingress typically reaches no greater than 0.3 m depth. Management action to return this sediment onto the beach face is likely to be the most appropriate option, as it is unlikely to be feasible to establish a dune at this location. Formation of a dune would also be unpopular with the community and life savers, as it may interfere with access and views to the beach.

4.3 Nobbys Beach

Nobbys Beach extends from the Fort Scratchley headland to Nobbys Head (Figure 1-1). The beach has formed adjacent to the southern breakwater of the entrance to Newcastle Harbour. This breakwater was constructed in the mid 1800's and connected the Fort Scratchley headland with Nobbys Island which is now known as Nobbys Head. The southern breakwater has effectively captured the natural net northerly littoral drift leading to the formation of Nobbys Beach. The effects of the Port of Newcastle upon sediment transport to the adjacent Stockton Beach are described in detail in Section 2.6.3.

The Nobbys Beach Surf Life Saving Club House and associated seawalls and promenades have been constructed at the southern end of the beach where there is effectively no dune system. Further to the north, a substantial dune system has formed adjacent to the breakwater (between Nobbys Head and the mainland). The dune and beach system broadens towards Nobbys Head and the beach extends around the base of the steep cliffs at Nobbys Head. The southern breakwater of Newcastle Harbour extends approximately 500m further offshore from Nobbys Head across the underlying rocky seabed.

4.3.1 Hazards Definition

Coastal hazards defined for Merewether to Bar Beaches are summarised in Table 4-13 to Table 4-16 below (excluding geo-hazards, see Section 4.3.1.4), and discussed in detail in the following section.

Table 4-13 Immediate Timeframe Hazards, Nobbys Beach

Likelihood	Erosion	Inundation	Wave Run up
Almost Certain	15 m	2.5 mAHD	N/A
Unlikely	25 m or limit of bedrock / seawall	2.7 mAHD	5.6 mAHD
Rare	40 m or limit of bedrock	2.9 mAHD	N/A

Table 4-14 2050 Hazards, Nobbys Beach

<table>
<tr><th>Likelihood</th><th>Erosion</th><th>Inundation</th><th>Wave Run up</th></tr>
<tr><td>Almost Certain</td><td rowspan="3">Variable,
see Hazard Map,
Figures B-5</td><td>2.5 mAHD</td><td>N/A</td></tr>
<tr><td>Unlikely</td><td>3.1 mAHD</td><td>5.9 mAHD</td></tr>
<tr><td>Rare</td><td>3.4 mAHD</td><td>N/A</td></tr>
</table>

Table 4-15 2100 Hazards, Nobbys Beach

Likelihood	Erosion	Inundation	Wave Run up
Almost Certain	Variable, see Hazard Map, Figures B-6	2.5 mAHD	N/A
Unlikely		3.6 mAHD	6.4 mAHD
Rare		4.1 mAHD	N/A

Table 4-16 Extreme Wave Overtopping Rates (l/s/m), Nobbys Beach

Location[1]	Immediate	2050	2100
Stockton SLSC	62.5	140.7	367.1
Nobbys Beach (south end)	107.8	240.5	846.3

[1] See Table 3-14 for details.

4.3.1.1 Beach Erosion and Recession

Nobbys Beach is essentially formed from the accretion of littoral drift sediment against the southern breakwater. The construction of the Hunter River entrance breakwaters commenced with a land bridge out to Nobbys Island completed in 1846, then the extension of the southern breakwater from Nobbys Island was completed in 1896. Historical paintings of Nobbys (Figure 4-15) at the time of the breakwater construction clearly illustrate waves breaking up onto the breakwater. The southern breakwater has interrupted the net northerly littoral drift, effectively capturing it against the breakwater to form Nobbys Beach (Figure 4-16).

Figure 4-15 Historical Painting of Nobbys Beach following Construction of Macquarie Pier (Newcastle Herald, 29 Sep 2010)

Figure 4-16 Nobbys Beach at Present (2011)

The photogrammetric data for Nobbys Beach demonstrates accretion of sand in the past, which has slowed and stabilised to the present position. For example, in the photogrammetric cross section in Figure 4-17, the formation of incipient dunes which have then been transported through wind landward to form a dune, then the formation of incipient dunes again is clearly evident, illustrating the processes through which the beach and dune system has formed. Contour plots for the 2 m and 4 m AHD position show a similar pattern of growth which has slowed to present, in Figure 4-18 and Figure 4-19.

At some point, the accumulation of sediment both above and below mean sea level has filled the available space at Nobbys and sediment will have then began to be transported past the southern breakwater. DHI (2006) model results indicate that bypassing of the southern breakwater is occurring, although much of this sediment is likely to accumulate within the navigation channel before being removed by periodic maintenance dredging works. The rate of accretion is expected to thus stabilise in the future, therefore Nobbys Beach is assumed to be stable into the future.

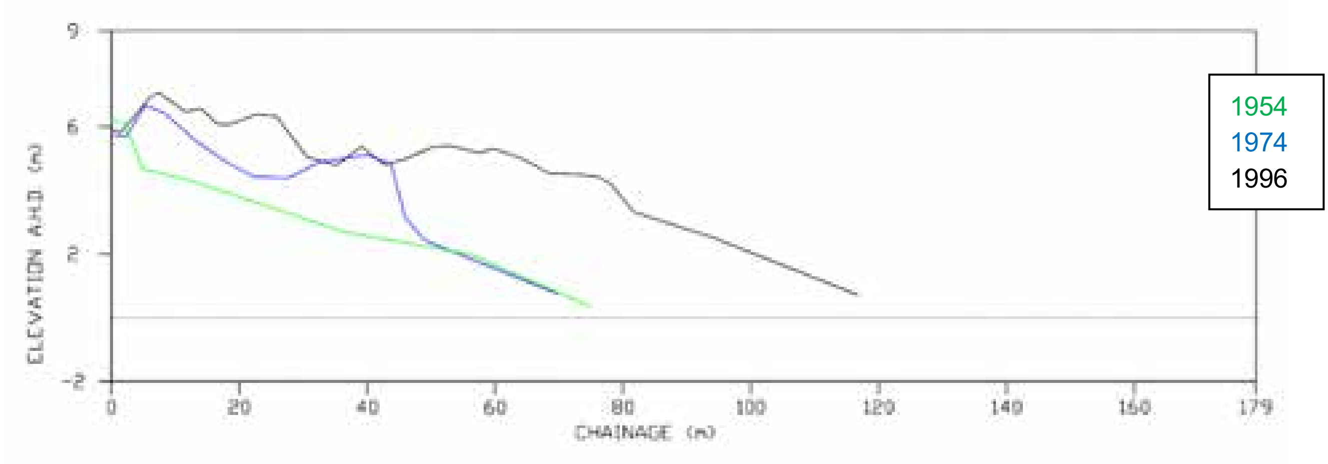

Figure 4-17 Photogrammetric Profile (B7P10) Illustrating Past Accretion on Nobbys Beach

Sand has also accumulated in Horseshoe Beach adjacent to the southern breakwater within the entrance channel, behind Nobbys Beach, as evident from historical photographs. Much of this sand is likely to have been blown over the southern breakwater and transported by wave/current action into Horseshoe Beach. DHI (2006) have also suggested a bypassing mechanism whereby sediment passes the southern breakwater and is transported along the entrance channel and eventually onto Horseshoe Beach.

The historical data at Nobbys Beach is obscured by the long term accretion, making it difficult to determine the potential extent of beach erosion during storms and periods of wave climate variability. Given the southern beaches of Newcastle are all well exposed to the ocean wave and water level climate, it is likely that Nobbys Beach would experience at least the same extent of erosion as evident on the other southern beaches. In fact, given the available sediment supply, actual volumes could be greater. However, the probabilistic approach to applying beach erosion estimates plus the ongoing supply of sediment into the system make it sensible to adopt the same values as at other southern beaches, as given in Table 4-13. Further details on derivation of the beach erosion hazard are given in Section 3.2.

While long term accretion has been evident at Nobbys Beach in the past, the rate of accretion has slowed in recent years, and would be expected to stabilise in the future without sea level rise.

A Shoreline Evolution Model was applied to determine the shoreline response at Nobbys Beach to the combined impact of future sea level rise and the effect of the southern breakwater to capture sediment within the system. The model results illustrate that as sea level rises, the water depths adjacent to the breakwater increase and the amount of sediment transport past the breakwater at these water depths is reduced. This results in sediment accumulating against the breakwater

This accumulation of sediment against the breakwaters with sea level rise is expected to reduce the potential recession on Nobbys Beach initially. However, by 2100 sediment transport into Nobbys is also reduced such that particularly the southern end of the beach will recede. The combined impacts of the trapping of sediment by the southern breakwater with sea level rise have been incorporated into defined hazard estimates at 2050 and 2100, using a probabilistic approach (outlined in Section 3.3). Erosion and recession hazard mapping is provided in the Drawings Section at the end of the report.

Title:
Position of the 2 m AHD Contour Over Time, Nobbys Beach

Figure: 4-18

Rev: A

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

N

0 100 200m
Approx. Scale

BMT WBM
www.bmtwbm.com.au

Filepath : K:\N2051_NewcastleCoastalHazards&Management\MI\Workspaces\DRG_014_111028_Drawing_4-18.WOR

Title:
Position of the 4 m AHD Contour Over Time, Nobbys Beach

Drawing: **4-19**

Rev: **A**

N

0 100 200m
Approx. Scale

BMT WBM
www.wbmpl.com.au

Filepath : K:\N2051_NewcastleCoastalHazards&Management\MI\Workspaces\DRG_014_111028_Drawing_4-19.WOR

4.3.1.2 Coastal Inundation and Wave Overtopping

Coastal inundation through elevated water levels plus wave run-up and overtopping was assessed in Section 3.3.4. For the sandy beach area of Nobbys Beach, a wave run-up level during the elevated water levels associated with a 100 year recurrence storm may reach 5.6 m AHD at present. This may increase to 5.9 m by 2050 with 0.4 m sea level rise and to 6.4 m with 0.9 m sea level rise by 2100.

Elevated ocean water levels, and areas that may be subject to wave run-up and overtopping at the immediate, 2050 and 2100 timeframes are given in the Figures Section at the end of this report.

Nobbys Beach is also backed by vertical seawalls and promenades that are exposed at the southern end of the beach. The seawall section along Shortland Esplanade is observed to overtop frequently at high tides at present, and the frequency and volumes of overtopping are expected to increase in the future with projected sea level rise. This will impact on both the condition of the structure itself as well as use of the roadway above. Seawall condition and performance under overtopping is discussed in Section 4.3.1.3 below.

4.3.1.3 Seawall Condition and Performance

In addition to the southern entrance breakwater and Macquarie Pier (i.e. the historic structure built between Newcastle Mainland and Nobbys Head) against which Nobbys Beach has formed, there are also vertical walled promenades along the southern end of the beach and adjacent Shortland Esplanade.

Overtopping calculations were undertaken at two sea wall sections along Nobbys Beach (Site 4 and 5, Figure 3-10). Site 4 is at the southern end of Nobbys Beach, at the northern end of the carpark and Site 5 is in front of the Nobbys Beach SLSC.

At the eastern end of Nobbys SLSC (Site 5), the beach is oriented to the north east and sheltered from the predominant swell, but exposed to the east and north east. The seawall is a vertical concrete wall of unknown construction. There is an accumulation of sand in front of the wall and the lower sections and toe are not visible. To the east there is rock exposed in the surf zone, adjacent to the continuing vertical seawall connected with Shortland Esplanade (Plate 2.16 and 2.15 to the south).

The crest level of the vertical seawall at Site 5 is 4.0 m AHD (estimated from 2007 LiDAR survey) and the level of the toe is not known. The overtopping assessment shows the potential for increasing overtopping rates to the east as the exposure of the wall increases. At this location (Plate 2.16) overtopping at present for peak storm conditions is 107.8 l/s/m which is unacceptable for pedestrian traffic and of concern for motor vehicles. Indeed, this section of wall (such as shown in Plate 2.15) is already known to overtop at high tide. This overtopping rate will continue to increase, doubling by 2050 and increasing by a factor of 8 to 2100. By that time the overtopping is estimated at 846 l/s/m and may result in damage to the paving behind the seawall and possibly to the seawall itself.

At the southern end of Nobbys Beach (Site 4), the beach is facing south-east and exposed to the predominant swell direction. The back beach is protected by a vertical, concrete finished wall of unknown construction (Plate 2.17). There is a buildup of sand to the north in front of the wall and the lower part of the wall and toe are not visible. Further north the wall disappears beneath the sand accretion against the wall, Macquarie pier and Nobbys Head. This sand buildup reaches a width of almost 150 metres at the base of Nobbys Head, buffering the wall at that location from wave attack. The crest level of the near vertical seawall at Site 4 is 5.8m AHD (estimated from 2007 LiDAR survey) and the level of the toe is not known. The overtopping assessment shows the potential for significant overtopping at present at rates of 62.5 l/s/m which is unacceptable for pedestrian traffic and of concern for motor vehicles during storms. This overtopping rate will continue to increase, doubling by 2050 and increasing by a factor of 6 to 2100. By that time the peak overtopping is estimated at 367.1 l/s/m and may result in damage to the paving behind the seawall and possibly to the seawall itself.

Overall the seawalls along Nobbys Beach are performing well (apart from potential storm overtopping) at present and appear in relatively sound condition based on the visual assessment.

Plate 2.15. Exposed section of the seawall at the south end of Nobbys Beach suggests a construction of stone blocks, possibly with a later addition of render. A substantial toe section can be seen and appears to be founded on the rock shelf. **Photo:** Coastal Environment 30/04/2011.

Plate 2.16. South of the SLSC and shelter shed, the roadway has been widened and a section of reinforced concrete seawall constructed. **Photo:** Coastal Environment 30/04/2011.

Plate 2.17. Along the northern section of Nobbys Beach there is a vertical seawall adjacent to the carpark. Construction details are unknown. The whole of Nobbys Beach to the north is backed by the early 19th century construction of Macquarie Pier joining Nobbys Head to the mainland. **Photo:** Coastal Environment 30/04/2011.

4.3.1.4 Cliff and Slope Stability Hazards: Nobbys Head

Cliff and slope stability hazards were identified along this segment of coastline at the locations identified in Table 4-11 and Table 4-12. The assessed risk to property and life from these geo-hazards are summarised below.

Refer to *Geotechnical Assessment Of Newcastle Coastal Cliffs/Slopes* by RCA (2013) in Appendix B for further details regarding the scope of these hazards.

Table 4-17 Geo-Hazard Risk to Property, Nobbys Beach (RCA, 2013)

Coastal Geo-Hazard Site	Location	Assessed Risk at Present M.S.L.	Assessed Risk at 2050 M.S.L.	Assessed Risk at 2100 M.S.L
1	Nobbys Headland, Breakwater Pathway	Low	No change	No change
2	Nobbys Headland, N Beach	Low	No change	No change
3	Nobbys Headland, Signal Station	Moderate	No change	No change

Table 4-18 Geo-Hazard Risk to Life, Nobbys Beach (RCA, 2013)

Coastal Geo-Hazard Site	Persons Most at Risk	Present Day Risk	Total Risk 2050	Total Risk 2100
1	Person(s) on breakwater footpath in the 20 m long rock fall risk zone hit by rock fall	2×10^{-5}	Not likely to be affected	Not likely to be affected
2	Person(s) within 16 m of cliff/slope toe	4.5×10^{-4}	Not likely to be affected	Not likely to be affected
3	Person(s) in building or behind brick fence when cliff top failure occurs	3.7×10^{-9}	Not likely to be affected	Not likely to be affected

4.3.1.5 Sand Drift Hazards

The northern end of Nobbys Beach presently has a substantial vegetated dune, with typically native Spinifex and occasional Bitou Bush plants.

Sand drift is known to be occurring at the southern end of Nobbys Beach, where sand occasionally accumulates across the roadway and up against the wall of the Nobbys Surf Club equipment shed. Some of this sand continues across into the river channel and is then reworked into Horseshoe Beach. Horseshoe Beach was known in Newcastle as 'the sand trap' around the 1940s and 50s. Small scale enterprises would collect sand from the 'sand trap' to sell to local builders.

The extent to which this sand drift poses a hazard to beach use is unknown. Management actions to excavate the sand and return it to Nobbys Beach are likely to be effective. There is also the possibility of extending dune vegetation works (using low lying species) along the southern part of the beach in front of the existing vertical wall. The loss of sediment is considered minor to the overall sediment budget, particularly as Nobbys Beach is effectively accreting at present.

The local surfing population who utilise the reefs at Nobbys Beach have raised concerns that the Spinifex may be accumulating sediment and affecting the surf break. The growth of incipient dunes through wind and wave processes is typically a short term process, with large storms reworking this sediment back into the surfzone. Prolific spinifex growth should therefore be considered short term. It is better for windblown sediments to be captured within the dunes by vegetation. Without capture by vegetation, the sediment would be readily blown across the breakwater and into the Hunter River channel, where it would likely be dredged and removed offshore to the offshore disposal site, lost permanently from the system. That is, it is better for the sand to be retained in the dunes of Nobbys Beach where it can provide a buffer to storm erosion than be lost to the river system.

4.4 Stockton Beach

Stockton Beach is located at the southern end of the larger embayed section of sandy coast known as Stockton Bight. The northern breakwater of the Hunter River entrance forms the southern end of the beach unit (Figure 1-1). Further north, the beach sweeps in a long gentle curve with a northeast alignment (facing southeast) some 32 kilometres to Birubi Point, Anna Bay.

Stockton Beach is known to have experienced ongoing recession, overlain on the natural periods of erosion and accretion. Following the CHDS (WBM, 2000), additional detailed investigations into the processes on Stockton Beach have been completed, including:

- *Shifting Sands at Stockton Beach* (Umwelt, 2002);
- *Stockton Beach Coastal Processes Study* (DHI 2006); and
- *Stockton Beach Coastal Processes Study Addendum – Revised Coastal Erosion Hazard Lines 2011* (DHI, 2011).

All of these studies indicate that Stockton Beach is experiencing ongoing recession as a result of the cessation of littoral drift past the Newcastle Harbour Breakwaters into the beach.

At the present time, Stockton Beach is in a relatively accreted state, following suitable wave climate conditions. For example, in Figure 4-20 a wide berm and accretion onto Mitchell Street seawall is evident; and Figure 4-21 illustrates accretion over former erosion escarpments north of the Stockton Surf Club.

The historical erosion has previously threatened development in the central section of the beach along Mitchell Street as well as facilities such as the Surf Life Saving Club House and pavilion at the southern end of the beach. At the northern end of the study area, the ponds of the Hunter Water Corporation's Wastewater Treatment Works are adjacent to the beach. Originally four ponds were constructed in the late 1960's, however, one pond has been lost to erosion and the next most seaward pond is now under threat.

In response to the erosion threat, in 1989, a substantial rock seawall was constructed between Pembroke Street and Stone Street to protect the adjacent section of Mitchell Street and residential properties. A sandbag wall with a design life of 5 years was also constructed in November 1996 to provide interim protection for the Stockton Surf Life Saving Club. The sandbag wall was implemented as a short term solution, however, it is still present and functional some 15 years later. An extension to the sandbag wall was constructed in June 2011, extending the structure at the base of the SLSC towards the north.

A dune system was formed between the northern breakwater and Pembroke Street and also north of the rock seawall to Meredith Street during the period 1988 to 1991. In the mid 1990s, Stockton Beach was severely eroded during storms to the extent that effectively all of the previous dune reconstruction works were lost. In the late 1990s, a new dune system was constructed south from the Surf Club area and seaward of the Stockton Caravan Park. The dune was constructed to RL 5.0m AHD along an alignment consistent with the recommendations of the Remedial Action Plan (WBM, 1996) and vegetated with native plants. Fencing has also been carried out to provide controlled pedestrian access to the beach thereby protecting the dune vegetation. Elsewhere along the beach a dune system is absent and the general ground level is as low as 4.0m AHD in places.

Figure 4-20 Stockton Beach (June 2011) With Sand Accreted Onto Mitchell St Seawall

Figure 4-21 Stockton Beach (June 2011) Looking South to the Surf Club

Figure 4-22 Stockton Beach (July 1999) Without Sand at Mitchell St Seawall

Figure 4-23 Stockton Beach (July 1999) Looking South to the Surf Club

4.4.1 Hazards Definition

Coastal hazards defined for Stockton are summarised in Table 4-19 to 1 Erosion distances increase in a northerly direction, see Hazard Maps, Figures C-1 to C-4

Table 4-22 below and discussed in detail in the following section.

Table 4-19 Immediate Timeframe Hazards, Stockton Beach

Likelihood	Erosion[1]	Inundation	Wave Run up
Almost Certain	10 – 24.5 m	2.5 mAHD	N/A
Unlikely	30 – 42.5 m, or limit of seawall	2.7 mAHD	5.5 mAHD
Rare	40 – 67 m	2.9 mAHD	N/A

[1] Erosion distances increase in a northerly direction, see Hazard Maps, Figures A-1 to A-4

Table 4-20 2050 Hazards, Stockton Beach

Likelihood	Erosion[1]	Inundation	Wave Run up
Almost Certain	10 – 59.7 m, or limit of seawall	2.5 mAHD	N/A
Likely	38.2 – 87.9 m, or limit of seawall	N/A	N/A
Unlikely	58.2 – 105.9 m, or limit of seawall	3.1 mAHD	5.8 mAHD
Rare	68.2 – 130.4 m	3.4 mAHD	N/A

[1] Erosion distances increase in a northerly direction, see Hazard Maps, Figures B-1 to B-4

Table 4-21 2100 Hazards, Stockton Beach

Likelihood	Erosion[1]	Inundation	Wave Run up
Almost Certain	10 – 99.7 m, or limit of seawall	2.5 mAHD	N/A
Likely	78.2 – 167.9 m, or limit of seawall	N/A	N/A
Unlikely	98.2 – 185.9 m, or limit of seawall	3.6 mAHD	6.3 mAHD
Rare	108.2 – 210.4 m	4.1 mAHD	N/A

[1] Erosion distances increase in a northerly direction, see Hazard Maps, Figures C-1 to C-4

Table 4-22 Extreme Wave Overtopping Rates (l/s/m), Stockton Beach

Location[1]	Immediate	2050	2100
Stockton Dunes North of Seawall	23.1	63.2	203.7
Stockton Seawall	1.2	6.0	37.1

[1] See Table 3-14 for details.

4.4.1.1 Beach Erosion and Recession

The complex coastal processes at Stockton Beach have been investigated using various modelling techniques as part of the *Stockton Beach Coastal Processes Study* (DHI, 2006) and *Stockton Beach Coastal Processes Study Addendum – Revised Coastal Erosion Hazard Lines 2011* (DHI, 2011). The study provides discussion and estimates for short and medium term beach erosion, ongoing recession and recession due to sea level rise at NSW Government projections of 0.4m AHD by 2050 and 0.9 m AHD by 2100.

Potential short term erosion for Stockton Beach was analysed by DHI (2006) using a dune erosion model. The erosion estimates adopted by DHI (2006) at various locations along Stockton Beach are listed in Table 3-6, and were recommended to present the 'almost certain' likelihood of occurrence. The erosion estimates by DHI (2006) included additional effects associated with the breakwater at the southern end of the beach.

Using photogrammetric data, DHI (2006) also attempted to estimate erosion relating to medium term wave climate variability, such as enhanced storminess or more easterly wave direction over a sustained period. From their analysis, DHI (2006) provided a best estimate of 20 m shoreline movement along the shoreline south of the Mitchell St seawall, and 18 m north of the seawall. These values combined with the short term erosion estimates are recommended to be adopted as the 'unlikely' erosion extent for the immediate timeframe, as given in Table 3-6. In accordance with the risk approach applied at the southern beaches, the 'rare' immediate erosion extent forms the addition of the 'almost certain' and 'unlikely' values, in Table 3-6 also.

Analysis was also undertaken to determine the impact of ongoing deepening of the nearshore off Stockton Beach upon potential erosion extents at the dune face. DHI (2006) estimated that a further deepening of the nearshore zone by 1 m would increase erosion rates by another 5%. However, these values were not incorporated into the hazard estimates by DHI (2006).

Detailed studies of coastal processes at Stockton Beach conducted by DHI (2006) indicated that the beach is experiencing ongoing recession due to the cessation of littoral drift into the compartment from the southern beaches past the entrance breakwaters. DHI (2006) results found that the southern end of Stockton Beach is in fact stable, while the northern end from Mitchell St seawall is receding. While bypassing of the southern breakwater is very likely to be occurring, the sediment is either removed through entrance maintenance dredging, or is in water depths too great for significant wave driven currents to transport the sediment back onto Stockton Beach (DHI, 2006).

The northern breakwater acts to shadow the southern end of Stockton Beach from south easterly swells, and a complex pattern of transport is generated towards the south and captured against the northern breakwater (DHI, 2006). Both the WBM (2000) and Umwelt (2002) studies also identified a slight accretionary trend at the southern end of Stockton Beach.

A nodal point where the transport changes direction is reported at the northern end of the seawall. Here, the transport changes from a net southerly drift to a net northerly drift, starting at low rates (~ 4,500 m^3/yr) and increasing to the regional rate of 30,000 m^3/yr at the sewage treatment ponds along Stockton Beach. However, because this section of coast is no longer supplied by littoral drift from the south, the shoreline is continuing to recede.

DHI (2006) model results determined a best estimate of shoreline retreat of 1 m/yr at the Meredith Street Child Care Centre increasing up to 1.3 m/yr at the sewage treatment ponds, then back to 0.8 m/yr at the Fort Wallace Stockton Centre to the end of Stockton Beach to the LGA Boundary. These rates were found to be in good agreement with historical recession rates of 1 – 1.3 m/yr along this stretch of beach (DHI, 2006).

Based upon the rationale applied to determine likelihood of erosion and recession extents given in Section 3.2, it is recommended that the long term recession by 2050 and 2100 extent be added to the immediate 'almost certain' beach erosion extent, as given in Table 3-7 and Table 3-8.

The 'unlikely' recession hazard should also account for the long term recession estimate, and additionally include the recession due to sea level rise. DHI (2011) estimated 28 m by 2050 and 68 m by 2100 additional recession along Stockton Beach due to sea level rise, using a Bruun Rule approach with the NSW Government's latest projections. These values have been added to derive the 'unlikely' recession hazard at 2050 and 2100 in Table 3-7 and Table 3-8.

Detailed modelling capable of investigating the combined impacts of the harbour breakwaters and sea level rise on shoreline response was conducted for this study, as detailed in Section 3.3.2. The outcomes of the modelling suggest the values given by DHI (2011) using a uniform Bruun Rule approach are suitable at Stockton Beach. Longshore sediment transport into Stockton Beach has been completely interrupted by the Port of Newcastle entrance, and no future change in this supply may be expected with sea level rise. The remainder of Stockton Beach is an uninterrupted sandy barrier without structures that may interrupt longshore sediment transport as sea level rises.

As part of the shoreline recession modelling, a higher than predicted sea level rise was investigated as a 'rare' scenario. The worst case scenario of either 'rare' immediate beach erosion plus ongoing recession plus recession due to projected sea level rise of 0.9m by 2100 or 'unlikely' immediate beach erosion plus ongoing recession plus recession due to a 0.5m higher than projected sea level rise was recommended for adoption. The worst case scenario values are listed under the 'rare' scenario for 2050 and 2100 in Table 3-7 and Table 3-8.

4.4.1.2 Coastal Inundation and Wave Overtopping

Coastal inundation through elevated water levels plus wave run-up and overtopping was assessed in Section 3.3.4. For the sandy beach area of Stockton Beach, a wave run-up level during the elevated water levels associated with a 100 year recurrence storm may reach 5.5 m AHD at present. This may increase to 5.8 m by 2050 with 0.4 m sea level rise and to 6.3 m with 0.9 m sea level rise by 2100.

The potential overtopping hazard for seawall sections along Stockton Beach at present and in the future with projected sea level rise is discussed in Section 4.4.1.3 below.

Elevated ocean water levels, and areas that may be subject to wave run-up and overtopping at the immediate, 2050 and 2100 timeframes are given in the Figures Section at the end of this report.

4.4.1.3 Seawall Condition and Performance

There are two seawalls located along the southern end of Stockton Beach in the Newcastle LGA:

- Stockton SLSC geotextile revetment; and

- Mitchell Street seawall.

Following concerns with erosion a revetment was constructed around the Stockton Surf Club as emergency protection in 1996. That structure is still in place and in early 2011 was augmented with construction of an extension, return and access way on the northern side. Details of the design for this later work and information relating to the design of the original work are included in the Review of Environmental Factors prepared by GBA Associates (GBA, 2011).

Plate 2.18. A temporary geotextile sand filled container wall was constructed in 1996 to protect the Stockton Surf Club building. This has recently been upgraded and extended further north. There are no formal protection works between the Surf Club and the Mitchell St. seawall. **Photo:** BMT WBM 26/07/1999.

The old and the new revetments are constructed of sand filled geotextile containers on a geotextile underlayer. The crest level varies from about 4.0 m AHD on the original works to 4.4 m AHD for the more recent works (GBA, 2010). The original section appears to have a toe level about -1.5m AHD and the more recent section is slightly elevated with the toe at -1.0m AHD. Both walls are constructed at a slope of 1.0V to 1.5H. The design life quoted for the most recent works is 20 years while the older section in front of the SLSC has exceeded its design life but is still in place. The older section of works were tested during a storm around 2000 when the structure was overtopped with water and sand washing through the ground floor of the SLSC (GBA, 2010).

Overtopping modelling undertaken for this assessment (Site 3, Figure 3-10) shows significant overtopping of the structure (38.0 l/s/m) is possible at present and will increase by a factor of 3 to 2050 and 10 to 2100 (315.7 l/s/m). Current overtopping rates pose a strong hazard to pedestrians during severe storms and are likely to cause damage to the building which is sited immediately behind the revetment crest. The design does not incorporate allowance for sea level rise and the increasing levels of overtopping in the future could be expected to result in damage to the seawall itself and place the SLSC building at extreme risk, should it still be in service at that time.

Mitchell Street seawall

The Mitchell Street seawall was constructed in 1989 and extends along 550 metres of the Stockton beach frontage between Pembroke Street in the south and Stone Street in the north (as shown in Figure 4-20 and Figure 4-22). Information on the wall design is recorded in the Newcastle City CoN files (50/00502/00000/13). The wall was constructed to a design prepared by the NSW Public Works Department. It comprises two layers of primary armour stone (3.2 tonne to 5.3 tonne) at a slope of 1V to 1.5H, and two layers of secondary armour with a geotextile filter underlayer. The crest of the wall is at 5.5 m AHD (approximately the same as the Mitchell St. road surface) and the toe is at a level of -2.0 m AHD.

The wall is frequently exposed to storm wave conditions and has been in service for over 20 years. It has performed satisfactorily through that period. The crest of the revetment was constructed at 5.5m AHD and is protected on the landward side by a buried gabion and reno mattress. Inspection of the wall suggests that sections of the crest may have settled, which is common for rock revetments subject to high wave energy. Survey of the crest is recommended to ascertain the present crest armour levels. If required, additional rock could be placed along the crest to restore the original design protection.

The original design incorporates a stormwater outlet through the wall. The pipe is cased in concrete and supported on a reno mattress and gabions at the exit through the wall. These gabions have corroded and are open, leaking rocks onto the beach (Plate 2.19). This should be repaired to avoid the potential of damage or breakage of the stormwater line within the wall and danger to the public.

Plate 2.19. Gabion baskets used to bed a concrete lined stormwater drainage pipe through the Mitchell St. seawall have rusted and broken. Maintenance is required to avoid more extensive damage. **Photo:** Coastal Environment 30/04/2011.

Overtopping modelling undertaken for this assessment (Site 2, Figure 3-10) shows minimal overtopping of the structure may occur at present (1.2 l/s/m) which could pose a low risk to some pedestrians on the crest. The overtopping and risk to pedestrians will increase by 2050 (6.0 l/s/m) and by 2100 may be as high as 37.1 l/s/m. At this time the inundation would pose a serious and unacceptable risk to pedestrians and a high level of hazard to motor vehicles on Mitchell Street during storms.

Subject to appropriate maintenance and the addition of measures to reduce future overtopping, this seawall should continue to perform in accordance with the design objectives for the foreseeable future.

Plate 2.20. North of the end of the Mitchell St seawall at Stone St., there is no protection of the back beach area which has eroded into the dune fronting the child care centre and further north. **Photo:** Coastal Environment 30/04/2011.

4.4.1.4 Sand Drift

North of Stockton SLSC to the seawall, ongoing recession has essentially impeded the growth of dunal vegetation. North of the seawall, dunal vegetation is present, but again is patchy due to more frequent erosion events. While the dune vegetation at these sites is limited, sand drift causing ingress and accumulation on private property does not appear to be a significant issue. It is recommended that dune vegetation works be continued, which will enable storage of sediment volumes as a buffer from erosion events.

Stockton Beach is also part of the larger Stockton Bight beach system which extends along some 32 kilometres to the north east. Aeolian processes are significant within this highly active and vast transgressive dune system. While this system is very dynamic, it is a natural system, and there is limited development.

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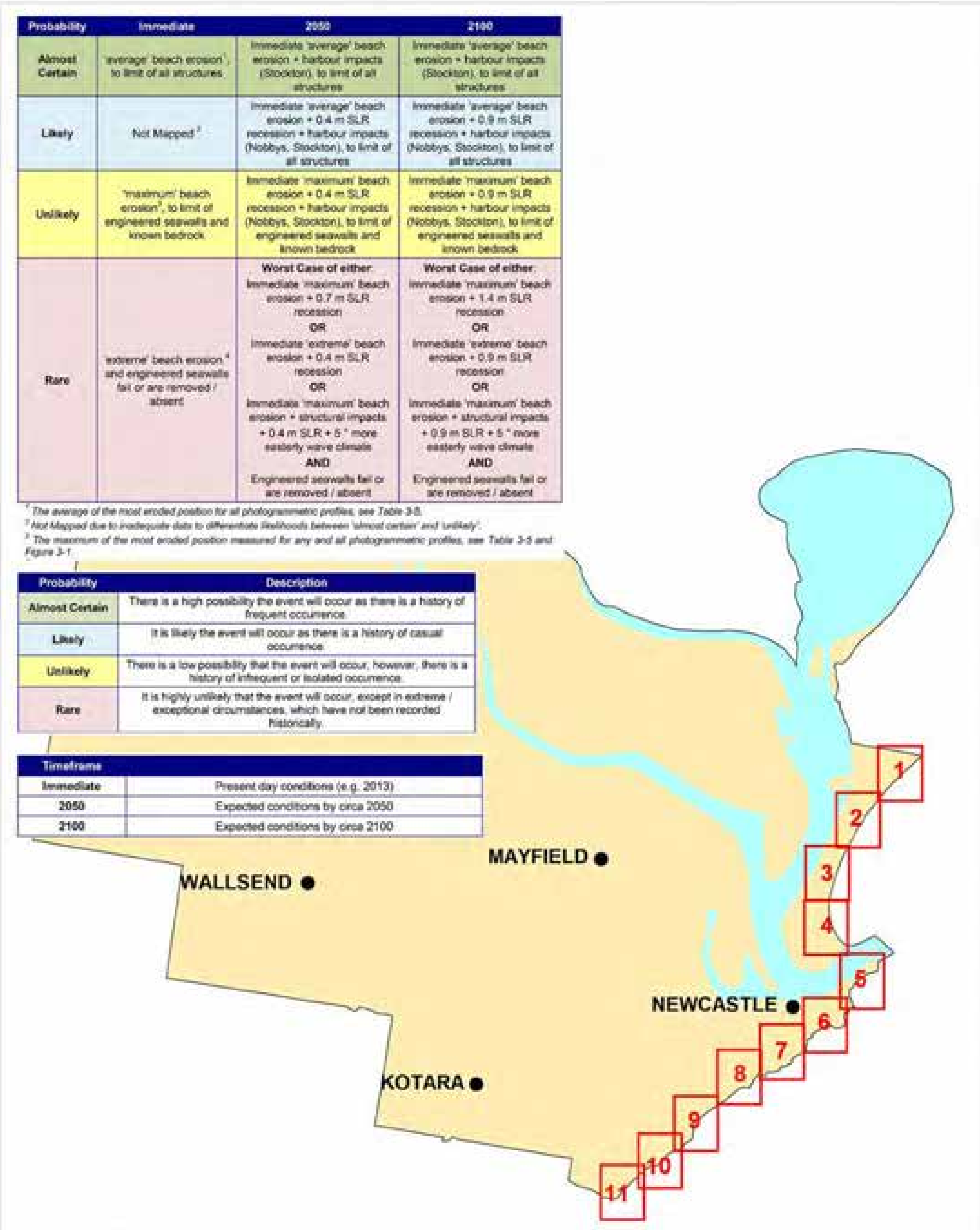
6 DRAWINGS

Probability	Immediate	2050	2100
Almost Certain	'average' beach erosion[1], to limit of all structures	Immediate 'average' beach erosion + harbour impacts (Stockton), to limit of all structures	Immediate 'average' beach erosion + harbour impacts (Stockton), to limit of all structures
Likely	Not Mapped[2]	Immediate 'average' beach erosion + 0.4 m SLR recession + harbour impacts (Nobbys, Stockton), to limit of all structures	Immediate 'average' beach erosion + 0.9 m SLR recession + harbour impacts (Nobbys, Stockton), to limit of all structures
Unlikely	'maximum' beach erosion[3], to limit of engineered seawalls and known bedrock	Immediate 'maximum' beach erosion + 0.4 m SLR recession + harbour impacts (Nobbys, Stockton), to limit of engineered seawalls and known bedrock	Immediate 'maximum' beach erosion + 0.9 m SLR recession + harbour impacts (Nobbys, Stockton), to limit of engineered seawalls and known bedrock
Rare	'extreme' beach erosion[4] and engineered seawalls fail or are removed / absent	**Worst Case of either** Immediate 'maximum' beach erosion + 0.7 m SLR recession **OR** Immediate 'extreme' beach erosion + 0.4 m SLR recession **OR** Immediate 'maximum' beach erosion + structural impacts + 0.4 m SLR + 5 ° more easterly wave climate **AND** Engineered seawalls fail or are removed / absent	**Worst Case of either** Immediate 'maximum' beach erosion + 1.4 m SLR recession **OR** Immediate 'extreme' beach erosion + 0.9 m SLR recession **OR** Immediate 'maximum' beach erosion + structural impacts + 0.9 m SLR + 5 ° more easterly wave climate **AND** Engineered seawalls fail or are removed / absent

[1] *The average of the most eroded position for all photogrammetric profiles, see Table 3-5.*
[2] *Not Mapped due to inadequate data to differentiate likelihoods between 'almost certain' and 'unlikely'.*
[3] *The maximum of the most eroded position measured for any and all photogrammetric profiles, see Table 3-5 and Figure 3-1.*

Probability	Description
Almost Certain	There is a high possibility the event will occur as there is a history of frequent occurrence.
Likely	It is likely the event will occur as there is a history of casual occurrence.
Unlikely	There is a low possibility that the event will occur, however, there is a history of infrequent or isolated occurrence.
Rare	It is highly unlikely that the event will occur, except in extreme / exceptional circumstances, which have not been recorded historically.

Timeframe	
Immediate	Present day conditions (e.g. 2013)
2050	Expected conditions by circa 2050
2100	Expected conditions by circa 2100



Title:
Index to Erosion and Recession Hazard and Risk Drawings

Figure: INDEX

Rev: A

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Title:

Erosion and Recession Hazard Definition Immediate Planning Horizon - Fern Bay

Figure: A-1

Rev: A

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Title:

Erosion and Recession Hazard Definition
Immediate Planning Horizon - Fort Wallace

Figure: **A-2**

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Erosion and Recession Hazard Definition
Immediate Planning Horizon - Stockton North

Figure: A-3

Rev: A

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Erosion and Recession Hazard Definition
Immediate Planning Horizon - Stockton South

Figure: **A-4**

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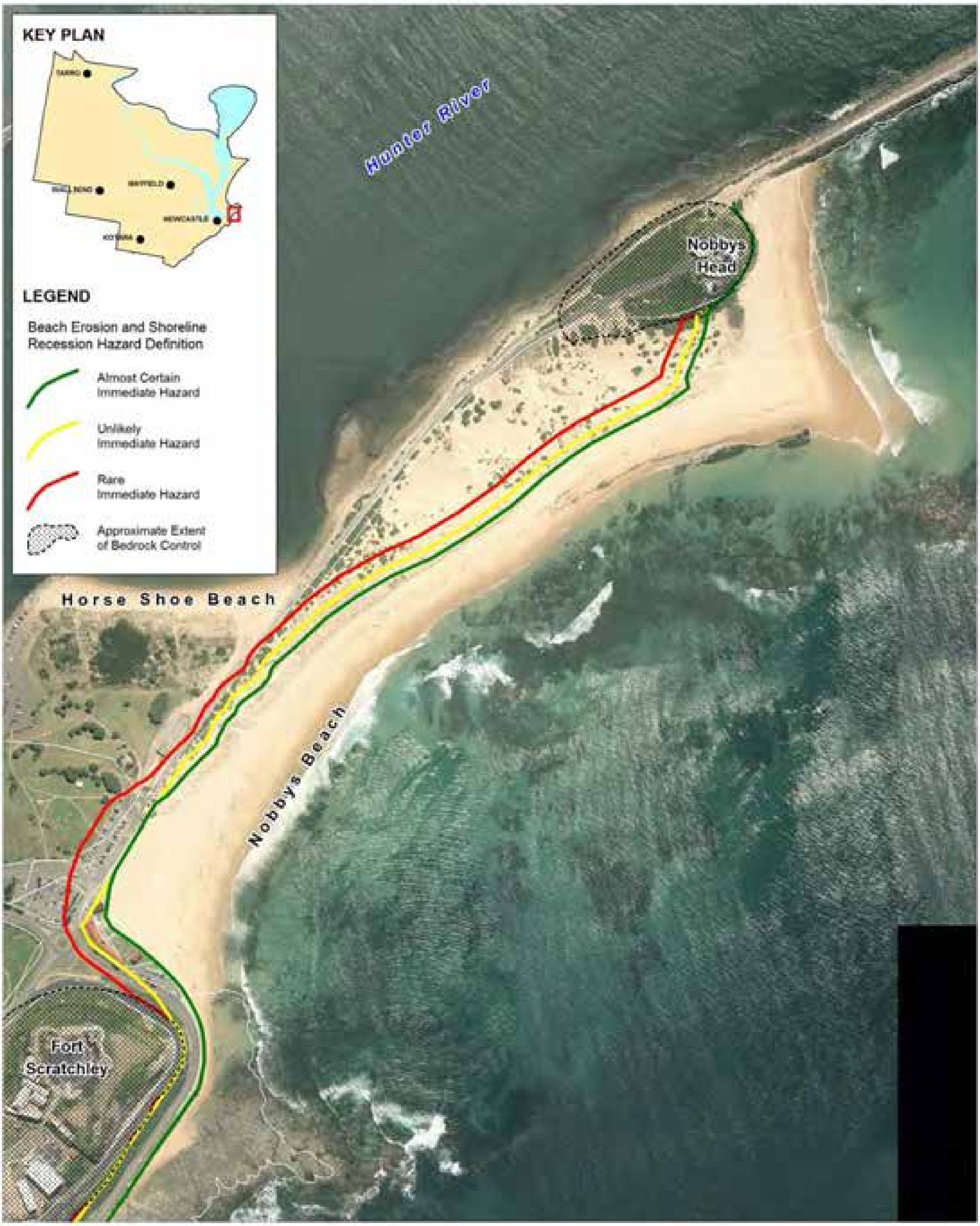

Title:

Erosion and Recession Hazard Definition
Immediate Planning Horizon - Nobbys Beach

Figure: **A-5**

Rev: **A**

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Title:
Erosion and Recession Hazard Definition
Immediate Planning Horizon - Newcastle Beach

Figure: **A-6**

Rev: **A**

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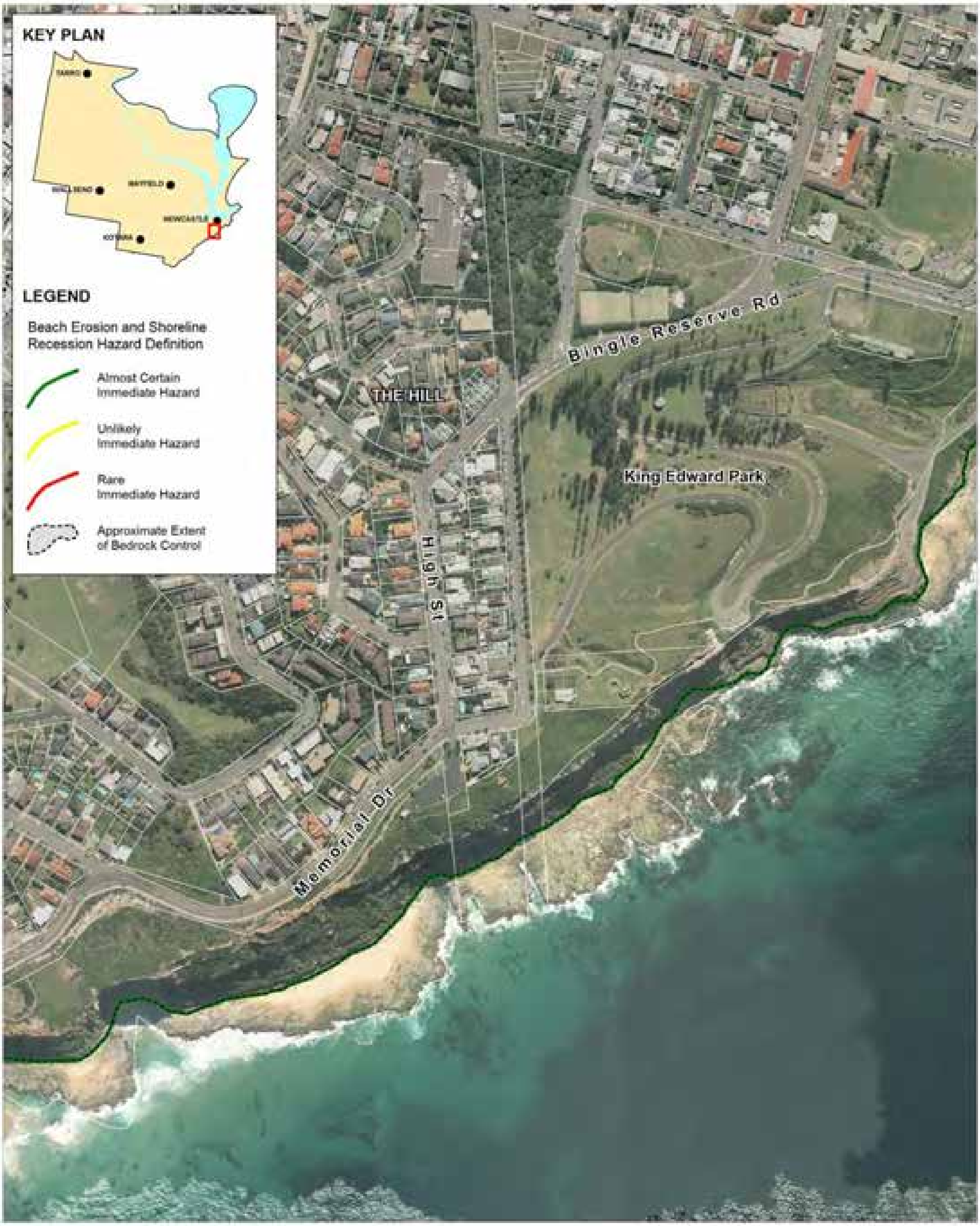

Title:

Erosion and Recession Hazard Definition Immediate Planning Horizon - The Hill

Figure: A-7

Rev: A

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Title:

Erosion and Recession Hazard Definition
Immediate Planning Horizon - Bar Beach

Figure: A-8

Rev: A

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Title:

Erosion and Recession Hazard Definition
Immediate Planning Horizon - Merewether Beach

Figure: **A-9**

Rev: **A**

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Approx. Scale

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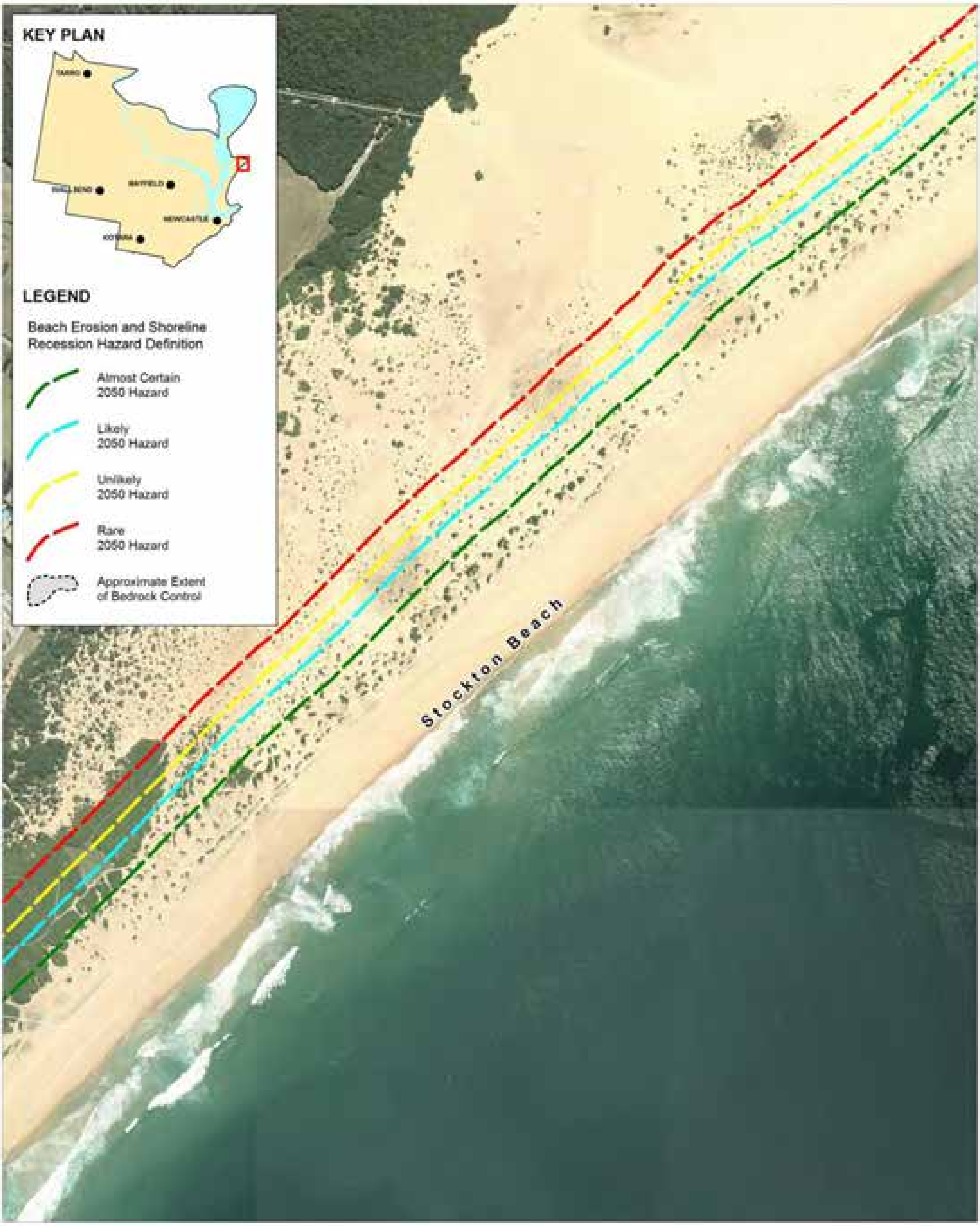

Title:	Figure:	Rev:
Erosion and Recession Hazard Definition 2050 Planning Horizon - Fern Bay	**B-1**	**A**

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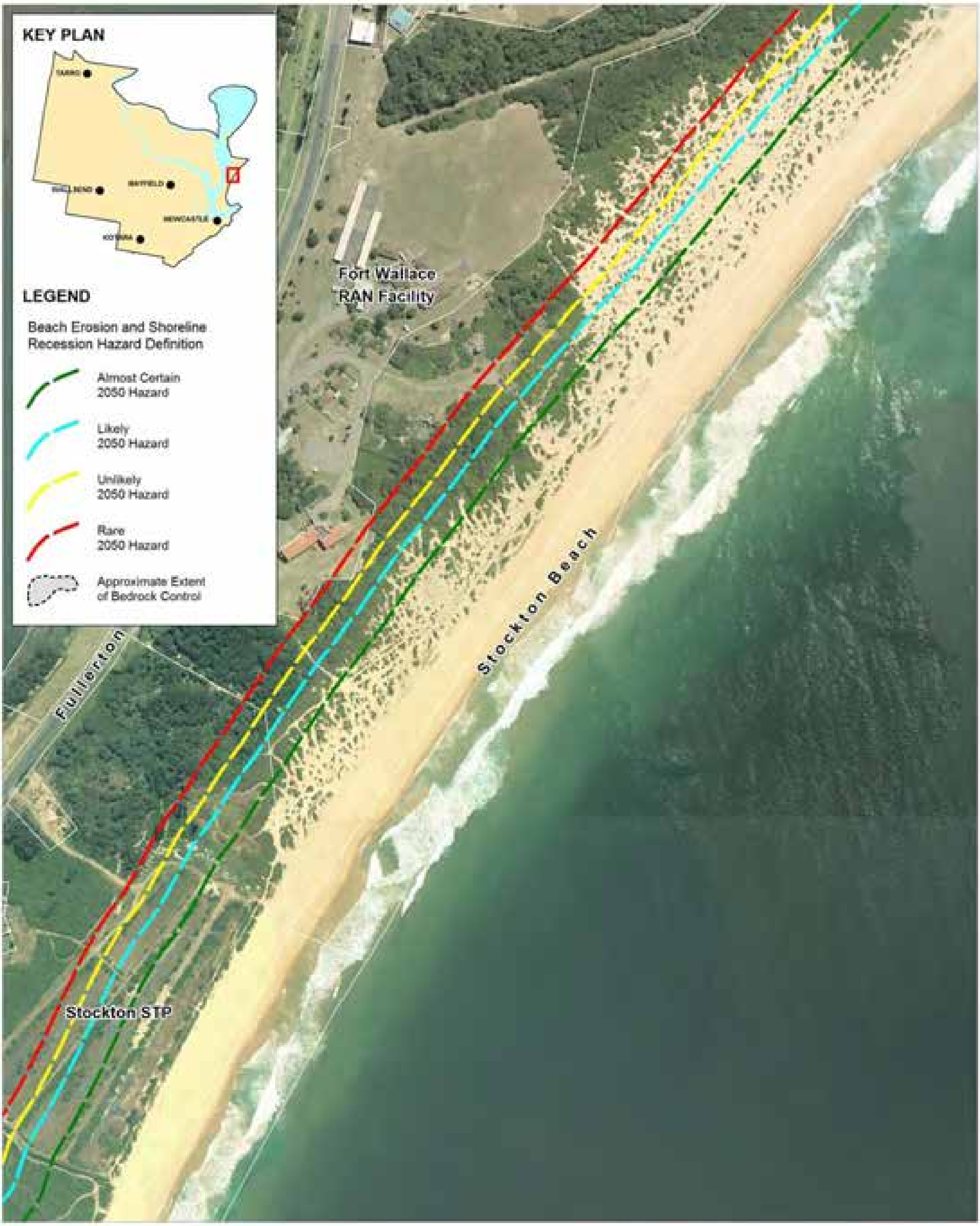

Title:

Erosion and Recession Hazard Definition 2050 Planning Horizon - Fort Wallace

Figure: B-2

Rev: A

N

0 100 200m

Approx. Scale

BMT WBM

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Filepath : K:\N2051_NewcastleCoastalHazards&Management\MI\Workspaces\DRG_202_111025_Drawing_B-2.WOR

Title:

Erosion and Recession Hazard Definition
2050 Planning Horizon - Stockton North

Figure: B-3

Rev: A

N

0 100 200m

Approx. Scale

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Title:
Erosion and Recession Hazard Definition 2050 Planning Horizon - Stockton South

Figure: **B-4**

Rev: **A**

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0 100 200m

Approx. Scale

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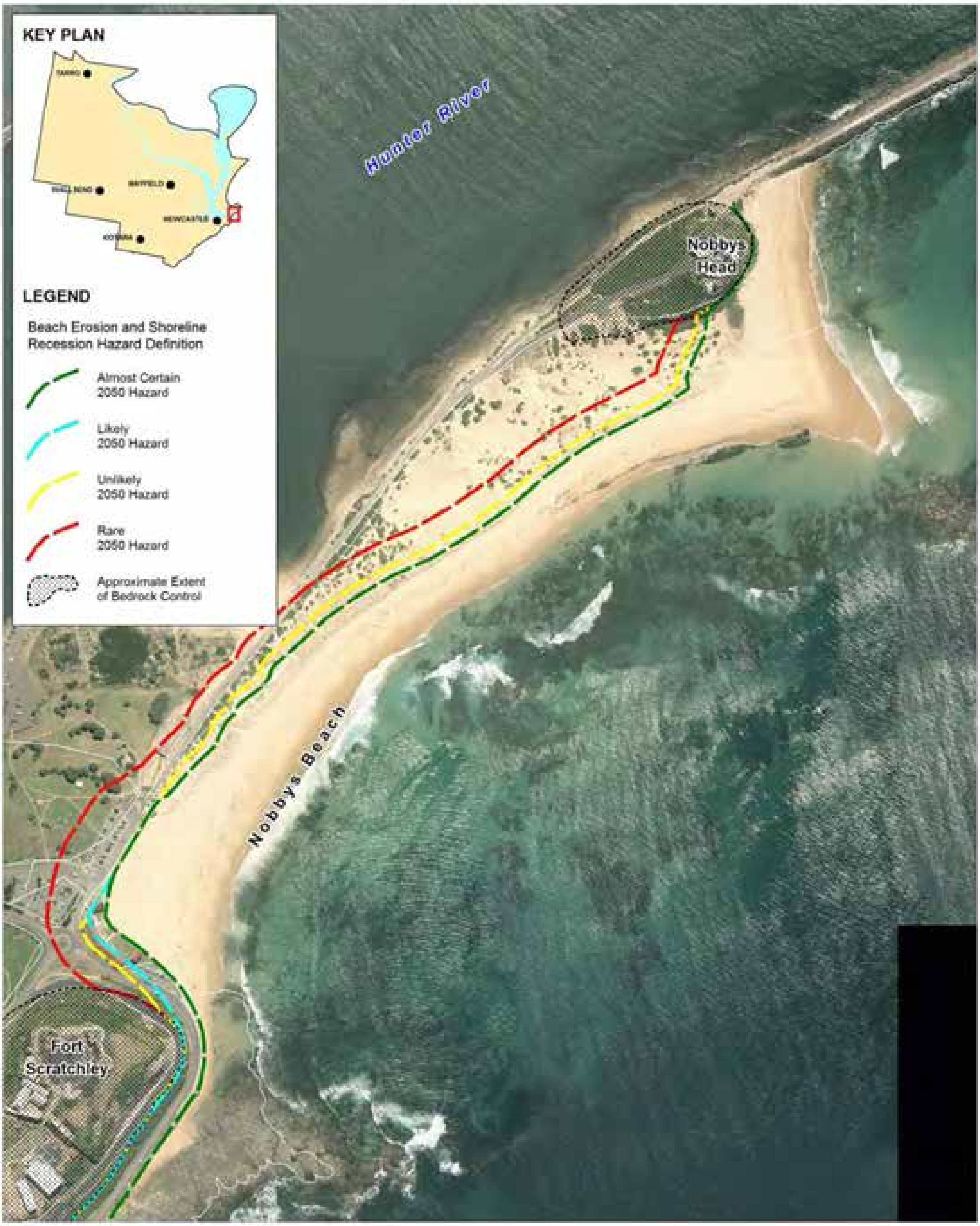

Title:

Erosion and Recession Hazard Definition 2050 Planning Horizon - Nobbys Beach

Figure: B-5

Rev: A

N

0 100 200m

Approx. Scale

BMT WBM

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Filepath : K:\N2051_NewcastleCoastalHazards&Management\MI\Workspaces\DRG_205_111025_Drawing_B-5.WOR

Title:

Erosion and Recession Hazard Definition 2050 Planning Horizon - Newcastle Beach

Figure: B-6

Rev: A

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0 100 200m

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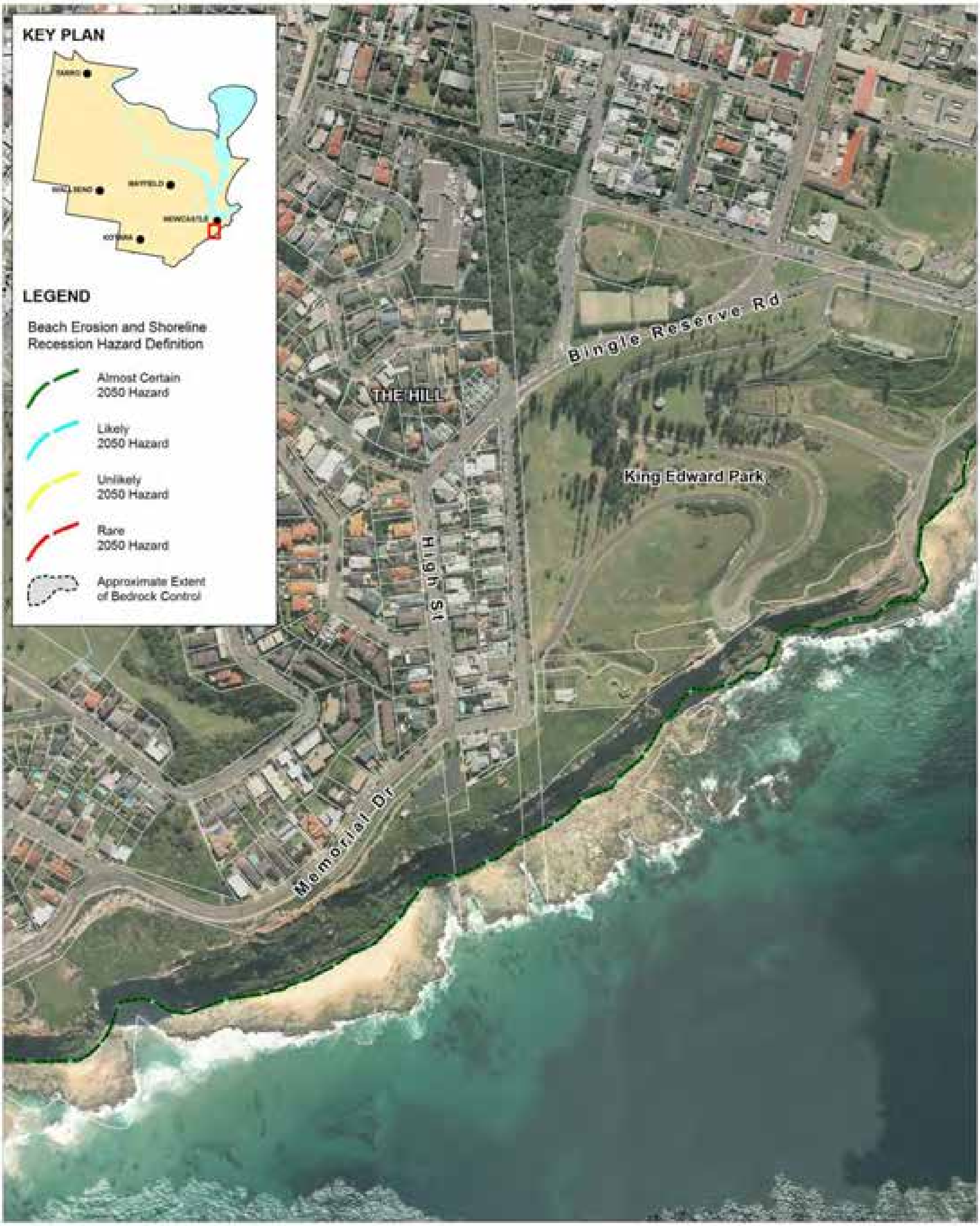

Title:

Erosion and Recession Hazard Definition 2050 Planning Horizon - The Hill

Figure: B-7

Rev: A

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0 100 200m

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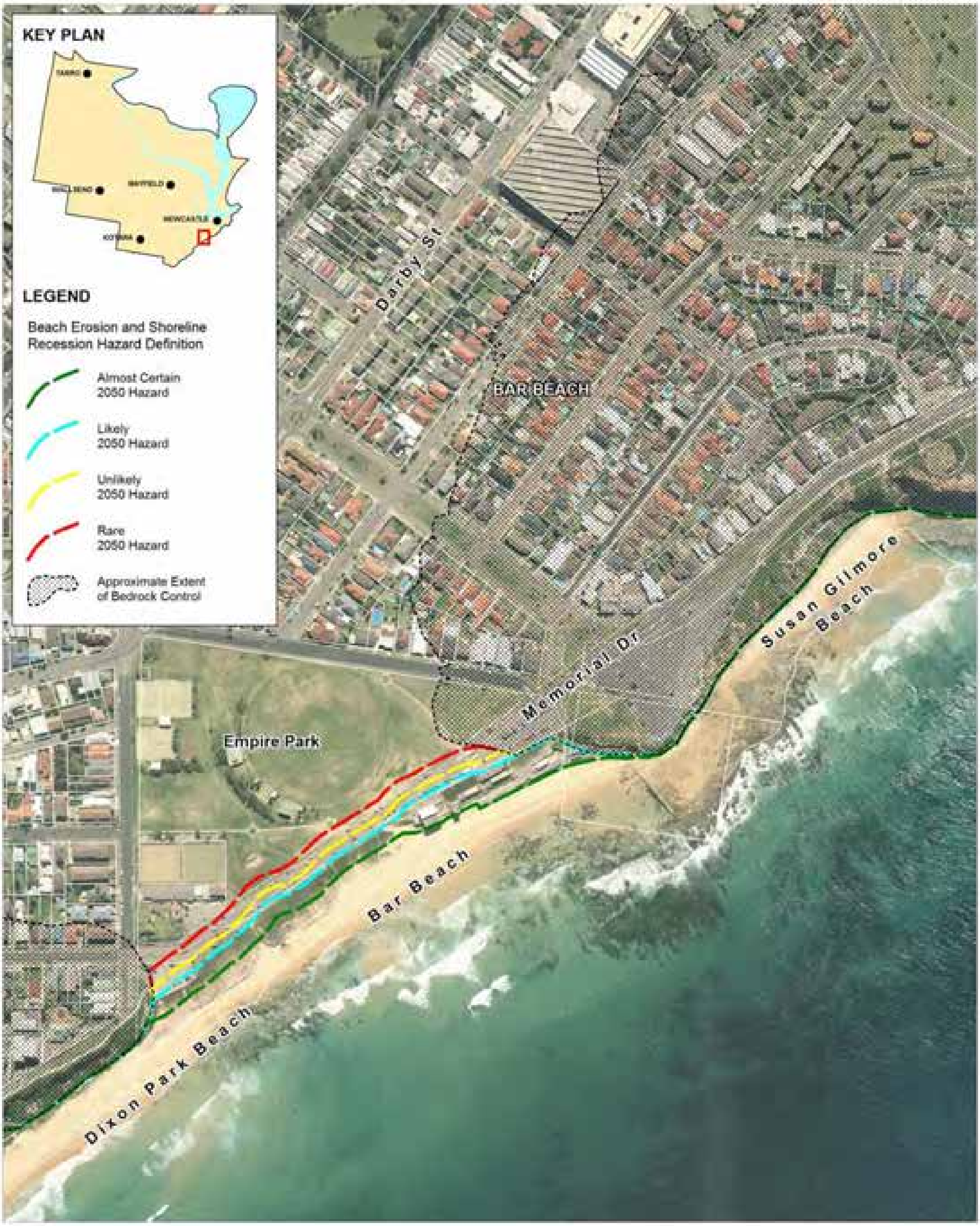

Title:

Erosion and Recession Hazard Definition
2050 Planning Horizon - Bar Beach

Figure: **B-8**

Rev: **A**

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Title:

Erosion and Recession Hazard Definition
2050 Planning Horizon - Merewether Beach

Figure: **B-9**

Rev: **A**

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0 100 200m

Approx. Scale

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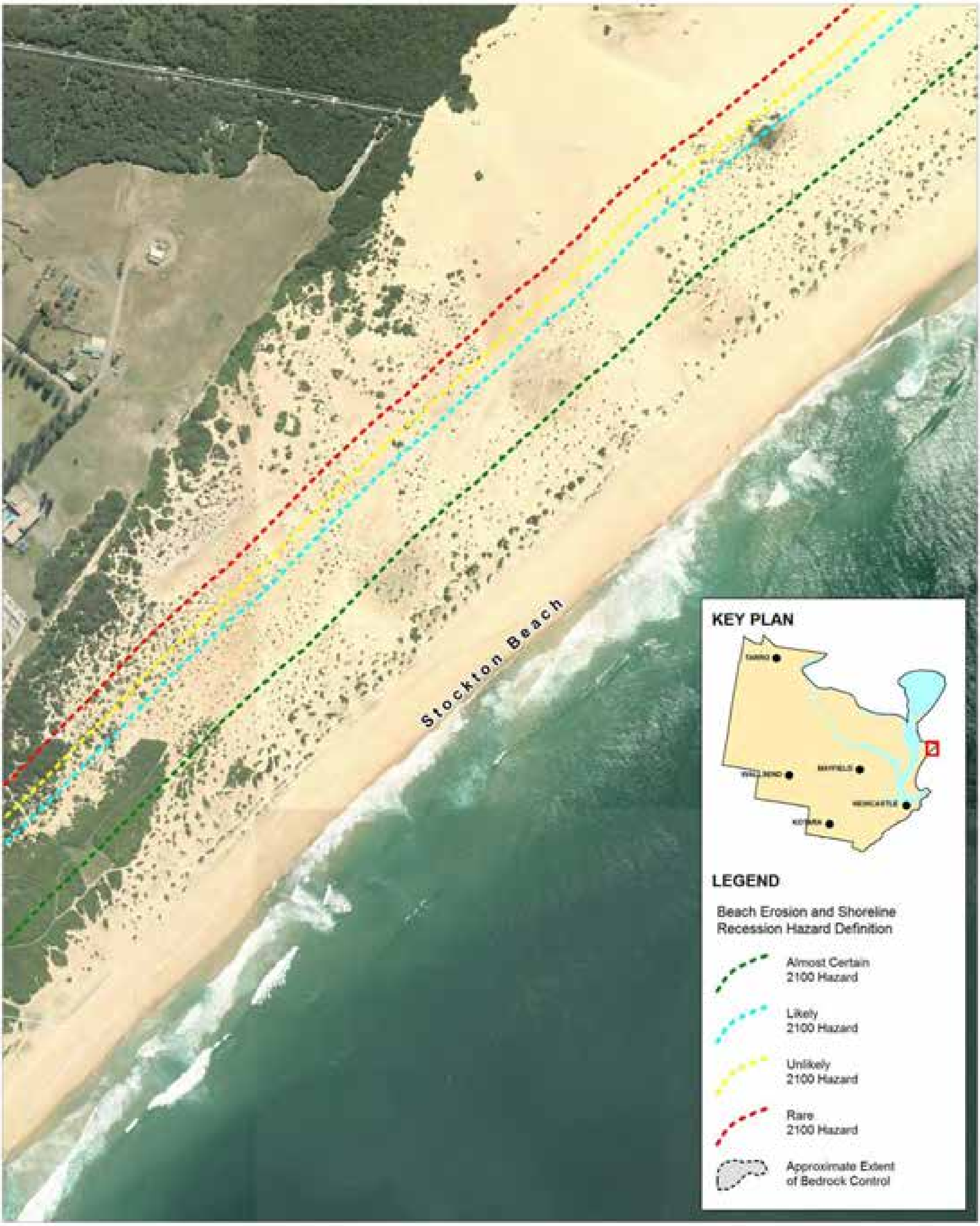

Title: **Erosion and Recession Hazard Definition 2100 Planning Horizon - Fern Bay**		Figure: **C-1**	Rev: **A**
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Title:

Erosion and Recession Hazard Definition 2100 Planning Horizon - Fort Wallace

Figure: C-2

Rev: A

N

0 100 200m

Approx. Scale

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Title:

Erosion and Recession Hazard Definition
2100 Planning Horizon - Stockton North

Figure: C-3

Rev: A

N

0 100 200m

Approx. Scale

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Filepath : K:\N2051_NewcastleCoastalHazards&Management\MI\Workspaces\DRG_303_111025_Drawing_C-3.WOR

Title:

Erosion and Recession Hazard Definition 2100 Planning Horizon - Stockton South

Figure: C-4

Rev: A

N

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Approx. Scale

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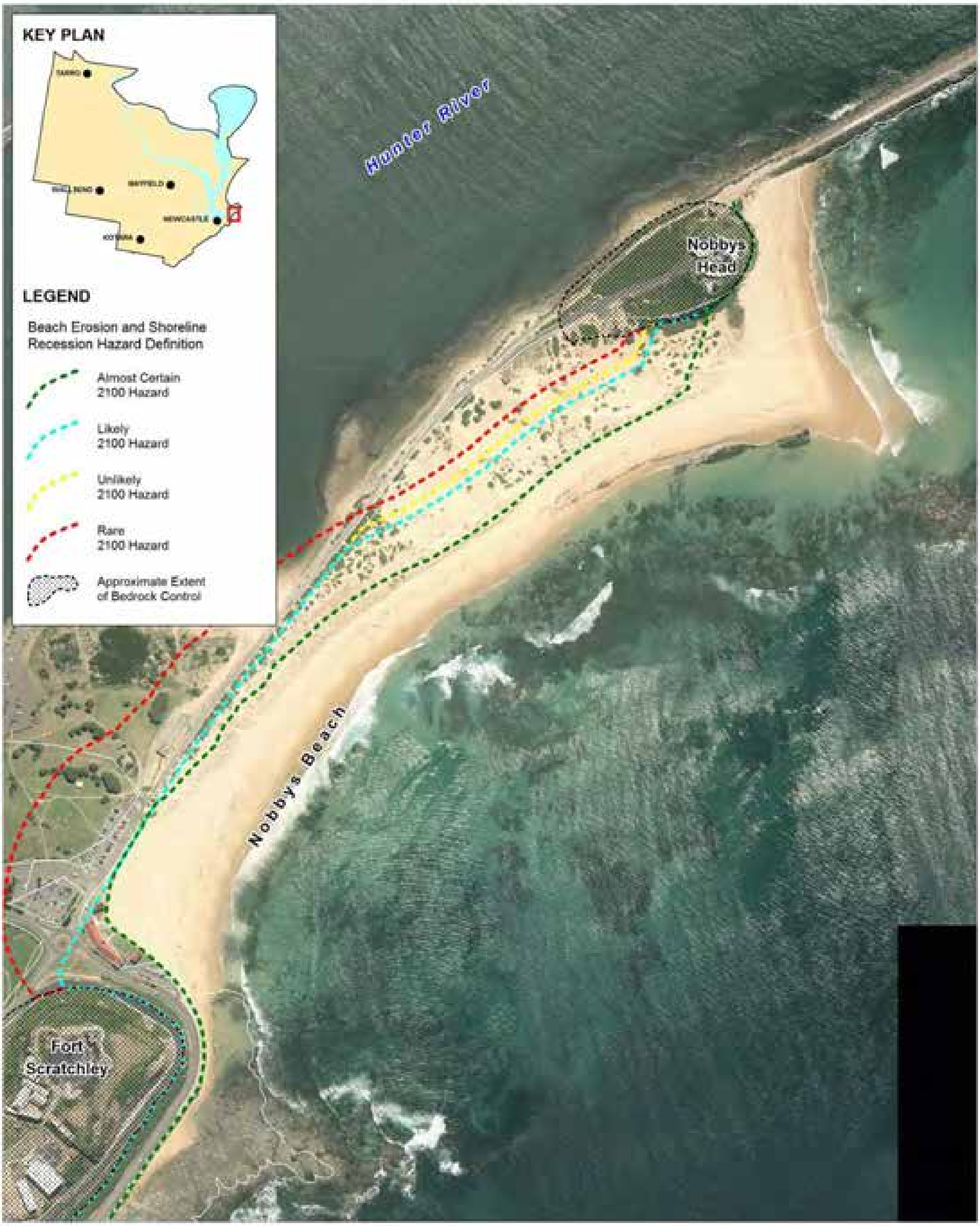

Title:

Erosion and Recession Hazard Definition 2100 Planning Horizon - Nobbys Beach

Figure: C-5

Rev: A

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Title:	Figure:	Rev:
Erosion and Recession Hazard Definition 2100 Planning Horizon - Newcastle Beach	**C-6**	**A**

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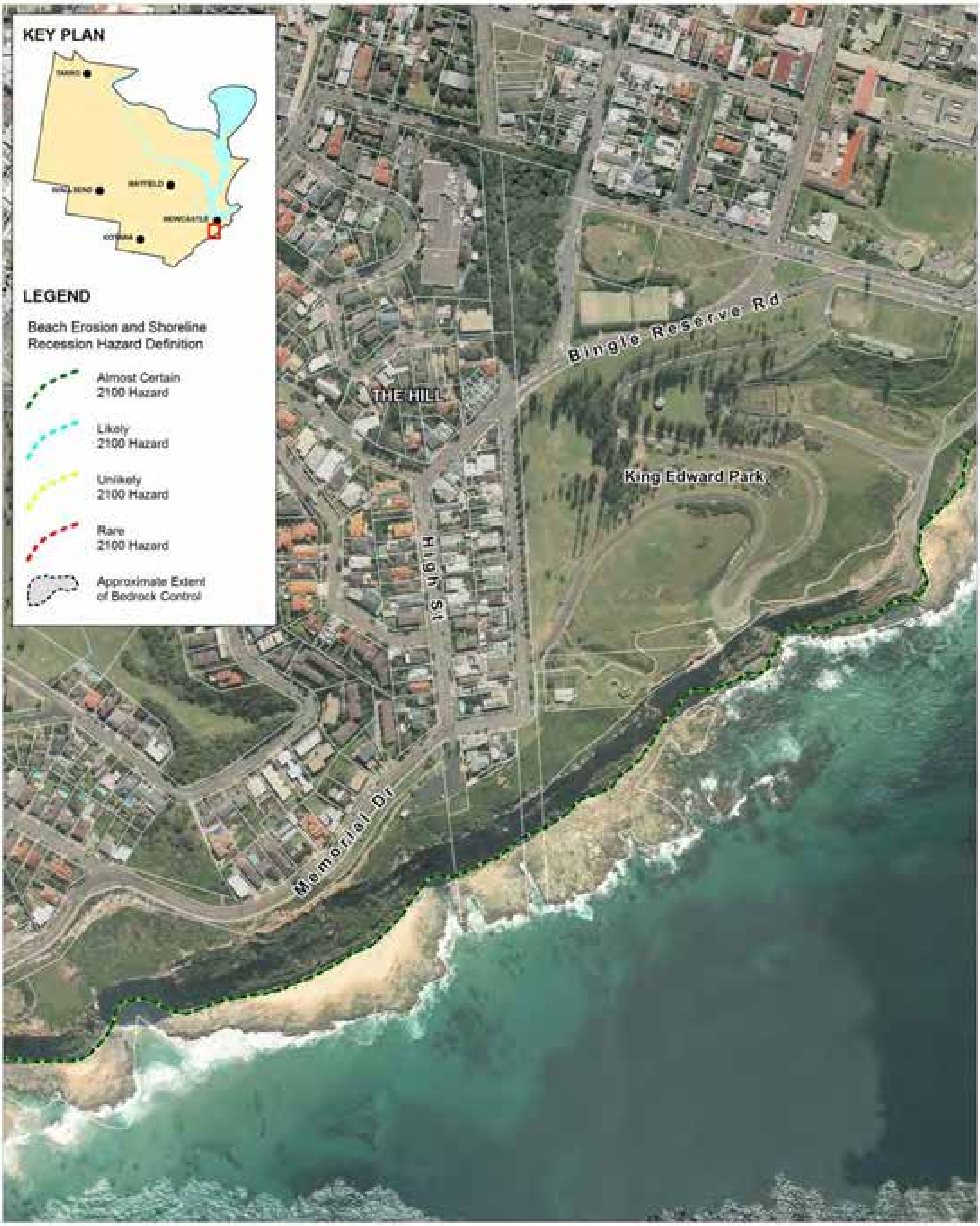

Title:
Erosion and Recession Hazard Definition 2100 Planning Horizon - The Hill

Figure: C-7

Rev: A

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0 100 200m

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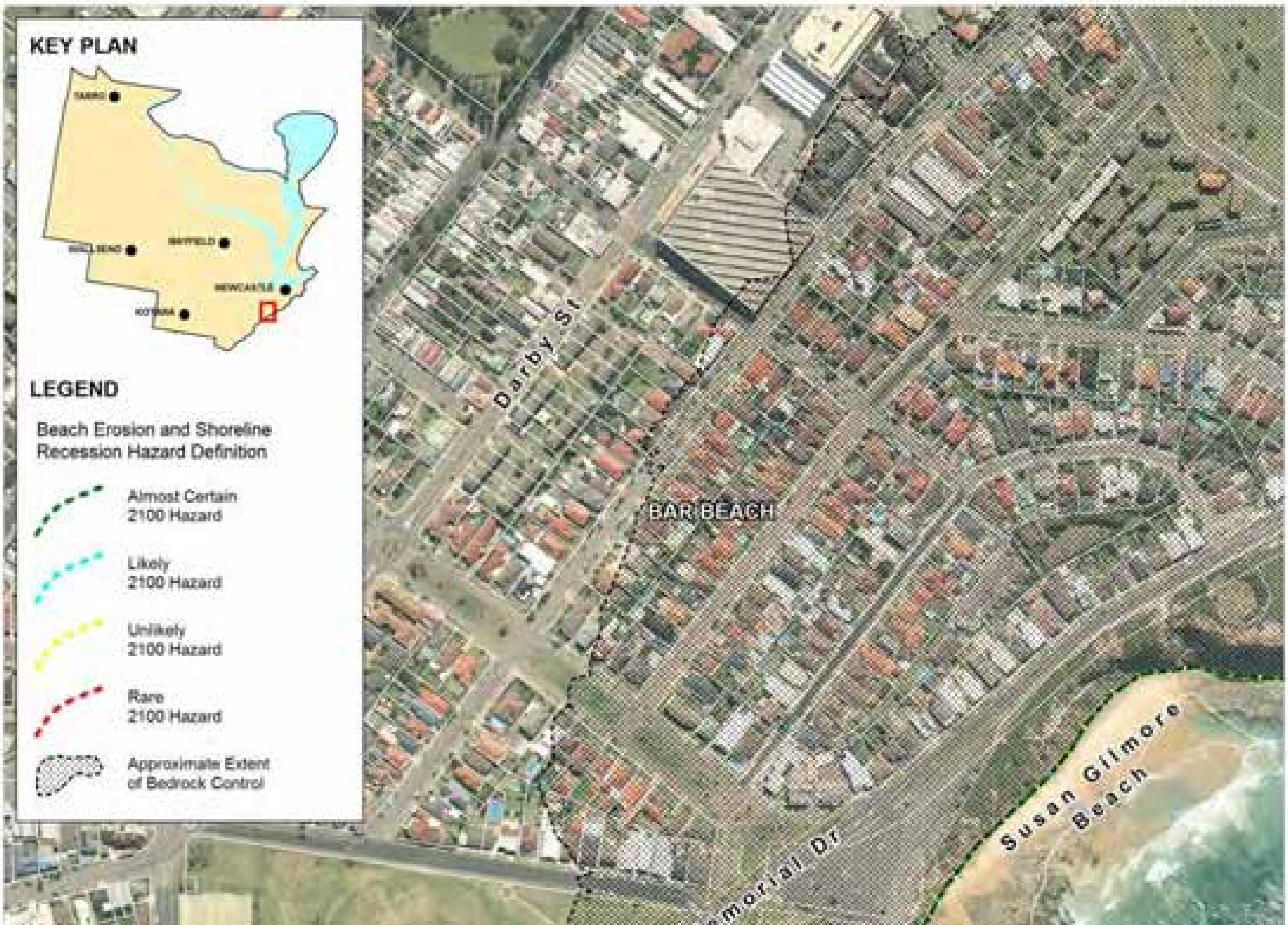

Title:

Erosion and Recession Hazard Definition
2100 Planning Horizon - Bar Beach

Figure: C-8

Rev: A

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0 100 200m

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Title:
Erosion and Recession Hazard Definition 2100 Planning Horizon - Merewether Beach

Figure: C-9

Rev: A

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Probability	Immediate	2050	2100
Almost Certain	1 in 20 yr storm surge and wave set up	As per immediate	As per immediate
Likely	NM[1]	NM	NM
Unlikely	1 in 100 yr storm surge and wave set up **AND** Wave run up and overtopping[2]	1 in 100 yr storm surge and wave set up + 0.4 m SLR and change in storm surge **AND** Indicative areas of potential overtopping[2] including 0.4 m SLR	1 in 100 yr storm surge and wave set up + 0.9 m SLR and change in storm surge **AND** Indicative areas of potential overtopping[2] including 0.9 m SLR
Rare	1 in 100 yr storm surge and wave set up + extreme climatic conditions (e.g. tropical cyclone, 1 in 1000 year east coast low)	**Worst Case of either:** 1 in 100 yr storm surge and wave set up + extreme climatic conditions + 0.4 m SLR and climate change impacts[3] **OR** 1 in 100 yr storm surge and wave set up + 0.7 m SLR and climate change impacts	**Worst Case of either:** 1 in 100 yr storm surge and wave set up + extreme climatic conditions + 0.9 m SLR and climate change impacts[3] **OR** 1 in 100 yr storm surge and wave set up + 1.4 m SLR and climate change impacts

[1] NM = Not Mapped

[2] Only applies at open coast barriers (not within lagoons, estuaries etc). Wave run up and overtopping are calculated using 1 in 100 yr storm surge + 1 in 100 yr 6 hr duration H_s

[3] Includes increase in set up levels associated with a 5 % and 10 % increase in storm wave heights by 2050 and 2100 respectively, refer Section 2.8.

Probability	Description
Almost Certain	There is a high possibility the event will occur as there is a history of frequent occurrence
Likely	It is likely the event will occur as there is a history of casual occurrence
Unlikely	There is a low possibility that the event will occur, however, there is a history of infrequent or isolated occurrence.
Rare	It is highly unlikely that the event will occur, except in extreme / exceptional circumstances, which have not been recorded historically.

Timeframe	
Immediate	Present day conditions (e.g. 2013)
2050	Expected conditions by circa 2050
2100	Expected conditions by circa 2100

Title:

Index to Inundation Hazard and Risk Drawings

Figure: **INDEX**

Rev: **A**

N

0 2.5 5km

Approx. Scale

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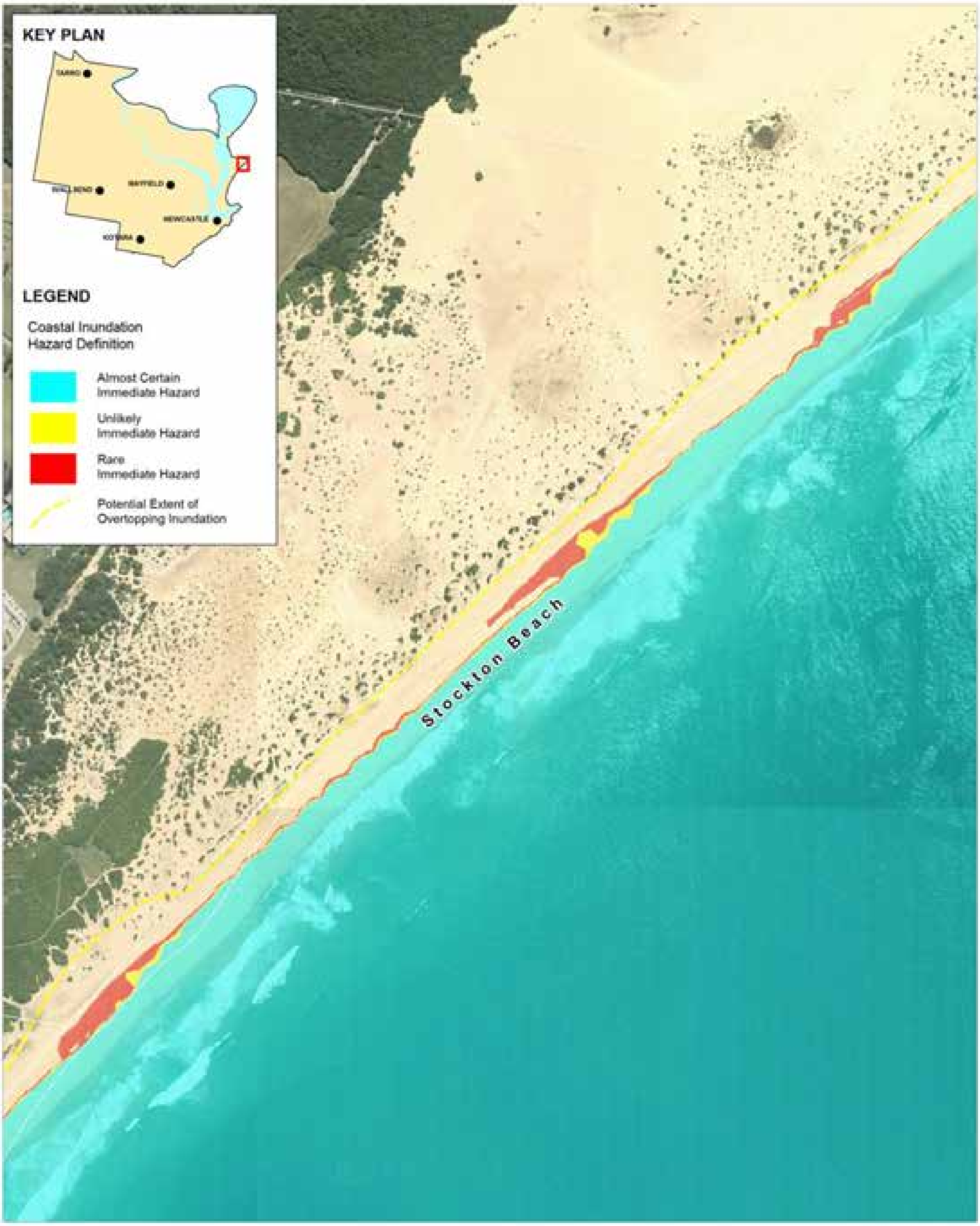

Title:

Coastal Inundation Hazard Definition
Immediate Planning Horizon - Fern Bay

Figure: D-1

Rev: A

N

0 100 200m

Approx. Scale

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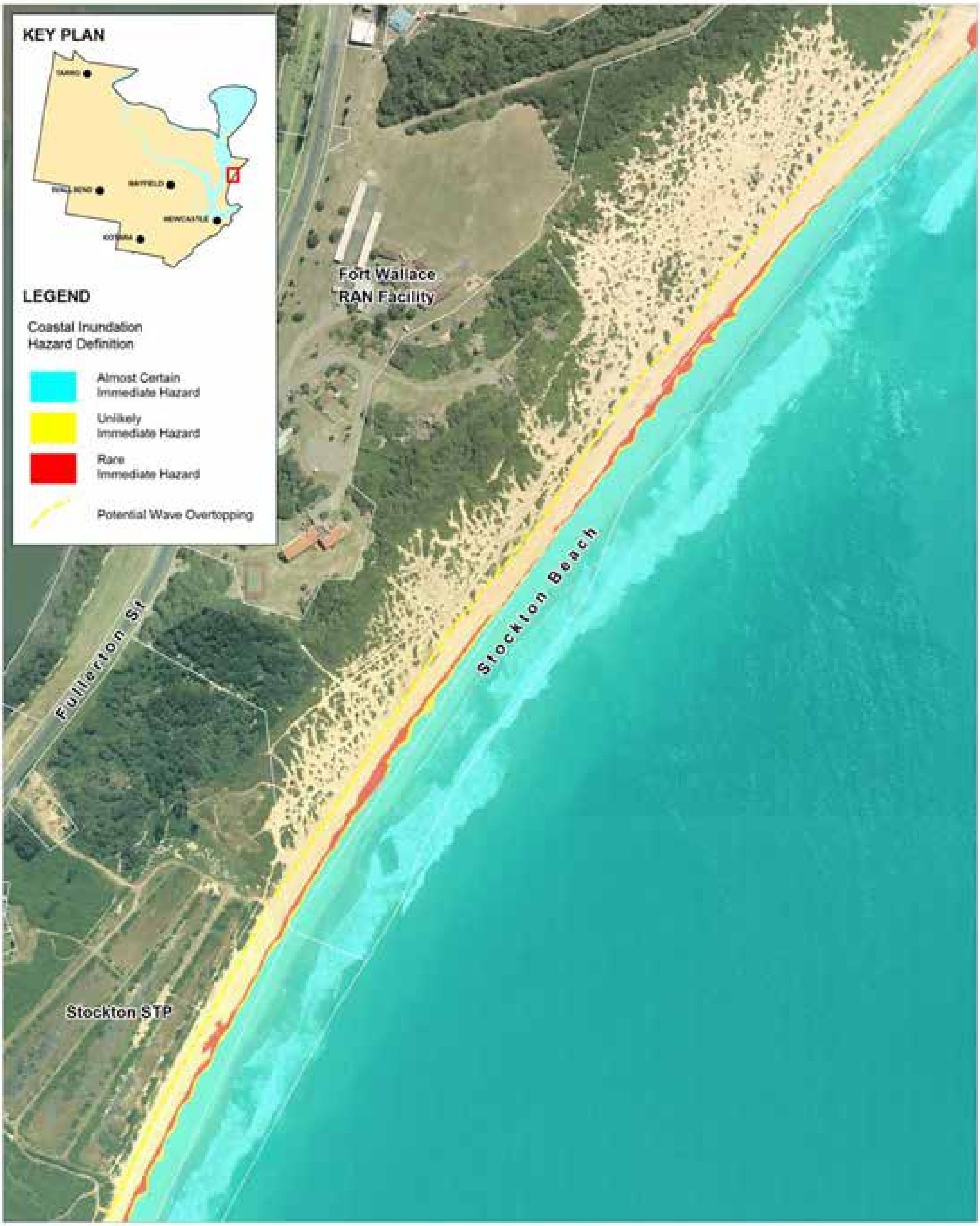

Title:

Coastal Inundation Hazard Definition
Immediate Planning Horizon - Fort Wallace

Figure: **D-2**

Rev: **A**

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0 100 200m

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Title:

Coastal Inundation Hazard Definition
Immediate Planning Horizon - Stockton North

Figure: **D-3**

Rev: **A**

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0 100 200m

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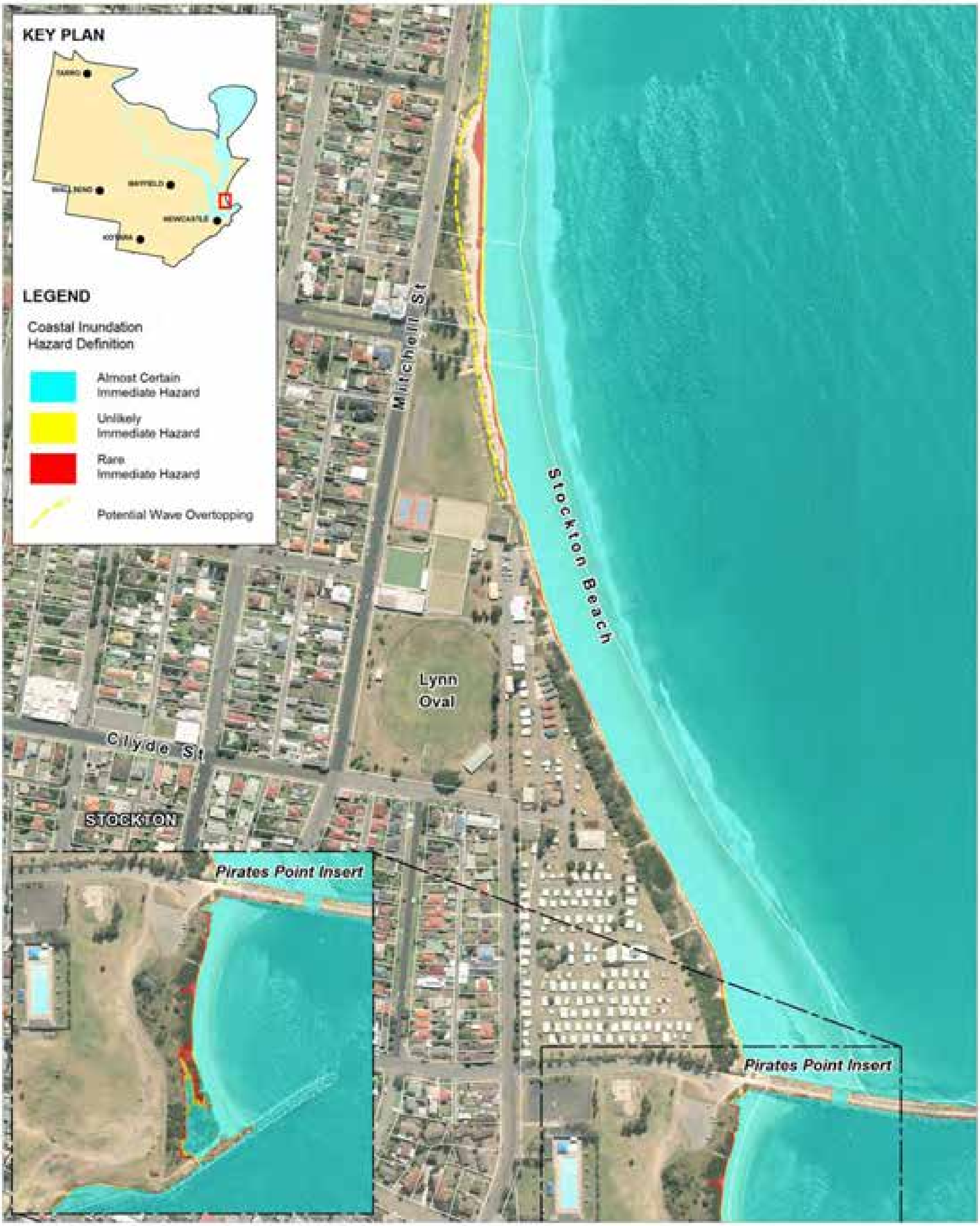

Title:

Coastal Inundation Hazard Definition
Immediate Planning Horizon - Stockton South

Figure: D-4

Rev: A

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0 100 200m

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Title:

Coastal Inundation Hazard Definition
Immediate Planning Horizon - Nobbys Beach

Figure: D-5

Rev: A

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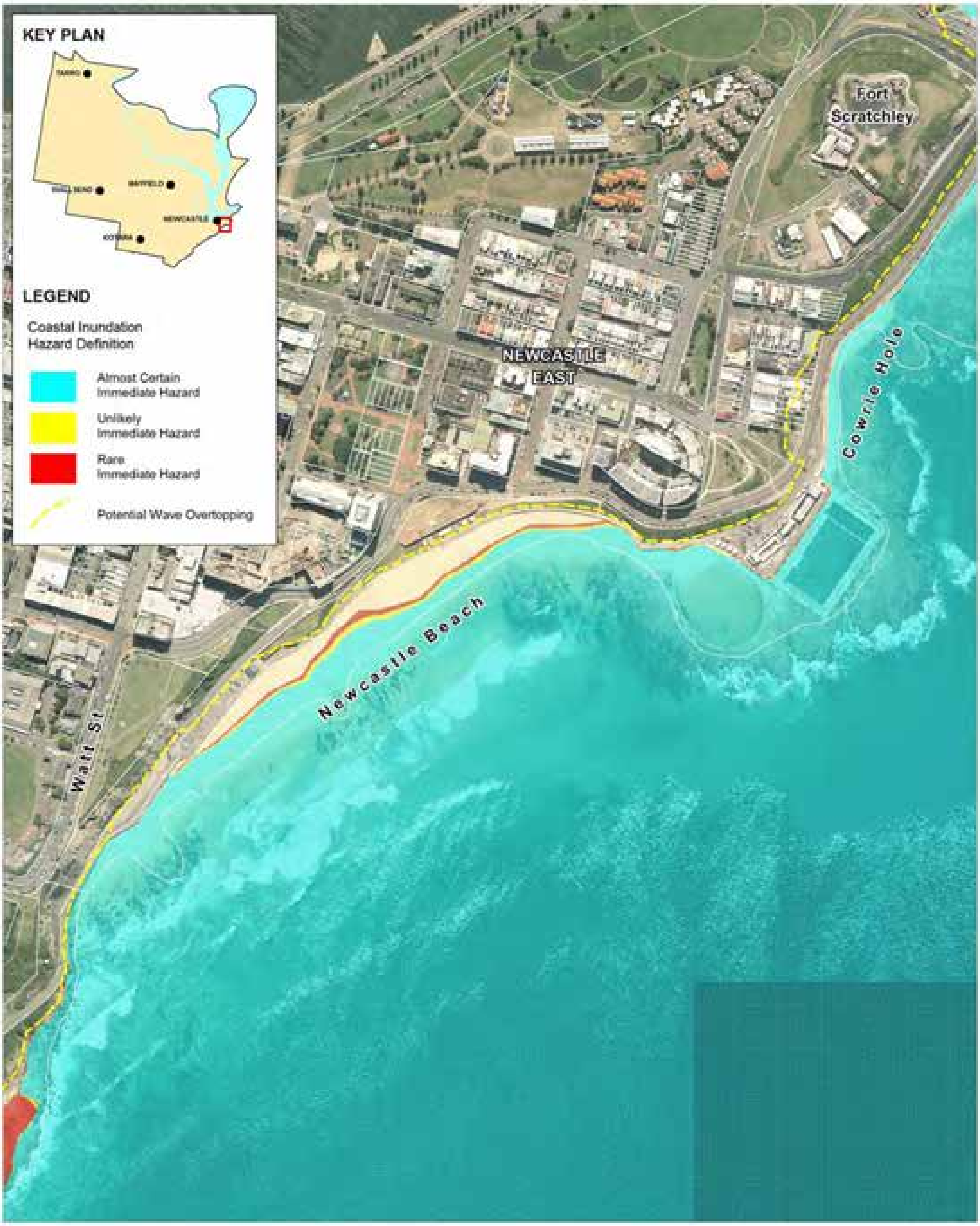

Title:
Coastal Inundation Hazard Definition
Immediate Planning Horizon - Newcastle Beach

Figure: **D-6**

Rev: **A**

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0 100 200m
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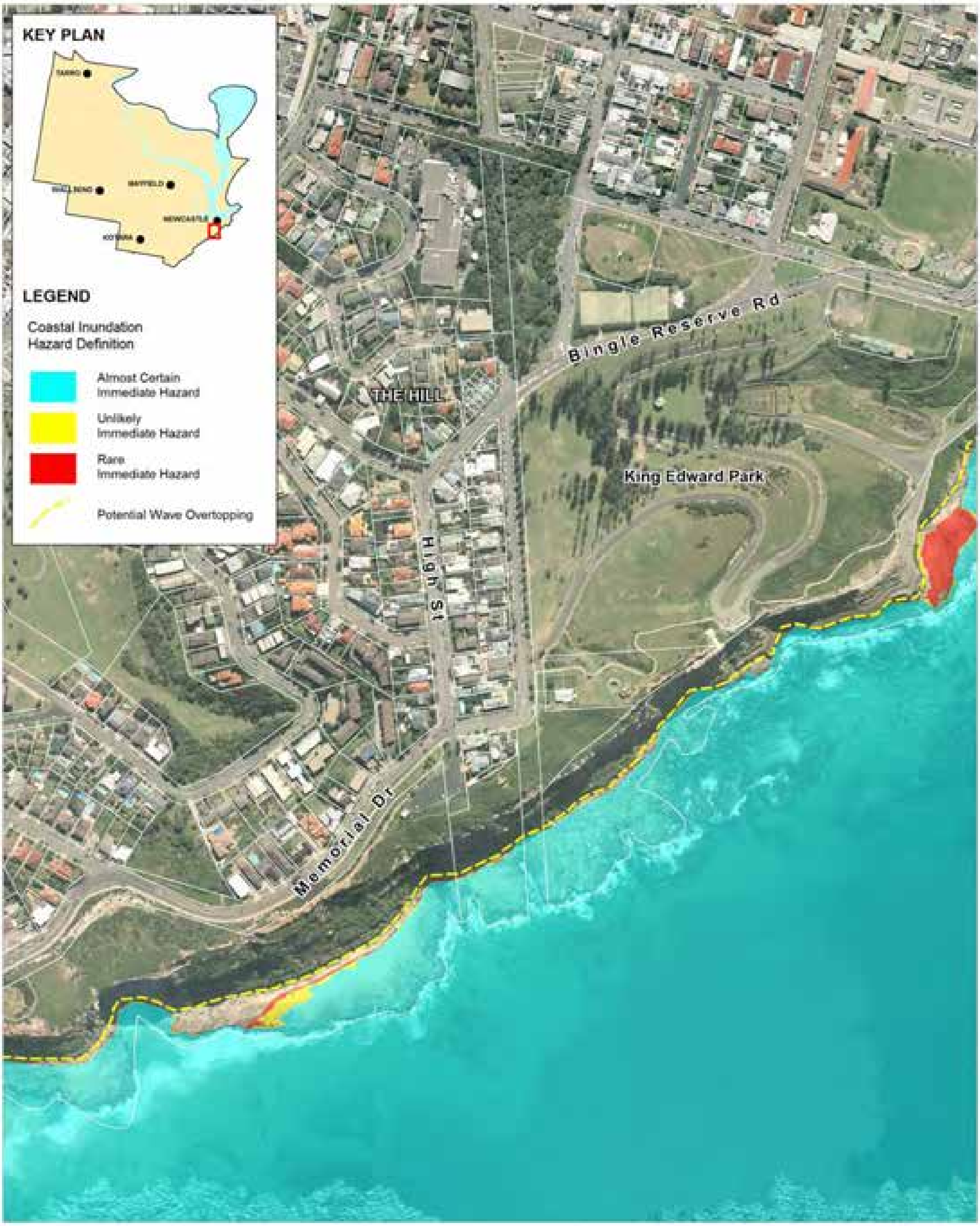

Title:

Coastal Inundation Hazard Definition
Immediate Planning Horizon - The Hill

Figure: D-7

Rev: A

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Title:

Coastal Inundation Hazard Definition
Immediate Planning Horizon - Bar Beach

Figure: D-8

Rev: A

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Title:
Coastal Inundation Hazard Definition
Immediate Planning Horizon - Merewether Beach

Figure: **D-9**

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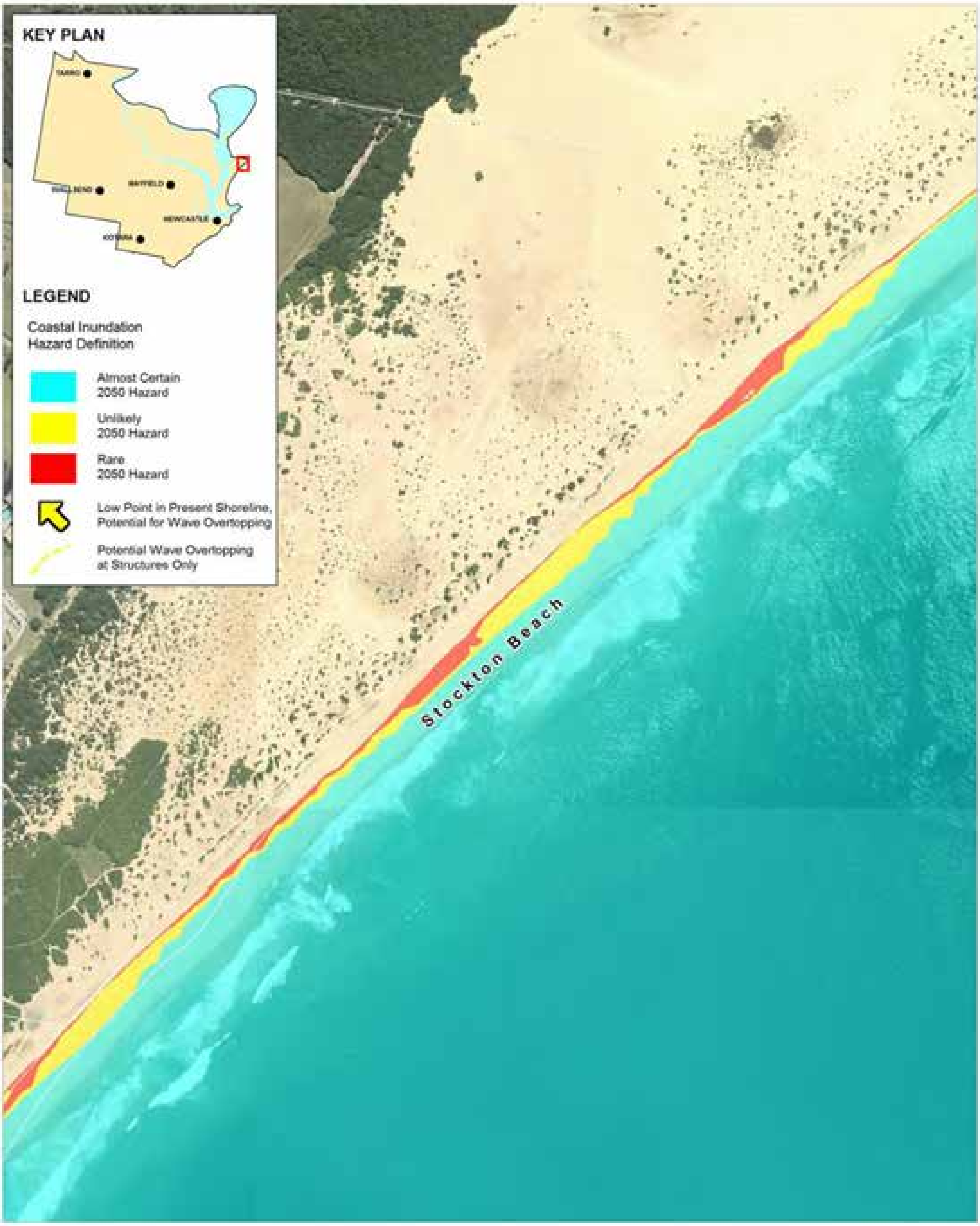

Title:

Coastal Inundation Hazard Definition
2050 Planning Horizon - Fern Bay

Figure: **E-1**

Rev: **A**

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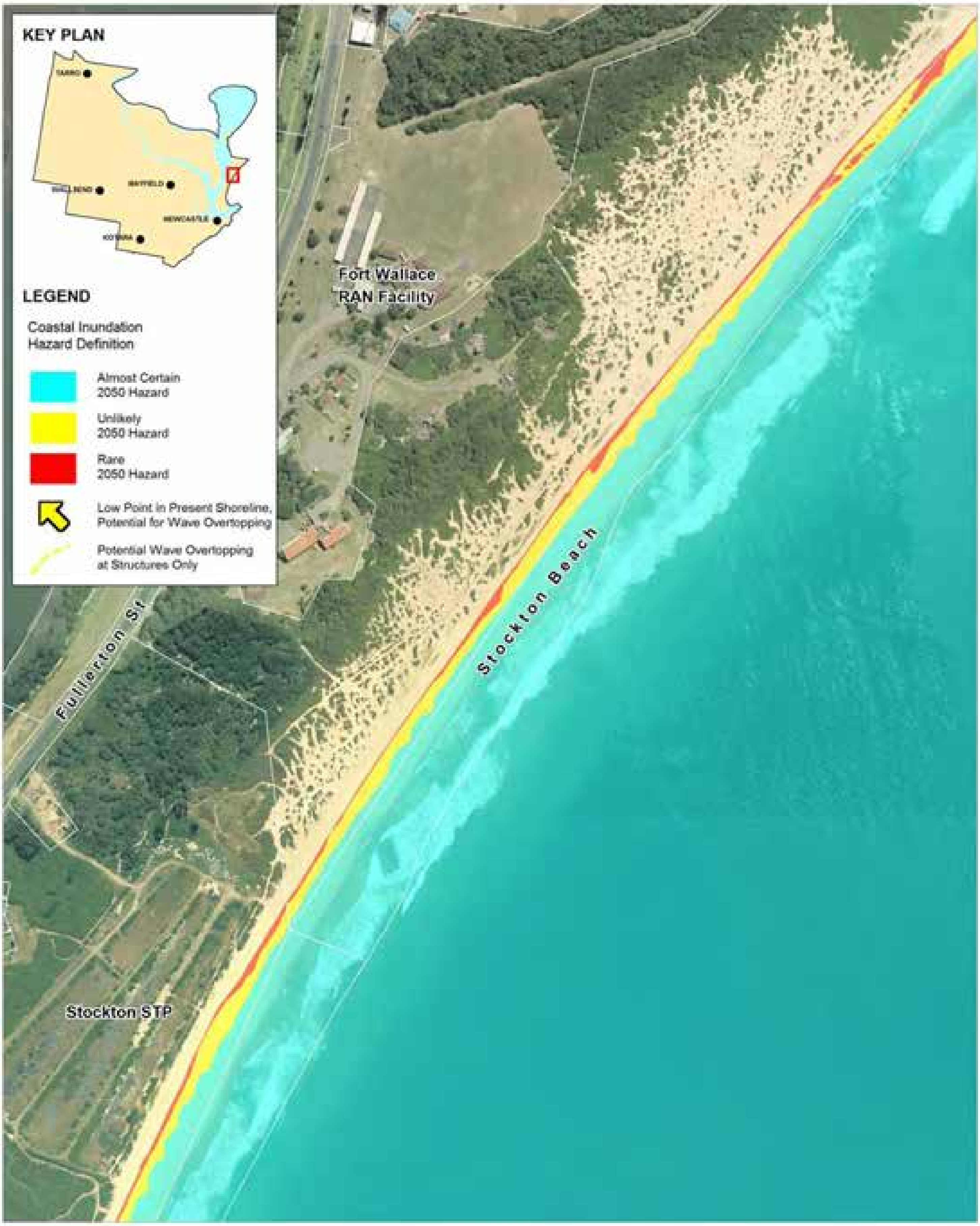

Title:

Coastal Inundation Hazard Definition
2050 Planning Horizon - Fort Wallace

Figure: **E-2**

Rev: **A**

N

0 100 200m

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Title:

Coastal Inundation Hazard Definition
2050 Planning Horizon - Stockton North

Figure: **E-3**

Rev: **A**

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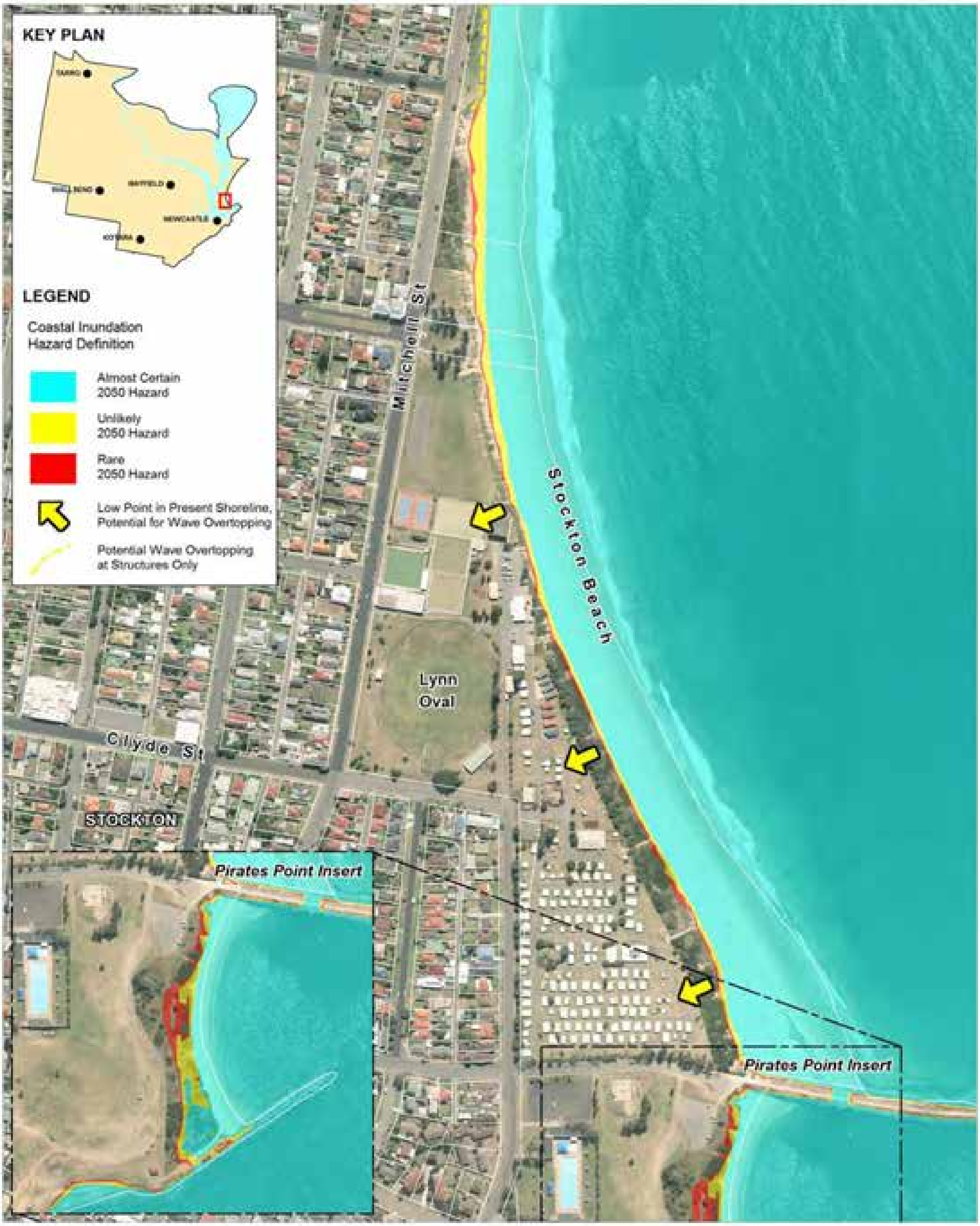

Title:

Coastal Inundation Hazard Definition 2050 Planning Horizon - Stockton South

Figure:	Rev:
E-4	A

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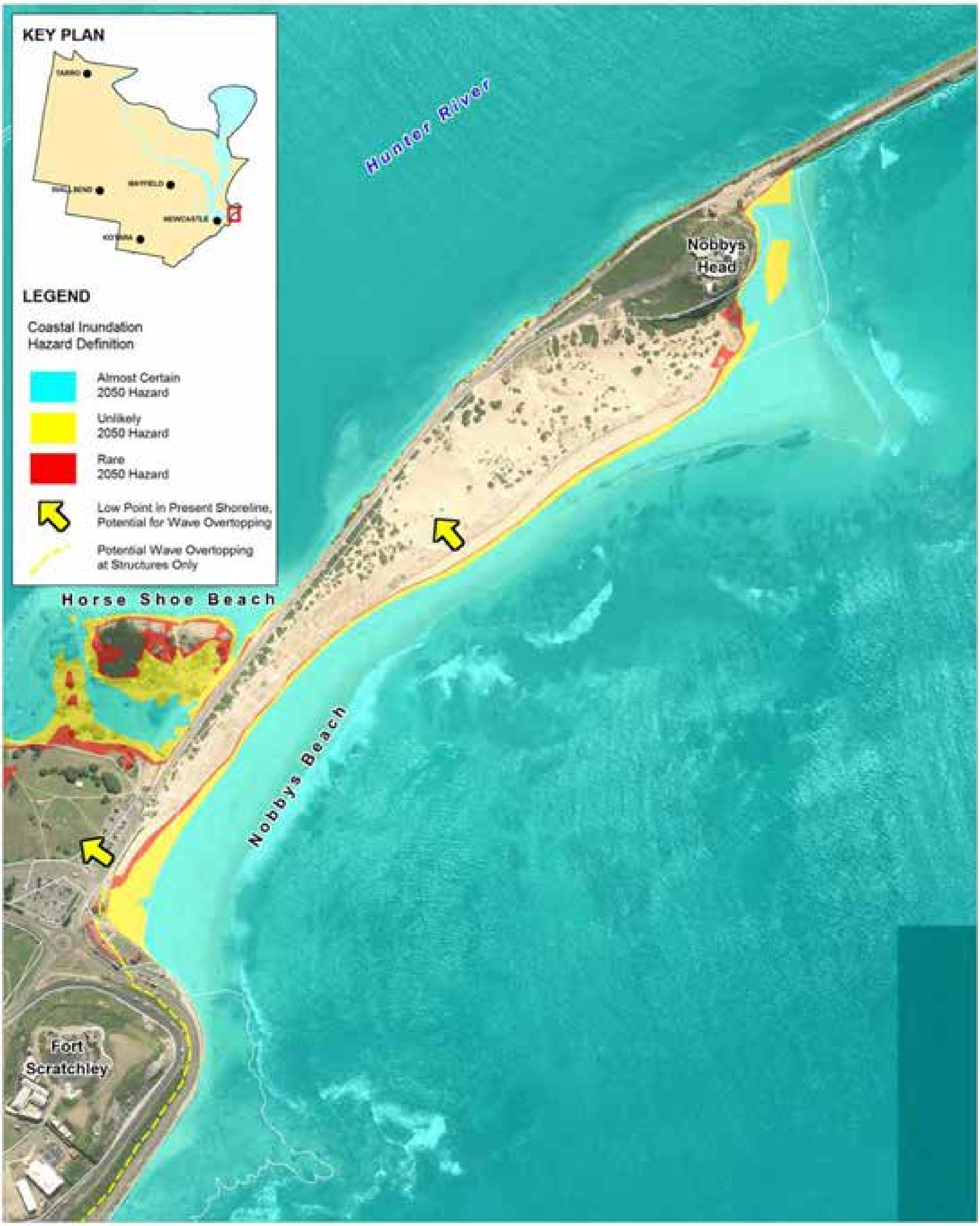

Title:
Coastal Inundation Hazard Definition
2050 Planning Horizon - Nobbys Beach

Figure: E-5

Rev: A

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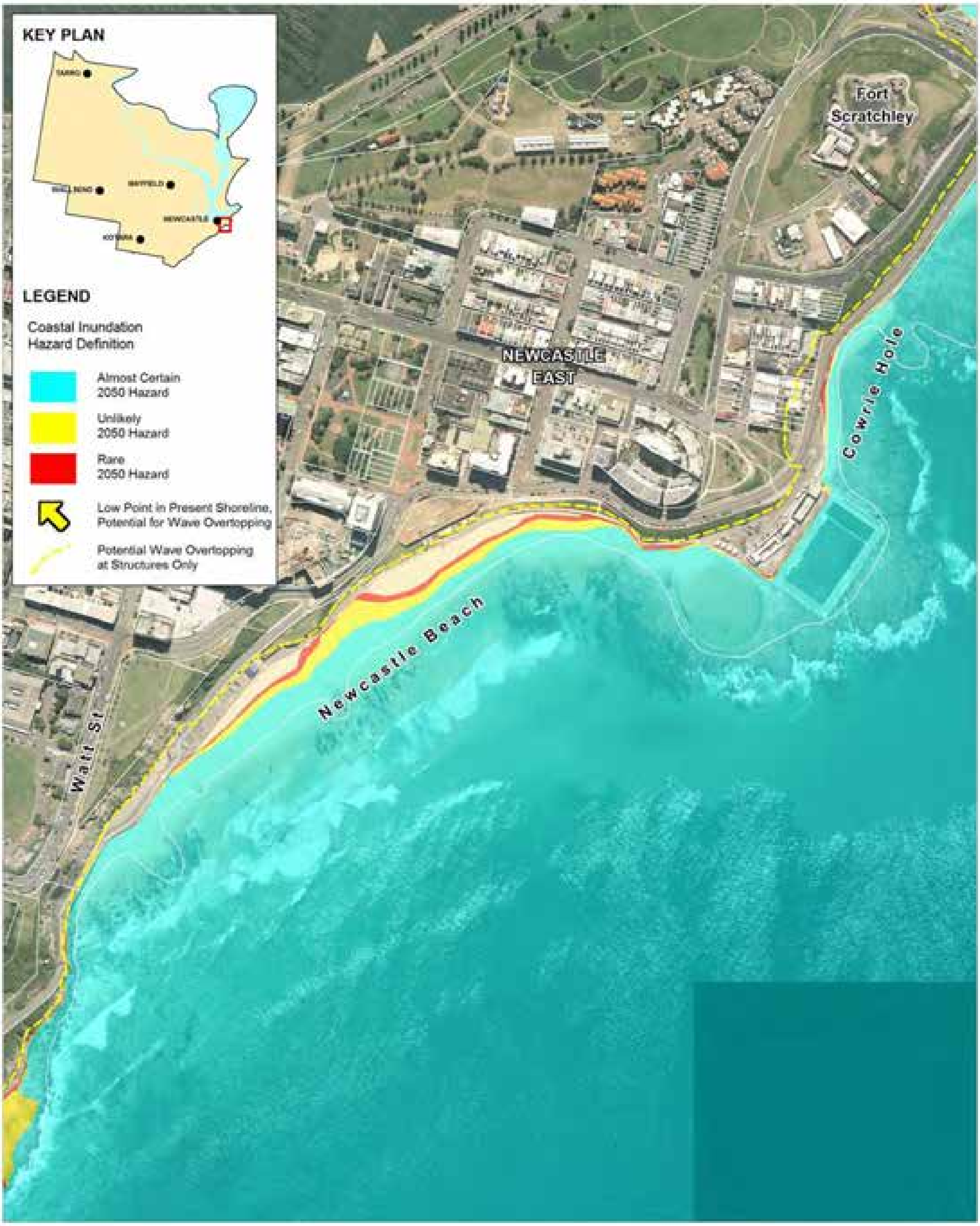

Title:
Coastal Inundation Hazard Definition
2050 Planning Horizon - Newcastle Beach

Figure: **E-6**

Rev: **A**

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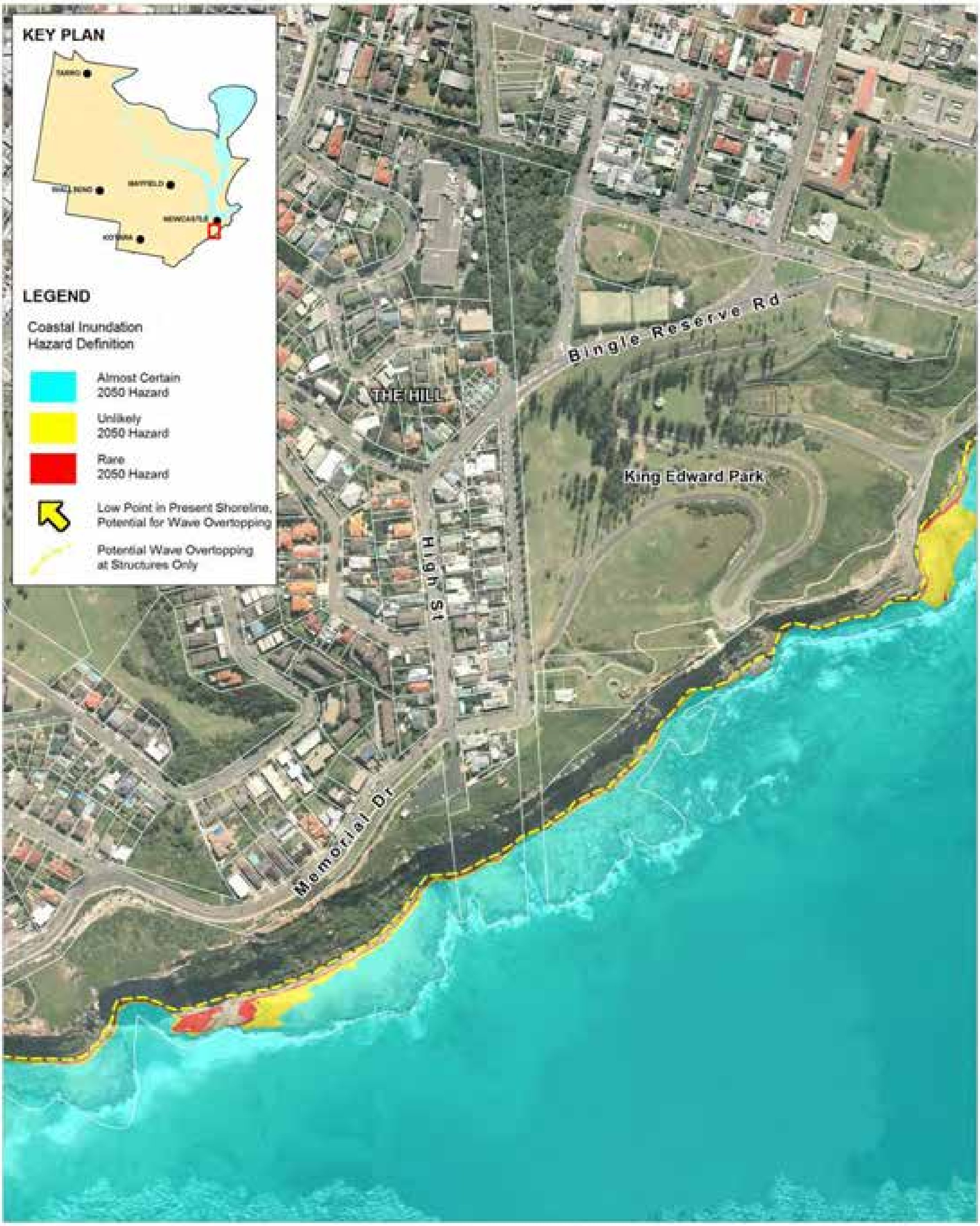

Title:

Coastal Inundation Hazard Definition 2050 Planning Horizon - The Hill

Figure: E-7

Rev: A

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Title:

Coastal Inundation Hazard Definition 2050 Planning Horizon - Bar Beach

Figure: **E-8**

Rev: **A**

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Title:

Coastal Inundation Hazard Definition 2050 Planning Horizon - Merewether Beach

Figure: E-9

Rev: A

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0 100 200m

Approx. Scale

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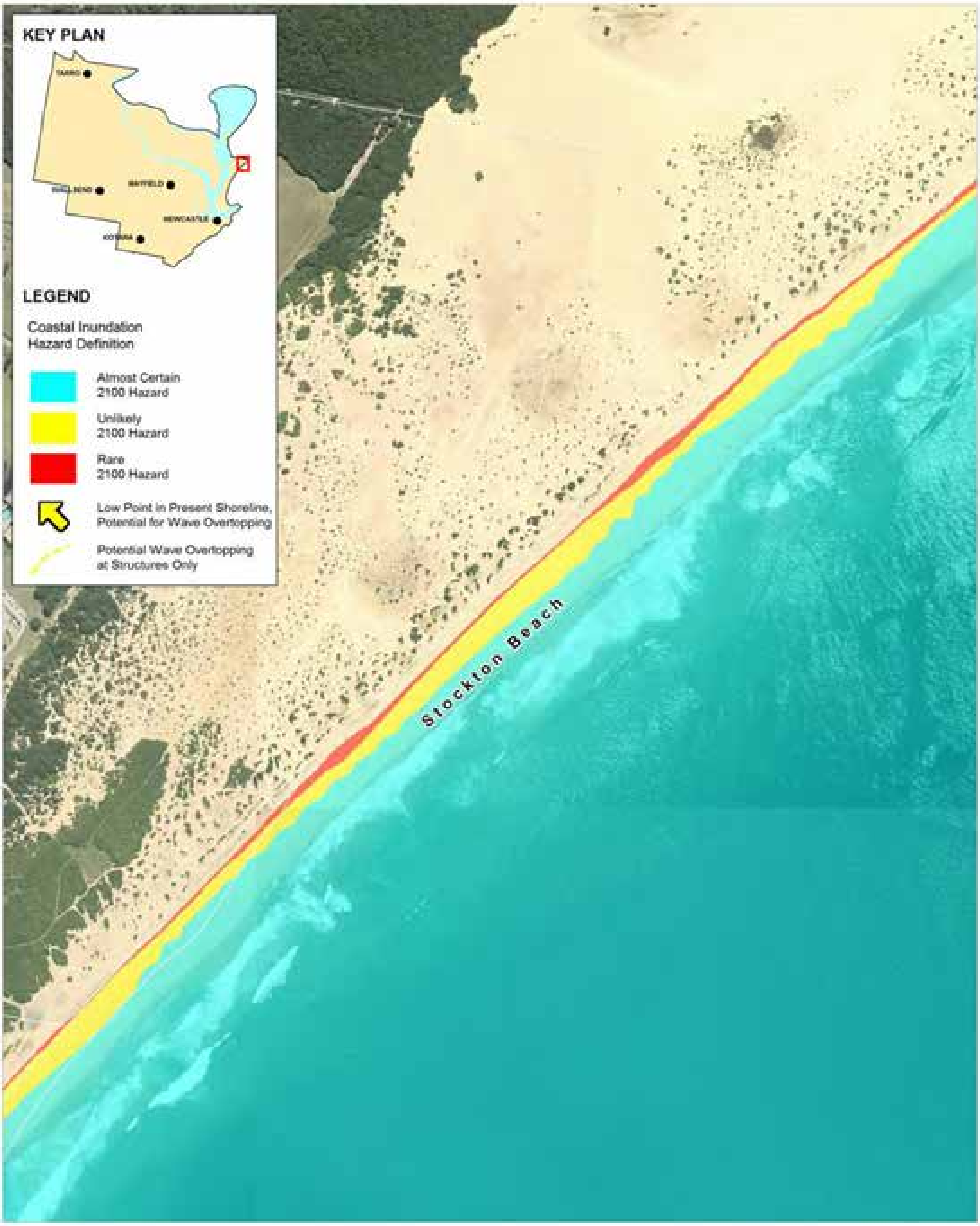

Title:	Figure:	Rev:
Coastal Inundation Hazard Definition 2100 Planning Horizon - Fern Bay	**F-1**	**A**

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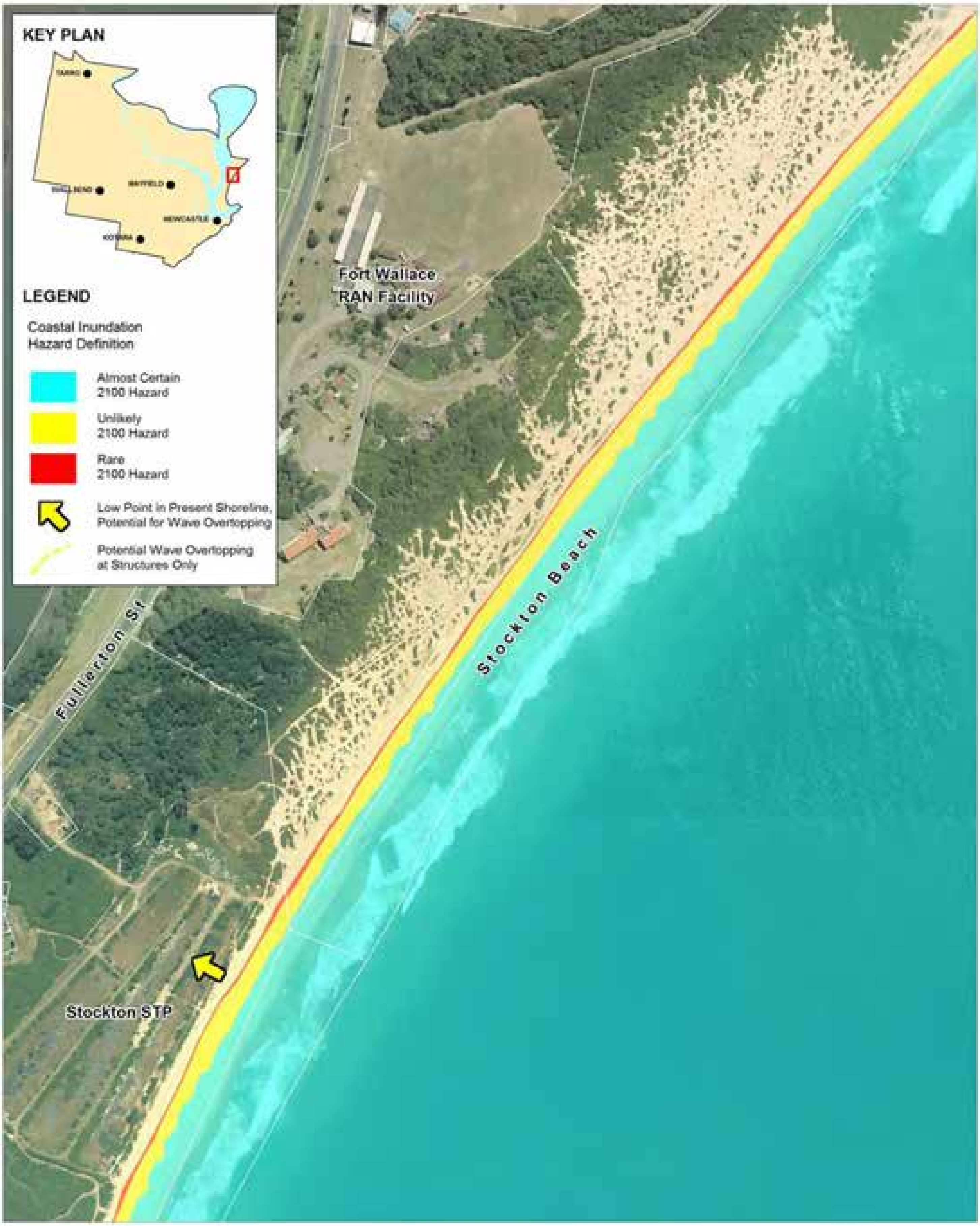

Title:

Coastal Inundation Hazard Definition
2100 Planning Horizon - Fort Wallace

Figure: **F-2**

Rev: **A**

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Title:
Coastal Inundation Hazard Definition 2100 Planning Horizon - Stockton North

Figure: F-3

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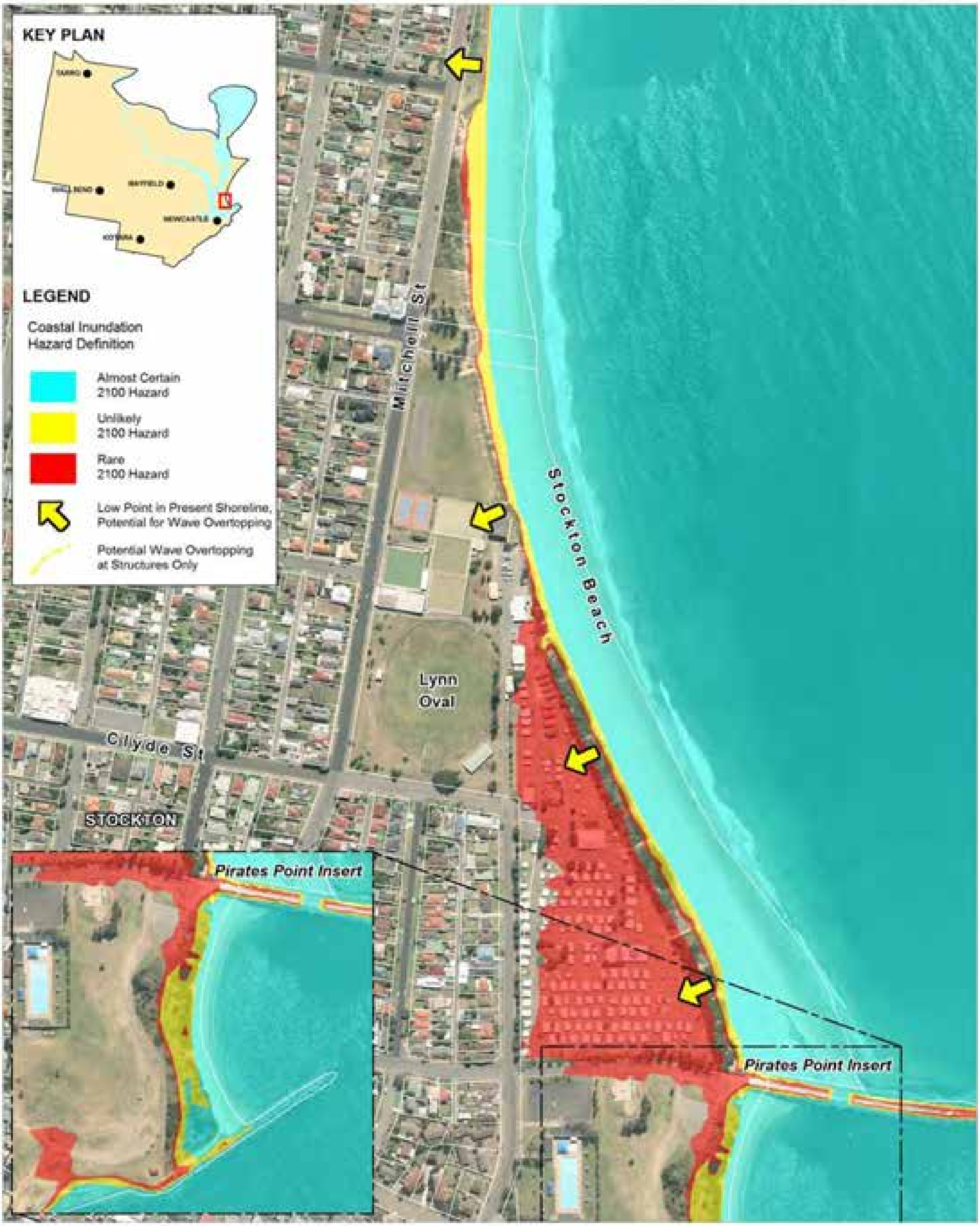

Title:

Coastal Inundation Hazard Definition
2100 Planning Horizon - Stockton South

Figure: F-4

Rev: A

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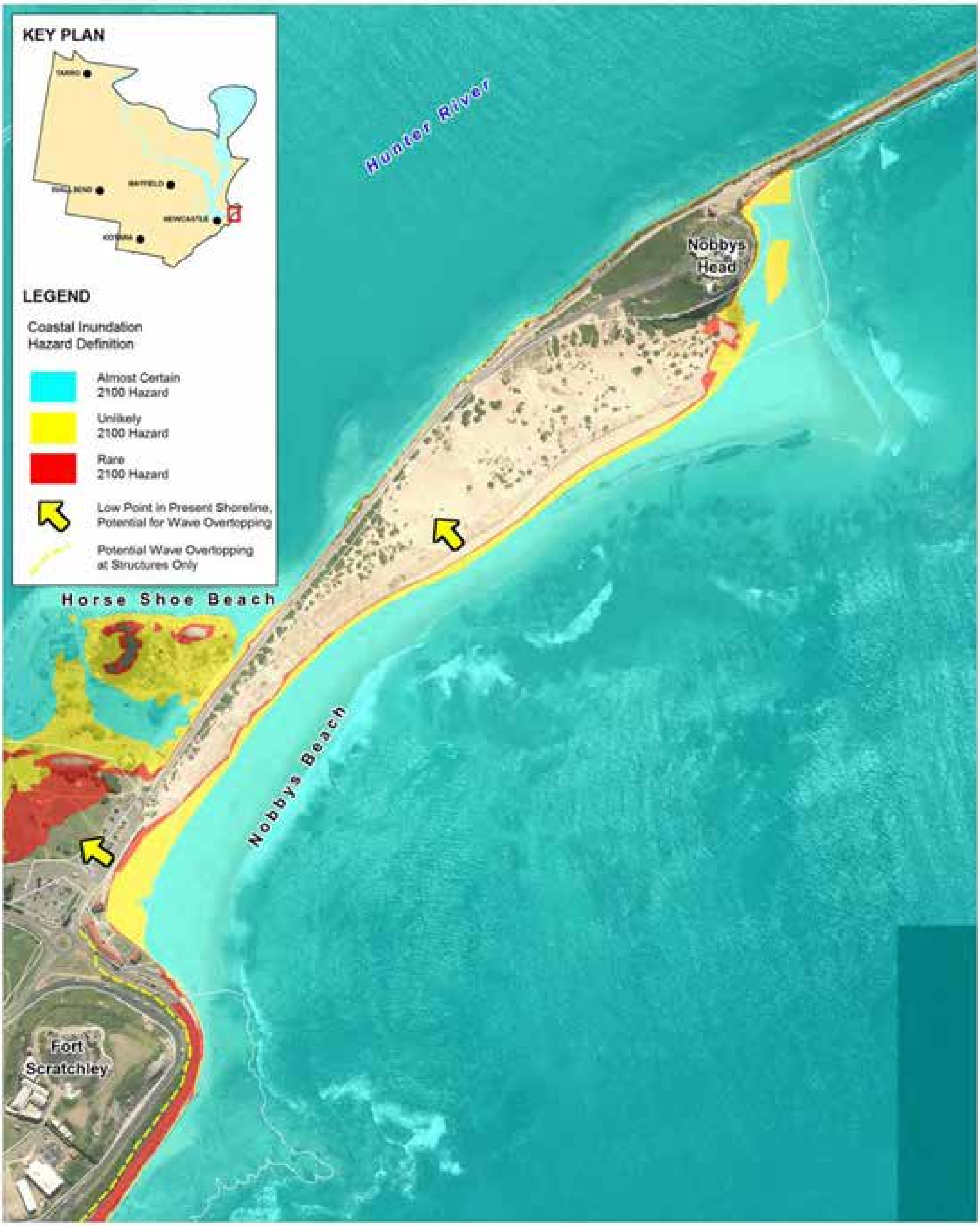

Title:

Coastal Inundation Hazard Definition
2100 Planning Horizon - Nobbys Beach

Figure: **F-5**

Rev: **A**

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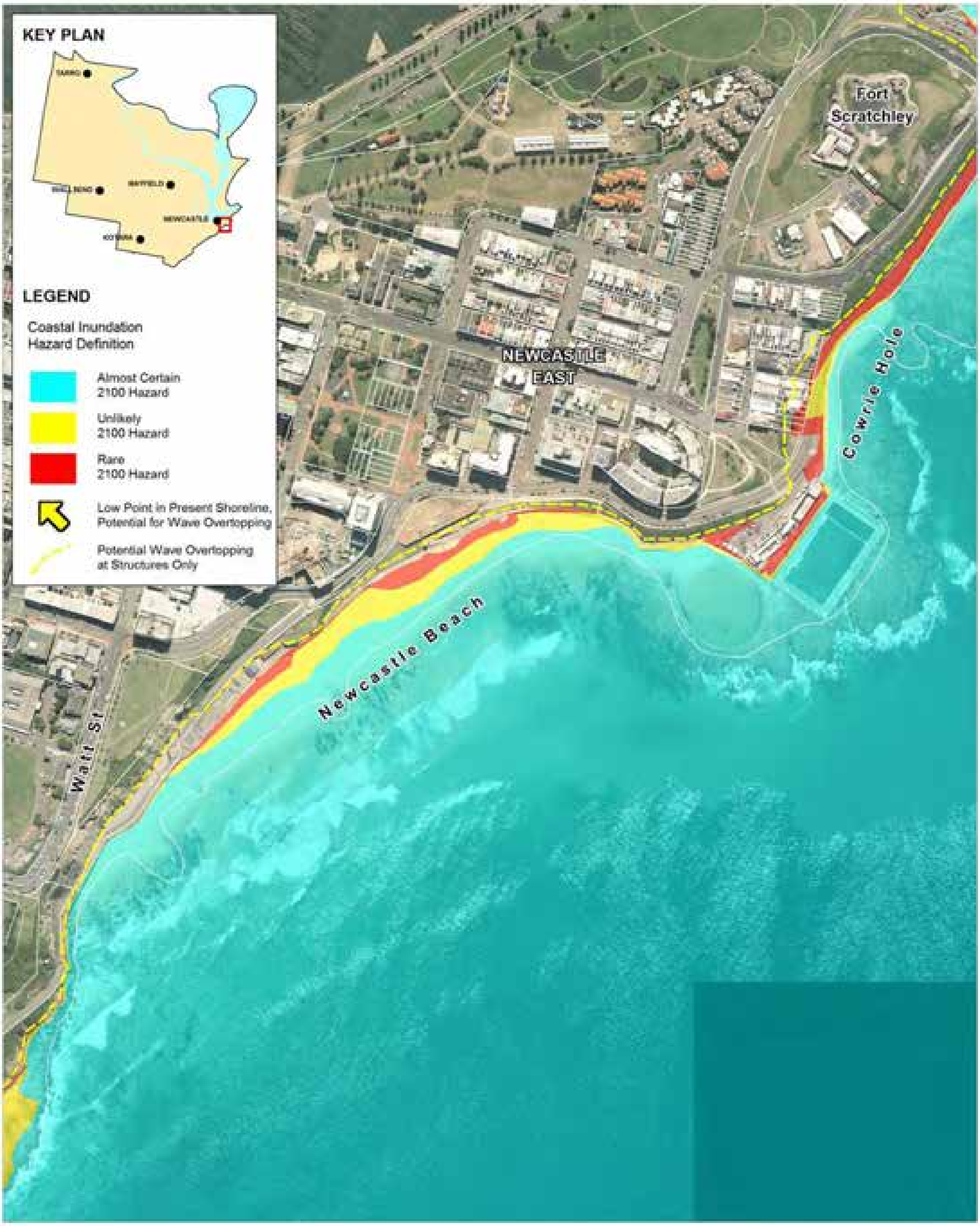

Title:
Coastal Inundation Hazard Definition
2100 Planning Horizon - Newcastle Beach

Figure: **F-6**

Rev: **A**

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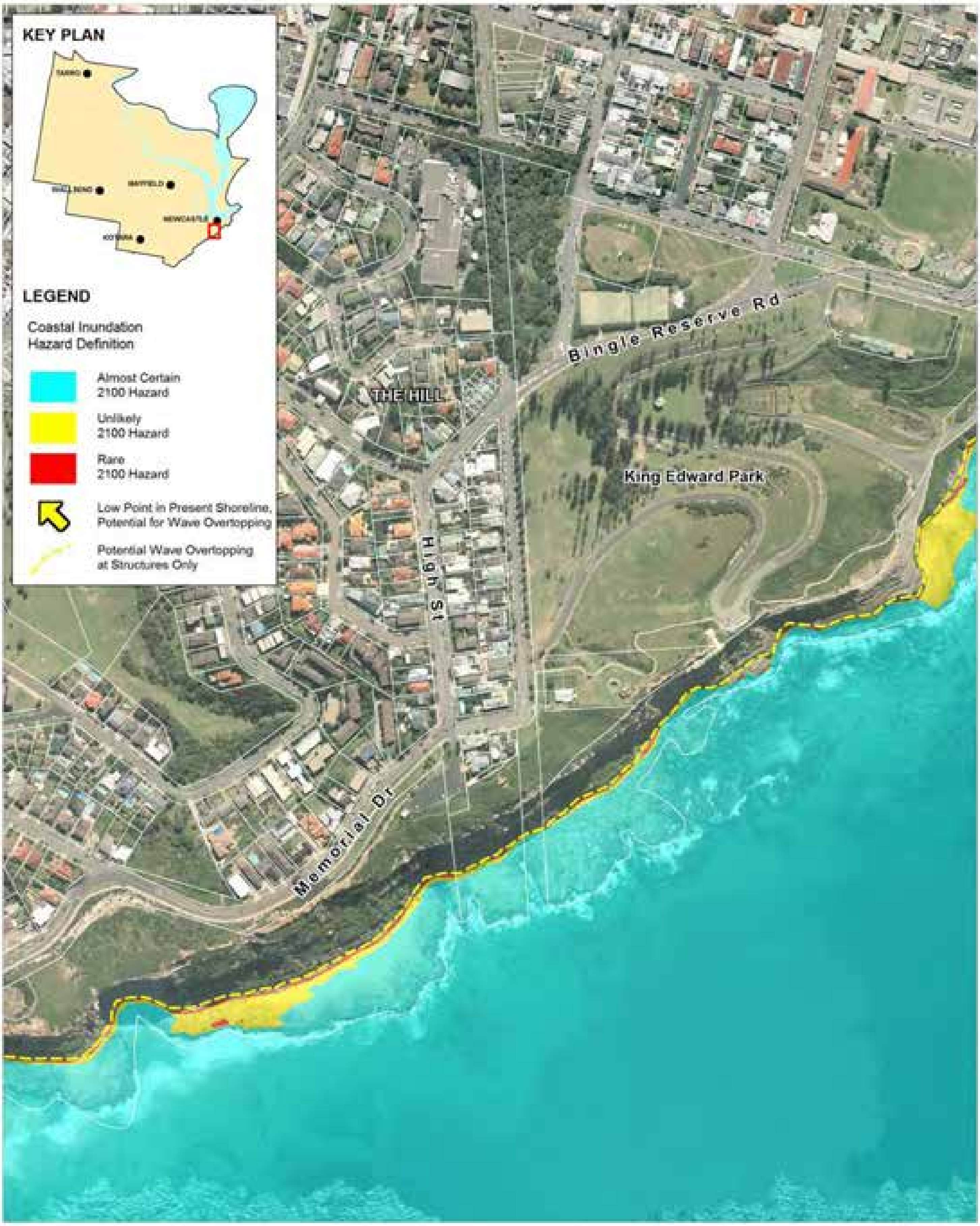

Title:

Coastal Inundation Hazard Definition
2100 Planning Horizon - The Hill

Figure: F-7

Rev: A

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Title:

Coastal Inundation Hazard Definition
2100 Planning Horizon - Bar Beach

Figure: **F-8**

Rev: **A**

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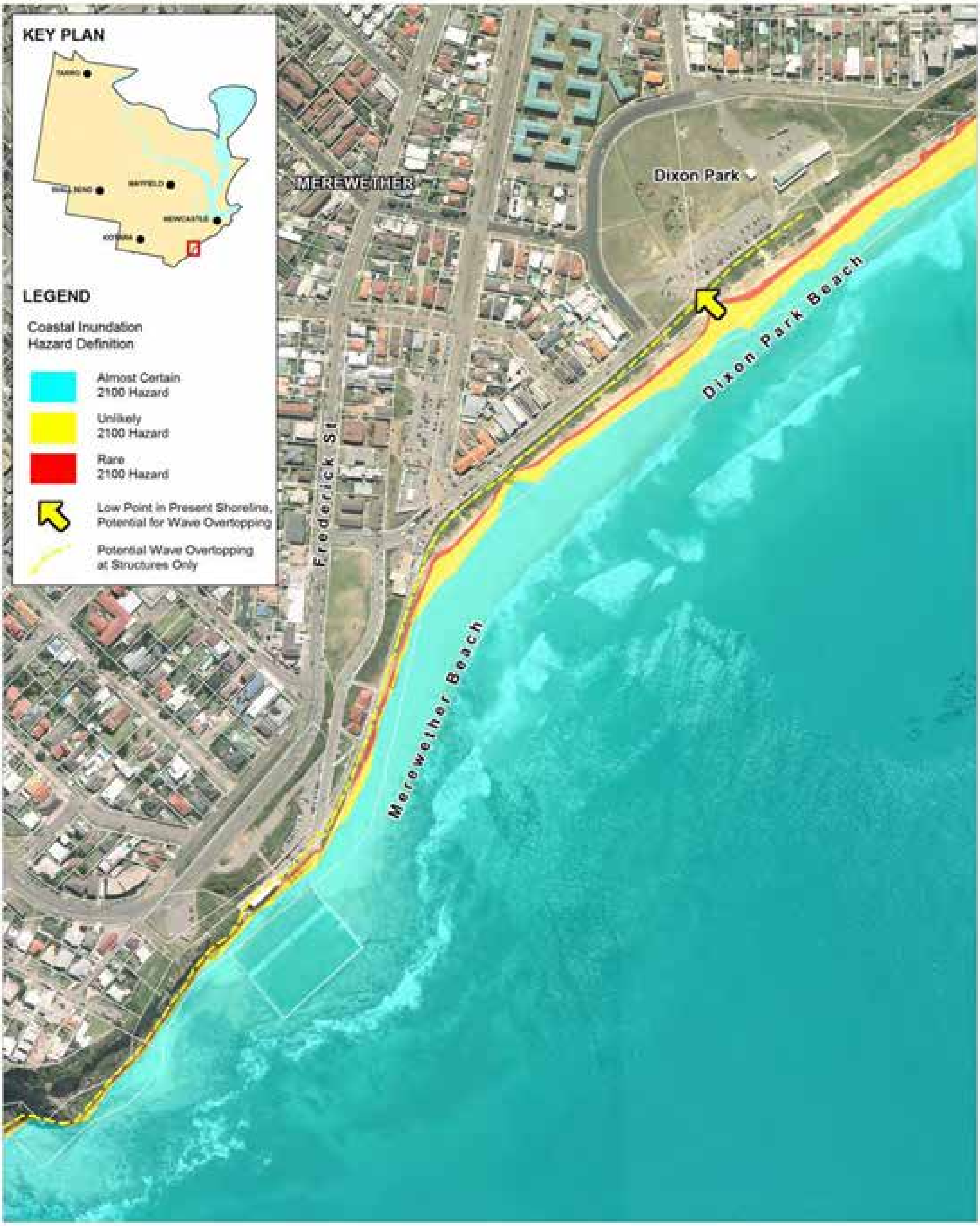

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Coastal Inundation Hazard Definition
2100 Planning Horizon - Merewether Beach

Figure: **F-9**

Rev: **A**

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APPENDIX A: PUBLIC ASSETS STRUCTURAL ASSESSMENT

The assessment of public structures and their construction details has been extracted from the CHDS (2000) with updating of information where relevant for 2011 (e.g. most notably regarding the Merewether Surfhouse structure). Based upon site inspections in 2011, various minor repair works were observed at all structures. However, comments regarding the overall condition of the structures and the processes causing conditions requiring maintenance from 1998 remain relevant, and have been retained in the summary below.

Ocean Pools and Structures

General

The ocean bath structures have been constructed on the sandstone rock platforms within the wave zone. The concrete structures are frequently over topped by waves during storm events and at high tide.

The baths have a high level of public utilisation and are considered by large sections of the Newcastle public as landmark structures.

In 1998, no significant deterioration or structural inadequacy was noted in a walk over survey of the bath structures. The outer concrete walls show only limited corrosion and are founded directly on the sandstone rock surface in tight contact with little or no erosion evident at the concrete rock interface. On-going settlement and wash out of loose sandy backfill material from beneath pool deck areas is resulting in some cracking of concrete pavements and the need for maintenance.

Specific Assessment

Ocean Baths

The Ocean Baths have been constructed on and excavated into a sandstone rock platform that occurs at about 1m to 1.5m AHD and extends beyond the eastern margin of the baths. The pool surrounds comprise low concrete walls that have been formed directly onto the rock surface and battered for wave deflection. In 1998, the wall / rock contact was noted to be generally sound with some localised undercutting of the external wall at the south western corner of the pool.

In 1998, the extent of concrete corrosion was said to be limited due to the use of more durable slag and rock aggregate in the construction. Severe local concrete corrosion up to a depth of 200mm occurring on the outer face of a 3m high wall surround that has been constructed at the north eastern corner of the baths using sandstone rock aggregate. Corrosion of the concrete inlet structure is also occurring. The old pump house structure is extensively cracked and is only being held together by corroding reinforcing. There is a high risk that this structure may collapse and there is evidence that people access the interior of the structure through the roof.

In 1998, seepage inflows into the drained baths occur through cracks and joints in the wall. Conversely, outflow from the baths into surrounding backfill materials will occur when they are full.

Construction of an access ramp to the baths indicated the presence of three concrete pavement layers forming the pool decking area. The layers consisted of a newer 150mm thick concrete pavement overlying two older layers up to 250mm thick over backfill comprising sand and rock with voids present. This suggests that settlement and cracking of the pool deck area routinely occurs, requiring repair or replacement. Steel stirrup reinforcing was noted within the pool wall.

Adjacent to the Ocean baths is an oval baths structure that has been partially infilled with sand. The outer wall comprises mass concrete founded directly onto the sandstone rock platform. The outer margin of the wall ranges from vertical to a 1V : 2H batter in profile with some minor surface spawling / corrosion of the concrete. Some concrete repair has been undertaken along sections of the wall and additional concrete revetments placed for wave deflection.

The baths are routinely over topped by waves during high tide or storm events, however the rock platform provides significant dissipation of wave energy. The 1955 wave action associated with a storm surge smashed sections of concrete pavements and damaged the lower floors of Ocean Baths. No damage to the pool surrounds or structure was noted.

Bogey Hole Baths

The Bogey Hole baths were hewn into the sandstone rock platform by convict labour in the 1820's for the military commandants use and as such are of significant historical value. A steep cliff section up to 10m in height occurs directly above the baths and the rock platform. A small cave or undercut section of cliff occurs at the south western corner of the baths. The cave is undercut up to 5m depth, is about 4 m wide with 4m to 5m of inter-bedded siltstone and sandstone rock cover. No tensional features suggesting instability were noted at the time of the field survey within the cave. The occurrence of a steep overhanging cliff section directly above a public bath area represents a hazard. Routine monitoring should be undertaken and the risk signposted or otherwise slope remediation works undertaken.

A stability assessment of the cliff face undertaken by SMEC (1994) indicated that the cliff face is retreating through coastal erosion and that there is a risk of personal injury from rock falls. Similarly, RCA (2013) identified from historical photographs that cliff line recession has occurred at some locations within the vicinity of the Bogie Hole, in the order of 2-4m from 1986 – present.

Lady's Baths, Merewether

Lady's baths comprised a small shallow baths area formed on the sandstone rock platform with low concrete walls. Deterioration of the structure has occurred with time requiring removal of some sections of the low concrete wall.

Merewether Baths

Merewether baths consists of two ocean pools constructed onto and excavated into a sandstone rock platform that occurs at about 1m AHD. The pool surrounds comprise low concrete walls that have been formed directly onto the rock surface and battered for wave deflection. In 1998, the wall/ rock contact was noted to be generally sound and the extent of concrete corrosion is limited. More durable slag and rock aggregate was used in the construction of the bath structures compared to seawall concrete construction where sandstone rock aggregate was extensively used.

At 2011, the baths are routinely over topped by waves during high tide and/ or higher wave events, however the rock platform provides significant dissipation of wave energy. With sea level rise to 2050 and 2100, the dissipation of waves across the rock platform will be reduced, and higher wave impacts can be expected.

In 1998, some minor cracking of the concrete walls was noted which is to be expected considering the extensive length of the wall. Well developed cracking of the concrete slab has occurred on the deck area between the two pools. The cracking is most likely associated with settlement of backfill materials and possibly some washout of fines through cracks when the pools are drained. The cracks have widened up to 25mm in places through concrete corrosion and this suggests that they have been present for a long period of time.

Surf Clubs and Buildings

General

Buildings within the immediate coastal zone comprise surf clubs and related structures with only limited residential structures present.

Residential structures in proximity to cliff crests occur at Lloyd and Hickson Streets, Merewether where property boundaries occur along the crest of the cliff line and to a lesser extent at Kilgour Avenue, Dixon Park and Cliff Street, Shepherds Hill where property boundaries are set back 15m to 20m. The structures are founded on residual clay soils or rock of adequate bearing capacity.

The only structures considered to be under threat at present from storm damage or loss of foundation support through erosion are the structures at Stockton such as the surf club which are founded on deep sand profiles. The remaining surf club structures are protected by seawalls and / or rock platforms with most founded down onto rock. The integrity of the seawall structures is integral to the long term protection of these structures from storm damage.

Due to the harsh nature of the immediate coastal environment, construction materials are subject to extreme corrosion levels requiring a high degree of maintenance and appropriate material selection in design.

Specific Assessment

Stockton Preschool, Sur/Club and Caravan Park

The above structures are founded on high level pad or slab footings bearing directly onto the sand. Available geotechnical information suggests that the subsurface profile at these sites comprises 10m to 20m of medium dense to dense sand over clay with rock at a depth of about 30m to 40m.

The foundation soils at these sites have adequate bearing capacity to support the structures but are highly susceptible to hydraulic erosion.

Newcastle Port Corporation Buildings, Nobbys

The lighthouse and signal station structures on Nobbys Headland are founded on rock and residual clay soils. The risk posed to the buildings associated with cliff line erosion and instability is very low considering a current erosion rate of 10-15mm per year (RCA, 2013). Future risk associated with sea level rise is also assessed to be low. The closest structure is about 2.5m from the cliff crest and comprises an old store room. A brick fence at the south eastern corner of headland is starting to become undercut by cliff erosion and will require remedial works in the short term.

Nobbys Surf Club

Nobbys Surf Club is located at the toe of the north eastern end of Fort Scratchley with rock slopes rising to the rear of the club and Shortland Esplanade with the club protected by a concrete seawall. Filling of the rock platform and construction of seawalls fanned the area along Shortland Esplanade. This was preceded by the construction of the seawall to Nobbys Headland, which resulted in sand deposition in the area of the surf club. The extent to which the surf club is founded over fill materials or sand deposits is unknown, however the performance of the structure suggests that foundations have most likely been taken to rock.

Newcastle Surf Club

Redevelopment of Newcastle Surf Club and pavilion (following storms in the 1970s) has involved taking all foundations to rock and the construction of a stepped concrete seawall.

Cooks Hill Surf Club and Pavilion, Bar Beach

The older Cooks Hill Surf Club structure and the newer beach pavilion and tower are founded on rock using a combination of pad, pier and buttress footings. Site investigation for the newer pavilion encountered rock at a level of about 3m to 4m, AHD. The older surf club structure is situated directly on the beach with the eastern facing wall supported by a continuous footing that acts as a seawall. Photographic evidence following storms in 1974 indicate bedrock below the older Cooks Hill Surf Club.

Dixon Park Surf Club

Dixon Park Surf Club is situated on gentle slopes at the base of a low hillside area that rises to the north west behind the fore dunes. The buildings appear to be supported on high level footings that occur in clayey residual soils with possibly some sandy soils at the southern end of the structure. The building is located about 20m behind the fore dunes at an elevation of about R.L. 14m.

Merewether Surf Club and Pavilion

Merewether Surf Club is located at the northern end of the rock platform on a low sand hill situated at the rear of the beach. It is unknown whether the club is founded on high level footings in the sand or on piers taken through the sand to rock which is likely to occur at a depth of about 3m to 5m.

The club structure was threatened by severe sand erosion during the 1974 storm event. Remedial works subsequently undertaken included construction of a rock wall in front of and to the north of the club and a concrete retaining wall in front of the club.

An open beach pavilion structure is constructed along the promenade directly above the lower seawall, which is about 1.5m in height and constructed of sandstone blocks. The structure is founded on concrete pads bearing directly onto the comers of the seawall. In 1998 uplift of the pads associated with wind loading and corrosion at the wall/slab contact had resulted in a gap of up to

15mm at the pad I wall contact and cracking of mortar within the wall below. The wall supporting the structure will continue to deteriorate under the static and live loading and there is a risk that this section of the wall may fail removing support for the corner of the structure. It is unknown if the 1998 recommendation that the footings should be taken down through the wall and founded into the sandstone rock below has been implemented.

Merewether Surfhouse

The formerly derelict surf house structure has been removed and a new Merewether Surfhouse has been constructed at the same location.

The new Merewether Surfhouse is situated on a terraced bank that rises from the rock platform to the access road to Merewether Baths. Given its recent construction, it is presumed to have been built to withstand coastal processes for the intended life of the structure, including foundations to rock. The height of the structure is just visible to the height of Scenic Drive (i.e., above the access road to the Baths), and the structure comprises 3 levels in total.

The lower promenades and walls below the new Surfhouse structure have not been upgraded. The lower promenades experience overtopping at present with high tides and high waves, and this is expected to increase over time with sea level rise. The lowest level of the new Surfhouse at about 8 m AHD would not expected to experience overtopping by 2100.

APPENDIX B: GEOTECHNICAL ASSESSMENT OF NEWCASTLE COASTAL CLIFFS/SLOPES: NEWCASTLE LGA COASTAL ZONE (RCA, 2013)

GEOTECHNICAL ASSESSMENT OF NEWCASTLE COASTAL CLIFFS/SLOPES

Newcastle LGA Coastal Zone

Prepared for BMT WBM Pty Ltd

Prepared by RCA Australia

RCA Ref 8365-202/2
Client ref 2011/265T

December 2013

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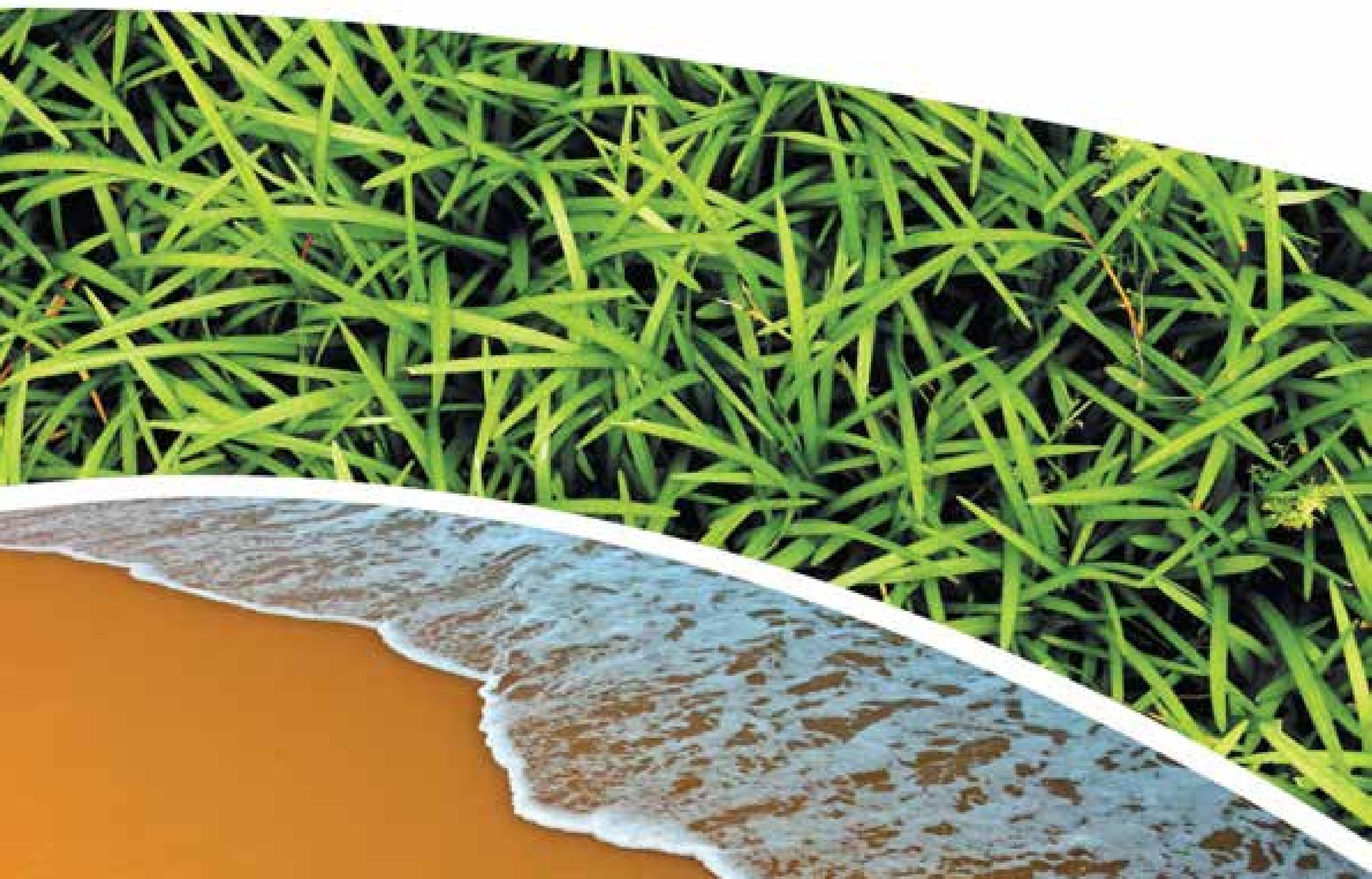

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/2	2	Bound Report	BMT WBM Pty Ltd, Paul Donaldson	18.12.13
/2	1	Electronic	RCA – Job archive	18.12.13
/2	1	Bound Report	RCA – Job archive	18.12.13

EXECUTIVE SUMMARY

This report presents the results of a geotechnical assessment of the City of Newcastle (CoN) coastal cliff/slope hazards from Nobbys Headland in the north to the Hickson Street, Merewether headland in the south.

The geotechnical assessment was commissioned by BMT WBM Pty Ltd (WBM) as part of the Newcastle Coastal Zone Hazards and Management Studies for the City of Newcastle (CoN) in accordance with CoN contract no. 2011/ 265T. The geotechnical assessment of coastline hazards specifically addresses the requirements set out in Section 4.2.2.3 “Coastal Cliff and Slope Stability” of the City of Newcastle (CoN) Newcastle Coastal Zone Hazards and Management Study 2011 Brief, CoN contract no. 2011/ 265T.

The principal geotechnical requirement set out in Section 4.2.2.3 “Coastal Cliff and Slope Stability” of the CoN 2011/265T brief was to assess Newcastle Coastline geotechnical hazards in accordance with the ‘*Practice Note Guidelines for Landslide Risk Management*’, formulated by the Australian Geomechanics Society Landslide Practice Note Working Group and published in the Australian Geomechanics, Volume 42 No 1 March 2007, herein referred to as *AGS LRM 2007*.

The geotechnical risk assessment of the 2011-12 Newcastle Coastline geotechnical hazards included a desktop review of previous geotechnical coastal hazard studies and historical photographs. Based on results of desktop review, initial site inspections along the length of the Newcastle LGA coastline and consultations with City of Newcastle, twenty-two locations (details in Section 5 of this report) were identified for detailed landslide risk assessment in accordance with *AGS LRM 2007* assessment procedures.

The landslide risk assessment for each of the identified coastal cliff and slope hazards comprised a qualitative assessment of risk to property and a quantitative assessment of risk of loss of life, in accordance with *AGS LRM 2007* guidelines. The landslide risk assessment included rock fall analysis where appropriate. At each location the risk assessment of the identified coastal cliff and slope hazards included consideration of the potential effects of projected sea level rises as supplied by WBM BMT (details in Section 8 of this report).

The identified coastal cliff and slope hazards were then ranked in order of the combined assessed risk to property and life. Risk management options are presented for each of the identified coastal cliff and slope hazards.

Based on the identified geotechnical coastal cliff and slope hazards, slope geometry and with reference to past slope instability, coastal landslide risk assessment zones were defined along the Newcastle LGA coastline (refer to **Drawings 7** to **10** in **Appendix A**) as part of the 2011-12 geotechnical assessment of coastline hazards.

It is suggested that the development approval process adopted by the City of Newcastle for development within the coastal landslide risk assessment zones follow the **AGS 2011 Landslide Risk Management** – **Development Assessment Flow Chart** attached in **Appendix B** of this report. This flow chart was developed by Wollongong City Council to provide regulator guidelines for assessing development applications in landslide risk areas. A detailed discussion is presented in Australian Geomechanics Volume 46 No.2 June 2011.

During the course of the geotechnical assessment of coastal cliff and slope hazards, sea levels approximating the projected sea level rises were observed during high seas and storm surges. Selected photographs of these ‘high’ sea levels affecting prominent public amenities along the Newcastle LGA coastline have been included in this report to assist CoN and relevant stakeholders in the management of these public amenities.

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APPENDIX A

Drawings 1 – 4: Geotechnical Assessment Location Plans
Drawing 5: Inferred Coastline Geology
Drawing 6: Inferred Depth of Coastline Sediments
Drawings 7 to 10 Coastal Landslide Assessment Zone Maps
Geo-hazard Long-sections: G1 – G6
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APPENDIX B

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Table B2: Risk to Life Assessment Matrix
Table B3: Combined Risk Ranking Matrix
AGS LRM 2007 Landslide Qualitative Risk to Property Classification
AGS LRM 2007 Australian Geoguide LR8 - for Hillside Construction
AGS 2011 Development Approval Flow Chart

APPENDIX C

Cliff Line Regression Photograph Sets

APPENDIX D

Photographs illustrating projected sea level rise

APPENDIX E

EJE Memorial Cliff Top Walk Conceptual Drawings

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Occupational Hygiene

RCA ref 8365-202/2
Client ref 2011/265T

18 December 2013

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Attention: Paul Donaldson

GEOTECHNICAL ASSESSMENT OF NEWCASTLE COASTAL CLIFF AND SLOPE STABILITY AND RISK MANAGEMENT OPTIONS

1 INTRODUCTION

This report presents the results of a geotechnical assessment of coastal cliff/slope stability commissioned by BMT WBM Pty Ltd (WBM) as part of the Newcastle Coastal Zone Hazards and Management Studies for the City of Newcastle (CoN) in accordance with CoN contract no. 2011/ 265T.

The geotechnical assessment of coastline hazards specifically addresses the requirements set out in Section 4.2.2.3 “Coastal Cliff and Slope Stability” of the City of Newcastle (CoN) Newcastle Coastal Zone Hazards and Management Study 2011 Specification, CoN contract no. 2011/ 265T (Ref [1]).

2 COUNCIL OF NEWCASTLE GEOTECHNICAL SCOPE OF WORK

The objectives of the geotechnical assessment for the CoN Newcastle Coastal Zone Hazards and Management Study 2011, as set out in “Section 4.2.2.3 Coastal Cliff and Slope Stability” of NCC contract no. 2011/ 265T are to:

- *“identify and map all reasonably identifiable geotechnical hazards along the Newcastle coastline, ”*
- *“prioritise risk mitigation and maintenance works to be undertaken by Council, ”*
- *“identify hazard monitoring requirements.”*

The assessment area defined in CoN contract no. 2011/265T brief included coastal cliffs/slopes and rock platforms, from Nobbys Headland in the north to the Hickson Street, Merewether headland in the south, as shown on **Drawings 1 – 4: Geotechnical Assessment Location Plans** in **Appendix A**.

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CoN specified the geotechnical assessment should be undertaken in accordance with the Australian Geomechanics Society Landslide Risk Management Guidelines 2007 by a suitably qualified consultant. Suitably experienced and qualified consultants from RCA carried out the geotechnical assessment as per RCA proposal document ref 8365-101 rev1 dated 3 February 2010.

The CoN contract no. 2011/ 265T "Section 4.2.2.3 Coastal Cliff and Slope Stability" also specifies the stability assessment should:

- *review existing geotechnical data for the Newcastle coastal zone;*
- *include field mapping of all reasonably identifiable geotechnical hazards;*
- *incorporate projected sea level rise of 0.4m by 2050 and 0.9m by 2100 into the geotechnical assessment of coastal cliff/ slope hazards;*
- *estimate likely changes to cliff/ slope regression rates at present and from projected sea level rises of 0.4m by 2050 and 0.9m by 2100;*
- *assess the risk(s) posed by the identified geotechnical hazards to people, property, services, community facilities, access, transport services and the environment, at present and that could potentially arise from the projected sea level rises of 0.4m by 2050 and 0.9m by 2100;*
- *a conclusion as to whether cliff/slope areas are stable, suitable for public/vehicular access, suitable for existing and future development;*
- *propose risk mitigation and maintenance options for the identified coastal cliff/slope geo-hazards; and*
- *recommend further investigations where required.*

3 DESKTOP REVIEW

3.1 REVIEW OF PREVIOUS RCA GEOTECHNICAL INVESTIGATIONS/ASSESSMENTS ALONG THE NEWCASTLE COASTAL ZONE

Previous studies completed by RCA and used to support the 2011-12 geotechnical assessment are listed in **Table 1**.

Table 1 *Summary of Previous RCA Reports for Newcastle Coastline*

RCA Report No.	Description	Year of investigation
698 a-c	Stability Assessment of South Newcastle Cliff Face, multiple rock falls	1998 to 2001
835	Newcastle Coastline Hazard Definition Study (2000) – Geotechnical Assessment	1998-99
2346	Geotechnical Assessment of Coastal Failures, including loss of stairs from Susan Gilmore cliff footpath	2001
2407	Geotechnical Assessment of Fort Scratchley Revetment Walls	2001
3064	Geotechnical Assessment of Coastal Sea Walls	2002
3246	Geotechnical Investigation of North Newcastle Beach Wall	2004
3678	Geotechnical Investigation of Bogie Hole Rock Fall from cliff face some 22m above pool that damaged fixed picnic table, fences at the viewing area above and stair railing to the Bogie Hole Pool	2003
6227	Geotechnical Assessment of Bathers Way, Bogie Hole	2007
6479	Geotechnical Assessment of landslides at the Cliff and Merewether Baths landslide ~200m^3	2007
7080	Geotechnical Assessment of north side of Nobbys Cliff stability – cliff regression rate 10 to 40mm per year	2009

3.2 REVIEW OF PREVIOUS COASTAL STUDIES

3.2.1 NEWCASTLE COASTLINE HAZARD DEFINITION STUDY 1998

A document review found a detailed geotechnical assessment of the City of Newcastle LGA coastline was presented in WBM Oceanics Australia Newcastle Coastline Hazard Definition Study (2000), herein referred to as *NCHDS 2000 (Ref [2])*.

The geotechnical coastline hazard assessment included in *Section 10* of *NCHDS 2000* covered issues beyond the scope specified in CoN contract no. 2011/ 265T for this current work. Issues addressed in *NCHDS 2000 Section 10* not covered in the scope of the 2011-12 geotechnical assessment included the effect of coastal processes on seawalls, ocean pools and surf club structures.

Geotechnical information pertinent to the 2011-12 geotechnical assessment of the coastal cliffs and slopes from *NCHDS 2000* has been incorporated into the current coastline hazard assessment.

Geotechnical long-sections and cross-sections from *NCHDS 2000* were used as a basis for the geotechnical risk assessment fieldwork. Coastal cliff and slope geotechnical hazards identified in *NCHDS 2000* were incorporated into the geotechnical assessment, as specified in CoN contract no. 2011/ 265T.

The *NCHDS 2000* report included four sets of historical photographs, showing cliff face profiles. It was decided to take a matching set of photos of the 2011-12 conditions to provide some control points for estimating coastal cliff regression rates.

In addition to the four coastal cliff photographs included in *NCHDS 2000*, RCA was granted access to an extensive library of historical photos compiled by Mr Robert Sirasch. From this extensive library a set of eight additional historical photos, showing coastal cliff profiles were selected for further analysis.

3.2.2 NEWCASTLE COASTLINE MANAGEMENT STUDY JAN 2003

Review of the "Newcastle Coastline Management Study" Umwelt, Jan 2003 (Ref [3]) revealed the following issues relevant to the 2011 coastal cliff/slope geotechnical assessment.

The predominant types of usage of the Newcastle coastal zone included: hang-gliding (take-off sites/landing sites); view observers; recreational walkers and rock fishers.

Risk management of erosion, stormwater runoff and regression processes affecting coastal cliffs and slopes.

Noted examples of cliff instability included the following:

- Rock falls from Nobbys headland.
- Fort Scratchley – rotational sliding of soil/clay at crest above Fort Drive.
- Unstable soil/rock structure (associated rock fall) especially along Shortland Esplanade between Nobbys and Newcastle Baths.
- Shortland Esplanade at South Newcastle Beach – preliminary works and planning for slope stabilisation works(rock bolting was used to mitigate rock fall risks).
- The Cliff, southern end of Kilgore Ave, Dixon Park: - rock fall in 1997 – fenced off.
- South Merewether Beach – rock falls below Hickson Street.

3.2.3 NEWCASTLE COASTLINE MANAGEMENT PLAN –MARCH 2003

A review of the Newcastle Coastal Management Plan –March 2003 (Ref [5]), indicated the issues relevant to the 2011-12 coastal cliff/ slope geotechnical assessment were as follows.

Identified coastal cliff/slope hazards included the following:

- Rock falls from Nobbys Headland and along Shortland Esplanade between Nobbys and Newcastle Baths.
- Cliff erosion and rock fall on to Shortland Esplanade at South Newcastle beach.
- Unstable soil structure in cliffs/potential for rock fall, along Shortland Esplanade.
- Runoff causing cliff erosion above Bogie Hole.
- Eroded tracks to cliff tops.
- Stormwater impacts on cliff stability and viability of cliff top access at Susan Gilmore Beach and associated rock fall from Susan Gilmore Beach and Bar Beach.
- Rock fall risk – Dixon Park –Kilgore Avenue.

Management actions included the following:

- Erection of warning signs around base of Nobbys (on beach).
- Erection of warning signs on Shortland Esplanade of slope instability.
- Slope stabilisation works/improvement strategies (long-term).
- Temporary closure of Shortland Esplanade during times of coastal inundation.

- Erection of rock fall warning signs around base of cliff on Shortland Esplanade around South Newcastle Beach.
- Implement slope stabilisation and improvement strategies for Shortland Esplanade between South Newcastle Beach and King Edward park.
- Erect warning signs concerning unstable cliff top and provide formalised pathways and restrict access by constructing fencing.
- Close Susan Gilmore Beach access.
- Erect warning sign for entry to Bogie Hole steps.
- Close cliff top walking track between Susan Gilmore Beach and Strzelecki scenic lookout.
- Undertake geotechnical risk assessments/risk mitigation measures at cliff top viewing locations.
- Close access to Susan Gilmore Beach and erect warning signage.
- Erect rock fall warning signage at Dixon Park cliff and undertake geotechnical risk assessment.
- Undertake geotechnical risk assessment of rock fall at northern end of Bar Beach.
- Erect rock fall warning signage at cliff below Lloyd Street, Merewether.
- Erect rock fall warning signage at cliff below Hickson Street, Merewether.

Section 9 of the 2011-12 geotechnical assessment presents a review of the risk management measures listed above.

3.3 GEOLOGY OF NEWCASTLE COASTAL CLIFF/SLOPE(S)

The geology of the Newcastle coastal zone was extensively reviewed in the *NCHDS 2000* document. The rocks exposed in the cliff lines between Nobbys and Hickson Street Ridge comprise Permian Age (approximately 260 million years old) sedimentary rocks of the Newcastle Coal Measures.

A geology map of the Newcastle coastal study zone is shown on **Drawing 5: Inferred Coastline Geology** in **Appendix A**. Details of the geological sub-groups shown on **Drawing 5** are presented in **Table 2**. **Drawing 5: Inferred Coastline Geology** also shows the approximate location of principal geological structures such as faults and dykes.

Table 2 *Geology of the Newcastle Coastline*

Sub - group	Formation	Member	Rock Type	Exposure
Adamstown	Kotara	Merewether Conglomerate	Sandstone, conglomerate	Shepherds Hill, Hickson Street Ridge, Obelisk Hill
Lambton	Victoria Tunnel Coal		Coal, tuffaceous claystone	Nobbys, Shepherds Hill, Merewether Hill
	Shepherds Hill	Nobbys Tuff	Tuffaceous claystone / siltstone	Nobbys to Hickson Street Ridge,
	Nobbys Coal		Coal, tuffaceous claystone	Nobbys to Hickson Street Ridge,
	Bar Beach	Signal Hill Conglomerate	Sandstone, siltstone, shale	Fort Scratchley to Hickson Street Ridge,
	Dudley Coal		Coal, tuffaceous claystone	Fort Scratchley to Hickson Street Ridge,
	Bogey Hole		Sandstone, siltstone, shale	Fort Scratchley to Merewether Hill
	Yard Coal		Coal, tuffaceous claystone	Newcastle , Shepherds Hill
	Tighes Hill		Sandstone, siltstone, shale	Newcastle , Shepherds Hill
	Borehole Coal		Coal, tuffaceous claystone	Not exposed Extensively mined

The main structural feature of the study area is the Delta Syncline comprising a broad open fold with a North East tending curvilinear axis from 'The Hill'.

To the south of the Shepherds Hill area, the cliff sections occur on the eastern flank of the Macquarie Syncline with gentle dips of typically 1° to 3° to the south west (into the cliff).

A smaller structural feature, the Shepherds Hill Anticline, influences the dip of rock strata in the Newcastle to Bar Beach area. The anticline strikes north-west with dips of typically 1° to 3° to the south west and north east (parallel to the cliff line). In general, the rock strata exposed in the cliffs is near to horizontally bedded with some localised variations associated with faulting and depositional erosion features (washouts).

North West trending normal faults are the dominant fault style in the Newcastle Region and can be noted in exposure along the cliff sections as shown in Drawings G1 to G6. They typically have moderate to steep dips with vertical displacements generally less than 6m.

Intrusive igneous dykes mainly trend to the north-west and are parallel to and often associated with the north-west trending normal faults. They are typically steeply dipping to vertical. Exposure of dykes can be noted at Nobbys Headland and at Shortland Esplanade at South Newcastle Beach.

A feature of the Newcastle region is the frequency of near vertical orthogonal joints trending generally North West (compass bearing 300° - 320°) and north-east (compass bearing 020° - 045°). The north-west direction is parallel to the major faults and dykes. These joints occur on a regional basis, however there is significant local variation in joint directions.

Jointing is more intense in the weaker finer grained sedimentary rock (claystone, shale, siltstone and coal) and becomes more widely spaced with increasing grainsize. Joint spacing in the sandstones is typically 0.5m to 1.0m and several metres to tens of metres in the conglomerates.

The regional stress field is characterised by high horizontal stress with respect to depth. Stress measurements from underground mining operations and road cuts west of Newcastle indicate high to very high horizontal stresses with respect to depth and a relatively balanced horizontal stress field. The high horizontal stresses and balanced stress field is indicative of overburden removal by erosion. In contrast, high but variable sub-horizontal stress fields were encountered in the investigation of road cuts. This has been attributed to unloading effects associated with valley incision (Lohe and Dean-Jones, 1995) and it is considered that similar stress fields may occur along the coastal cliffs.

3.4 ENGINEERING PROPERTIES OF COASTLINE GEOLOGY

The engineering properties of the Newcastle coastal zone geology was extensively reviewed in the *NCHDS 2000* document. The discussion on the engineering properties of coastline geology from that document is presented below.

The unconfined compressive strength data in **Table 4** highlights the variability of rock strengths that can occur within particular stratigraphic units and rock types. These strengths apply to slightly weathered to fresh rock that is likely only to be encountered behind the weathering face of the coastal cliffs. Lower strengths are likely to be applicable within the weathering zone of the cliff lines.

As well as variable strength, the rock types exhibit a highly variable durability. The sandstone and conglomerate rock types are the most resistant, however they undergo surface spalling of grains (sand and pebbles). The finer grained siltstone and shale rock types are less resistant and, on exposure, undergo fretting involving the breakdown into small blocky units which accelerates the rate of clay weathering. The tuffaceous claystone rock types typically have a high percentage of swelling clay and on exposure often weather to a plastic clay material.

Table 3 *Unconfined Compressive Strength of Coastal Rock Units (Ives 1995)*

Formation	Unconfined Compressive Strength (MPa)		
	Mean	Range	No. of Tests
Kotara (sandstone)	85	14 - 127	13
Shepherds Hill (conglomerate and sandstone)	93	49 - 210	53
Nobbys Tuff	72	39 - 116	15
Nobbys and Dudley Coal (coal)	25	10 - 48	28
Bogie Hole (siltstone, sandstone and conglomerate)	103	54 - 136	36

3.5 EFFECT OF PAST MINE WORKINGS ON COASTAL CLIFFS/SLOPES

The effect of past coal mining on the stability of the Newcastle coastal zone cliffs and slopes was extensively reviewed in the *NCHDS 2000* document. The discussion on this topic from that document is presented below.

Large areas of the Newcastle region are undermined by bord and pillar workings that commenced as early as the late nineteenth century.

The Mine Subsidence Board of NSW documents the extent of known workings. The extent of known workings beneath the coastal cliff areas has been provided by the Mine Subsidence Board of NSW on a 1:10,000 plan (ref 10.46 JOD.VS, dated 10 August 1998). Based on this plan and a more detailed plan of mine workings in the Merewether area as supplied by a local resident, the documented extent of mine workings along the coastal strip comprises the following:

- Workings in the Borehole Seam beneath sea level at depths of about R.L. -30m to -70m. Workings occur along most of the coastline including all coastal cliff and escarpment areas except for Fort Scratchley.
- Workings in the Victoria Tunnel Seam at Merewether extending from Lloyd Street under and to about 40m south of Hickson Street. The workings occur at an R.L. of about 40m with areas along Lloyd Street and to the south of Hickson Street having shallow cover of about 10m or less. The workings appear to extend to within about 10m to 15m from the cliff face at Lloyd Street and within about 10m at the south eastern end of Hickson Street where adit entries may exist. The workings have involved secondary or goaf pillar extraction with an area of first (bord and pillar) workings to the south of Hickson Street.
- Limited first workings in the Yard Seam under the Royal development above Newcastle Beach. An old ventilation adit into the Yard Seam can still be observed in the sandstone cliff face above Shortland Esplanade at South Newcastle Beach.

It should be noted that the Mine Subsidence Board documents known mine workings. There are some areas in the Newcastle region where illegal workings (rat holes) were undertaken prior to approximately the 1930s. Along the Newcastle coastline relatively fresh coal outcrops in the cliffs provided a readily accessible source for extraction. The extent of superficial coal extraction along the cliff sections is unknown, however localised undermining of some cliff sections may have impacted on the rate of cliff erosion.

The risk of subsidence effects in the Borehole Seam at depths of about R.L. -30m to -70m adversely impacting on the stability and erosion rate of the overlying cliff sections is considered to be low.

In contrast, the presence of shallow workings in the Victoria Tunnel Seam occurring behind and in close proximity to the coastal cliffs at Lloyd and Hickson Streets at Merewether is likely to have an effect on past and future cliff regression. Goaf extraction of the workings involved collapse of the first bord and pillar workings as pillars were progressively removed. This would have resulted in the formation of a zone of fractured and subsided ground above the workings and within the angle of draw. Where the workings occur close to the cliff line, this could lead to the opening of joints within the cliff face rocks under tensional stresses. This is likely to have contributed to a higher rate of cliff line regression in the Lloyd to Hickson Street areas than would have occurred in the absence of the workings. The effects of mining on cliff line stability have been documented elsewhere (Kay and Carter, 1992).

Cliff line stability and erosion rates would be adversely affected if cliff line regression continued to the point where the goafed workings became exposed in the cliff face. The presence of unconfined, unconsolidated and broken ground would be highly susceptible to erosion and slope failure of overlying cliff sections. Were this to occur, remedial works such as Shotcrete treatment, concrete pillars and pressure grouting may be required.

3.6 PREVIOUSLY IDENTIFIED CLIFF REGRESSION RATES

NCHDS 2000 included an assessment of cliff regression rates along the Newcastle coastline. A detailed extract of this assessment is presented below.

Cliff regression is essentially an episodic and localised process associated with both long-term slope degradation/erosion as well as short-term storm induced wave, rain and wind action.

Actual erosion rate is the average value of the recession distance over a short period of time during which the actual erosion is actively occurring. The actual erosion rate is usually significantly greater than the long-term erosion rate where the length of time under consideration is typically 10 to 100 years.

3.6.1 HISTORICAL ASSESSMENT

A qualitative assessment of Newcastle coastline cliff line erosion over the past 100 years was undertaken comparing cliff profiles and features from historical photographs to the present.

Review of historical photos indicated as follows:

- Newcastle Beach (1907 to 1998) – erosion of a cliff pathway present in 1907 gave an erosion rate of about 1m to 2m in a period of 90 years (see **Figures 3a** and **3b Appendix C**).
- Bogie Hole lower cliff face and rock platform (1908 to present) indicated erosion of the competent rock materials is discernible (see **Figure 4**, **Appendix C**).
- Ridge and cliff line above Bogie Hole Pool (1896 to present) - erosion of a sloping cliff bench has occurred up to an estimated 2m to 4m. This cliff is located above an inlet that penetrates the rock platform, which suggests that increased wave action at the base of the cliff has resulted in increased rate of cliff face regression at this location (see **Figures 5a-5c**, **Appendix C**).
- **Figure 7**, **Appendix C** compares a coastal view taken from ridge line between Shepherds Hill and Strzelecki Lookout in 1900 looking south to Bar Beach. The observations are made:
    - Erosion of the friable conglomerate unit along cliff crest in the foreground has progressed to form a more ‘ragged’ edge along the cliff crest.
    - The overall slope profile is similar.
    - Rock fall debris occurs at the base of the cliff below Bar Beach car park similar to that now present.
    - A significant amount of material was excavated from the Bar Beach to Susan Gilmore Beach ridge to form the Bar Beach car park.

- South Newcastle Beach (1907) – erosion of about 90mm behind a metal bracket on the rock face indicated an erosion rate of approximately 1mm per year for sandstone rock faces subject to salt crystallisation erosion. Examination of sandstone rock footings and block wall corrosion elsewhere indicates an erosion rate for more permeable sandstones of up to 3mm per year with the higher strength less permeable sandstones as exposed on the rock platforms eroding at rates of less than 1mm per year.

3.6.2 SURVEY ASSESSMENT

Assessment of cliff line regression based on comparing a map scaled set back of a permanent structure from a cliff edge relative to the distance as directly measured, was undertaken at Nobbys Lighthouse and Signal Station, the corner of Watt and Ordnance Streets, Newcastle and Lloyd Street, Merewether.

Contemporary measurement indicated the following:

- At three locations the crest of Nobbys cliff was measured to have regressed 1.0 to 1.2m relative to location shown on the survey plan, indicating a cliff regression rate of about 10mm to 15mm a year in the top of the Nobbys Tuff and the Victoria Tunnel Coal Seam that outcrops along the crest of the headland (see **Drawings S2** and **S3**, **Appendix A** of this report).
- At the corner of Watt and Ordnance Streets the present cliff line is located about 0.5m to 1.0m from a 1864 survey mark, originally located about 3m from the crest, suggesting a cliff crest regression of 2.0m to 2.5m in the last 100 years (rate of about 20mm to 25mm/year) in the conglomerate and pebbly sandstone material capping the crest of the escarpment.
- At the east end of Lloyd Street, Merewether, review of 1940s subdivision plans indicates the crest of the cliff has potentially regressed about 7m in the last 86 years (since 1912). This indicates the rate of cliff regression in the order of 80mm a year, well in excess of that noted elsewhere, potentially due to shallow workings in the Victoria Tunnel Coal Seam in close proximity to the coastal cliffs at Lloyd Street (see **Figure 9**, **Appendix C** of this report).

3.6.3 GEOLOGICAL ASSESSMENT

Assessment was made of coastal rock platform widths, based on their comparative strength/resistance, compared to regression rate of the cliffs comprising inter-bedded layers of variable strength over the past 6000 years (Holocene marine transgression).

Assuming that the platforms have formed under relative static sea levels during the last 6000 years due to preferential cliff line erosion along a resistant sandstone layer, the following general estimates were made:

- Cliff line regression of 60 to 80m in 6000 years gives a minimum regression rate of about 10mm per year assuming nil erosion of the rock platform.
- A maximum erosion rate of about 2mm per year for the sandstone platform gives a maximum regression rate of about 15mm per year for the cliff sections.
- Rock platform areas up to 120m wide occur beneath low bluffs at Merewether and Ocean Baths. The assumed maximum regression rate in these areas may have been up to 25mm per year.

- The high tide rock platform off Nobbys Headland is about 300m out from the shore. Based on the erodible nature of the Nobbys Tuff exposed in the headland and the position of the rock platform, a regression rate of up to 50mm per year may have occurred.

3.6.4 SUMMARY: RATE OF REGRESSION

The rate of cliff line regression for the Newcastle Coastline assessed from various methods (above) is summarised in **Table 4**.

Table 4 *Rates of Cliff Line Regression Applicable to Newcastle Coastline*

Method	Location	Rate (mm/year)	Comment
Literature	Australia, England	10 – 20	Inter-bedded sedimentary rocks
Historical	Newcastle Beach, Bogie Hole, Merewether.	1 - 40	
Survey	Nobbys	10 – 15	Direct survey
Survey	Watt Street	20 – 25	Direct survey
Survey	Lloyd street	75 – 100?	Assumed property locations Mine subsidence effects?
Geological	Rock platforms	10 - 15	High cliff areas
	Rock platforms	25 - 50	Low cliff areas
Rock surface	Newcastle Beach, Dixon Park, seawalls	1 - 5	Erosion rate of sandstone exposures

The review in *NCHDS 2000* identified that the projected sea level rise, would result in more pronounced wave impact and toe scour at the base of the cliffs. This increased wave impact, would result in greater erosion/regression of weaker coal seams and siltstone / shale bed where present along the bases of the cliffs.

A discussion of coastal slope and cliff morphology changes since *NCHDS 2000* is presented in Section 6 of this report. **Table 5** in Section 6 of this report presents pertinent observations from our analysis of historical photo sets spanning the last 90 to 110 years.

3.7 DEPTH OF ESTUARY SEDIMENT ALONG THE BAR BEACH TO MEREWETHER BEACH COASTLINE

Literature review indicated the most recent compilation of sediment depth data was compiled by Fityus et al and reported in Australian Geomechanics Volume 40 no.1 March 2005. The Fityus et al paper indicates that Newcastle and its inner suburbs are located within an infilled estuary. The estuary was infilled by eroded materials transported down local creek systems rather than from sediment transported down the Hunter River channel.

Fityus et al concluded there was no evidence that the Hunter River once flowed out between the Dixon Park (Kilgour Avenue) and Merewether (Lloyd and Hickson Street) headlands. The depth of sediment does increases to over 10m in this section of the coastline; which may represent a paleo-channel of a buried estuary or lagoon.

The inferred depth of estuary sediment along the Newcastle coastline is shown on **Drawing 6: Inferred Depth of Coastline Sediments** in **Appendix A**. The sediment contours that extend beyond the sedimentary basin boundary have been ignored.

3.8 DOCUMENTED INSTABILITY

In the *NCHDS 2000* the following documented coastal/cliff instabilities were listed:

- Fort Scratchley where rotational sliding of fill and clay soils at the crest of the slope above Fort Drive has occurred and some minor regrading works undertaken.
- Shortland Esplanade between Nobbys and Ocean Baths where rock bolting was undertaken to reduce the risk of rock falls onto the roadway.
- Shortland Esplanade at South Newcastle Beach where preliminary works (drainage, barrier fencing) has been undertaken to minimise the risk and impact of rock falls. Slope processes and stability issues have been assessed along this section of the cliff by consultants SMEC and RCA and slope stabilisation and improvement works outlined.
- Dixon Park at the end of Kilgour Avenue where a rock fall of sandstone blocks on to the beach occurred in June 1997 and the toe of the cliff was fenced off.
- Merewether Beach where loose blocks and rock falls in the cliff below Hickson Street were documented in 1981 and remedial options assessed.

Other coastal slope instability events known to RCA include the following:

- Sporadic rock falls from Nobbys Headland both onto the southern breakwater shared pathway and northern end of Nobbys Beach. Warnings signs in place.
- Sporadic rock falls from cliff faces above Bogie Hole Pool, in particular where rock overhangs exist. A 2003 rock fall from the cliff/slope some 22m above the Bogie Hole Pool damaged fixtures and came to rest in pool. Additional loose rock was removed from this area of the cliff/slope in 2003. Approximately 2m of a rock overhang adjacent to the pool has collapsed and been removed since last study was completed in 2000.
- Rock slide destroyed timber staircase to Susan Gilmore Beach around August 2001. Pedestrian access was fenced off and closure sign erected.
- The Cliff below Kilgour Avenue, north of Dixon Park where old fill had accumulated on natural cliff bench became saturated during the June 2007 rainfall event and became a mixed debris flow onto the beach below. The mixed debris was removed from the beach by CoN.
- Merewether Baths mixed debris slide in June 2007. Old cliff top spoil covering a natural slope became saturated and slide down onto pool side picnic benches during June 2007 rainfall event. Slide debris removed and slope re-vegetated by CoN.

During the course of the geotechnical hazard assessment CoN asked RCA to inspect the following failures:

- A retrograding slope failure along the upper portion of the cliff/slope threatened to undermine a 30m long section of the Bar Beach Car Park (*BBCP*). Review of aerial photographs indicates an upper slope landslide that was initiated sometime between December 2006 and August 2009 (probably June 2007) has continued to degrade to the point it now undermines a 10m long section of the *BBCP* fence. In February 2012

CoN closed the car parking spaces adjacent to this failure, then in April 2012 removed all the car parking spaces along the crest of the coastal cliff/slope and converted them into a 6m wide coastal pathway (part of the Bathers Walk).

- Loss of support to a 2.6m long section of a mortared sandstone block wall that has no footing support, within 1m of an asphalt footpath adjacent to South Newcastle Beach. This section of wall failed a few months after inspection and was remediated by CoN.

4 GEOTECHNICAL ASSESSMENT METHODOLOGY

The geotechnical assessment of the Newcastle coastal cliff/slope stability has been assessed in accordance with the '*Practice Note Guidelines for Landslide Risk Management*', formulated by the Australian Geomechanics Society Landslide Practice Note Working Group and published in the Australian Geomechanics, Volume 42 No 1 March 2007, herein referred to as *AGS LRM 2007 (Ref [6])*. The *AGS LRM 2007* guidelines incorporate a qualitative and quantitative classification system for the assessment of the risk to property and the risk to life.

The risk assessment process included mapping of the identified coastal cliff and slope hazards, reference to Newcastle Coastline Hazard Definition Study 2000 (*NCHDS 2000*), reference to historical photos and inferred sea level rise contour plan provided by BMT WBM.

Specific tasks undertaken during site inspections for coastal cliff/slope stability included the following:

- The review of the condition of coastal cliff/slope geo-hazards, previously identified in the 2000 study.
- Field mapping of coastal cliff lines and shore platforms in the assessment area, including photographic recording and identification and mapping of potential cliff/slope hazards.
- Identification and mapping of new geo-hazards.
- Assessment of the impact of existing vegetation on coastal cliff/slope stability.
- Assessment of existing cliff/slope regression rates, comparing the results of previous investigations against present day conditions.
- Estimation of likely changes to cliff/slope base regression rates due to wave action over topping the existing wave platforms at projected sea level rises for 2050 and 2100.
- Assessment of the risk and potential impacts of coastal cliff/slope geo-hazards on people, infrastructure and the environment, at present and that could potentially arise from the projected sea level rises of 0.4m by 2050 and 0.9m by 2100.

5 IDENTIFIED COASTAL CLIFF/SLOPE GEO-HAZARD RISK SITES

The identified coastal cliff/slope geotechnical hazards or geo-hazards are discussed below, in order of occurrence from north to south. The anticipated effects of the projected sea level rise are discussed hazard by hazard.

The location of the identified geo-hazards, running from north to south are shown on **Drawings 1** to **4** in **Appendix A**. Idealised long sections of the identified hazards are shown on **Drawings G1** to **G6** in **Appendix A**. Idealised cross-sections of the identified geo-hazards are shown on **Drawings S1** to **S21** in **Appendix A**.

Annotated photographs of the identified geo-hazards are presented as **Figures 1** to **23** in **Appendix B**.

In Section 8 of this report the risk to property and risk to life from the identified geo-hazards are assessed, under 2011-12 conditions and based on the anticipated effects of the projected sea level rise.

5.1 GEO-HAZARD # 1: ROCK FALL ONTO BREAKWATER PATHWAY, NOBBYS HEADLAND

Details of the geo-hazard are shown on **Drawing 1**, **Long-section G1** and **Cross-section S1** in **Appendix A**. An annotated photograph of the identified geo-hazard/ risk(s) is presented as **Figure 1** in **Appendix B**.

On the harbour side of Nobbys headland the north and north-western cliff faces and steep slopes of Nobbys headland rise up to 25m above the Breakwater shared pathway. The 2011-12 alignment of the pathway cuts through the toe of these slopes for a distance of some 140m on the western side of the renovated but closed gun emplacement building. The identified geo-hazard(s) comprises:

- On the harbour side of Nobbys headland weathering and erosion of near vertical rock faces and steep slopes have resulted in rock fall(s) on to the breakwater shared walkway. Site inspection and rock fall analysis indicates the rock fall risk zone runs along a 21m length of the walkway on the western side of the gun emplacement building.
- Within the 21m long section of the breakwater footpath on the western side of the gun emplacement building rock fall(s) pose a potential risk to people walking/riding/running along the pathway.

Site inspection and rock fall analysis indicated rock falls from other northerly or north-westerly facing rock faces/slopes have been prevented from reaching the shared walkway by slope morphology, separation distance between toe of slope and the pathway; dense vegetation and/or the existing fence around the abandoned gun emplacement building.

The Breakwater Pathway is approximately 2-3m above the projected 2100 mean sea level, with the rock fall source a further 14m above the pathway surface level. No increase in risk is anticipated due to the projected sea level rise.

5.2 GEO-HAZARD # 2: ROCK FALL ONTO BEACH, NOBBYS HEADLAND

Details of the geo-hazard are shown on **Drawing 1**, **Long-section G1** and **Cross-section S2** in **Appendix A**. An annotated photograph of the identified geo-hazard/ risk(s) is presented as **Figure 2** in **Appendix B**.

The identified hazard affects a 60-80m length of Nobbys Beach adjacent to the eastern side of Nobbys headland comprised of near vertical rock cliffs. The identified geo-hazard(s) comprise:

- Rock fall(s) from a near vertical cliff face up to 25m in height, on to existing debris fan have ‘rolled out’ to a distance of some 16m from the cliff face. Rock fall roll out is facilitated by an existing talus/debris slope that is up to 8m wide and slopes away from the cliff face at up to 1.5H:1V. The debris fan acts as a 'ramp' for detached blocks to 'roll out' on to beach.

- Rock fall(s) pose a potential risk to people standing/sitting/lying on the beach below Nobbys headland to within the 16m wide 'run out' zone from the cliff face.

Site inspection and rock fall back analysis indicated about 10% of past rock falls have 'escaped' the existing prohibited zone marked by warning signs around the base of the cliff at the north end of Nobbys Beach.

The base of Nobbys Headland is at least 45m landward of and some 3m above the projected 2100 mean sea level. Although storm wave set up can reach the base of the talus slope at the toe of Nobbys Headland no increase in rock fall risk from the cliff face above is anticipated due to the projected sea level rise.

5.3 GEO-HAZARD # 3: CLIFF TOP REGRESSION, NOBBYS HEADLAND

Details of the geo-hazard are shown on **Drawing 1**, **Long-section G1** and **Cross-section S3** in **Appendix A**. An annotated photograph of the identified geo-hazard/ risk(s) is presented as **Figure 3** in **Appendix B**.

The identified hazard affects a historic complex of structures known as "Nobbys Signal Station" that are located on top of Nobbys Headland. Sections of the brick perimeter wall around the complex are located on or within a few metres of the crest of cliff faces/slopes of Nobbys Headland. The identified geo-hazard(s) comprise the following:

- A 10m long-section of the brick fence on south side of development is being undermined by cliff top regression/ erosion, with potential for localised slump failure in proximity to an existing stormwater discharge point.
- A 30m long-section of the brick perimeter fence on the west-north-west side of the complex is cracked in several places and appears to be affected by erosion/soil creep of sandy soils along the crest of a steep slope.

Preferential erosion of dyke (igneous intrusion aligned north-west-south-east) along cliff top and face, causing increased erosion and cliff regression along the dyke alignment has kept the existing signal station development setback ≥ 6m from the north-eastern side of the headland.

The geo-hazard is at least 45m landward of and approximately 28-30m above the projected 2100 mean sea level. No increase in risk is anticipated due to the projected sea level rise.

5.4 GEO-HAZARD # 4: ROCK FALL(S) ONTO FORT DRIVE AND SHORTLAND ESPLANADE, FORT SCRATCHLEY HILL – NORTH-EAST

Details of the geo-hazard are shown on **Drawing 1**, **Long-section G1** and **Cross-section S4** in **Appendix A**. Annotated photographs of the identified geo-hazard/ risk(s) are presented as **Figures 4** and **5** in **Appendix B**.

The identified geo-hazard(s) affects a 20 to 30m long section of Fort Drive and Shortland Esplanade on the north-east slopes of Fort Scratchley Hill. The identified geo-hazard(s) comprise:

- An existing sandstone rock cut some 30m in length and up to 8m high, with detached blocks and overhangs, setback only 1 to 2m from the northbound traffic lane of Shortland Esplanade. Rock fall(s), with individual block(s) up to 0.6m in dimension into the path of northbound traffic on Shortland Esplanade. Reference to an aerial photograph dated 12/11/2006 indicated past rock falls have come to rest in the northbound traffic lane, up to 3-4m from the toe of the rock face.

- An existing 20m long sandstone outcrop some 5m above Fort Drive. Site inspection and rock fall analysis indicate the rock fall hazard extends into the westbound traffic lane of Fort Drive pavement adjacent to the blocky outcrop. Rock fall(s), with individual block(s) up to 0.4m in dimension into the path of westbound traffic on Fort Drive. Site inspection indicates past rock falls have come to rest 2-3m from the toe of the concrete revetment and/or retaining wall.

The geo-hazard is at least 20m landward of and at least 4m above the projected 2100 sea level and the principal contributing geotechnical factors for this geo-hazard are drainage failure, weathering and erosion, therefore no increase in risk is anticipated due to the projected sea level rise.

5.5 GEO-HAZARD # 5: MIXED DEBRIS SLIDE ONTO FORT DRIVE OR SHORTLAND ESPLANADE, FORT SCRATCHLEY HILL

Details of the geo-hazard are shown on **Drawing 1**, **Long-section G1,** and **Cross-section S5** in **Appendix A.** An annotated photograph of the identified geo-hazard/ risk(s) is presented as **Figure 6** in **Appendix B**.

The identified geo-hazard affects a section of Shortland Esplanade some 260m in length, along the eastern foot slopes of Fort Scratchley Hill and a section of Fort Drive some 130m in length, along the northern slopes of Fort Scratchley Hill.

The identified geo-hazard(s) comprise the following:

- Mixed debris slide of fill and soil and rock on 1.5H:1V or steeper slopes above Shortland Esplanade and Fort Drive impacting and/or blocking adjacent traffic lane. At present existing cover of vegetation helps protect these slopes; except where stormwater run-off from above has scoured slope and/or erosion has prevented vegetation taking hold.
- Cracking in the concrete retaining wall that supports the toe of northern slopes above Fort Drive indicate active ‘creep’ mass movement of this slope area and the potential for failure is increasing as the condition of the retaining wall deteriorates.

The geo-hazard is at least 20m landward of and at least 4m above the projected 2100 sea level and the principal contributing geotechnical factors for this geo-hazard are drainage failure, weathering and erosion, therefore no increase in risk is anticipated due to the projected sea level rise.

5.6 GEO-HAZARD # 6: BLOCK WALL FAILURE NEWCASTLE BEACH

Details of the geo-hazard are shown on **Drawing 2**, **Long-section G2,** and **Cross-section S6** in **Appendix A.** An annotated photograph of the identified geo-hazard/ risk(s) is presented as **Figure 7** in **Appendix B**.

The identified geo-hazard affects a section of Bathers Way footpath some 2.6m in length, adjacent to Newcastle Beach.

The identified geo-hazard(s) comprises the following:

- A 2.6m long section of a mortared sandstone block wall that has no footing support, within 1m of an asphalt footpath.

The geo-hazard is at least 50m landward of and approximately 5-6m above the projected 2100 mean sea level. No increase in risk is anticipated due to the projected sea level rise.

5.7 GEO-HAZARD # 7: MASSIVE BLOCK FAILURE, SOUTH NEWCASTLE

Details of the geo-hazard are shown on **Drawing 2**, **Long-section G2,** and **Cross-section S7** in **Appendix A.** An annotated photograph of the identified geo-hazard/ risk(s) is presented as **Figure 8** in **Appendix B**.

The identified geo-hazard affects a section of Shortland Esplanade some 30m in length, adjacent to South Newcastle Skate Park.

The identified geo-hazard(s) comprises the following:

- A near vertical sandstone cliff face some 15m high, set back 10-13m from Shortland Esplanade. Partially detached blocks up to 8m in dimension observed along this section of cliff face comprise a rock fall hazard.
- Rock fall analysis indicates 1-2% of rock falls could reach the Waratah fence that runs along the kerb of Shortland Esplanade at this location.

The geo-hazard is at least 40m landward of and at least 10m above the projected 2100 sea level and the principal contributing geotechnical factors for this geo-hazard are weathering and erosion; therefore no increase in risk is anticipated due to the projected sea level rise.

5.8 GEO-HAZARD # 8: ROCK FALL(S) FROM SOUTH NEWCASTLE CLIFF

Details of the geo-hazard are shown on **Drawing 2**, **Long-section G2,** and **Cross-section S8** in **Appendix A.** An annotated photograph of the identified geo-hazard/ risk(s) is presented as **Figure 9** in **Appendix B**.

The identified geo-hazard affects a section of Shortland Esplanade some 290m in length that runs along the base of South Newcastle cliff/rock slope.

The identified geo-hazard(s) comprises the following:

- Rock falls from South Newcastle cliff face.
- This section of coastal cliff/rock slope was the subject of extensive slope remediation works in 2005 as a result of several investigations over a period of years and detailed analysis by GHD Geotechnics. Remediation works were supervised by GHD Geotechnics and CoN. The landslide risk management strategy included the construction of a rock fall barrier fence.
- These works were subject to review by GHD Geotechnics and CoN in 2011 and were found to be performing to expectation.

The geo-hazard is at least 10m landward of and at least 8m above the projected 2100 sea level, with the principal contributing geotechnical factors for this geo-hazard being weathering and erosion, therefore no increase in risk is anticipated due to the projected sea level rise.

Risk management of this geo-hazard should follow the recommendations of the detailed investigation and report submitted to CoN by GHD Geotechnics.

5.9 GEO-HAZARD # 9: CRACKING/SETTLEMENT OF SHARED WALKWAY ALONG TOP OF SEA WALL – SOUTH NEWCASTLE BEACH

Details of the geo-hazard are shown on **Drawing 2**, **Long-section G2,** and **Cross-section S8** in **Appendix A.** An annotated photograph of the identified geo-hazard/ risk(s) is presented as **Figure 10** in **Appendix B**.

The identified geo-hazard affects a section of a pedestrian walkway some 30m long, along a section of Shortland Esplanade closed to vehicular traffic at South Newcastle Beach. The identified geo-hazard(s) comprise:

- Differential settlement of fill up to 5m thick behind bulge in concrete/mortar block retaining/ sea wall up to 5m high. Tension crack is 3-4m long and up to 5mm wide in asphalt surface of shared walkway. Tension crack offset ~1m from top of retaining/sea wall.

Figure 5 in **Appendix B** shows a new crack in recently re-surfaced asphalt walkway, indicating differential settlement is on-going.

It is anticipated the frequency of wave impact on the retaining/ seawall will increase due to the projected sea level rise. Increased wave impact on the retaining/seawall is likely to increase the rate of deterioration of the seawall and likelihood of failure.

5.10 GEO-HAZARD # 10: CRACKING/SETTLEMENT OF SHORTLAND ESPLANADE, KING EDWARD PARK - SOUTH NEWCASTLE

Details of the geo-hazard are shown on **Drawing 2**, **Long-section G2,** and **Cross-section S9** in **Appendix A**. An annotated photograph of the identified geo-hazard/ risk(s) is presented as **Figure 11** in **Appendix B**.

The identified geo-hazard affects a section of Shortland Esplanade some 60m in length, closed to public vehicles but accessible to pedestrians and bicycles, at the coastal edge of King Edward Park. The identified geo-hazard(s) comprise the following:

- Settlement of coastal edge of Shortland Esplanade cracks in pavement 5-10mm wide, affecting a section of pavement some 30 m long and 5 m wide.
- Settlement/cracking of adjacent footpath up to 20mm wide, with loss of support to sections of wooden railing due to cliff top erosion.
- Discharge of stormwater from Shortland Esplanade onto coastal slope has stripped vegetation from a 8m long 5m wide section of the slope, exposing a fill embankment up to 8m high, overlying shallow clay soils/bedrock. Erosion scar not evident in aerial photograph dated 1/10/2007, developing in photo dated 28/9/2009, then close to 2011-12 extent in aerial photograph dated 20/3/2010.

It is anticipated the frequency of wave impact on the retaining/seawall will increase due to the projected sea level rise. Increased wave impact on the retaining/seawall is likely to increase the rate of deterioration of the seawall and likelihood of failure.

5.11 GEO-HAZARD # 11: FILL EMBANKMENT FAILURE, SOUTH END OF SHORTLAND ESPLANADE

Details of the geo-hazard are shown on **Drawing 2**, **Long-section G2,** and **Cross-section S10** in **Appendix A.** An annotated photograph of the identified geo-hazard/risk(s) is presented as **Figure 12** in **Appendix B**.

The identified geo-hazard affects the southern end of Shortland Esplanade, some 185m in length at the coastal edge of King Edward Park and to the north of the Bogie Hole Pool steps. The identified geo-hazard(s) comprise:

- Instability of cliff top fill embankment, with continuous seepage from fill interface with natural soil/rock. Tension cracks up to 40mm wide, with vertical displacement of up to 60mm noted in Shortland Esplanade asphalt surface.

Past cliff top erosion and instability of the overlying fill embankment has been managed by retreat, with the loss of a 60m long section of footpath and hand rail.

It is anticipated the frequency of wave impact on the sea cliff will increase due to the projected sea level rise. Increased wave impact on the sea cliff is likely to increase the rate of deterioration of the cliff and likelihood of fill embankment slip failure and rock falls on to the rock platform.

5.12 GEO-HAZARD # 12: ROCK FALL FROM CLIFF(S) ABOVE BOGIE HOLE OCEAN POOL

Details of the geo-hazard are shown on **Drawing 2**, **Long-section G2,** and **Cross-section S11** in **Appendix A.** Annotated photographs of the identified geo-hazard/ risk(s) are presented as **Figure 13** in **Appendix B**.

The identified geo-hazard affects the rock platform and ocean pool at the Bogie Hole. The identified geo-hazard(s) comprise:

- Rock falls from the coastal cliff/rock slope above the Bogie Hole viewing area and into the Bogie Hole pool.
- Rock falls from the 7m high sea cliff adjacent to the Bogie Hole Ocean Pool. It appears up to 2m of an existing 3m deep overhang has been removed or collapsed and then removed since the last assessment in 1998.

In 2003 a rock fall from a sandstone section of cliff/slope some 22m above pool damaged viewing area outdoor furniture and timber fence, pool steps and reached pool. As a result of damage the remaining ‘loose’ blocks were removed from the rock fall source area. A site inspection of this rock slope completed during the 2011-12 study indicated weathering and erosion since 2003 has resulted in more ‘loose’ rocks that are a potential rock fall hazard (refer to **Figure 13** in **Appendix B**).

The coastal cliff/slope above the Bogie Hole viewing area is at least 10m landward of and at least 10m above the projected 2100 sea level, with the principal contributing geotechnical factors for this geo-hazard being weathering and erosion, therefore no increase in rock fall risk is anticipated due to the projected sea level rise.

It is anticipated the frequency of wave impact on the sea cliff adjacent to the Bogie Hole ocean pool will increase due to the projected sea level rise. Increased wave impact on the sea cliff is likely to increase the rate of deterioration of the cliff and likelihood of rock fall(s) onto the rock platform and into Bogie Hole ocean pool below the sea cliff.

5.13 GEO-HAZARD # 13: CLIFF TOP NARROWING, STRZELECKI LOOKOUT TO SHEPHERDS HILL (PROPOSED MEMORIAL CLIFF TOP WALK)

Details of the geo-hazard are shown on **Drawing 3**, **Long-section G3,** and **Cross-sections S12 and S13** in **Appendix A**. Annotated photographs of the identified geo-hazard/ risk(s) are presented as **Figure 14** in **Appendix B**.

The identified geo-hazard affects the crest of a ridge that runs from Strzelecki Lookout to Shepherds Hill. The identified geo-hazard(s) comprise the following:

- Localised narrowing of the ridge crest appears to be controlled by increased erosion rates associated with localised joint swarms in the weathered conglomerate unit that forms the ridge crest.

The ridge crest has narrowed to only 0.3m wide for a length of some 6m at the proposed location of the northern bridge on the proposed Memorial Walk alignment. The ridge crest has narrowed to ≤ 2m wide for a length of some 19m at the proposed location of the southern bridge on the proposed Memorial Walk alignment.

The proposed viewing platform is located on a broad hill top area some 65m ENE of Shepherds Hill Trig Station and approximately 45m SE of the proposed southern bridge location. The ridge crest geo-hazard does not affect the proposed location of the cliff top viewing platform.

The ridge crest geo-hazard is some 70m above the existing sea level, with no increase in risk anticipated due to the projected sea level rises.

5.14 GEO-HAZARD # 14: CLIFF FACE REGRESSION, SHEPHERDS HILL (PROPOSED MEMORIAL WALK)

Details of the geo-hazard are shown on **Drawing 3**, **Long-section G4,** and **Cross-section S14** in **Appendix A**. Annotated photographs of the identified geo-hazard/ risk(s) are presented as **Figure 15** in **Appendix B**.

The identified geo-hazard affects a section of the coastal margin of Shepherds Hill to the south-east of the Trig Station, some 130m in length. The proposed Memorial Walk cliff top barrier fence alignment is adjacent to this geo-hazard. The identified geo-hazard(s) comprise:

- accelerated cliff line regression along the intersection of conjugate joint swarms resulting in near vertical cliff face and unstable cliff top margins, due to -
- wave action at present sea level attacking toe of the sea cliff.

The concave cliff face, the absence of vegetation and natural benches on this section of the coastal cliff/slope as shown in **Figure 15** in **Appendix B** are indicative of a higher cliff line regression rate at this location relative to adjacent coastal cliff/slopes.

It is anticipated the frequency of wave impact at the toe of the sea cliff will increase due to the projected sea level rise. Increased wave attack at the toe of the sea cliff is likely to increase the rate of deterioration of the cliff and likelihood of increased rate of slip failure and rock falls all the way to the crest of the sea cliff.

5.15 GEO-HAZARD # 15: CLIFF ABOVE SUSAN GILMORE BEACH

Details of the geo-hazard are shown on **Drawing 3**, **Long-section G4,** and **Cross-section S15** in **Appendix A**. Annotated photographs of the identified geo-hazard/risk(s) are presented as **Figure 16** in **Appendix B**.

The identified geo-hazard affects the coastal cliff and slopes above Susan Gilmore Beach. The geo-hazard(s) have led to the closure of the pedestrian pathway access from the cliff top car park down to Susan Gilmore Beach. The identified geo-hazard(s) comprise:

- Rock falls, mixed debris slides from cliff faces and slopes above Susan Gilmore Beach. Past slope instability has resulted in the destruction of a timber stairway at the toe of the cliff. Back analysis of debris slide that destroyed the timber stairway, indicates the approximate dimensions of the debris slide was some 8 m wide, 12m in length and up to 3m thick.
- On-going scouring/erosion of the cliff face has partially blocked sections of the remaining concrete footpath that leads down from the cliff top to where the timber stairs used to be.

Reference to RCA report ref 2346 indicates the mixed debris slide that destroyed the timber stairs occurred in May 2001 during an intense rainfall event. A review of recent historical aerial photographs indicates that only minor rock falls and scouring of exposed sections of the cliff/slope have occurred since the May 2001 failure.

It appears the principal processes leading to cliff/slope instability are differential rates of weathering and erosion of the different rock types (refer to **Figure 16** in **Appendix B**) that are exposed in the cliff/slope above Susan Gilmore Beach. No increase in risk is anticipated due to the projected sea level rises.

5.16 GEO-HAZARD # 16: CLIFF BELOW BAR BEACH CAR PARK

Details of the geo-hazard are shown on **Drawing 3**, **Long-section G4,** and **Cross-section S16** in **Appendix A**. Annotated photographs of the identified geo-hazard/risk(s) are presented as **Figure 17** in **Appendix B**.

The identified geo-hazard affects the coastal cliff immediately below the eastern portion of the Bar Beach Car Park (BBCP). The identified geo-hazard(s) comprise the following:

- Accelerated regression of the Yard Coal Seam at present day high tide mark, undercuts the overlying massive sandstone unit, resulting in mass movement and–block(s) (up to 4m in dimension) sliding/ toppling at base of cliff face and contributes to instability of the coastal cliff/ slope above.
- Accelerated erosion/regression of the Dudley coal seam, and associated low strength rock types located mid-slope leading to instability of the upper cliff/slope.

Rock falls, block toppling and mixed debris slides associated with accelerated regression of the Dudley Seam and associated low strength rock outcrops mid-slope are undermining the upper portion of the coastal cliff/slope adjacent to BBCP.

Review of aerial photographs indicates an upper slope landslide that was initiated sometime between December 2006 and August 2009 (probably June 2007) has continued to degrade to the point it now undermines a 10m long section of the BBCP fence. In February 2012 CoN closed the car parking spaces adjacent to this failure, then in April 2012 removed all the car parking spaces along the crest of the coastal cliff/slope and converted them into a 6m wide coastal pathway (part of the Bathers Walk).

Analysis of the existing landslide geometry indicates a width of some 2-3m by a length of some 30m of the BBCP coastal pathway is under threat from further landslide degradation and/or re-activation of the existing landslide.

Past block failures from the massive sandstone unit above the Yard Seam do not appear to be providing effective protection of the Yard Seam from wave action under 2011-12 conditions.

It is anticipated the frequency of wave attack will increase with the projected sea level rises and subsequently increase the frequency of lower slope block falls and landslides. The increased rates of block falls and landslides from the toe of the coastal cliff/slope are expected to result in increasing rate of cliff top retreat affecting the eastern edge of Bar Beach carpark.

5.17 GEO-HAZARD # 17: THE CLIFF, KILGOUR AVENUE, DIXON PARK

Details of the geo-hazard are shown on **Drawing 3**, **Long-section G5,** and **Cross-section S17** in **Appendix A.** Annotated photographs of the identified geo-hazard/ risk(s) are presented as **Figure 18** in **Appendix B**.

The identified geo-hazard affects the beach below the northern half of the Kilgour Avenue cliff face. The identified geo-hazard(s) comprise:

- mixed debris slides of over crest spoil and/or eroded cliff/slope materials that have accumulated on natural benches in slope, affecting beach amenity/access.

As observed in June 2007 most of the previous debris slides/flows have coincided with high intensity and/or prolonged rainfall events.

The plotted location of projected sea level rises provided by WBM are still over 40m seaward from the toe of the cliff face/slope and the toe of cliff/slope will still be some 3m above projected rises in mean sea level. Although it is anticipated storm wave set up will reach the base of the talus slope at the toe of ‘The Cliff’, no increase in rock fall and/or debris slide risk from the cliff/slope above is anticipated due to the projected sea level rise.

5.18 GEO-HAZARD # 18: ROCK FALL/DEBRIS SLIDE(S), LLOYD ST CLIFF, MEREWETHER

Details of the geo-hazard are shown on **Drawing 4**, **Long-section G6,** and **Cross-section S18** in **Appendix A**. Annotated photographs of the identified geo-hazard/ risk(s) are presented as **Figure 19** in **Appendix B**.

The identified geo-hazard affects the beach below the cliff and the southern end of the Merewether Baths Amenities. The identified geo-hazard(s) comprise the following:

- Rock falls and cliff top instability affecting cliff top development. The crest of coastal slope is only offset some 4m from residence, above cliff line offset some 12m from residence. The crest of coastal slope offset some 2-3m from Lloyd Street road reserve fence.
- Rock falls from cliff face on to beach and rock platform south of Merewether Baths.
- Mixed debris slide/failure of over crest spoil and/or eroded material that has accumulated along toe of cliff/slopes, affecting beach amenity/ access to Merewether Bath’s fixtures following high rainfall events, such as June 2007.

RCA completed a geotechnical assessment of a mixed debris slide that occurred at this location during the June 2007 rainfall event. Two fixed picnic table and bench sets were destroyed by slide debris and debris reached the pool side footpath. RCA recommended the remaining length of some 15m of vegetated spoil above the Merewether Baths picnic fixtures be removed and the slope be protected and re-vegetated as done for the 2007 landslide area.

Large sandstone blocks up to 4m in dimension litter the toe of the cliff face adjacent to a narrow rock platform and Hunter Water pipeline, just south of Merewether Baths.

The plotted location of projected sea level rises provided by WBM indicate the 2100 MSL will move landward some 5 to 10m from the existing MSL towards the toe of the Lloyd Street cliff.

It is anticipated the projected sea level rise will see erosion of the talus material that 2011-12ly protects the Dudley Coal Seam that out crops along the toe of the cliff face. It is anticipated that erosion and the regression rate of the Dudley Coal will increase leading to an increase in block falls from cliff face above.

5.19 GEO-HAZARD # 19: ROCK FALL/DEBRIS SLIDE(S), HICKSON STREET CLIFF, MEREWETHER

Details of the geo-hazard are shown on **Drawing 4**, **Long-section G6,** and **Cross-section S19** in **Appendix A**. Annotated photographs of the identified geo-hazard/ risk(s) are presented as **Figure 20** in **Appendix B**.

The identified geo-hazard affects residential development located at the eastern end of Hickson Street, Merewether. The identified geo-hazard(s) comprise the following:

- Cliff top retreat adjacent to fault line, threatening cliff-top Hickson Street residential development. At present a ragged, near vertical bare rock face some 5m in height is located within 3-6m of an existing residence.
- Rock falls and/or landslides on to rock platform below.

Cliff top regression has left a section of brushwood fence 'suspended' over the ragged rock crest. Existing Lloyd Street residences within 3-5m of ragged 5m high bare rock face are 34A and 38A, with any development to the rear of 36 equally at risk.

Sandstone blocks typically less than 1m in dimension, some up to 2m in dimension and landslide debris litter/line the toe of the cliff/slope and the near edge of the rock platform below. Rock blocks thought to have rolled out of cliff/slope have come to rest typically 6 to 14m from toe of cliff/slope, with some outliers up to 30m from toe of cliff/slope.

At present MSL the high tide scours the toe of the talus slope, exposing numerous sandstone blocks typically 6 to 14m from toe of cliff/slope. The plotted location of the projected sea level rises provided by WBM indicate the 2100 MSL will move landward some 1m to 20m from the existing MSL.

It is anticipated the projected sea level rise will see increased erosion of the talus material that 2011-12ly protects the Dudley Coal Seam that out crops along the toe of the Hickson Street cliff/ slope. It is anticipated that erosion and the regression rate of the Dudley Coal will increase, leading to an increase in talus slope instability and potentially increase block falls from the sandstone unit immediately above the Dudley Coal Lower Seam split.

It is anticipated the projected sea level rise will have no discernible effect on the rate of cliff line regression at the level of Hickson Street properties.

5.20 GEO-HAZARD # 20: ROCK FALL FROM OBELISK – WESTERN CLIFF FACE

Details of the geo-hazard are shown on **Drawing 2** and **Cross-section S20** in **Appendix A**. Annotated photographs of the identified geo-hazard/ risk(s) are presented as **Figure 21** in **Appendix B**.

The geo-hazard comprises the western side of the Obelisk rock face, which poses the greatest risk to the public. Along this side of the Obelisk Hill a 4-6m high near vertical sandstone and conglomerate rock face comes to within 2m of the public footpath along

Wolfe Street and is immediately above a concrete path and set of concrete steps that scale the northern portion of the cliff face at this location.

The identified geo-hazard(s) comprise(s):

- rock fall(s) from the western (Wolfe Street) rock face on to the steps and/or concrete footpath, with the potential to impact pedestrians.

A masonry block retaining wall has been constructed to protect the stairs. Vegetation is growing in defects of the rock face above pedestrian approach to stairs. Rock falls litter the base of adjacent sections of the cliff face, particularly where tree roots are propagating in rock face defects. Based on our observations past rock fall(s) comprise blocks ≤ 300mm in diameter that have come to rest within 2m of the cliff face.

It appears the principal process causing the observed rock falls is tree roots ‘jacking’ open rock defects.

The geo hazard is located some 400m landward of the existing high tide mark and some 60m above AHD. No increase in risk is anticipated due to the projected sea level rises.

5.21 GEO-HAZARD # 21-22: ROCK FALL FROM OBELISK – NORTHERN AND SOUTHERN CLIFF FACES

Details of the geo-hazards are shown on **Drawing 2** and **Cross-section S21** in **Appendix A**. Annotated photographs of the identified geo-hazard/ risk(s) are presented as **Figures 22** and **23** in **Appendix B**.

The geo-hazards comprise exposed rock faces on the northern (Ordnance Street) and southern side of Obelisk Hill.

The identified geo-hazard(s) comprise(s):

- rock fall(s) from the northern (Ordnance Street) rock face with the potential to impact persons on grassy slope below within 3m of rock face; or
- rock fall(s) from the southern (Cooks Hill Tennis Court) rock face impacting the tennis courts below.

It appears the principal process causing the observed rock falls are tree or Ficus Vine roots ‘jacking’ open rock defects. The observed rock falls typically comprised blocks ≤ 300mm in diameter, with one or two blocks approximately 1m in diameter. All the observed rock falls came to rest within 1-3m of the adjacent rock face.

The nearest tennis court fence is at least 4m from the southern rock face. The Ordnance Street pedestrian footpath is some 14m down slope of the north rock face.

The geo hazards are located some 400m landward of the existing high tide mark and some 60m above AHD. No increase in risk is anticipated due to the projected sea level rises.

6 CLIFF-LINE REGRESSION RATES AND HISTORICAL PHOTO SETS

The previous *NCHDS 2000 (Ref [2])* concluded the rate of cliff line regression for the Newcastle Coastline assessed by various methods and sources indicated cliff line regression rates are highly variable and actual measurements are very limited. A summary of applicable regression rates for the Newcastle Coastline is presented in **Table** 4 in Section **3.6** of this report.

More recent observations and document reviews are discussed below.

A recently completed stability assessment of the Nobbys headland by Douglas Partners ("*Cliff Stability Assessment Proposed Restaurant Nobbys Head", ref No 39479, 11 April 2006*) suggested the cliff face regression rate of the Nobbys Tuff ranged from 10 to 40mm per year. This suggested regression rate is comparable to the geological rate of 50mm per year presented in **Table 4** in Section **3.6** of this report.

Nine sets of historical photographs compiled for cliff regression estimation are presented in **Appendix C**. These sets of historical photographs were compared to present day photographs of the corresponding view for indicators of cliff regression. Pertinent observations from our analysis of these sets of photographs are presented in **Table 5**.

Table 5 *Cliff Regression Rate Comments from Historical Photo Sets in* ***Appendix C*** *of this Report*

Appendix C Figure No.	Location and time period	Comments
1	Nobbys from the east (1900 and present)	Cliff top has become more rounded. The cliff face has become more concave. Present day debris pile/talus almost non-existent in 1900. The estimated volume of the present day debris pile over a 350m length of cliff is ~ 3,215m^3, with evidence of talus/ debris material being eroded during high seas and storm events. Based on an average cliff height of 25m it is inferred the talus has come from a cliff area of 3,375m^2. This equates to an average loss of some 950mm from this cliff face area over a 110yr period or ~ 9mm/yr. This inferred average regression rate is lower than the survey assessed rate 10-15mm/yr from *NCDS 2000*; probably due to loss of talus during high seas.
2	Nobbys from the South (1887 to present)	Cliff top has become more rounded; whilst the cliff face has become more jagged and concave
3	Signal Hill down to Bogie Hole from North (1906 to present)	Cliff tops have become more rounded
4	Bogie Hole sea cliff from south (1908 to present)	It appears 1-2m has been lost from top of cliff face above the Bogie Hole rock pool
5	Cliff/Slope above Bogie Hole from SW (1896 to present)	Upper portion of cliff face has steepened, with most rock mass loss from mid-slope section
6	Northern Cliff top Strzelecki to Shepherds Hill (1900 to present)	Significant degradation of cliff top from gently convex and typically 6m wide in 1900 to deeply incised, with some sections less than a 2m wide at present
7	Southern cliff top Strzelecki to Shepherds Hill (1900 to present)	Loss of up to 1m along cliff top edge
8	Susan Gilmore cliff (1999 to present)	Landslide volume ~ 600 m^3 lost from mid-slope section destroying access stairs to beach in late 2001
9	Lloyd Street cliff (1900 to present)	Loss of 1 to 2m from ocean side crest of old tunnel entrance cut face. Landslide volume ~ 200m^3 in June 2007.

As per previous coastline regression assessment, it is assumed that the seaward margin of the existing rock platforms coincides with the coastal cliff line approximately 6,000 years ago. Distance measurements and inferred regression rates based on seaward margin of rock platforms and present day cliff positions at selected locations, using Google Earth satellite images and measurement tools are presented in **Table 6**.

Table 6 *Inferred Rates of Cliff Line Regression Based on Rock Platform Development*

Geo Hazard No.	Location of rock platform	Distance from seaward margin of rock platform to 2011-12 cliff base (m) [2]	Inferred rate of cliff line regression (mm/yr)
5	Fort Scratchley Hill	100-210	16.5 to 35
	Cowrie Hole 'Gap' [1]	145-190 [3]	24 to 32 [3]
	Nx Ocean Baths	150-175	25 to 29
	Ordnance Street 'Gap' [1], South Newcastle	70-170 [3]	11.5 to 28 [3]
11	King Edward Park	25-70	4 to 12
12	Bogie Hole	25-30	4 to 5
	Signal Hill 'Gap'[1]	88-125 [3]	14.5 to 21 [3]
	Signal Hill to Strzelecki	60-90	10 to 15
	Strzelecki 'Gap' [1]	78-90 [3]	13 to 15 [3]
13	Strzelecki Lookout to Shepherds Hill	45-55	7.5 to 9
14	Shepherds Hill 'Gap' [1]	80-115 [3]	13 to 14 [3]
	Susan Gilmore Beach 'Gap' [1]	150 [3]	25 [3]
16	Bar Beach Car Park	100-115	16.5 to 19
	Merewether Baths	100 to 150	16.5 to 25
18	Lloyd St, Cliff	60 to 100	10 to 16.5
19	Hickson St Cliff	100 to 125	16.5 to 21

Notes

1. 'Gap' describes an embayment or slot in the typical width of the adjacent rock platform.
2. Variation in distance measurements include tidal variation in seaward margin of rock platform.
3. Regression measurements include submerged portion of rock platform adjacent to 'Gaps'.

7 PROPOSED CLIFF TOP MEMORIAL WALK

A copy of a conceptual design document, prepared by EJE Architecture for CoN, showing the Memorial Walk alignment and conceptual design, dated January 2011, is presented in **Appendix E**. The Memorial Cliff-Top Walk project comprises a raised walking track along the cliff-top area from the northern end of Bar Beach car park to Strzelecki Lookout.

The proposed alignment of the walk, traverses geotechnical hazard 13 and runs past geotechnical hazards 14 and 15. The details of these geo-hazards are discussed in Section 5 of this report.

Geo-hazard 13 was identified as the cliff-top area from Shepherds Hill to Strzelecki Lookout, subject to deeply incised erosion and block toppling of the conglomerate unit which forms the cliff crest along this section of the proposed Memorial Walk alignment. Erosion and crest instability have resulted in two 'narrowing's' of the cliff top. These narrowed cliff top sections are less than 2m wide and would require bridges to carry the proposed 3m wide Memorial Walk across them.

The proposed Memorial Walk alignment is offset some 12m from Geo-hazard 14, identified as a 130m long section of coastal cliff line that is regressing at approximately 13 to 14mm/year, which is double the apparent regression rate of adjacent cliff areas.

The associated risks to the proposed Memorial Walk and people using the walkway from these geo-hazards are discussed in Section 8 of this report.

8 GEOTECHNICAL RISK ASSESSMENT FOR IDENTIFIED GEO-HAZARDS

Having considered the geotechnical features, inferred subsurface geology and existing development details, the landslide risk associated with the identified coastal cliff/slope hazards has been assessed in accordance with the '*Practice Note Guidelines for Landslide Risk Management*', formulated by the Australian Geomechanics Society Landslide Practice Note Working Group and published in the Australian Geomechanics, Volume 42 No 1 March 2007, herein referred to as *AGS LRM 2007*.

The risk assessment matrices for assessing risk to property and life are presented in **Appendix B** of this report along with relevant explanation and information sheets sourced from *AGS LRM 2007*.

8.1 QUALITATIVE ASSESSMENT FOR RISK TO PROPERTY

A qualitative assessment of the risk level of the identified coastal cliff/slope hazard occurring and causing damage to property has been assessed using the *AGS LRM 2007* risk analysis matrix. A detailed risk matrix for each of the identified geo-hazards is presented in **Table B1, Appendix B**. The assessed risk to property is summarised in **Table 7**.

Table 7 *Summary of Assessed **Risk to Property** from the Identified Geo-hazards*

Coastal Geo-Hazard No.(1)	Location	Assessed Risk to Property and Indicative Cost of Damage (2) at present M.S.L.	Assessed Risk to property at projected 2050 M.S.L. (3)	Assessed Risk to property at projected 2100 M.S.L. (3)
1	Breakwater Pathway, Nobbys headland	Low (≤ 1%)	Not likely to be affected	Not likely to be affected
2	North Nobbys Beach, Nobbys headland	Low (≤ 1%)	Not likely to be affected	Not likely to be affected
3	Signal Station, Nobbys headland	Low (≤10%)	Not likely to be affected	Not likely to be affected
4	Fort Scratchley Hill - NE	Low (≤ 1%)	Not likely to be affected	Not likely to be affected
5	Fort Scratchley Hill - East	Moderate (≤10%)	Not likely to be affected	Not likely to be affected
6	Footpath Newcastle Beach	Low (≤ 1%)	Not likely to be affected	Not likely to be affected
7	Shortland Esplanade, Newcastle Beach Skate Park	Low (≤ 1%)	Not likely to be affected	Not likely to be affected
8	Cliff above shared Walkway, South Newcastle	Very Low (≤ 1%)	Not likely to be affected	Not likely to be affected
9	Shared Walkway, South Newcastle	Low (≤ 40%)	Likely to increase	Likely to increase
10	Shortland Esp., King Edward Park	Low (≤ 40%)	Likely to increase	Likely to increase
11	Shortland Esp., Bogie Hole	High (≤ 40%)	Not likely to be affected	Not likely to be affected
12a	Cliff above Bogie Hole Viewing Area	Moderate (≤10%)	Not likely to be affected	Not likely to be affected
12b	Bogie Hole Pool Cliff	Moderate (≤10%)	Likely to increase	Likely to increase
13	Cliff Top Walk, Strzelecki to Shepherds Hill	Low (≤10%)	Not likely to be affected	Not likely to be affected
14a	Shepherds Hill proposed viewing area	Low (≤10%)	Likely to increase	Likely to increase
14b	Rock Platform below Shepherds Hill	Low (≤ 1%)	Likely to increase	Likely to increase
15	Susan Gilmore Beach	Low (≤ 1%)	Not likely to be affected	Not likely to be affected
16a	Bar Beach Car Park	Moderate to High (≤ 40%)	Likely to increase	Likely to increase
16b	Beach below BBCP	Low (≤ 1%)	Likely to increase	Likely to increase

Coastal Geo-Hazard No.(1)	Location	Assessed Risk to Property and Indicative Cost of Damage (2) at present M.S.L.	Assessed Risk to property at projected 2050 M.S.L. (3)	Assessed Risk to property at projected 2100 M.S.L. (3)
17	'The Cliff', North Dixon Park Beach	Low (≤ 1%)	Not likely to be affected	Not likely to be affected
18	Baths and Beach below Lloyd Street, Merewether	Moderate (≤10%)	Not likely to be affected	Not likely to be affected
19a	East end of Hickson Street, Merewether	Moderate to High (≤ 40%)	Not likely to be affected	Not likely to be affected
19b	Rock platform below Hickson Street cliff	Low (≤ 1%)	Not likely to be affected	Not likely to be affected
20-21	Obelisk Hill –N and W rock faces	Low (≤ 1%)	Not likely to be affected	Not likely to be affected
22	Obelisk Hill – S rock face (Tennis Courts)	Low (≤10%)	Not likely to be affected	Not likely to be affected

Notes:

(1) Coastal Geo-hazard number, as listed in Section 5 of this report.

(2) Indicative cost of Damage expressed as a percentage of asset value, as defined in AGS Table "Qualitative Measures of Consequences to Property" in Appendix C, pp.91 AGS LRM 2007.

(3) Change to assessed risk due to projected sea level rise discussed on a hazard by hazard basis in Section 5 of this report.

The above assessments indicated the assessed risk to property from the identified geo-hazards ranges from Very Low to High and therefore the inferred risks range from acceptable through tolerable to unacceptable as defined in *AGS LRM 2007* and summarised in **Table 8**.

Table 8 *Risk Level Implications from AGS LRM 2007, Practice Note Guidelines for Landslide Risk Management.*

Risk Level		Example Implications*
VH	Very High risk	**Unacceptable without treatment**. Extensive detailed investigation and research, planning and implementation of treatment options essential to reduce risk to Low; may be too expensive and not practical. Work likely to cost more than the value of the property.
H	High Risk	**Unacceptable without treatment**. Detailed investigation, planning and implementation of treatment options required to reduce risk to Low. Work would cost a substantial sum in relation to the value of the property.
M	Moderate Risk	**May be tolerated** in certain circumstances (subject to regulators approval) but requires investigation, planning and implementation of treatment options to reduce risk to Low. Treatment options to reduce to Low risk should be implemented as soon as practicable
L	Low risk	**Usually acceptable** to regulators. Where treatment has been required to reduce the risk to this level, ongoing maintenance is required.
VL	Very Low Risk	**Acceptable**. Manage by normal slope maintenance procedures.

NOTE: * The implications for a particular situation are to be determined by all parties to the risk assessment and may depend on the nature of the property at risk; these are only given as a general guide.

Tolerable Risks are risks within a range that society can live with so as to secure certain benefits. It is a range of risk regarded as non-negligible and needing to be kept under review and reduced further if possible[(1)].

Acceptable Risks are risks which everyone affected is prepared to accept. Action to further reduce such risk is usually not required unless reasonably practicable measures are available at low cost in terms of money, time and effort [(1)].

[(1)] Commentary on Practice Note Guidelines for Landslide Risk Management 2007, Section C8.2.

Risk management options are discussed in Section 9 of this report.

The onus is on the owner or CoN to decide whether the assessed level of risk is acceptable, taking into consideration the guidelines presented in **Table 8**, likely economic or safety related consequences of the hazard and the recommended geotechnical guidelines.

8.2 QUANTITATIVE ASSESSMENT OF RISK TO LIFE

A quantitative assessment of the risk to life arising from each of the identified coastal geo-hazards has been calculated using the *AGS LRM 2007* formula presented below.

The risk to an individual is calculated using this formula:

$$\mathbf{R_{(LOL)}=P_{(H)} \times P_{(S:H)} \times P_{(T:S)} \times V_{(D:T)}}$$

Where:

$R_{(LOL)}$ is the annual probability of loss of life of an individual due to coastal geo-hazard failure;

$P_{(H)}$ is the annual probability of the coastal geo-hazard failure occurring;

$P_{(S:H)}$ is the probability of spatial impact of the failure impacting a building taking into account the travel distance and travel direction given the event;

$P_{(T:S)}$ is the temporal spatial probability (eg, of the building or location being occupied by an individual) given the spatial impact and allowing for the possibility of evacuation given there is warning of the landslide occurrence; and

$V_{(D:T)}$ is the vulnerability of the individual (probability of loss of life of the individual given the impact).

When a number of people may be at risk from one of the identified geo-hazards then a total annual risk to life is calculated by:

Total $R_{(LOL)}$ = individual $R_{(LOL)}$ x number of persons at risk.

A detailed risk calculation for risk to life from each of the identified coastal geo-hazards is presented in **Table B2**, in **Appendix B**. The assessed total risk to life for each of the identified coastal geo-hazards is summarised in **Table 9**.

Table 9 *Summary of Assessed **Risk to Life** from the Identified Geo-hazards*

Coastal Hazard No.(1)	Location	Persons Most at Risk	Present day Total Risk to Life $R_{(LOL)}$	Total $R_{(LOL)}$ at projected 2050 M.S.L. (2)	Total $R_{(LOL)}$ at projected 2100 M.S.L. (2)
1	Breakwater shared Pathway, Nobbys headland	Person(s) on breakwater footpath in the 20m long rock fall risk zone hit by rock fall	2×10^{-5}	Not likely to be affected	Not likely to be affected
2	North Nobbys Beach, Nobbys headland	Person(s) within 16m of cliff/slope toe	4.5×10^{-4}	Not likely to be affected	Not likely to be affected
3	Nobbys headland	Person(s) in building or behind brick fence when cliff top failure occurs	3.7×10^{-9}	Not likely to be affected	Not likely to be affected
4a	Shortland Esp., Fort Scratchley Hill - NE	Person(s) in vehicle that impacts rock fall	8×10^{-6}	Not likely to be affected	Not likely to be affected
4b	Fort Drive, Fort Scratchley Hill - NE	Person(s) in vehicle that impacts rock fall	3×10^{-7}	Not likely to be affected	Not likely to be affected
5	Fort Scratchley Hill - SE	Person(s) in vehicle that impacts failure debris	3.6×10^{-6}	Not likely to be affected	Not likely to be affected
6	Footpath, Newcastle Beach	Person(s) impacted by block fall from wall	6×10^{-5}	Not likely to be affected	Not likely to be affected
7	Shortland Esplanade, Newcastle Beach skate park	Maintenance personnel and/or vehicles working under cliff/slope	1.6×10^{-5}	Not likely to be affected	Not likely to be affected
8	Shared Walkway, South Newcastle	Person(s) using walkway protected by rock fall barrier fence	8.9×10^{-12}	Not likely to be affected	Not likely to be affected
9	Shared Walkway, South Newcastle	Person(s) using walkway	2.2×10^{-7}	Not likely to be affected	Not likely to be affected
10	Shortland Esp., King Edward Park	Person(s) using walkway	8.9×10^{-8}	Not likely to be affected	Not likely to be affected
11	Shortland Esp., Bogie Hole	Person(s) using walkway	3.6×10^{-5}	Not likely to be affected	Not likely to be affected
12a	Cliff above Bogie Hole Pool	Person(s) using viewing area, steps to pool	3.4×10^{-5}	Not likely to be affected	Not likely to be affected
12b	Cliff above Bogie Hole Pool	Person(s) within 16m of cliff/slope toe	3.4×10^{-5}	Likely to increase	Likely to increase

Coastal Hazard No.(1)	Location	Persons Most at Risk	Present day Total Risk to Life $R_{(LOL)}$	Total $R_{(LOL)}$ at projected 2050 M.S.L. (2)	Total $R_{(LOL)}$ at projected 2100 M.S.L. (2)
13	Cliff Top Walk, Strzelecki to Shepherds Hill	Person(s) using walkway	5.8×10^{-8}	Not likely to be affected	Likely to increase
14a	Shepherds Hill cliff top	Person(s) standing at cliff top barrier	1.5×10^{-8}	Not likely to be affected	Likely to increase
14b	Rock Platform below Shepherds Hill Cliff	Person(s) crossing ‘notch’ in rock platform	3×10^{-4}	Likely to increase	Likely to increase
15	Susan Gilmore Cliff	Person(s) within 16m of cliff/slope toe	5×10^{-5}	Not likely to be affected	Not likely to be affected
16a	Bathers Way, Bar Beach carpark	Person(s) walking or leaning against cliff top barrier	2.9×10^{-5}	Likely to increase	Likely to increase
16b	Beach below Bar Beach carpark	Person(s) within 16m of cliff/slope toe	5×10^{-5}	Likely to increase	Likely to increase
17	Cliff above north Dixon Park Beach	Person(s) within 16m of cliff/slope toe	5×10^{-5}	Not likely to be affected	Not likely to be affected
18	Lloyd Street cliff, Merewether	Person(s) within 16m of cliff/slope toe	6×10^{-6}	Likely to increase	Likely to increase
19a	Hickson Street cliff top, Merewether	Person(s) in residence or cliff top backyard	2.7×10^{-5}	Not likely to be affected	Not likely to be affected
19b	Rock platform below Hickson Street Cliff	Person(s) within 16m of cliff/slope toe	5×10^{-5}	Not likely to be affected	Not likely to be affected
20	Obelisk Hill – west face	Person(s) within 3m of rock face	7.2×10^{-5}	Not likely to be affected	Not likely to be affected
21	Obelisk Hill – north face	Person(s) within 3m of rock face	6×10^{-5}	Not likely to be affected	Not likely to be affected
22	Obelisk Hill – south face	Person(s) on tennis court nearest to rock face	6.7×10^{-9}	Not likely to be affected	Not likely to be affected

Notes:

(1) Coastal cliff/slope hazard number, as listed in Section 5 of this report.

(2) Change to assessed risk due to projected sea level rise is discussed on a hazard by hazard basis in Section 5 of this report.

The risk to life for persons most at risk from any of the cliff/slope hazards, as listed in **Table 9** is 4.5×10^{-4}, which is considered to be **Tolerable** for existing slopes and existing development in accordance with criteria presented in **Table 10**, taken from *AGS LRM 2007*.

Table 10 *AGS LRM 2007 Suggested Tolerable Risk for Individual Loss of Life*

Situation	Suggested Tolerable Loss of Life Risk for the person most at risk
Existing slope/existing development	10^{-4}/annum
New constructed slope/new development/existing landslide	10^{-5}/annum

The onus is on the owner or CoN to decide whether the assessed level of risk is acceptable, taking into consideration the risk definitions presented in **Table 8**, likely economic or safety related consequences of the hazard and the recommended geotechnical guidelines.

To provide further assistance to the regulator in determining whether the assessed level of risk is acceptable, reference to *AGS LRM 2007 pp.78* indicates:

- "*Tolerable Risks* are risks within a range that society can live with so as to secure certain benefits. It is a range of risk regarded as non-negligible and needing to be kept under review and reduced further if practicable."
- "*Acceptable Risks* are risks which everyone affected are prepared to accept. Action to further reduce such risks is usually not required unless reasonably practicable measures are available at low cost in terms of money, time and effort."

The assessed risks to life for all coastal hazards listed in **Table 9** are within the Tolerable risk limit presented in **Table 10**, which is usually acceptable for most urban developments.

9 RISK MANAGEMENT OF GEOTECHNICAL HAZARDS

Risk management of South Newcastle cliff should follow recommendations of the detailed investigation and report submitted to City of Newcastle by GHD.

The risk management measures for the identified geotechnical risks for Newcastle coastal cliff/slope geotechnical hazard discussed in this section of the report are based on a review of risk management measures previously employed along the Newcastle Coastal Zone and the results of the risk assessment discussed in Section 8 of this report.

9.1 DEVELOPMENT APPROVAL PROCESS

It is suggested the development approval process adopted by the City of Newcastle for development in proximity to coastal cliffs and slopes follow the **AGS 2011 Landslide Risk Management** – **Development Assessment Flow Chart** attached in **Appendix B** of this report. This flow chart was developed by Wollongong City Council to provide regulator guidelines for assessing development applications in landslide risk areas. A detailed discussion is presented in Australian Geomechanics Volume 46 No.2 June 2011.

It is suggested that all proposed developments within the coastal landslide risk assessment zone shown on **Drawings 7** to **10** in **Appendix A**, are subject to an AGS LRM 2007 landslide risk assessment as part of the development application.

The coastal landslide risk assessment zone shown on **Drawings 7** to **10** in **Appendix A** was determined by slope geometry and with reference to past slope instability. The slope geometry was defined by a 1H:1V line from adjacent coastal cliff(s) ≥ 0.75H:1V (~53°) or within a 3H:1V line of coastal slope(s) ≥ 2H:1V (~27°).

All proposed and existing developments within the coastal landslide risk assessment zone should comply with good hillside practice as presented in *AGS LRM 2007*. A copy of the **AGS LRM 2007 Geoguide LR8 for Hillside Construction Practice** is attached in **Appendix B** of this report.

The onus is on the CoN and relevant stakeholders to decide whether the assessed level of landslide risk is acceptable, taking into consideration likely economic, conservation and preservation consequences of the risk and the recommended geotechnical risk management strategies.

Consultations with the Mine Subsidence Board of NSW should be sought to determine what development constraints may be applicable for proposed developments due to past mining activities.

9.2 Suggested Geotechnical Risk Management Options

In general the risk associated with the Newcastle coastline can be managed by the following measures:

- Adopt development guidelines as discussed above.
- Review all existing developments within the coastal landslide risk assessment zones shown on **Drawings 7** to **10** in **Appendix A**, with reference to good hillside practice as recommended in AGS LRM 2007 Appendix G pp.113-114 Guidelines for hillside construction. A copy of the AGS illustration of hillside construction guidelines is attached in Appendix B of this report. These guidelines incorporate comments on drainage and erosion control.
- It is advantageous to encourage vegetation cover on slopes comprised of soil and/or extremely low to low strength rock.
- In competent rock faces ≥ 1H:1V, trees, Ficus vines or any vegetation with robust root systems propagating in rock defects ‘jack’ open rock defects causing rock falls. Trees, Ficus vines or any vegetation with robust root systems propagating in rock defects needs to be cut and poisoned or removed where appropriate with respect to cliff/slope stability.
- It is recommended a geotechnical re-assessment of the landslide risks along the Newcastle coastline is conducted every 10 years, or as required by slope failures or by proposed development guidelines as discussed in previous section of this report.

Based on the results of the risk assessments discussed in Section 8 of this report the identified geotechnical coastal cliff/slope hazards have been ranked in order of the combined assessed landslide risk to property and life, as set out on **Table B3** in **Appendix B** of this report and summarised in **Table 11**.

Specific geotechnical risk management measures for the ranked coastal geo-hazards are presented in **Table 11**.

Table 11 *Risk Mitigation/Management for Geo-hazards ranked in order of Present Day Assessed Risk*

Combined Risk Ranking (1)	**Geo-Hazard No.** (2)	**Location**	**Risk Mitigation/Management**	**Indicative Cost of Mitigation Measure compared to Asset Value** (3)
1	11	Shortland Esp, Bogie Hole	Specific geotechnical investigation, including installation of inclinometers to determine depth and rate of existing failure and stabilisation strategy for cliff top fill embankment	~\$15-20K (4) (for sub-surface investigation and instrumentation)
2	16a	Bathers Way, Bar Beach carpark	April 2012 CoN removed cliff top row of car spaces. RCA recommends CoN immediately re-instate barricades 2m from fence to keep BBCP pathway users out of at risk area. Recommend at risk section of BBCP is protected by a retaining structure founded below base of landslide. and Specific geotechnical investigation to determine overall stabilisation strategy for vulnerable cliff top. Large or long reach excavator working from BBCP to confirm base of slide prior to wall construction.	~10% and ~\$15-20K (4) (for sub-surface investigation)
3	19a	Hickson Street cliff top, Merewether	Specific geotechnical investigation to determine stabilisation strategy for ragged soil/EW rock face 3-6m from Lloyd Street residential properties No.34a – 38a	~\$15-20K (4) (for sub-surface investigation and instrumentation)
4	12	Cliff above Bogie Hole pool	Slope 'groomed' after rock fall in 2003. Re-assessment of rock fall hazard at least once every 10 years.	\$3-5K (4) (AGS surface risk assessment)
5	18	Lloyd Street cliff	Remove remaining spoil on slope above Merewether Bath's picnic tables and benches and Re-assessment of landslide hazard at least once every 10 years.	~ 10% and \$3-5K (4) (AGS surface risk assessment)
6	5	Fort Scratchley Hill - east	Structural engineer to assess condition of the existing concrete revetments and retaining walls. and Specific geotechnical investigation to determine risk more accurately	~10% and \$10-15K (4) (for sub-surface investigation)
7	2	Nobbys headland	Flatten the debris fan along the beach side of cliff to 'catch' rock falls rather than promote 'run out'	5-10%

Combined Risk Ranking (1)	**Geo-Hazard No.** (2)	**Location**	**Risk Mitigation/Management**	**Indicative Cost of Mitigation Measure compared to Asset Value** (3)
8	14b	Rock platform below Shepherds Hill cliff	Post Warning Signs ‘Beware Falling Rocks’ on rock platform both sides of hazard	≤ 1%
9	20	Obelisk cliff above Wolfe Street footpath	Remove and poison vegetation growing in rock face defects and remove or support unstable blocks as needed	10%
10	21	Obelisk Hill – north face	Remove and poison vegetation growing in rock face defects and remove or support unstable blocks as needed	10%
11	6	Newcastle beach	At meeting on 23/3/2012 CoN indicated crumbling wall to be demolished and slopes regraded. RCA recommends: soils battered at ≤ 2H:1V weathered rock cut at ≤ 1.5H:1V; Fresh competent rock cut at ≤ 0.75H:1V; or Support steeper slopes with engineer designed retaining wall(s).	10-40%
12	19b	Rock platform below Hickson Street cliff	Post warning signs ‘Beware Falling Rocks’ on rock platform 16m offset from base of slope	≤ 1%
13	15	Susan Gilmore cliff	Susan Gilmore footpath to remain closed to public and Re-locate stormwater outlets to base of slope	No cost and 20%
14	17	The Cliff, Kilgour Avenue, Dixon Park	CoN to monitor cliff/slope condition on an annual basis and/or after rainfall events ≥ 1 in 100yr. CoN to commission a detailed Landslide Risk Assessment if cliff top assets come under threat.	$3-5K (4) (AGS surface risk assessment)
15	16b	Beach –rock platform below Bar Beach carpark cliff	CoN to monitor slope stability on an annual basis and/or after rainfall events ≥ 1 in 100yr. CoN to commission a detailed Landslide Risk Assessment if cliff top assets come under threat.	$5-7K (4) (AGS slope risk assessment) or ~$15-20K (4) (for sub-surface investigation)

Combined Risk Ranking (1)	**Geo-Hazard No.** (2)	**Location**	**Risk Mitigation/Management**	**Indicative Cost of Mitigation Measure compared to Asset Value** (3)
16	1	Nobbys headland	Install 21m of concrete jersey kerb to protect people using the breakwater walkway from rock fall hazard	≤ 1%
17	7	South Newcastle cliff, above skate park	Cliff/slope to be inspected for rock fall/landslide risks prior to any work being undertaken behind fence	≤ 1%
18	4a	Shortland Esp, Fort Scratchley Hill - NE	Remove loose and/or detached blocks from exposed rock faces, remove and poison vegetation growing in rock defects	~10%
19	4b	Fort Drrive Fort Scratchley hill - NE	Install 'No stopping rock fall hazard signs'. Prevent car parking along toe of slope, revetments and retaining walls.	1-5%
20	9	Shared walkway, south Newcastle	CoN to re-seal pavement crack to prevent ingress of water into fill behind sea wall and monitor pavement crack development. Geotechnical re-assessment of hazard at least once every 10 years. and Replace existing cracked retaining wall to support Shortland Esplanade.	≤ 1% $3-5K (4) (AGS slope risk assessment) and 100%
21	10	Shortland Esp, King Edward Park	Recommend CoN: 1. Remove broken footpath and cracked asphalt. 2. Re-grade and compact upper metre of fill. 3. Re-instate asphalt seal and concrete kerb and gutter. 4. Re-instate concrete footpath, optional. Specific geotechnical investigation to determine stabilisation strategy for Shortland Esp. cliff top fill embankment and retaining wall or Construct new retaining wall to support Shortland Esplanade.	~20% ~$15K (4) (for sub-surface investigation) Or 100%
22	13	Cliff top walk, Strzelecki to Shepherds Hill	Specific geotechnical investigation for proposed hill top walk bridges and viewing platforms. Likely outcomes: 1. Found supports for cliff top walkway 600mm below G.L. 2. Found supports for footbridges below the base of the 'friable' cliff top conglomerate unit; typically 7-10m thick	$15-25K (4) (for sub-surface investigation)

Combined Risk Ranking (1)	**Geo-Hazard No.** (2)	**Location**	**Risk Mitigation/Management**	**Indicative Cost of Mitigation Measure compared to Asset Value** (3)
23	14a	Shepherds Hill cliff top	Specific landslide risk assessment for proposed barrier fence	\$7-10K (4) (for sub-surface investigation)
24	22	Obelisk Hill – south face	Remove and poison vegetation growing in rock face defects and remove or support unstable blocks as needed.	10%
25	3	Nobbys headland	Relevant authority to monitor cliff top retreat. Conduct AGS LRM landslide risk assessment at least once every 10 years and/or Upgrade existing brick wall to protect buildings from cliff retreat.	\$3-5K (4) (AGS slope risk assessment) 10-20%
26	8	South Newcastle cliff	Maintain existing rock barrier fence and inspect cliff/slope rock fall/landslide risks prior to work being undertaken behind barrier fence. Conduct five yearly AGS LRA reviews.	< 5% / yr

Notes:

1. Combined risk ranking assessment matrix is presented in **Table B3** in **Appendix B**.
2. Coastal Geo-hazard No., as identified in **Table 7** of this report.
3. Indicative cost of mitigation measures have been estimated as a percentage of the asset value using AGS assigned values as per Qualitative Risk Matrix, Appendix C pp.92 AGS LRM 2007. A copy of **AGS LRM 2007 Appendix C** is presented in **Appendix B** of this report.
4. Cost estimates for geotechnical investigation will vary depending on ease of access, scope of work and investigation objectives.

10 PUBLIC AMENITIES AT RISK FROM PROJECTED SEA LEVEL RISE

The public amenities discussed below are not at risk from any identified geotechnical hazard associated with a coastal cliff or slope. The discussion below is intended to share observations made during the course of the risk assessments that may assist CoN and relevant stakeholders in the management of these public amenities.

The photographs referenced in **Appendix D** are intended to show an approximation of the projected mean sea level rises.

10.1 FORT SCRATCHLEY SEA WALL

Fort Scratchley-Shortland Esplanade Sea Wall is located on a wide rock platform along the shoreline from Nobbys Beach to The Cowrie Hole, as shown on **Drawing 2** in **Appendix A**. A photograph illustrating the projected sea level rise is presented as **Photograph 1** in **Appendix D**. It is anticipated the projected sea level rise will result in:

- mean sea level residing at the base of the sea wall;
- higher maintenance costs due to increased wave action increasing the deterioration rate of amenities; and
- wave spray affecting traffic on Shortland Esplanade during storms and large swell events, with reduced access to bathers walk footpath.

10.2 NEWCASTLE BATHS

Newcastle Baths complex is located on a rock platform at the shoreline of Newcastle East headland, as shown on **Drawing 2** in **Appendix A**. A photograph illustrating the projected sea level rise is presented as **Photograph 2** in **Appendix D**. It is anticipated the projected sea level rise will result in reduced access to Newcastle Baths due to increasing frequency of inundation as sea levels rise and higher maintenance costs due to increased wave action increasing the deterioration rate of amenities.

10.3 BOGIE HOLE POOL

The rock platform and ocean pool at the Bogie Hole, as shown on **Drawing 2** in **Appendix A**. A photograph illustrating the projected sea level rise is presented in **Photographs** 3 and **4** in **Appendix D**. It is anticipated the projected sea level rise will result in reduced access to the Bogie Hole pool due to increasing frequency of inundation as sea levels rise and increased deterioration rate of amenities.

10.4 BAR BEACH TO SUSAN GILMORE BEACH ROCK PLATFORM AND SUSAN GILMORE BEACH

The rock platform between Bar Beach and Susan Gilmore Beach is located as shown on **Drawing 3** in **Appendix A**. A photograph illustrating the projected sea level rise is presented as **Photograph 5** in **Appendix D**. It is anticipated the projected sea level rise will result in reduced access from Bar Beach to Susan Gilmore Beach and the rock platform under Shepherds Hill.

10.5 MEREWETHER BATHS

Merewether Baths located at the southern end of Merewether Beach, as shown on **Drawing 4** in **Appendix A**. A photograph illustrating the projected sea level rise is presented as **Photograph 6** in **Appendix D**. It is anticipated the projected sea level rise will result in reduced access to the Merewether Baths pools due to increasing frequency of inundation as sea levels rise and increased deterioration rate of amenities.

10.6 HUNTER WATER SEWER - SOUTH MEREWETHER – BURWOOD BEACH

A section of the Hunter Water Corporation Merewether to Burwood sewer line is located on rock platform under the Hickson-Lloyd Street cliff. The location of the most vulnerable section of the pipeline is shown on **Drawing 4** in **Appendix A**. A photograph illustrating the projected sea level rise is presented as **Photograph 7** in **Appendix D**. It is anticipated that the projected sea level rise will result in more frequent flooding of the sewer pipeline.

11 LIMITATIONS

This report has been prepared for BMT WBM Pty Ltd in accordance with the agreement with RCA. The services performed by RCA have been conducted in a manner consistent with that generally exercised by members of its profession and consulting practice.

This report has been prepared for BMT WBM Pty Ltd, acting on behalf of the City of Newcastle for the specific purpose and the specific development described in the report. The report may not contain sufficient information for purposes or developments other than that described in the report or for parties other than BMT WBM Pty Ltd and the City of Newcastle. This report shall only be presented in full and may not be used to support objectives other than those stated in the report without permission.

The information in this report is considered accurate at the date of issue with regard to the 2011-12 conditions of the site. The conclusions drawn in the report are based on interpolation between boreholes or test pits. Conditions can vary between test locations that cannot be explicitly defined or inferred by investigation.

Yours faithfully
RCA AUSTRALIA

Jeremy Everitt
Principal Engineering Geologist

Robert Carr
Principal Geotechnical Engineer

REFERENCES

[1] Newcastle City Council, *Specification for Newcastle Coastal Zone Hazard and Management Studies*, Contract Number 2011/265T.

[2] WBM Oceanics Australia, '*Newcastle Coastline Hazard Definition Study*', WBM ref 11381.R1.5, 12 October 1998.

[3] UMWELT (Australia) Pty Limited, '*Newcastle Coastline Management Study*', Umwelt ref 1411/R02/V4, January 2003.

[4] UMWELT (Australia) Pty Limited, '*Reference Document, Newcastle Coastline Management Study*', Umwelt ref 1411/R06/V1, June 2002.

[5] UMWELT (Australia) Pty Limited, '*Newcastle Coastline Management Plan*', Umwelt ref 1411/R03/V5, March 2003.

[6] Australian Geomechanics Society Landslide Practice Note Working Group, '*Practice Note Guidelines for Landslide Risk Management 2007*'. Australian Geomechanics, Volume 42 No 1, March 2007.

Appendix A

Drawings 1 – 4: Geotechnical Assessment Location Plans

Drawing 5: Inferred Coastline Geology

Drawing 6: Inferred Depth of Coastline Sediments

Drawings 7 to 10 Coastal Landslide Assessment Zone Maps

Geo-hazard Long-sections: G1 – G6

Geo-hazard Cross-sections: S1 – S21

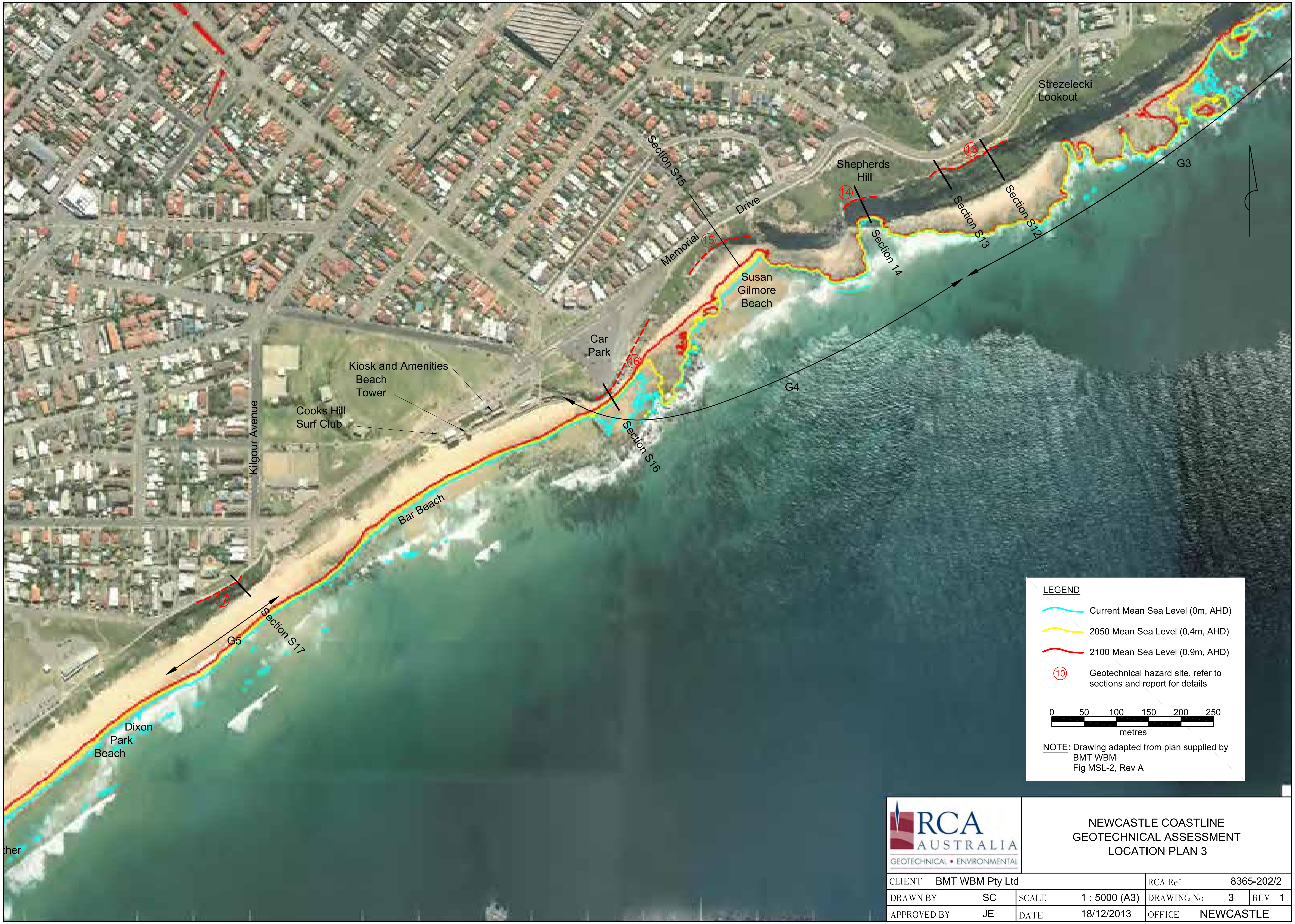
RCA AUSTRALIA
GEOTECHNICAL • ENVIRONMENTAL

NEWCASTLE COASTLINE
GEOTECHNICAL ASSESSMENT
LOCATION PLAN 1

CLIENT	BMT WBM Pty Ltd			RCA Ref	8365-202/2
DRAWN BY	SC	SCALE	1 : 5000 (A3)	DRAWING No	1 REV 1
APPROVED BY	JE	DATE	18/12/2013	OFFICE	NEWCASTLE

CDT-DWG-A3H-001/1

Scratchley
G1
Section S5
Shortland Esplanade
Ocean Baths
Pavillion
The Cowrie Hole
Newcastle Surf Club
and Pavillion
Ocean
Baths
Baths
Newcastle
Beach
Section S6
Shortland
Esplanade
Section S7
South
Newcastle
Beach
Section S20
Section S21
Section S8
G2
Section S9
King Edward Park
York Drive
Bogie Hole rock baths
The Terrace
High Street
Section S10
Section S11
ezelecki
okout
G3
5
6
7
8
9
10
11
12
20
21
22
LEGEND
Current Mean Sea Level (0m, AHD)
2050 Mean Sea Level (0.4m, AHD)
2100 Mean Sea Level (0.9m, AHD)
10
Geotechnical hazard site, refer to sections and report for details
0 50 100 150 200 250
metres
NOTE: Drawing adapted from plan supplied by BMT WBM Fig MSL-3, Rev A
RCA AUSTRALIA
GEOTECHNICAL • ENVIRONMENTAL
NEWCASTLE COASTLINE
GEOTECHNICAL ASSESSMENT
LOCATION PLAN 2
CLIENT BMT WBM Pty Ltd
RCA Ref 8365-202/2
DRAWN BY SC
SCALE 1 : 5000 (A3)
DRAWING No 2
REV 1
APPROVED BY JE
DATE 18/12/2013
OFFICE NEWCASTLE
CDT-DWG-A3H-001/1



RCA AUSTRALIA
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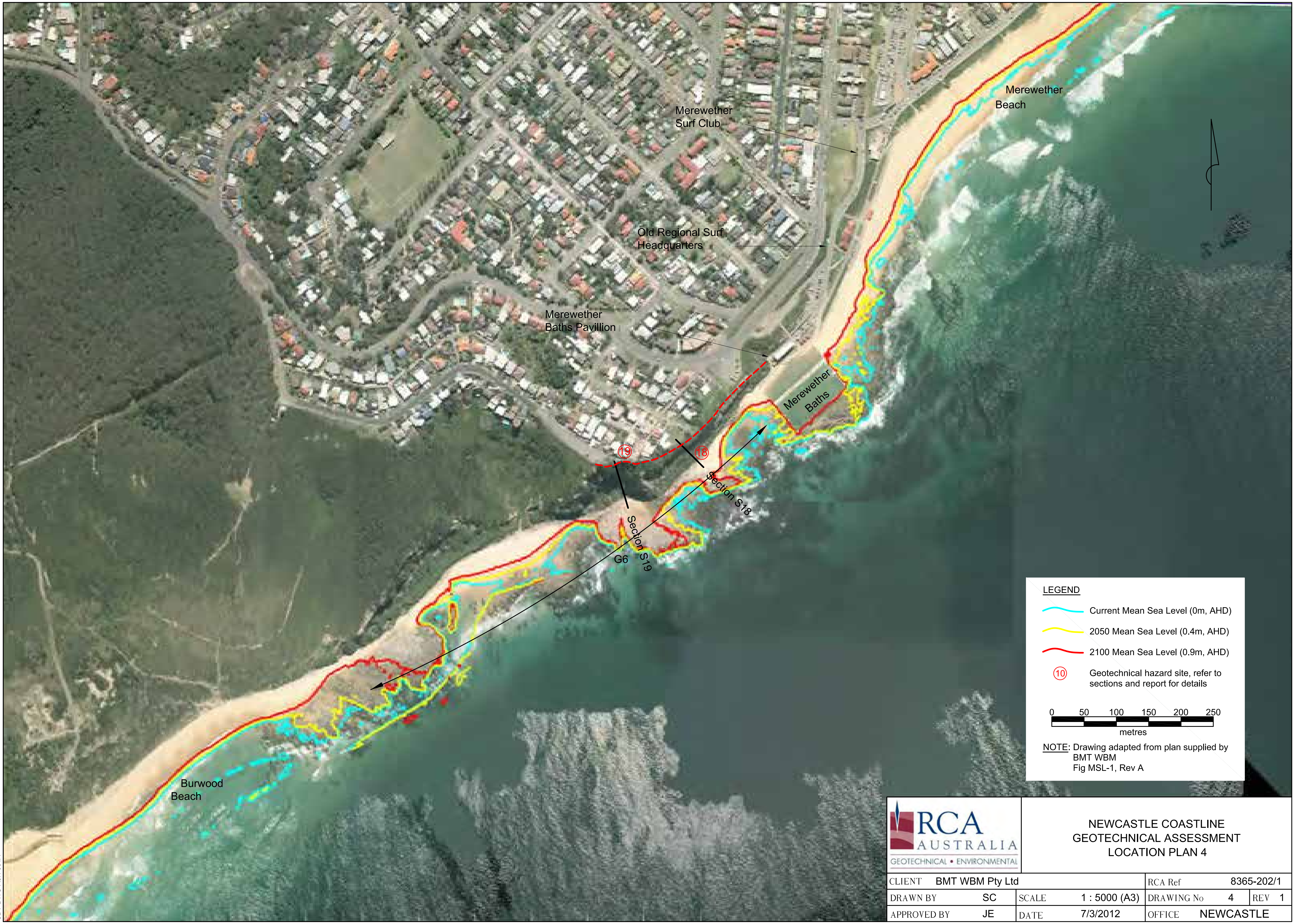
NEWCASTLE COASTLINE
GEOTECHNICAL ASSESSMENT
LOCATION PLAN 3

CLIENT	BMT WBM Pty Ltd			RCA Ref	8365-202/2
DRAWN BY	SC	SCALE	1 : 5000 (A3)	DRAWING No	3 REV 1
APPROVED BY	JE	DATE	18/12/2013	OFFICE	NEWCASTLE

CDT-DWG-A3H-001/1

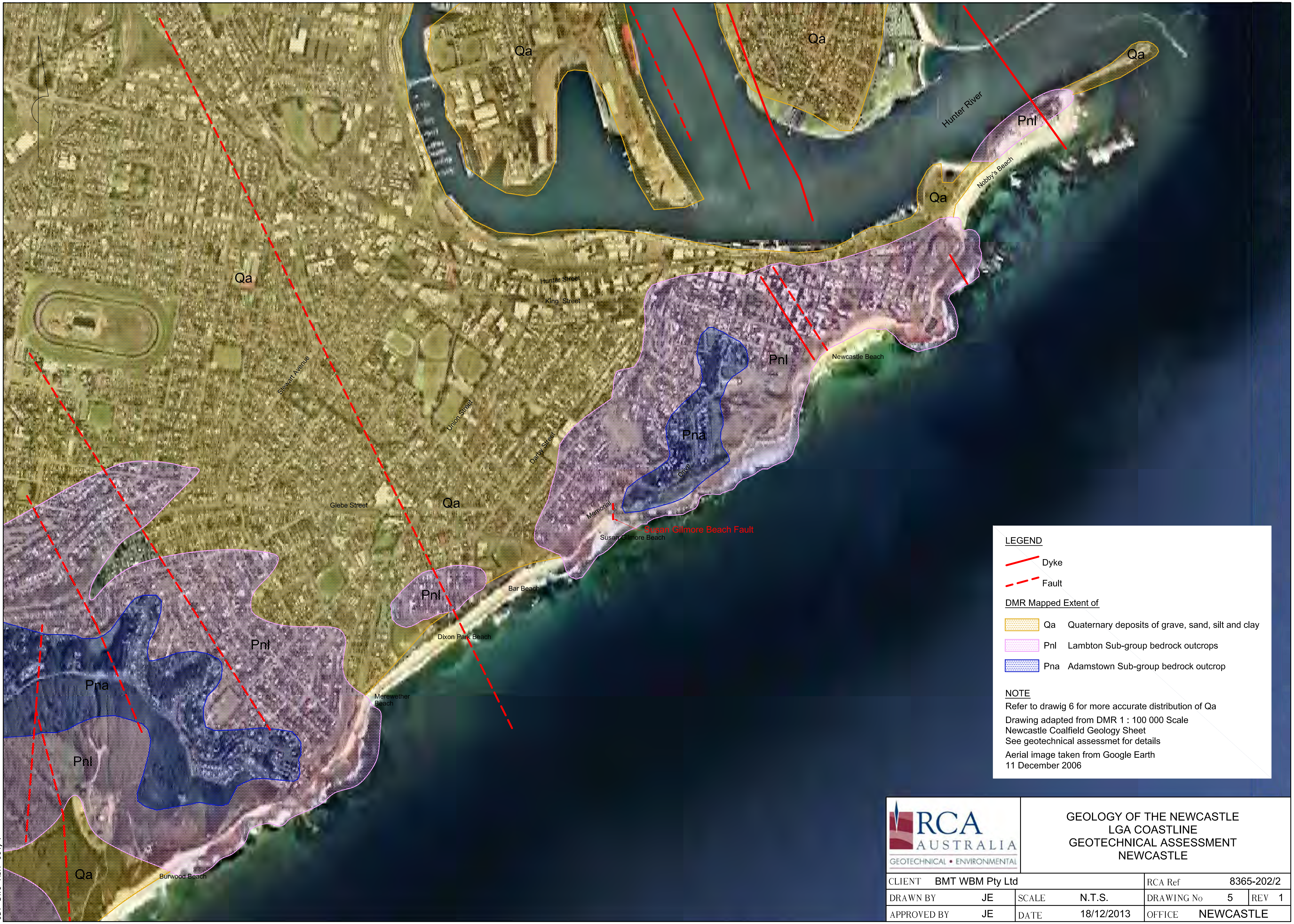


RCA AUSTRALIA
GEOTECHNICAL • ENVIRONMENTAL

NEWCASTLE COASTLINE
GEOTECHNICAL ASSESSMENT
LOCATION PLAN 4

CLIENT	BMT WBM Pty Ltd			RCA Ref	8365-202/1
DRAWN BY	SC	SCALE	1 : 5000 (A3)	DRAWING No 4	REV 1
APPROVED BY	JE	DATE	7/3/2012	OFFICE	NEWCASTLE

CDT-DWG-A3H-001/1



LEGEND

Dyke

Fault

DMR Mapped Extent of

	Qa	Quaternary deposits of grave, sand, silt and clay
	Pnl	Lambton Sub-group bedrock outcrops
	Pna	Adamstown Sub-group bedrock outcrop

NOTE

Refer to drawig 6 for more accurate distribution of Qa

Drawing adapted from DMR 1 : 100 000 Scale
Newcastle Coalfield Geology Sheet
See geotechnical assessment for details

Aerial image taken from Google Earth
11 December 2006

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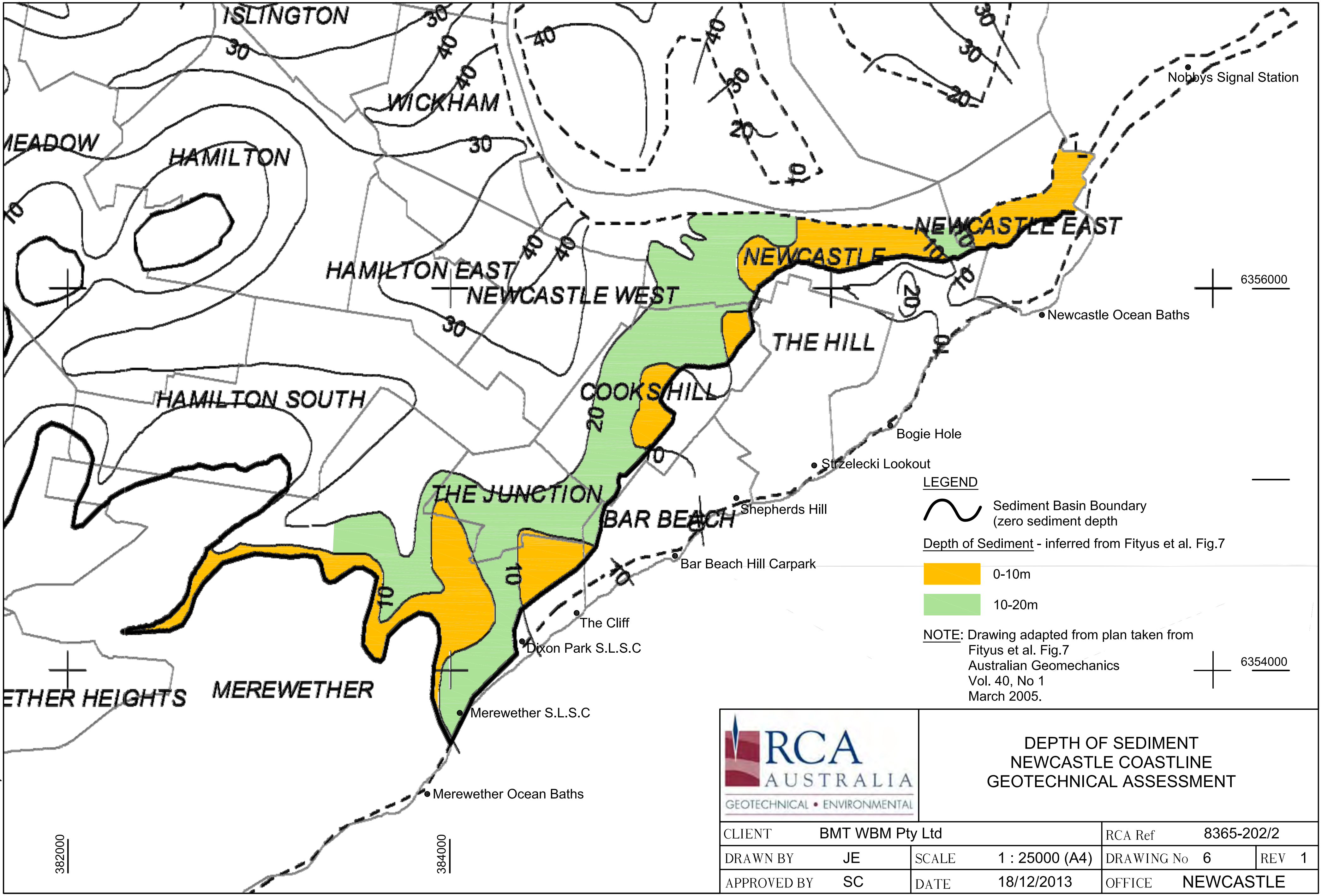
GEOLOGY OF THE NEWCASTLE
LGA COASTLINE
GEOTECHNICAL ASSESSMENT
NEWCASTLE

CLIENT	BMT WBM Pty Ltd			RCA Ref	8365-202/2
DRAWN BY	JE	SCALE	N.T.S.	DRAWING No	5 REV 1
APPROVED BY	JE	DATE	18/12/2013	OFFICE	NEWCASTLE

CDT-DWG-A3H-001/1



RCA AUSTRALIA
GEOTECHNICAL • ENVIRONMENTAL

DEPTH OF SEDIMENT
NEWCASTLE COASTLINE
GEOTECHNICAL ASSESSMENT

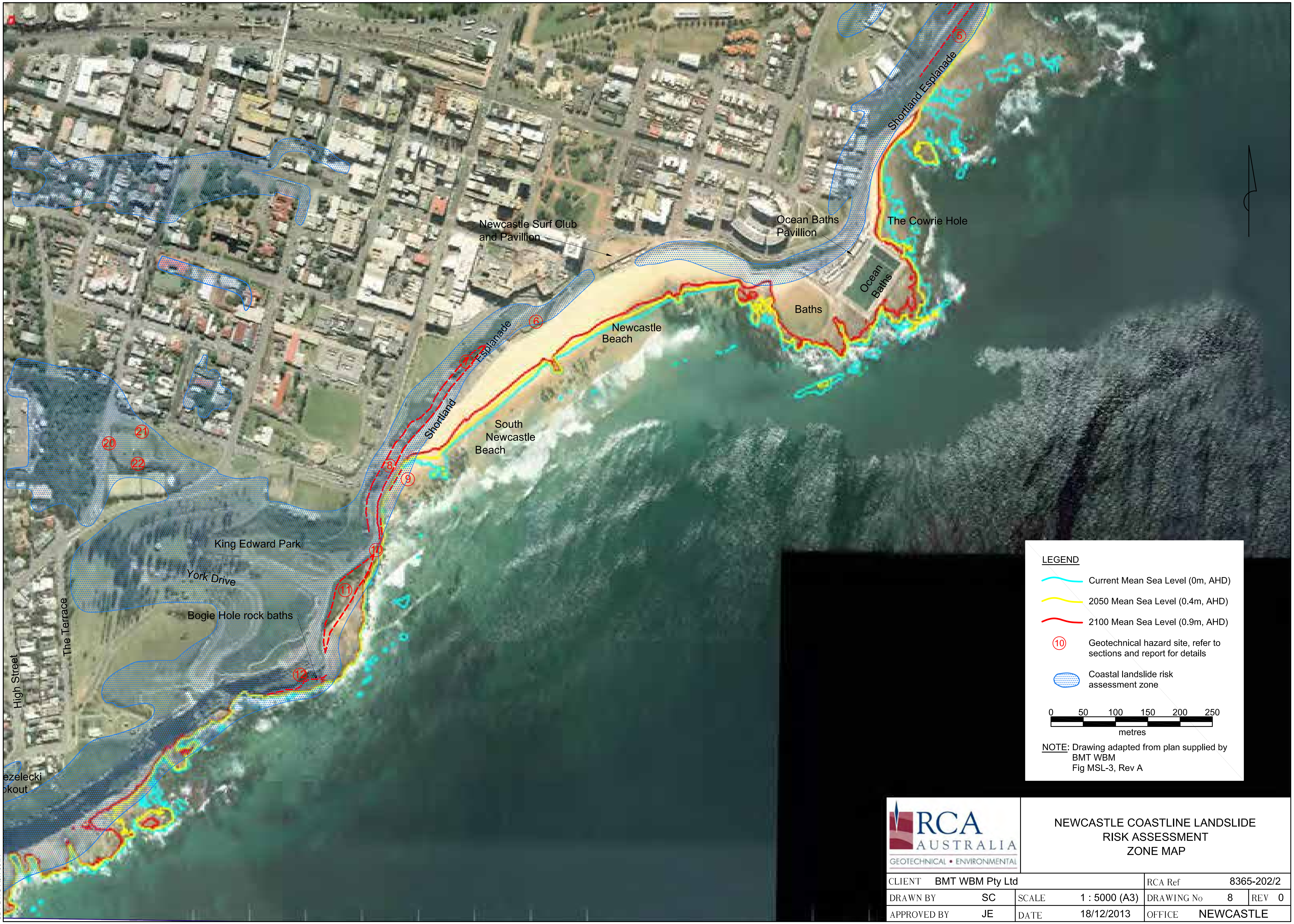
CLIENT	BMT WBM Pty Ltd			RCA Ref	8365-202/2
DRAWN BY	JE	SCALE	1 : 25000 (A4)	DRAWING No	6 REV 1
APPROVED BY	SC	DATE	18/12/2013	OFFICE	NEWCASTLE

CDT-DWG-A4H-001/1

NEWCASTLE COASTLINE LANDSLIDE RISK ASSESSMENT ZONE MAP

CLIENT	BMT WBM Pty Ltd			RCA Ref	8365-202/2
DRAWN BY	SC	SCALE	1 : 5000 (A3)	DRAWING No	7 REV 0
APPROVED BY	JE	DATE	18/12/2013	OFFICE	NEWCASTLE

CDT-DWG-A3H-001/1



Shortland Esplanade
The Cowrie Hole
Ocean Baths Pavillion
Newcastle Surf Club and Pavillion
Ocean Baths
Baths
Newcastle Beach
Shortland Esplanade
South Newcastle Beach
King Edward Park
York Drive
Bogie Hole rock baths
The Terrace
High Street
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21
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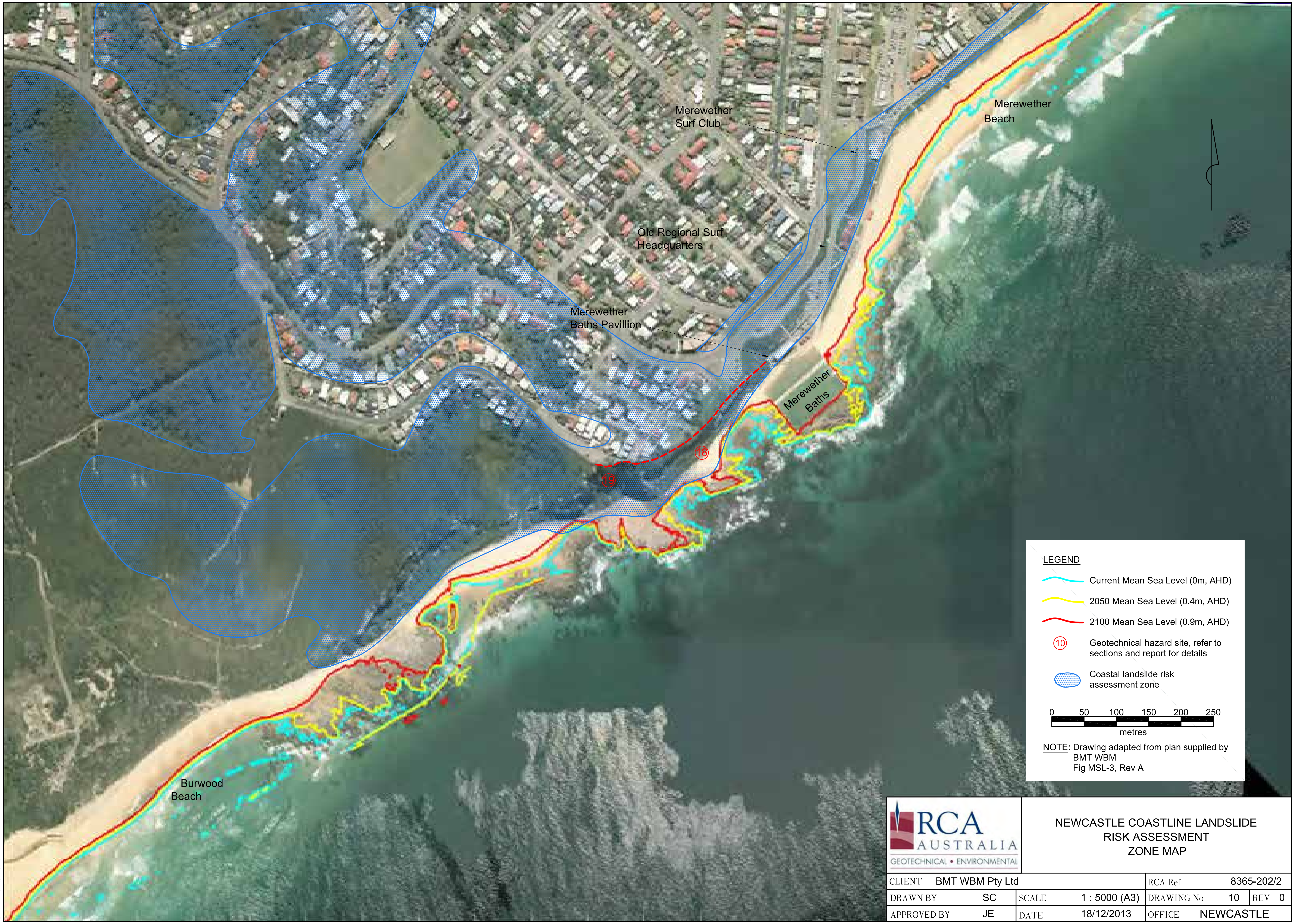
LEGEND
Current Mean Sea Level (0m, AHD)
2050 Mean Sea Level (0.4m, AHD)
2100 Mean Sea Level (0.9m, AHD)
10 Geotechnical hazard site, refer to sections and report for details
Coastal landslide risk assessment zone
0 50 100 150 200 250
metres
NOTE: Drawing adapted from plan supplied by BMT WBM Fig MSL-3, Rev A
RCA AUSTRALIA
GEOTECHNICAL • ENVIRONMENTAL
NEWCASTLE COASTLINE LANDSLIDE RISK ASSESSMENT ZONE MAP
CLIENT BMT WBM Pty Ltd
RCA Ref 8365-202/2
DRAWN BY SC
SCALE 1 : 5000 (A3)
DRAWING No 8
REV 0
APPROVED BY JE
DATE 18/12/2013
OFFICE NEWCASTLE
CDT-DWG-A3H-001/1

RCA AUSTRALIA
GEOTECHNICAL • ENVIRONMENTAL

NEWCASTLE COASTLINE LANDSLIDE
RISK ASSESSMENT
ZONE MAP

CLIENT	BMT WBM Pty Ltd			RCA Ref	8365-202/2
DRAWN BY	SC	SCALE	1 : 5000 (A3)	DRAWING No	9 REV 0
APPROVED BY	JE	DATE	18/12/2013	OFFICE	NEWCASTLE

CDT-DWG-A3H-001/1



RCA AUSTRALIA
GEOTECHNICAL • ENVIRONMENTAL

NEWCASTLE COASTLINE LANDSLIDE RISK ASSESSMENT ZONE MAP

CLIENT	BMT WBM Pty Ltd			RCA Ref	8365-202/2
DRAWN BY	SC	SCALE	1 : 5000 (A3)	DRAWING No	10 REV 0
APPROVED BY	JE	DATE	18/12/2013	OFFICE	NEWCASTLE

CDT-DWG-A3H-001/1

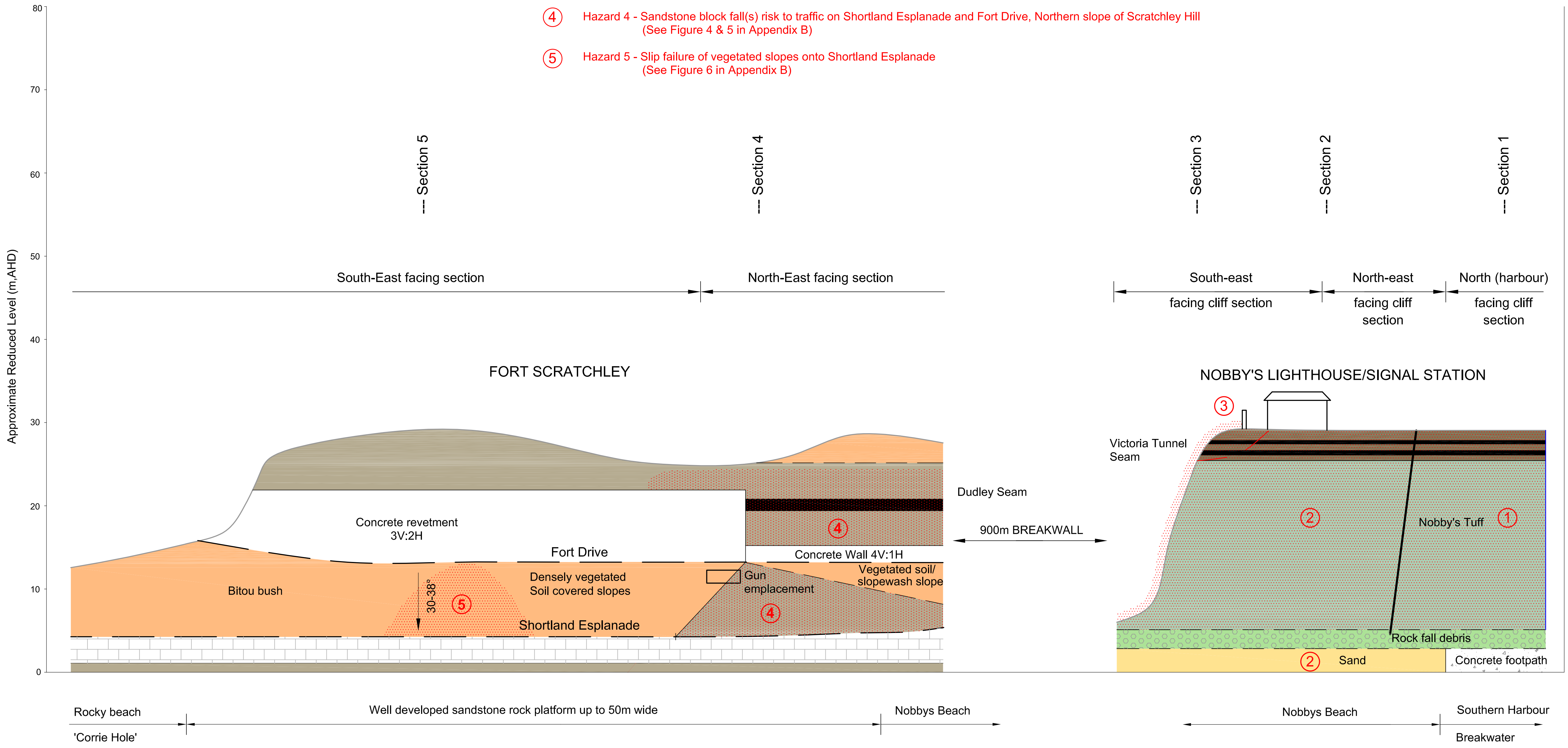
(1) Hazard 1 - Rock fall from north face of Nobby's Headland onto breakwater shared pathway
(See Figure 1 in Appendix B)

(2) Hazard 2 - Rock fall from Nobby's Headland cliff face onto public beach below
(See Figure 2 in Appendix B)

(3) Hazard 3 - Existing development within 3-5m of cliff affected by cliff instability/regression
(See Figure 3 in Appendix B)

(4) Hazard 4 - Sandstone block fall(s) risk to traffic on Shortland Esplanade and Fort Drive, Northern slope of Scratchley Hill
(See Figure 4 & 5 in Appendix B)

(5) Hazard 5 - Slip failure of vegetated slopes onto Shortland Esplanade
(See Figure 6 in Appendix B)



LEGEND

- Soil/slopewash
- Coal/Claystone
- Tuff
- Siltstone/Shale
- Sandstone/Conglomerate
- Seawall
- Rock debris
- Fill
- Sand
- Fault
- Dyke
- Cliff line regression dominated by weathering and erosion
- Cliff line/or coastline regression due to wave action

NOTE:
The cliff geological sections are interpretative sketches only.
No survey control has been undertaken

SCALE Vertical 1 : 500
Horizontal 1 : 2000

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GEOTECHNICAL • ENVIRONMENTAL

LONG - SECTION G1
NEWCASTLE COASTLINE
GEOTECHNICAL ASSESSMENT
NOBBYS HEADLAND AND FORT SCRATCHLEY

CLIENT	BMT WBM Pty Ltd			RCA Ref	8365-202/2
DRAWN BY	JE	SCALE	As Shown	DRAWING No	G1 REV 1
APPROVED BY	JE	DATE	18/12/2013	OFFICE	NEWCASTLE

CDT-DWG-A3H-001/1

6 Hazard 6 - Block wall failure onto footpath, Newcastle Beach
(See Figure 7 in Appendix B)

7 Hazard 7 - Rock fall from cliff onto slope adjacent to Shortland Esplanade, South Newcastle Skate Park
(See Figure 8 in Appendix B)

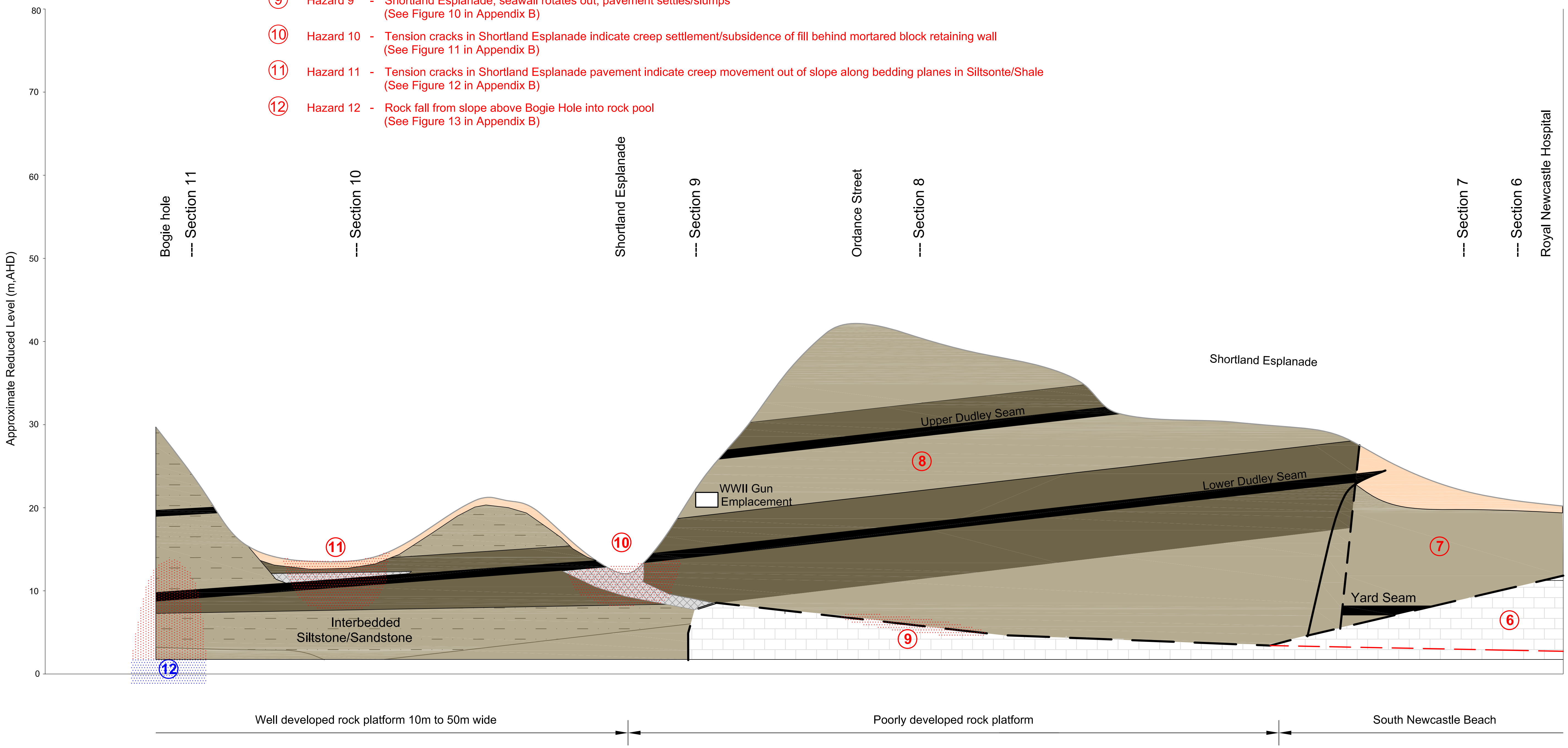
8 Hazard 8 - Rock fall from cliff adjacent to Shortland Esplanade, South Newcastle Beach
(See Figure 9 in Appendix B)

9 Hazard 9 - Shortland Esplanade, seawall rotates out, pavement settles/slumps
(See Figure 10 in Appendix B)

10 Hazard 10 - Tension cracks in Shortland Esplanade indicate creep settlement/subsidence of fill behind mortared block retaining wall
(See Figure 11 in Appendix B)

11 Hazard 11 - Tension cracks in Shortland Esplanade pavement indicate creep movement out of slope along bedding planes in Siltsonte/Shale
(See Figure 12 in Appendix B)

12 Hazard 12 - Rock fall from slope above Bogie Hole into rock pool
(See Figure 13 in Appendix B)



LEGEND

- Soil
- Coal/Claystone
- Tuff
- Siltstone/Shale
- Sandstone/Conglomerate
- Seawall
- Rock debris
- Fill
- Sand
- Fault
- Dyke
- Cliff line regression dominated weathering and erosion
- Cliff line/or coastline regression due to wave action

NOTE:
The cliff geological sections are interpretative sketches only.
No survey control has been undertaken

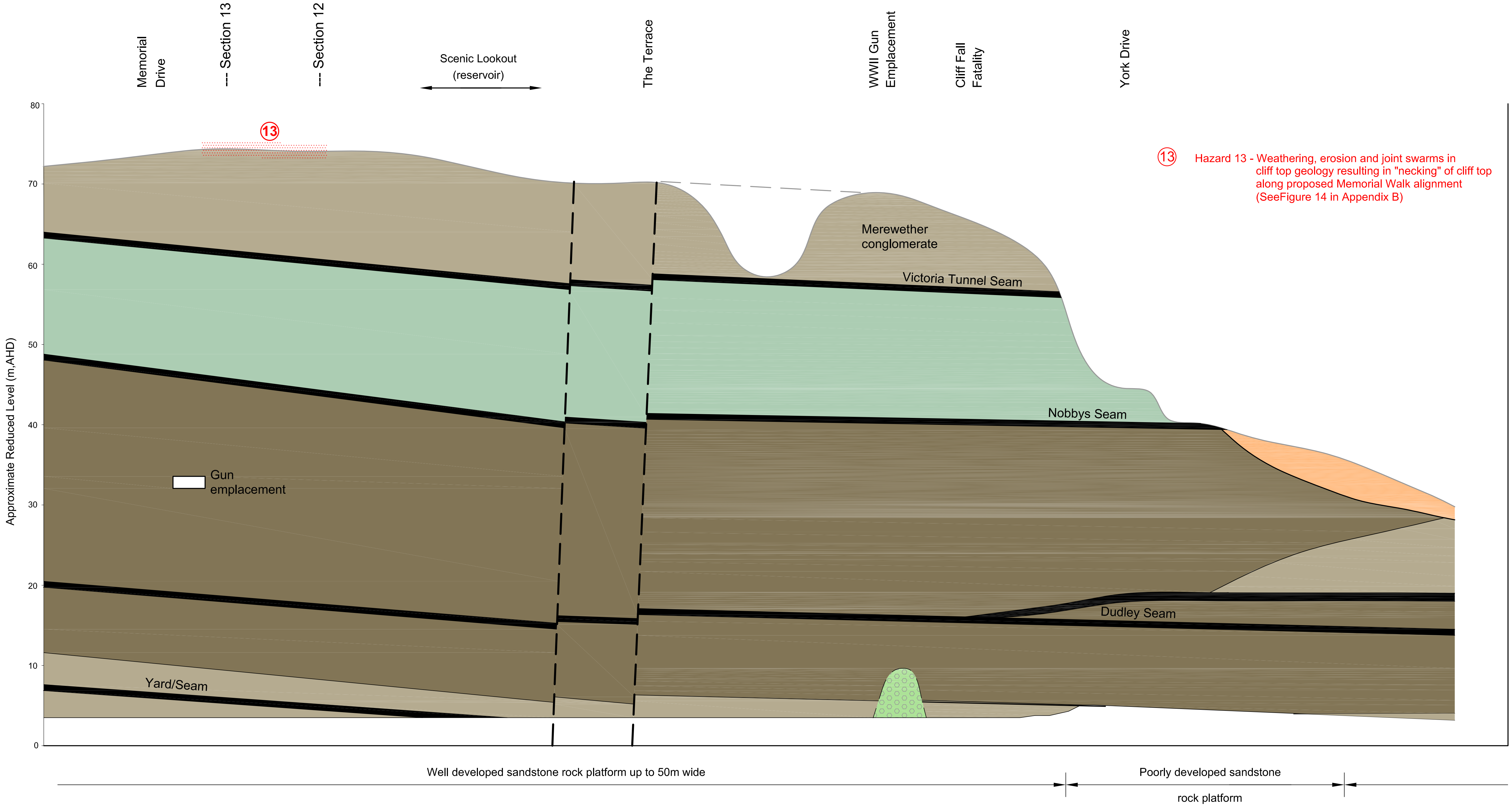
SCALE Vertical 1 : 500
Horizontal 1 : 2000

RCA AUSTRALIA
GEOTECHNICAL • ENVIRONMENTAL

LONG - SECTION G2
NEWCASTLE COASTLINE
GEOTECHNICAL ASSESSMENT
SOUTH NEWCATLE BEACH TO BOGIE HOLE

CLIENT	BMYWBM Pty Ltd			RCA Ref	8365-202/2
DRAWN BY	JE	SCALE	As Shown	DRAWING No	G2 REV 1
APPROVED BY	JE	DATE	18/12/2013	OFFICE	NEWCASTLE

CDT-DWG-A3H-001/1



LEGEND

- Soil
- Coal/Claystone
- Tuff
- Siltstone/Shale
- Sandstone/Conglomerate
- Seawall
- Rock debris
- Fill
- Sand
- Fault
- Dyke
- Cliff line regression dominated weathering and erosion
- Cliff line/or coastline regression due to wave action

NOTE:
The cliff geological sections are interpretative sketches only.
No survey control has been undertaken

SCALE Vertical 1 : 500
Horizontal 1 : 2000

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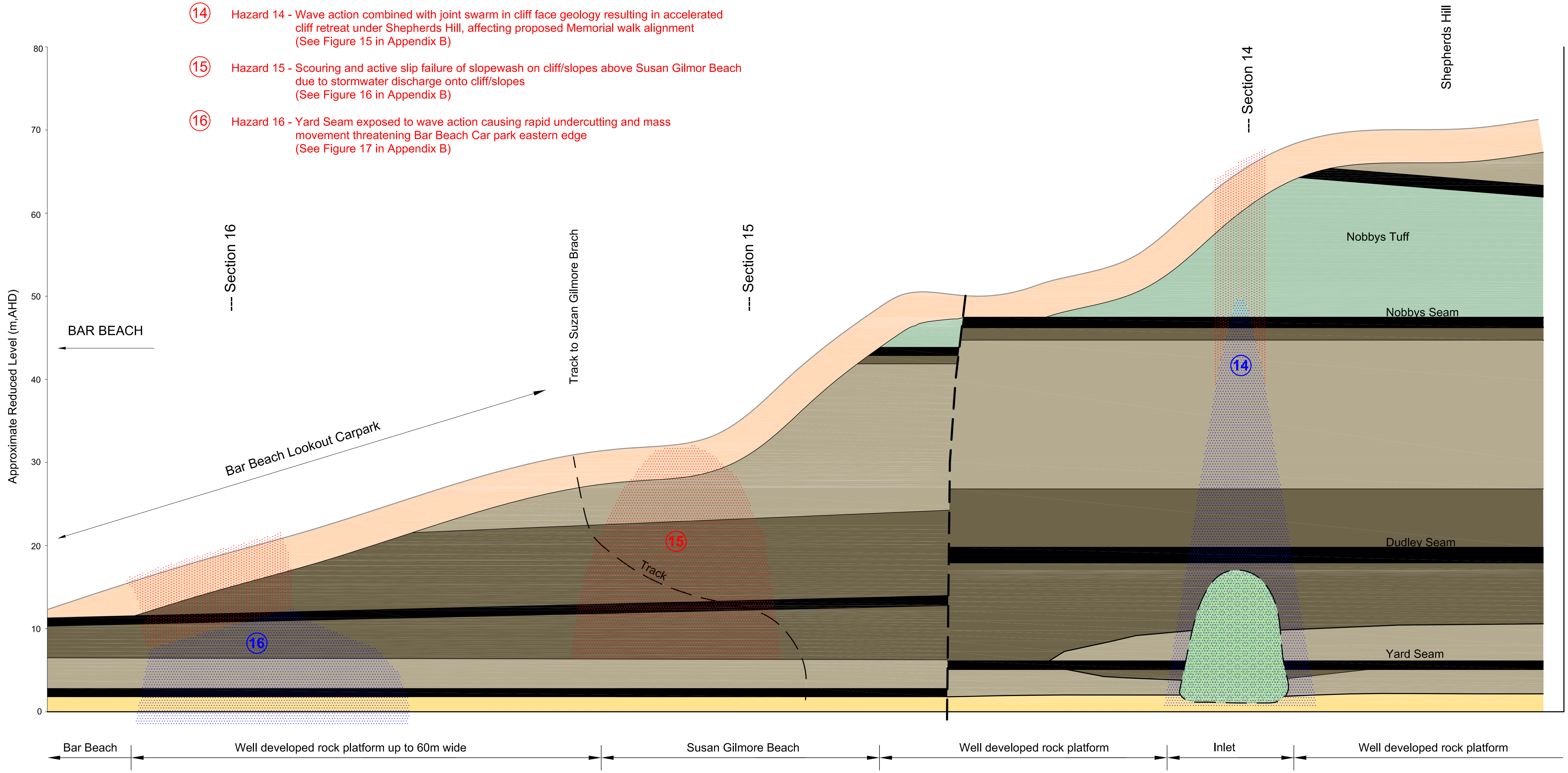
LONG - SECTION G3
NEWCASTLE COASTLINE
GEOTECHNICAL ASSESSMENT
BOGIE HOLE TO
MEMORIAL DRIVE SHEPERDS HILL

CLIENT	BMT WBM Pty Ltd			RCA Ref	8365-202/2
DRAWN BY	JE	SCALE	As Shown	DRAWING No	G3 REV 1
APPROVED BY	JE	DATE	18/12/2013	OFFICE	NEWCASTLE

CDT-DWG-A3H-001/1



LEGEND

- Soil
- Coal/Claystone
- Tuff
- Siltstone/Shale
- Sandstone/Conglomerate
- Seawall
- Rock debris
- Fill
- Sand
- Fault
- Dyke
- Cliff line regression dominated weathering and erosion
- Cliff line/or coastline regression due to wave action

NOTE:
The cliff geological sections are interpretative sketches only.
No survey control has been undertaken

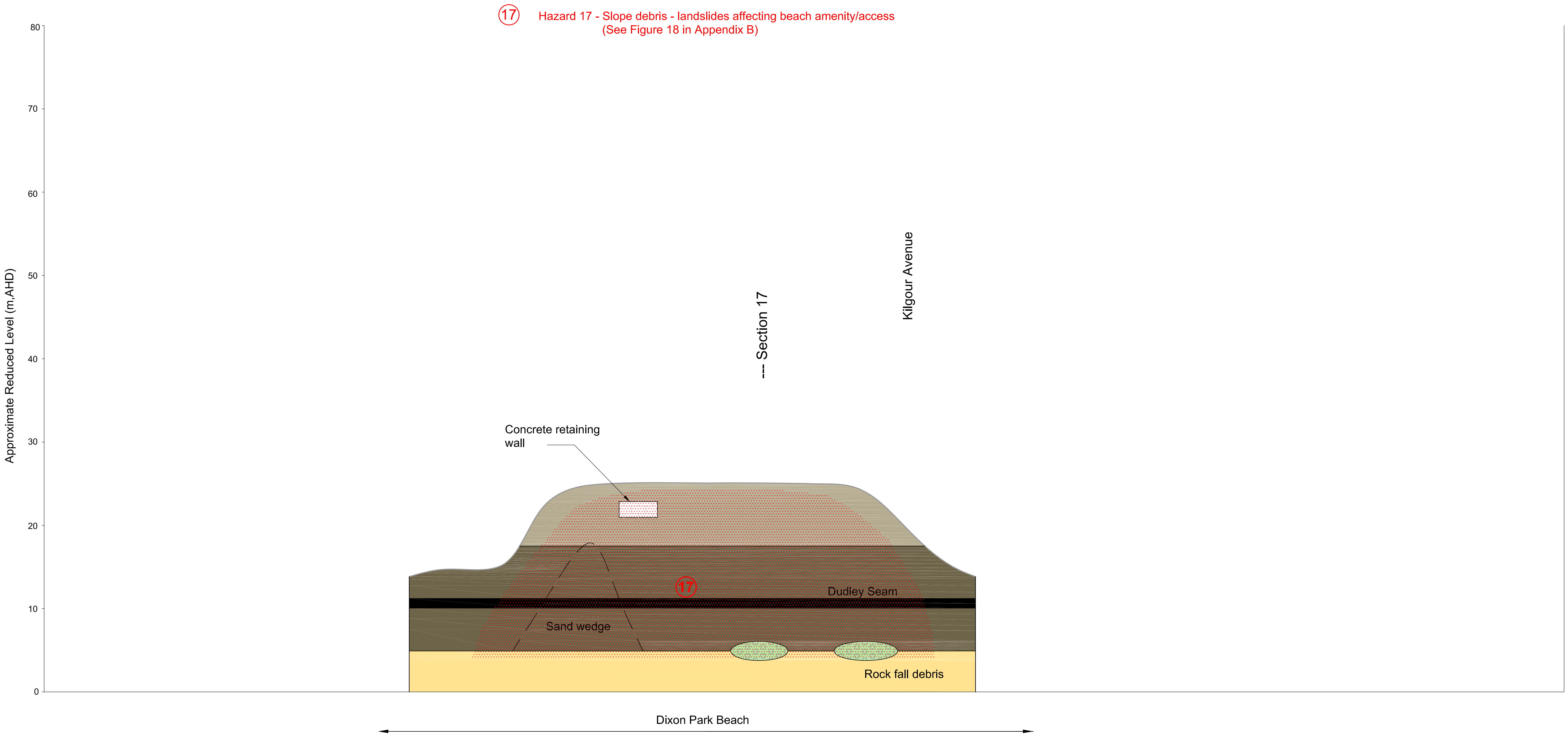
SCALE
Vertical 1 : 500
Horizontal 1 : 2000

RCA AUSTRALIA
GEOTECHNICAL • ENVIRONMENTAL

LONG - SECTIN G4
NEWCASTLE COASTLINE
GEOTECHNICAL ASSESSMENT
MEMORIAL DRIVE SHEPHERDS HILL
TO BAR BEACH

CLIENT	BMT WBM Pty Ltd			RCA Ref	8365-202/2
DRAWN BY	JE	SCALE	As Shown	DRAWING No	G4 REV 1
APPROVED BY	JE	DATE	18/12/2013	OFFICE	NEWCASTLE

CDT-DWG-A3H-001/1



LEGEND

Soil	Fill
Coal/Claystone	Sand
Tuff	Fault
Siltstone/Shale	Dyke
Sandstone/Conglomerate	Cliff line regression dominated weathering and erosion
Seawall	Cliff line/or coastline regression due to wave action
Rock debris	

NOTE:
The cliff geological sections are interpretative sketches only.
No survey control has been undertaken

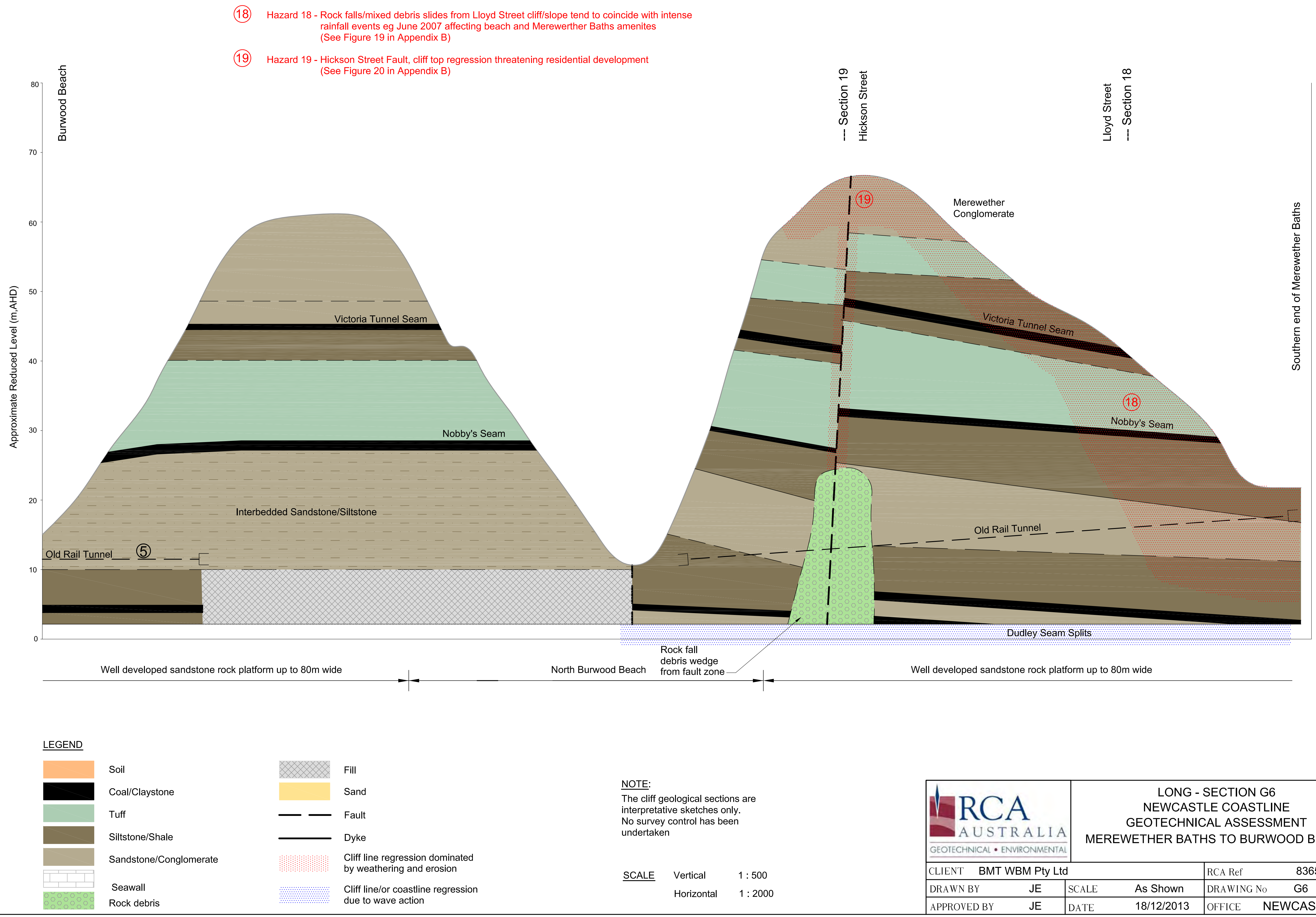
SCALE Vertical 1 : 500
Horizontal 1 : 2000

RCA AUSTRALIA
GEOTECHNICAL • ENVIRONMENTAL

LONG - SECTION G5
NEWCASTLE COASTLINE
GEOTECHNICAL ASSESSMENT
DIXON PARK (KILGOUR AVENUE)

CLIENT	BMT WBM Pty Ltd			RCA Ref	8365-202/2
DRAWN BY	JE	SCALE	As Shown	DRAWING No	G5 REV 1
APPROVED BY	JE	DATE	18/12/2013	OFFICE	NEWCASTLE

CDT-DWG-A3H-001/1



NOTE:
The cliff geological sections are interpretative sketches only.
No survey control has been undertaken

SCALE Vertical 1 : 500
Horizontal 1 : 2000

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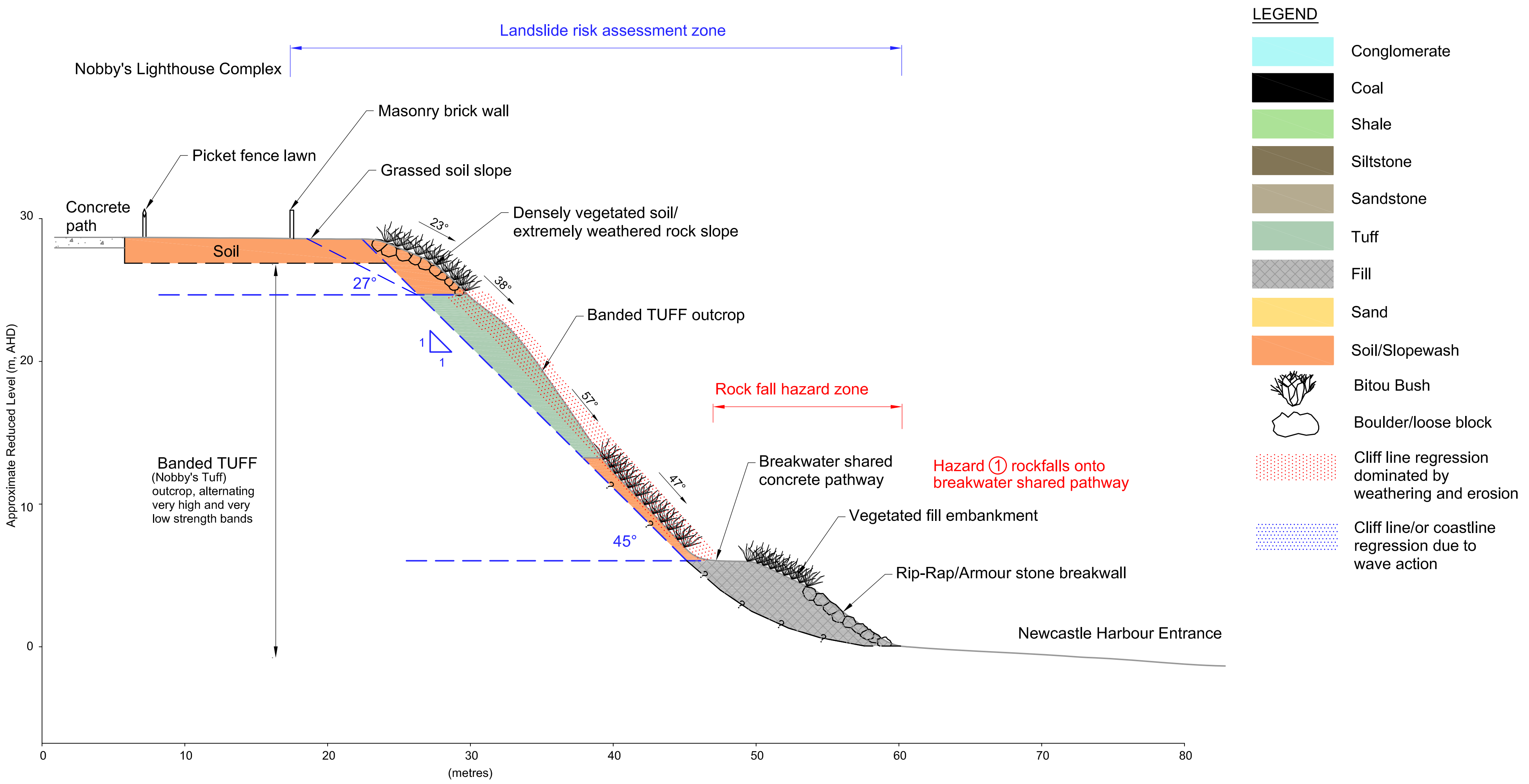
GEOTECHNICAL • ENVIRONMENTAL

LONG - SECTION G6
NEWCASTLE COASTLINE
GEOTECHNICAL ASSESSMENT
MEREWETHER BATHS TO BURWOOD BEACH

CLIENT	BMT WBM Pty Ltd			RCA Ref	8365-202/2
DRAWN BY	JE	SCALE	As Shown	DRAWING No	G6 REV 1
APPROVED BY	JE	DATE	18/12/2013	OFFICE	NEWCASTLE

CDT-DWG-A3H-001/1



NOTE:

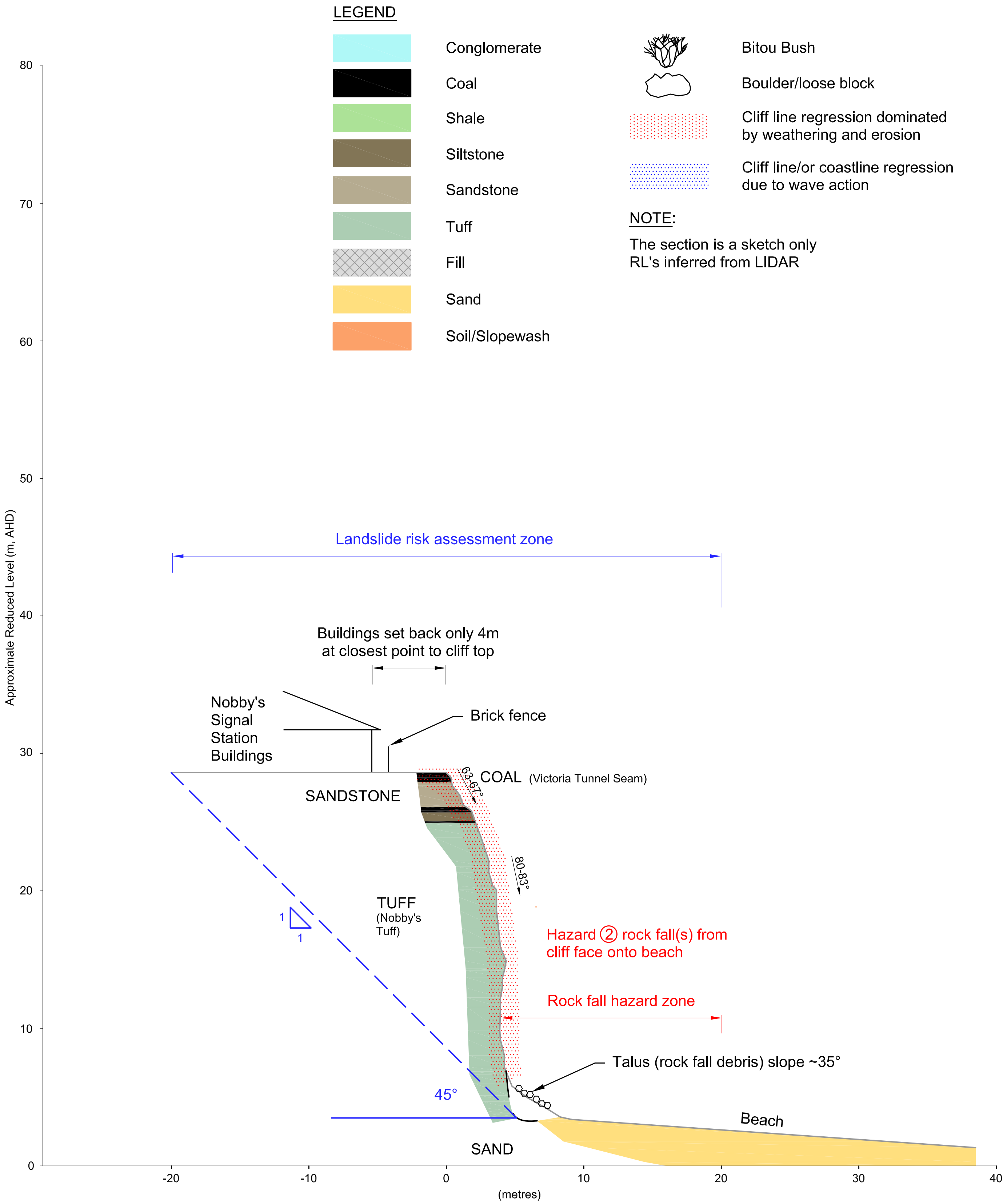
The section is a sketch only
RL's inferred from LIDAR

RCA AUSTRALIA
GEOTECHNICAL • ENVIRONMENTAL

CROSS - SECTION SKETCH S1
NEWCASTLE COASTLINE
GEOTECHNICAL ASSESSMENT
NORTH SIDE NOBBY'S HEAD

CLIENT	BMT WBM Pty Ltd			RCA Ref	8365-202/2
DRAWN BY	JE	SCALE	1:400 H=V	DRAWING No	S1 REV 1
APPROVED BY	SC	DATE	18/12/2013	OFFICE	NEWCASTLE

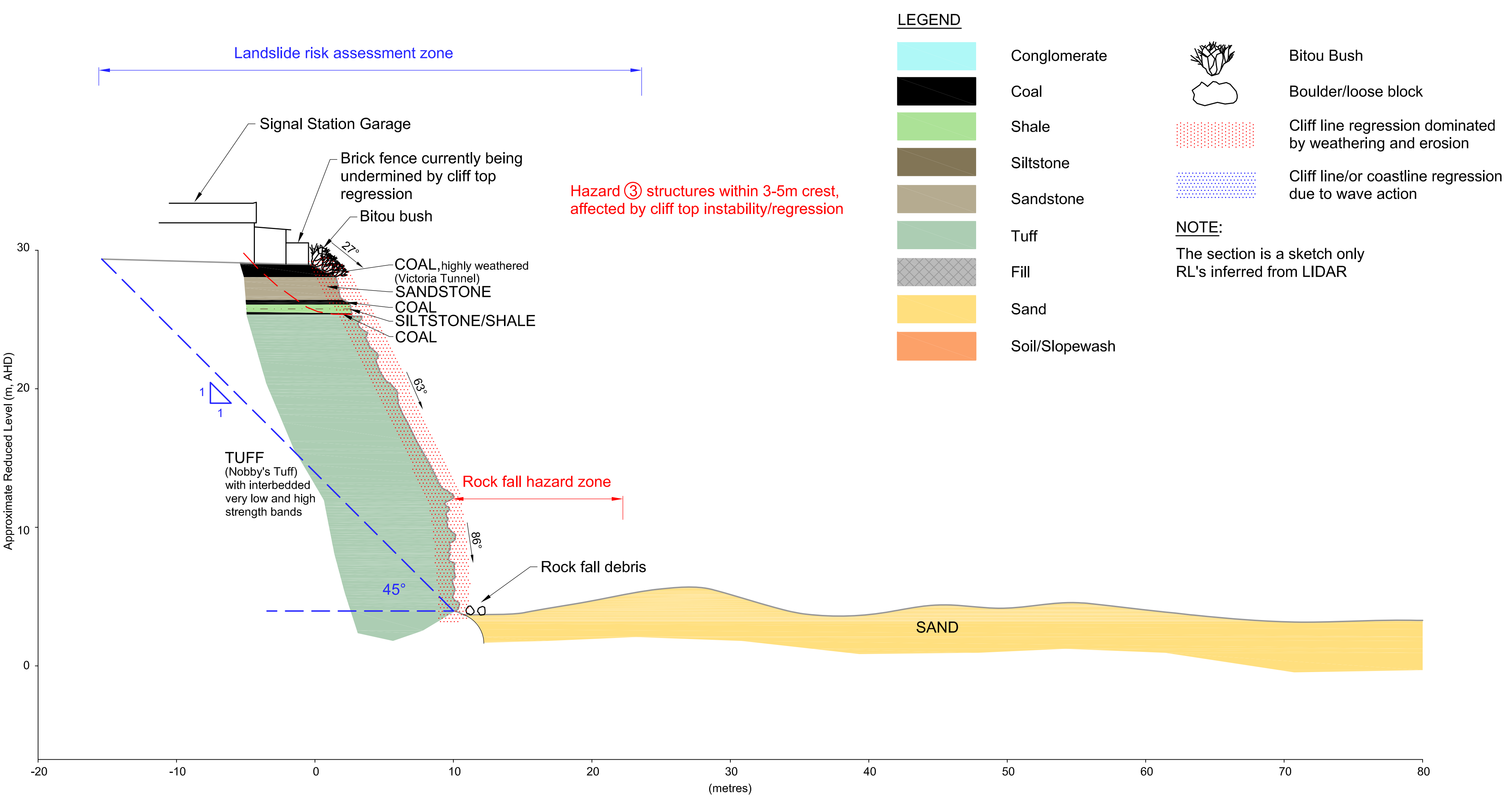
CDT-DWG-A4H-001/1



CROSS - SECTION SKETCH S2
NEWCASTLE COASTLINE GEOTECHNICAL ASSESSMENT
EAST FACE OF NOBBY'S HEAD

CLIENT	BMT WBM Pty Ltd				
DRAWN BY	AG	SCALE	1:400 H=V	RCA Ref	8365-202/2	OFFICE NEWCASTLE
APPROVED BY	JE	DATE	18/12/2013	DRAWING No	S2	Rev 1

CDT-DWG-A4V-001/1

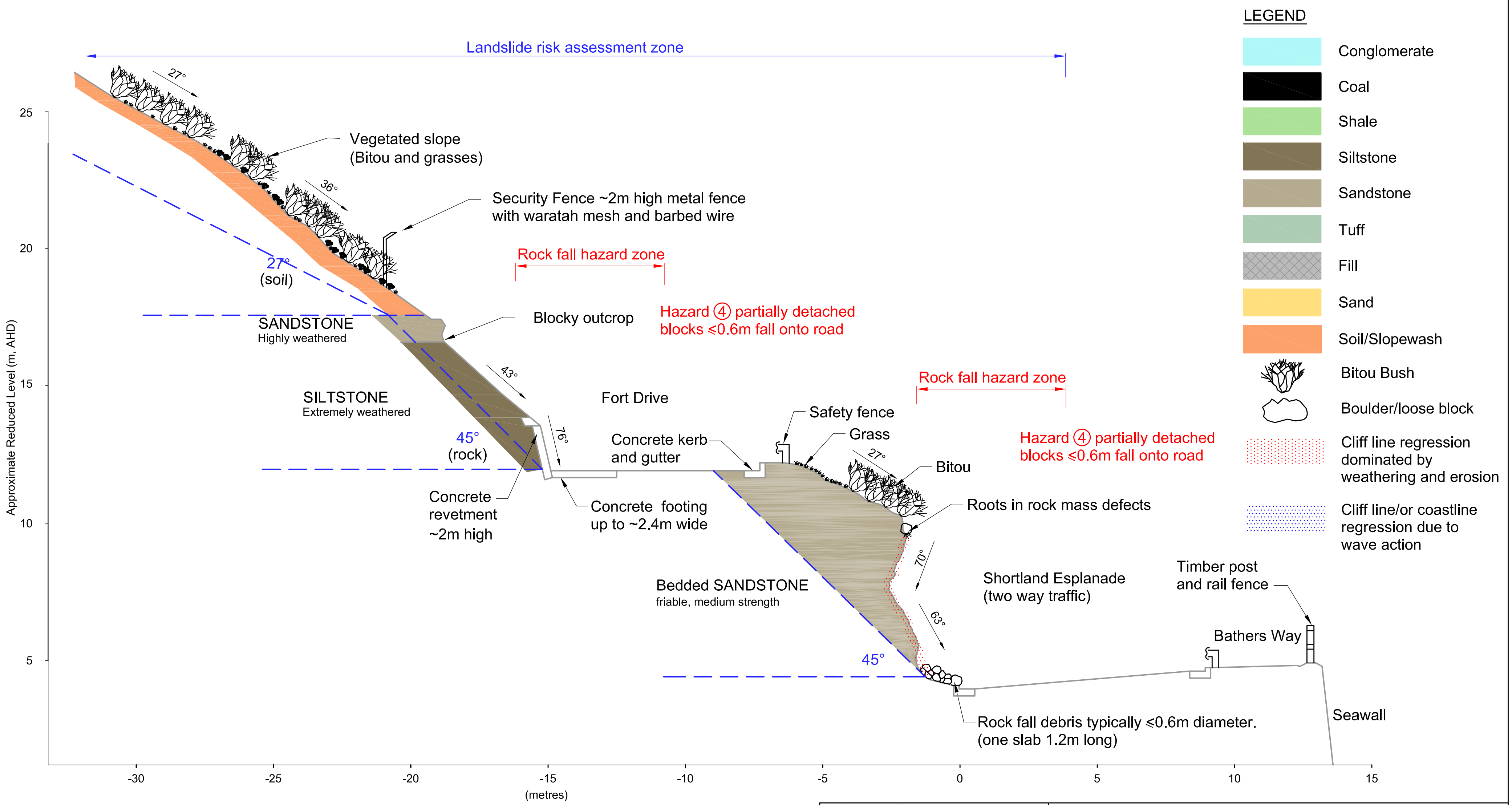


RCA AUSTRALIA
GEOTECHNICAL • ENVIRONMENTAL

CROSS - SECTION SKETCHS3
NEWCASTLE COASTLINE
GEOTECHNICAL ASSESSMENT
SOUTH SIDE NOBBY'S HEAD

CLIENT	BMT WBM Pty Ltd			RCA Ref	8365-202/2
DRAWN BY	JE	SCALE	1:400 H=V	DRAWING No	S3 REV 1
APPROVED BY	SC	DATE	18/12/2013	OFFICE	NEWCASTLE

CDT-DWG-A4H-001/1



NOTE:

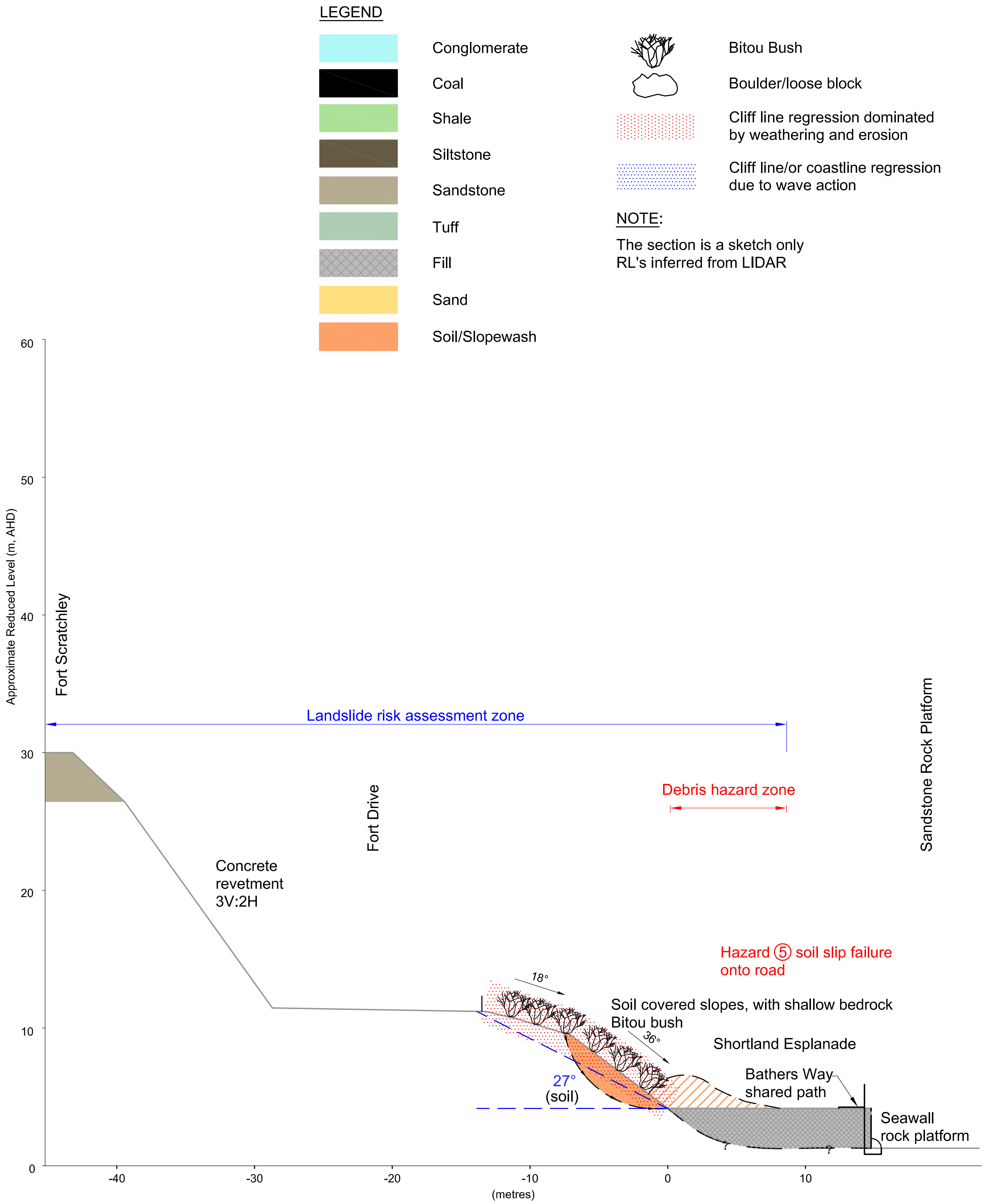
The section is a sketch only
RL's inferred from LIDAR

RCA AUSTRALIA
GEOTECHNICAL • ENVIRONMENTAL

CROSS-SECTION SKETCH S4
NEWCASTLE COASTLINE
GEOTECHNICAL ASSESSMENT
FORT DRIVE AND SHORTLAND ESPLANADE
FORT SCRATCHLEY HILL, NEWCASTLE

CLIENT	BMT WBM Pty Ltd			RCA Ref	8365-202/2
DRAWN BY	JE	SCALE	1:200 H=V	DRAWING No	S4 REV 1
APPROVED BY	SC	DATE	18/12/2013	OFFICE	NEWCASTLE

CDT-DWG-A4H-001/1



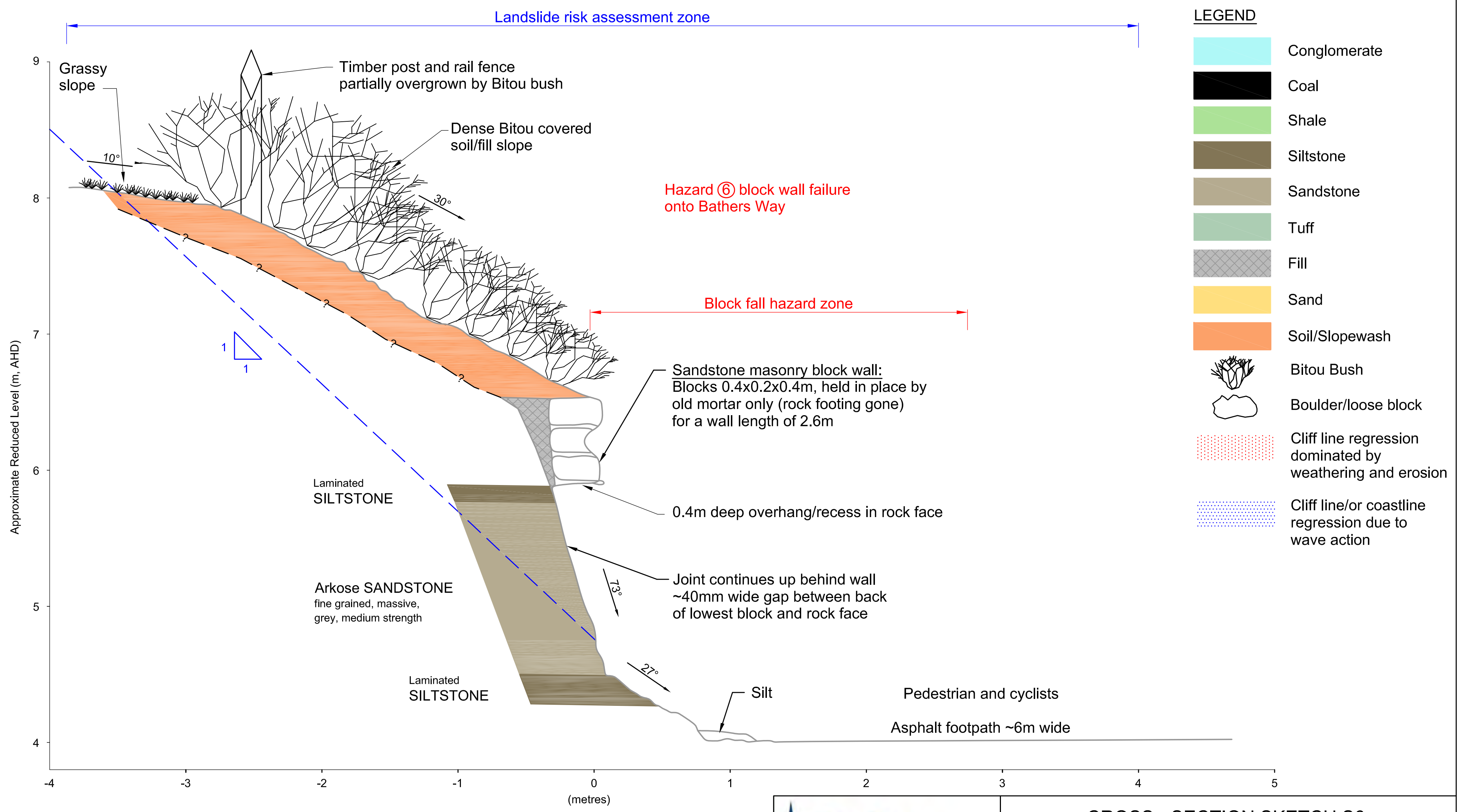
CROSS - SECTION SKETCH S5
NEWCASTLE COASTLINE GEOTECHNICAL ASSESSMENT
FORT SCRATCHLEY

RCA AUSTRALIA
GEOTECHNICAL • ENVIRONMENTAL

CLIENT	BMT WBM Pty Ltd				
DRAWN BY	AG	SCALE	1:400 H=V	RCA Ref	8365-202/2
APPROVED BY	JE	DATE	18/12/2013	DRAWING No	S5 Rev 1

OFFICE NEWCASTLE

CDT-DWG-A4V-001/1



NOTE:

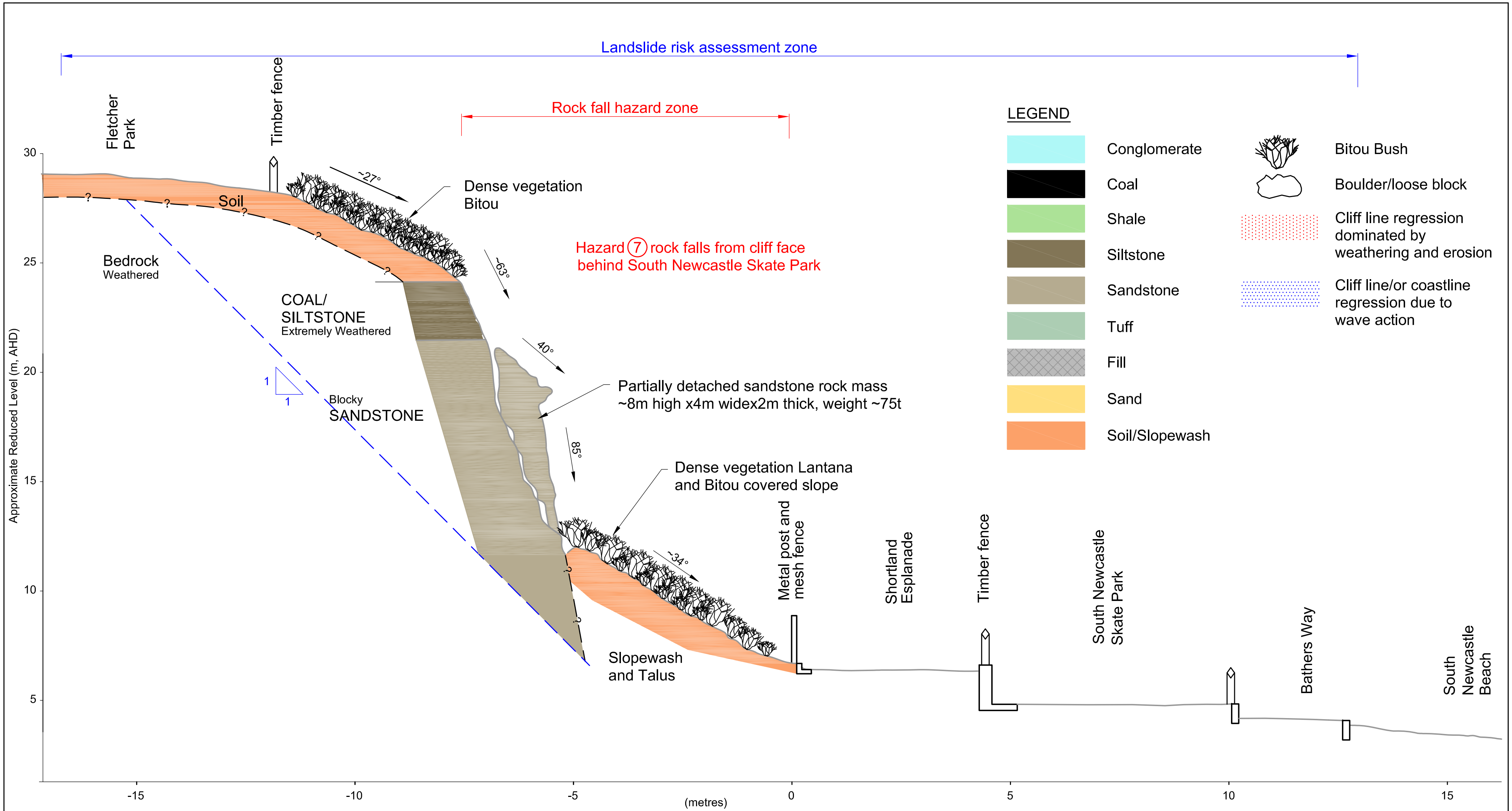
The section is a sketch only
RL's inferred from LIDAR

RCA AUSTRALIA
GEOTECHNICAL • ENVIRONMENTAL

CROSS - SECTION SKETCH S6
NEWCASTLE COASTAL
GEOTECHNICAL ASSESSMENT
BATHERS WAY FOOTPATH
NEWCASTLE BEACH

CLIENT	BMT WBM Pty Ltd			RCA Ref	8365-202/2
DRAWN BY	JE	SCALE	1:40 H=V	DRAWING No	S6 REV 0
APPROVED BY	SC	DATE	18/12/2013	OFFICE	NEWCASTLE

CDT-DWG-A4H-001/1



NOTE:

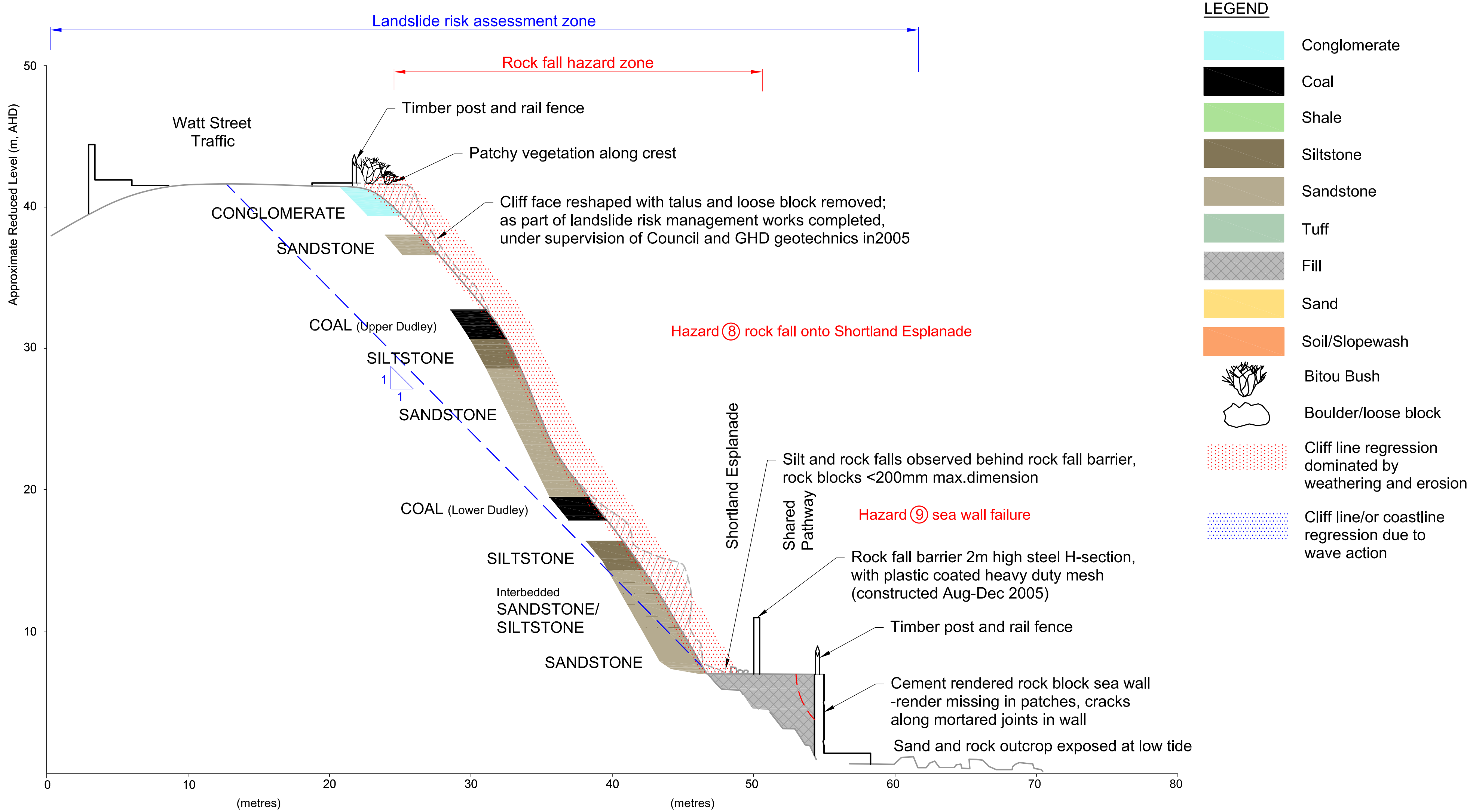
The section is a sketch only
RL's inferred from LIDAR

RCA AUSTRALIA
GEOTECHNICAL • ENVIRONMENTAL

CROSS - SECTION SKETCH S7
NEWCASTLE COASTAL
GEOTECHNICAL ASSESSMENT
SHORTLAND ESPLANADE
SOUTH NEWCASTLE BEACH

CLIENT	BMT WBM Pty Ltd			RCA Ref	8365-202/2
DRAWN BY	JE	SCALE	1:250 H=V	DRAWING No	S7 REV 0
APPROVED BY	SC	DATE	18/12/2013	OFFICE	NEWCASTLE

CDT-DWG-A4H-001/1



NOTE:

The section is a sketch only
RL's inferred from LIDAR

RCA AUSTRALIA
GEOTECHNICAL • ENVIRONMENTAL

CROSS - SECTION SKETCH S8
NEWCASTLE COASTAL
GEOTECHNICAL ASSESSMENT
SHORTLAND ESPLANADE
SOUTH NEWCASTLE

CLIENT	BMT WBM Pty Ltd			RCA Ref	8365-202/2
DRAWN BY	JE	SCALE	1:250 H=V	DRAWING No	S8 REV 1
APPROVED BY	SC	DATE	18/12/2013	OFFICE	NEWCASTLE

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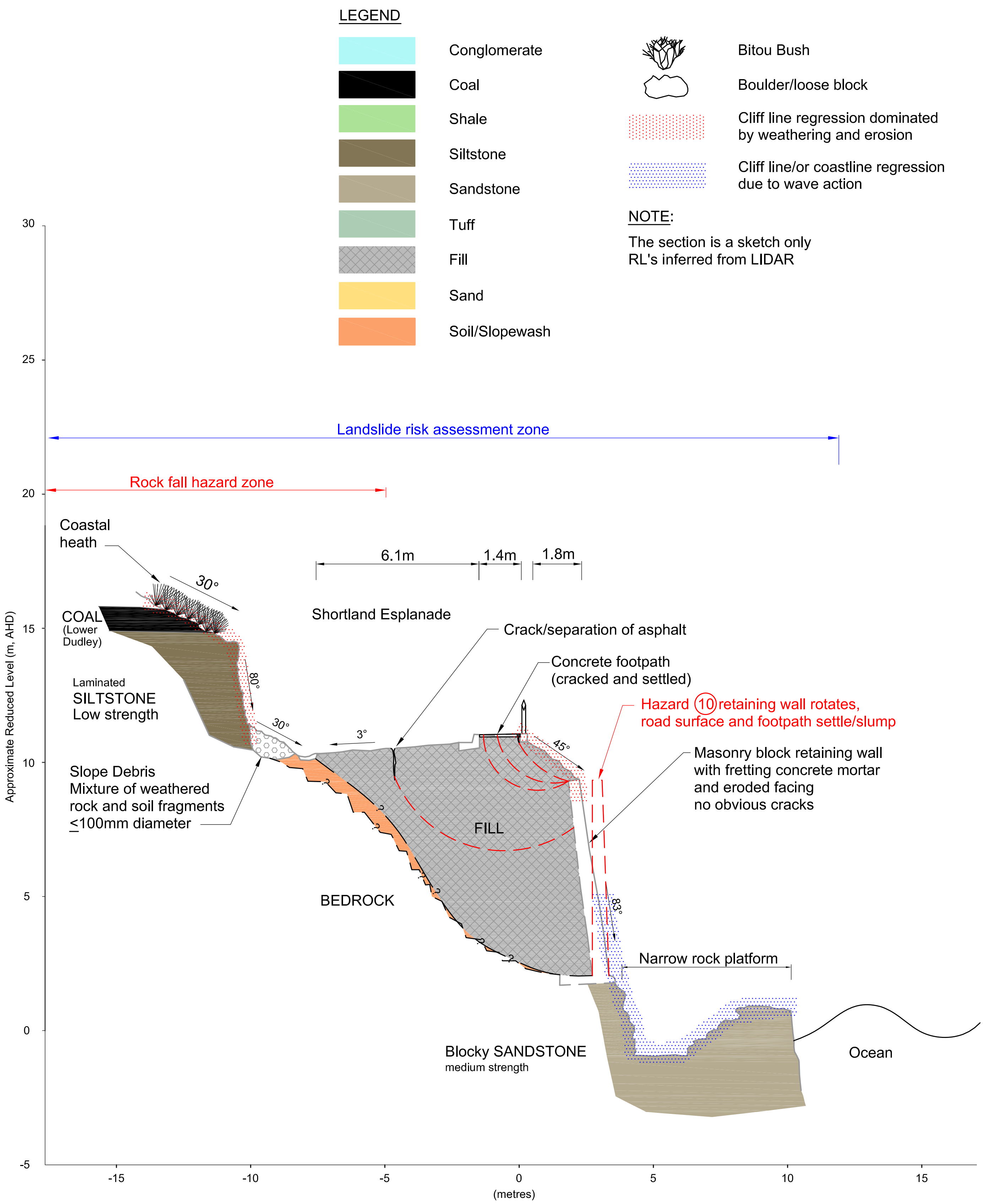

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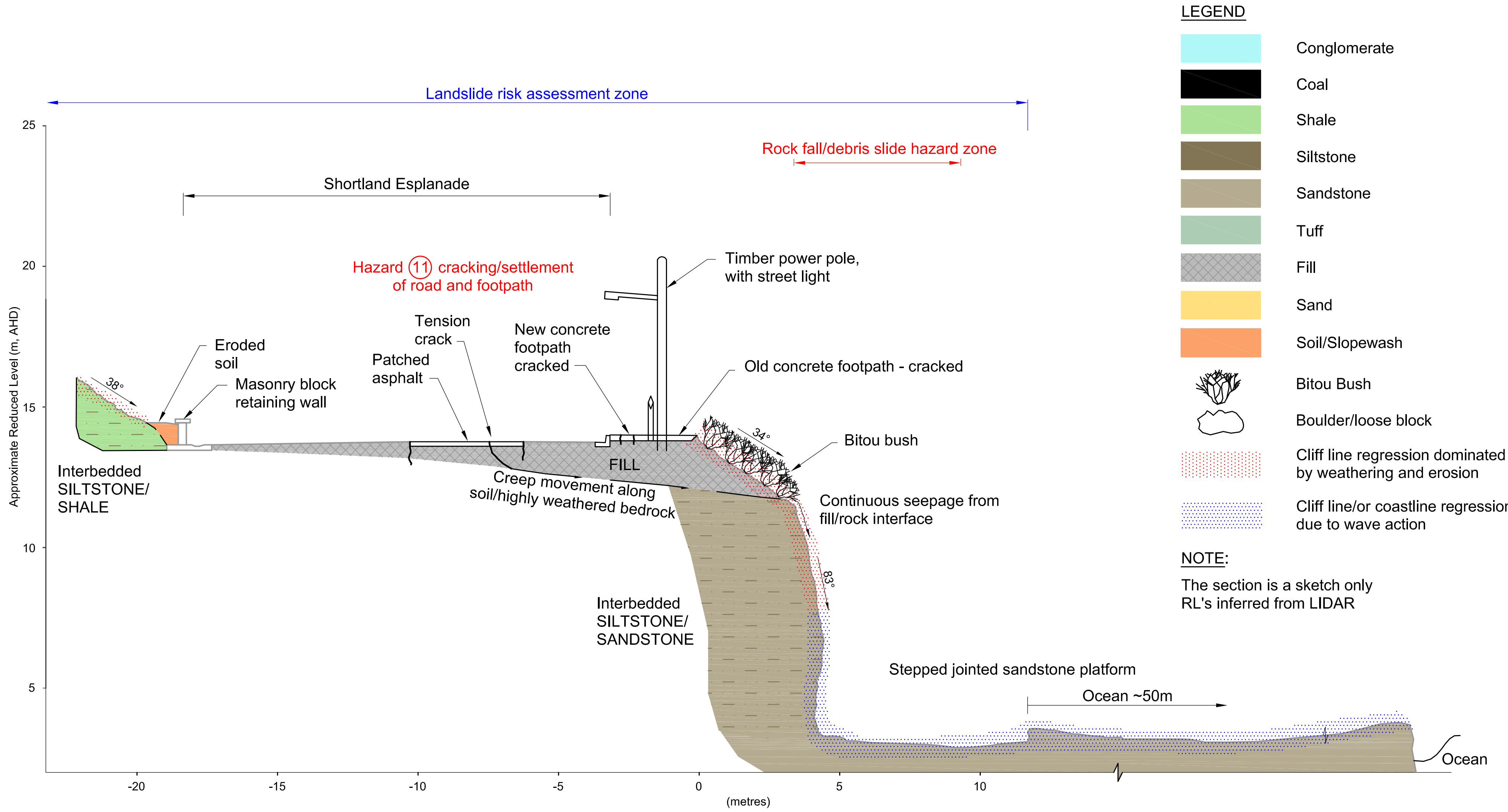
GEOTECHNICAL • ENVIRONMENTAL

CROSS - SECTION SKETCH S9
NEWCASTLE COASTLINE GEOTECHNICAL ASSESSMENT
SOUTH NEWCASTLE - KING EDWARD PARK

CLIENT	BMT WBM Pty Ltd					
DRAWN BY	JE	SCALE	1:200 H=V	RCA Ref	8365-202/2	OFFICE
APPROVED BY	SC	DATE	18/12/2013	DRAWING No	S9 Rev 1	NEWCASTLE

CDT-DWG-A4V-001/1



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CROSS - SECTION SKETCH S10
NEWCASTLE COASTLINE
GEOTECHNICAL ASSESSMENT
KING EDWARD PARK

CLIENT	BMT WBM Pty Ltd			RCA Ref	8365-202/2
DRAWN BY	JE	SCALE	1:200 H=V	DRAWING No	S10 REV 1
APPROVED BY	SC	DATE	18/12/2013	OFFICE	NEWCASTLE

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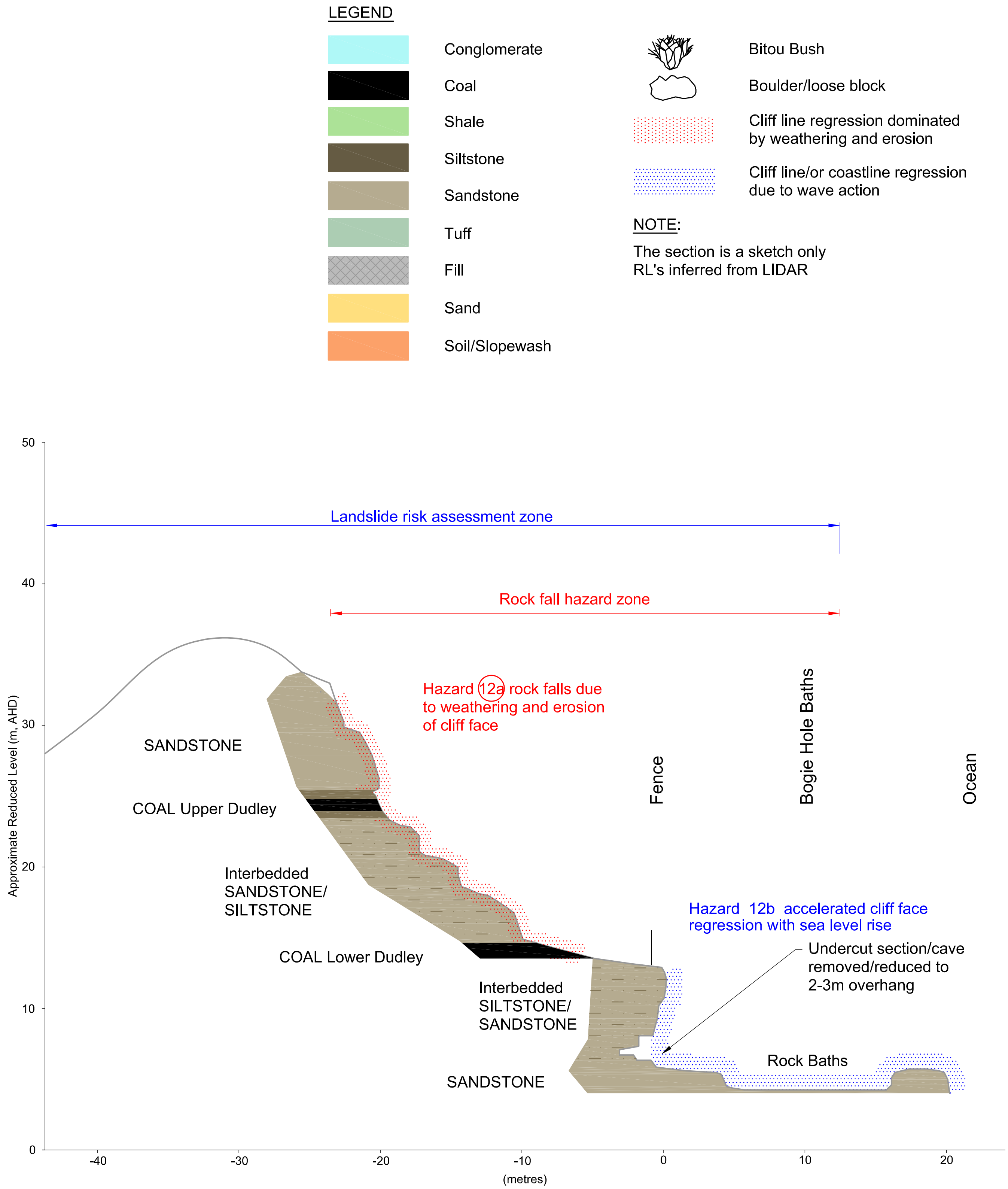

CROSS - SECTION SKETCH S11
NEWCASTLE COASTLINE GEOTECHNICAL ASSESSMENT
BOGIE HOLE

CLIENT	BMT WBM Pty Ltd				
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APPROVED BY	JE	DATE	18/12/2013	DRAWING No	S11 Rev 1	NEWCASTLE

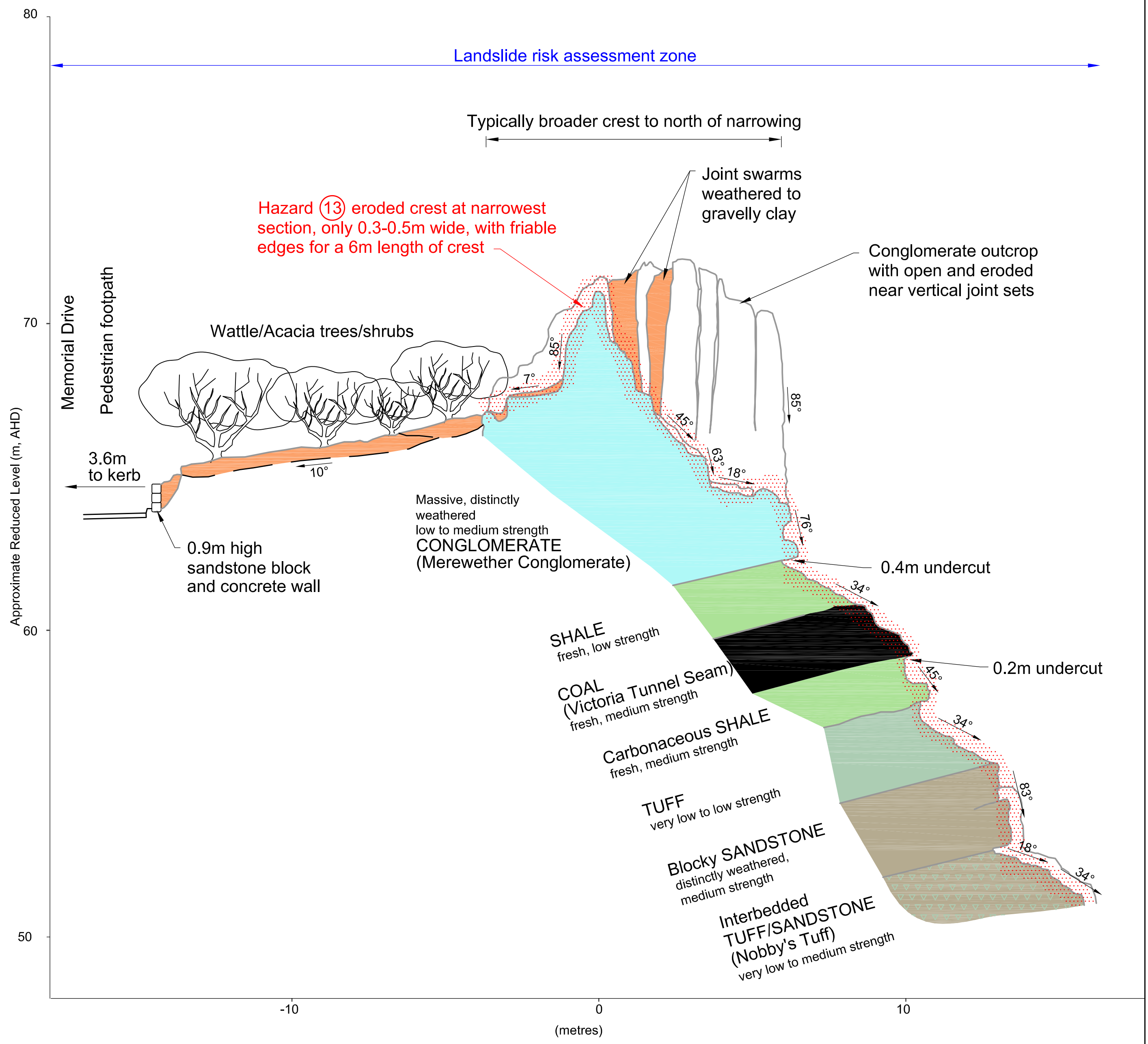
CDT-DWG-A4V-001/1

LEGEND

Conglomerate	Bitou Bush
Coal	Boulder/loose block
Shale	Cliff line regression dominated by weathering and erosion
Siltstone	Cliff line/or coastline regression due to wave action
Sandstone	
Tuff	
Fill	
Sand	
Soil/Slopewash	

NOTE:

The section is a sketch only
RL's inferred from LIDAR
Dip of strata measured using geological compass, typically 10-285°/310-355°



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CROSS - SECTION SKETCH S12
NEWCASTLE COASTLINE GEOTECHNICAL ASSESSMENT
MEMORIAL WALK ALIGNMENT
SHEPHERDS HILL - NORTH

CLIENT	BMT WBM Pty Ltd				
DRAWN BY	JE	SCALE	1:200 H=V	RCA Ref	8365-202/2	OFFICE
APPROVED BY	JE	DATE	18/12/2013	DRAWING No	S12 Rev 1	NEWCASTLE

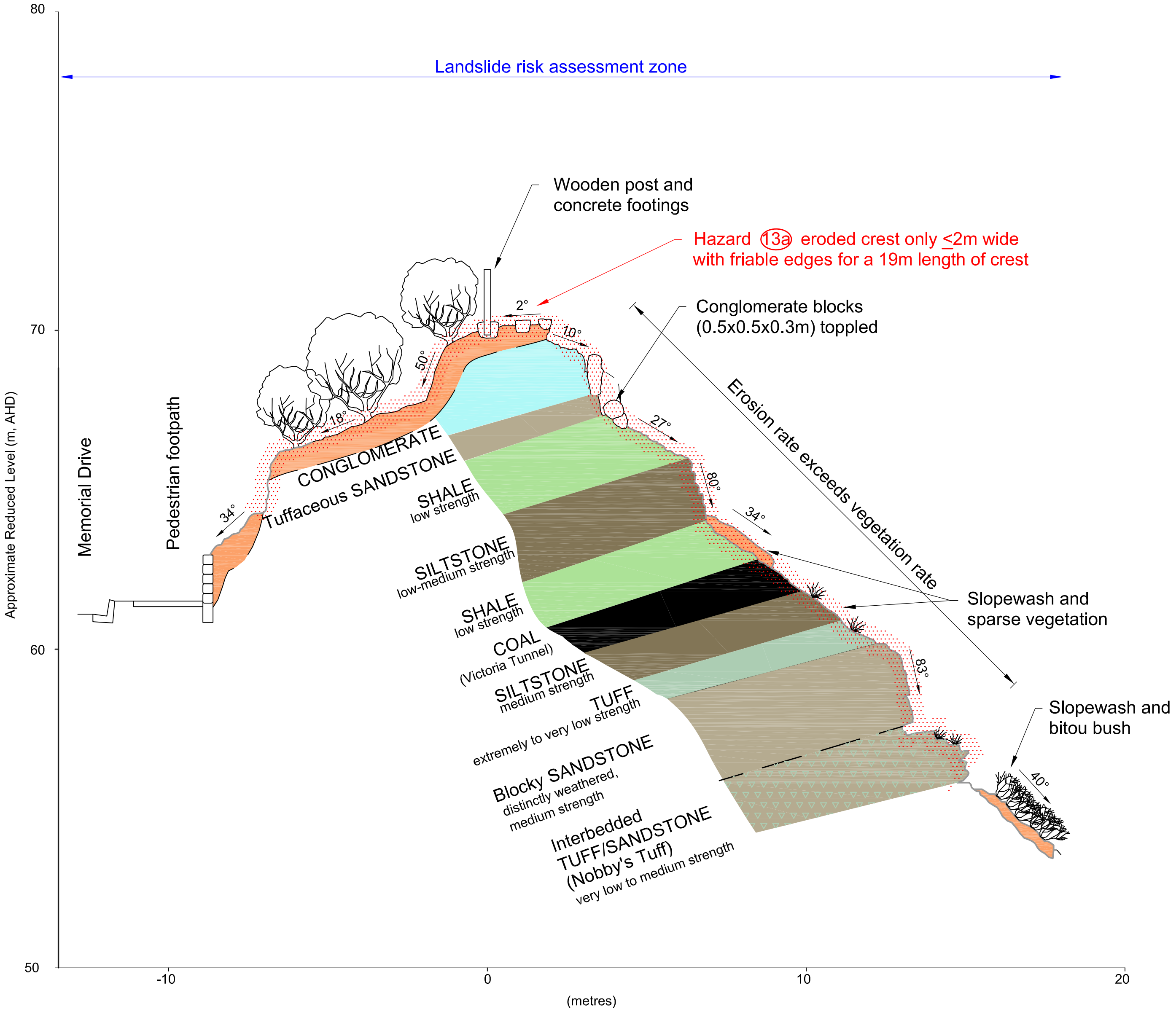
CDT-DWG-A4V-001/1

LEGEND

- Conglomerate
- Coal
- Shale
- Siltstone
- Sandstone
- Tuff
- Fill
- Sand
- Soil/Slopewash
- Bitou Bush
- Boulder/loose block
- Cliff line regression dominated by weathering and erosion
- Cliff line/or coastline regression due to wave action

NOTE:

The section is a sketch only
RL's inferred from LIDAR
Dip of strata measured using geological compass, typically 10-30°/320-335°



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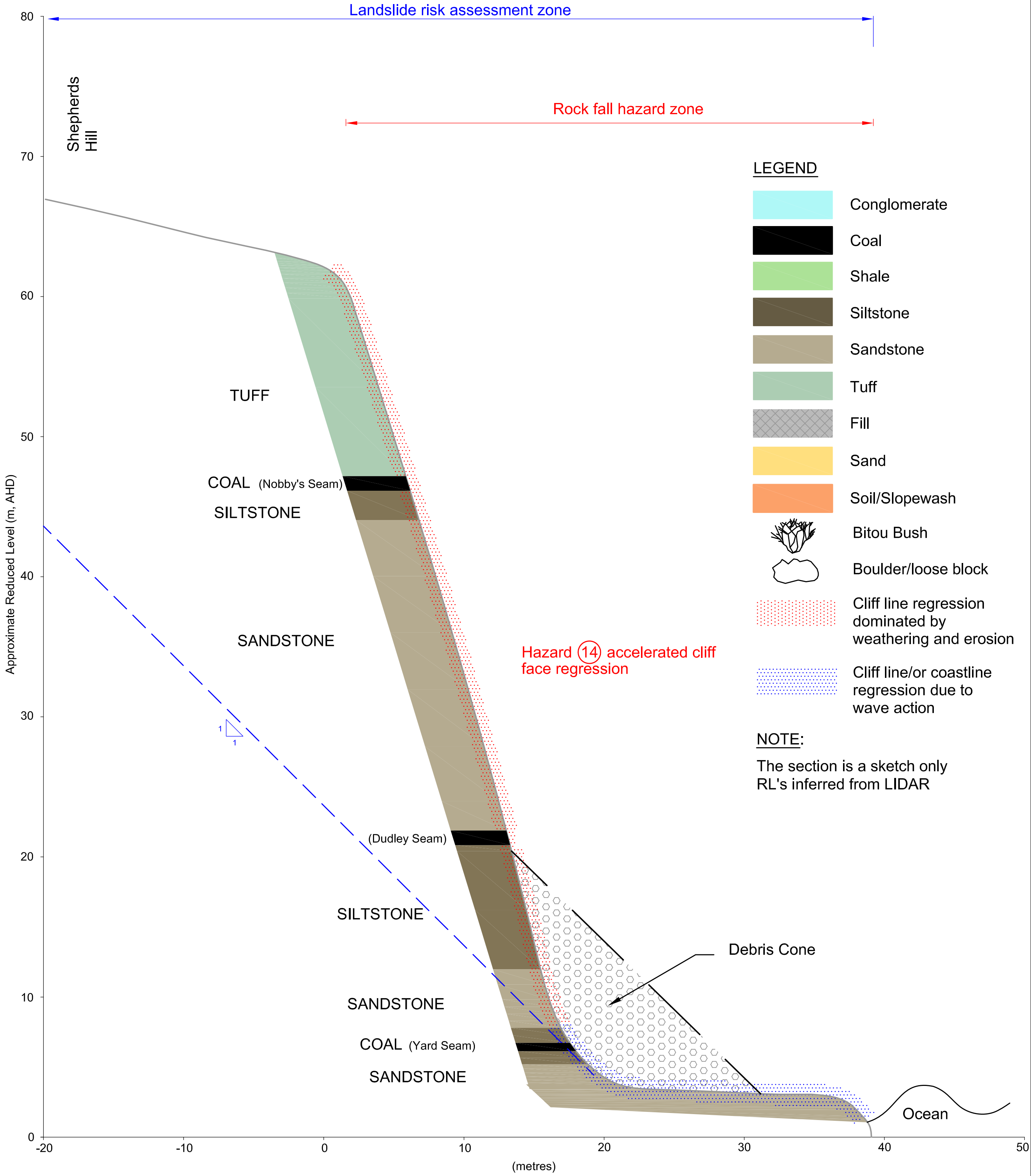
CROSS - SECTION SKETCH S13
NEWCASTLE COASTLINE GEOTECHNICAL ASSESSMENT
MEMORIAL WALK ALIGNMENT
SHEPHERDS HILL - CENTRAL

CLIENT	BMT WBM Pty Ltd					
DRAWN BY	JE	SCALE	1:200 H=V	RCA Ref	8365-202/2	OFFICE NEWCASTLE
APPROVED BY	JE	DATE	18/12/2013	DRAWING No	S13 Rev 1	

CDT-DWG-A4V-001/1



CDT-DWG-A4V-001/1

RCA AUSTRALIA GEOTECHNICAL • ENVIRONMENTAL

CROSS - SECTION SKETCH S14
NEWCASTLE COASTLINE GEOTECHNICAL ASSESSMENT
SHEPHERDS HILL - EAST
(TRIG STATION)

CLIENT	BMT WBM Pty Ltd				
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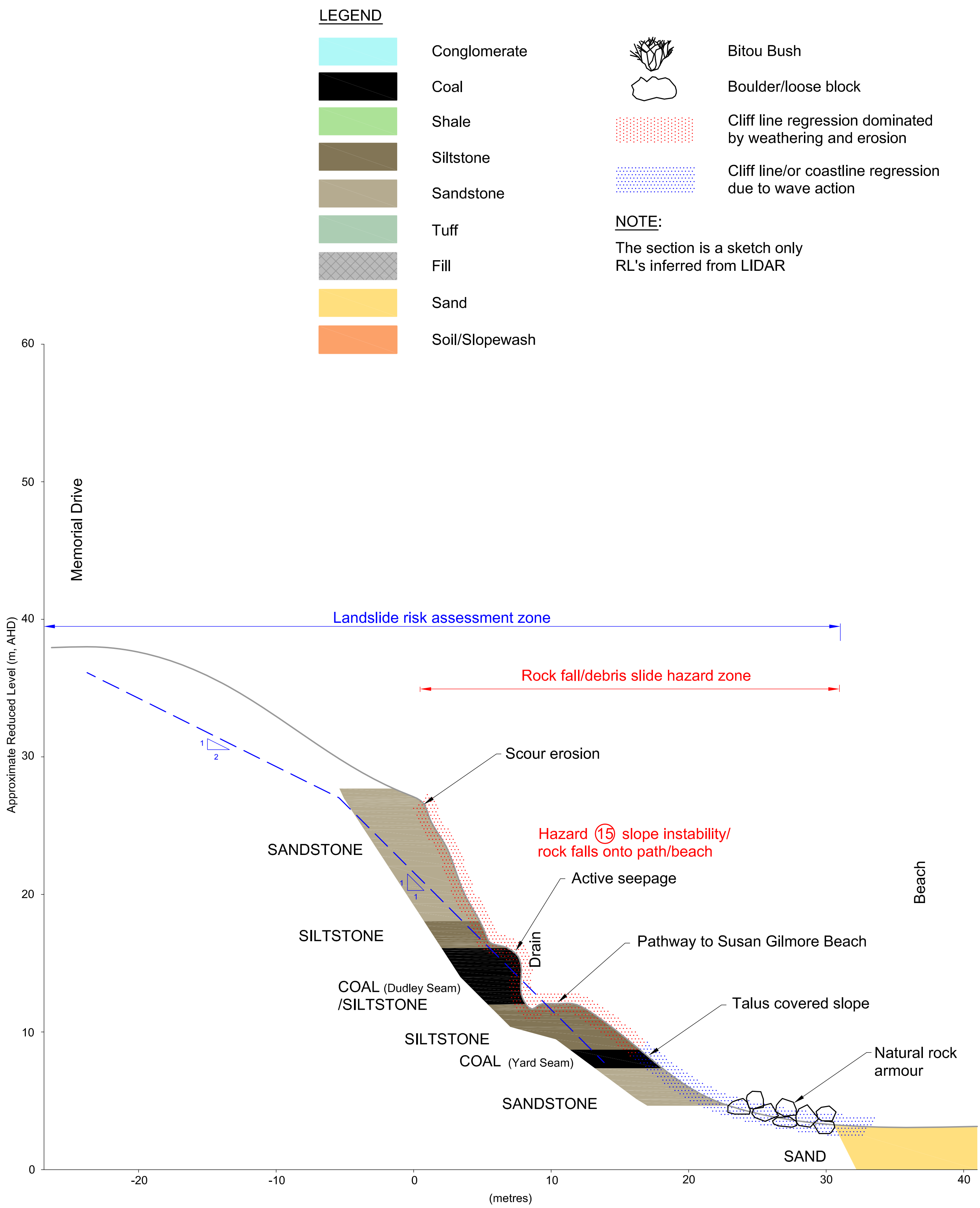
APPROVED BY	JE	DATE	18/12/2013	DRAWING No	S14 Rev 1	NEWCASTLE



CROSS - SECTION SKETCH S15
NEWCASTLE COASTLINE GEOTECHNICAL ASSESSMENT
SUSAN GILMORE BEACH

CLIENT	BMT WBM Pty Ltd				
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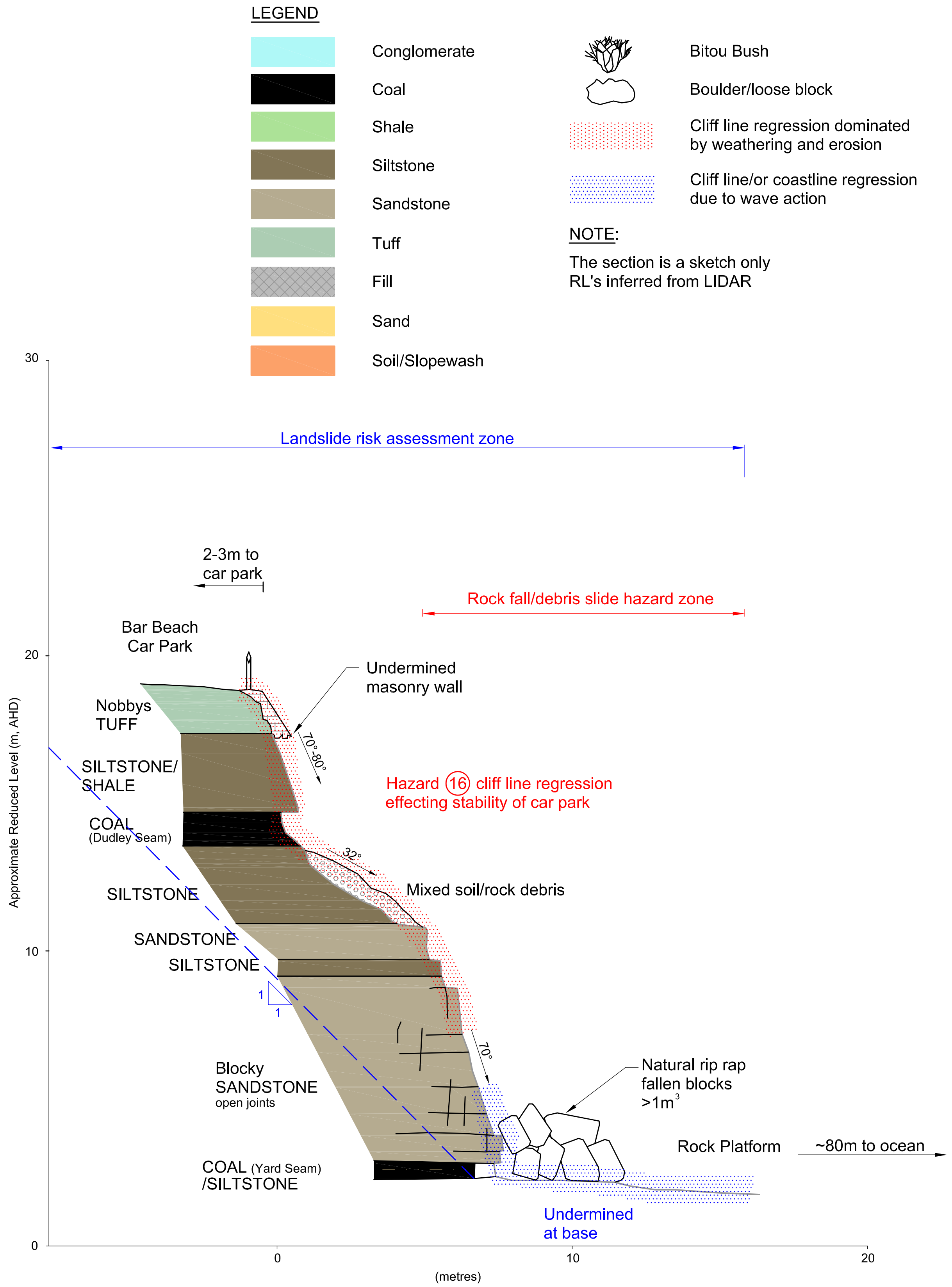
APPROVED BY	JE	DATE	18/12/2013	DRAWING No	S15 Rev 1	

CDT-DWG-A4V-001/1



CROSS - SECTION SKETCH S16
NEWCASTLE COASTLINE GEOTECHNICAL ASSESSMENT
BAR BEACH CAR PARK

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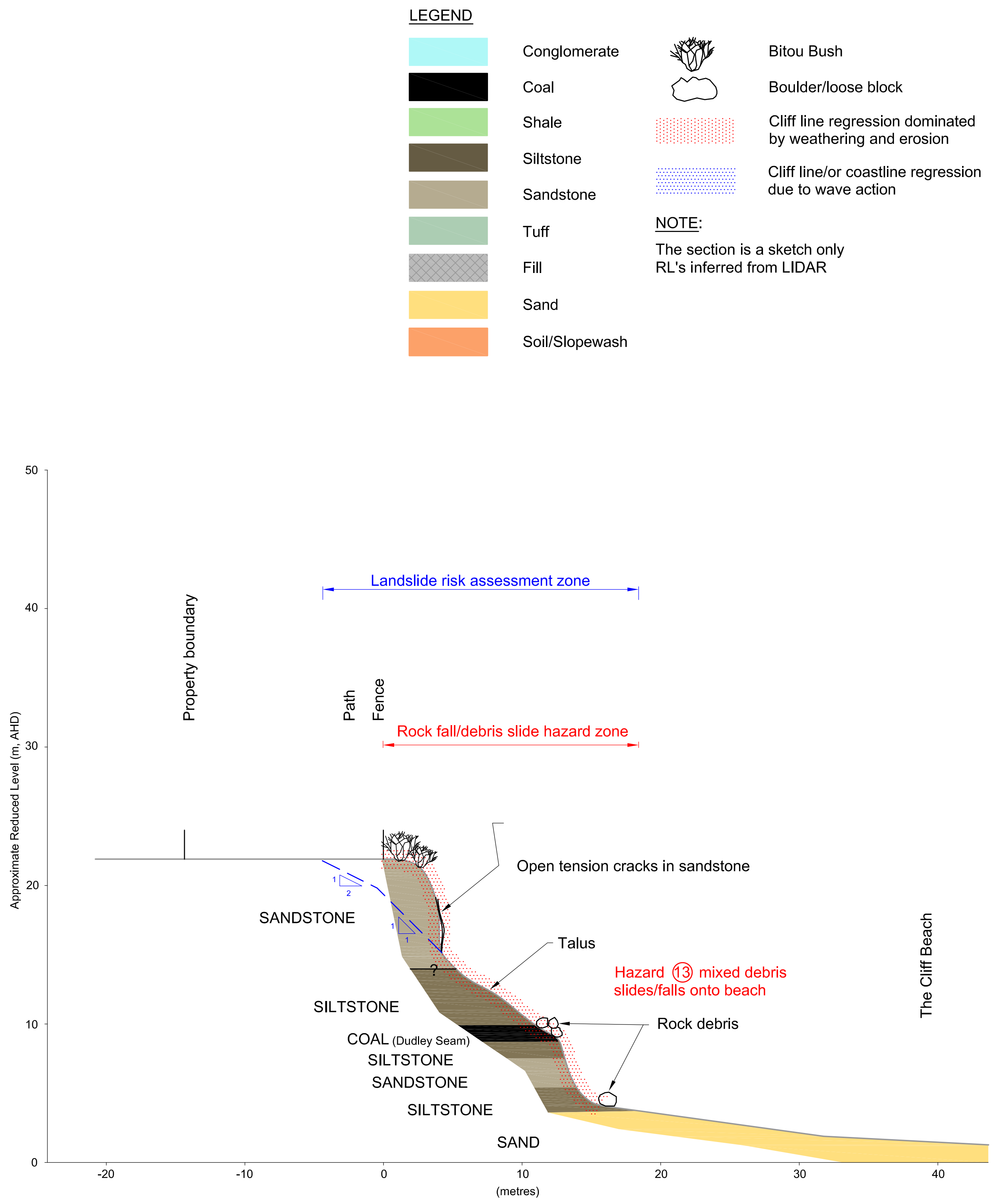
CLIENT	BMT WBM Pty Ltd				
DRAWN BY	SC	SCALE	1:200 H=V	RCA Ref	8365-202/2
APPROVED BY	JE	DATE	18/12/2013	DRAWING No	S16 Rev 1

OFFICE NEWCASTLE

CDT-DWG-A4V-001/1

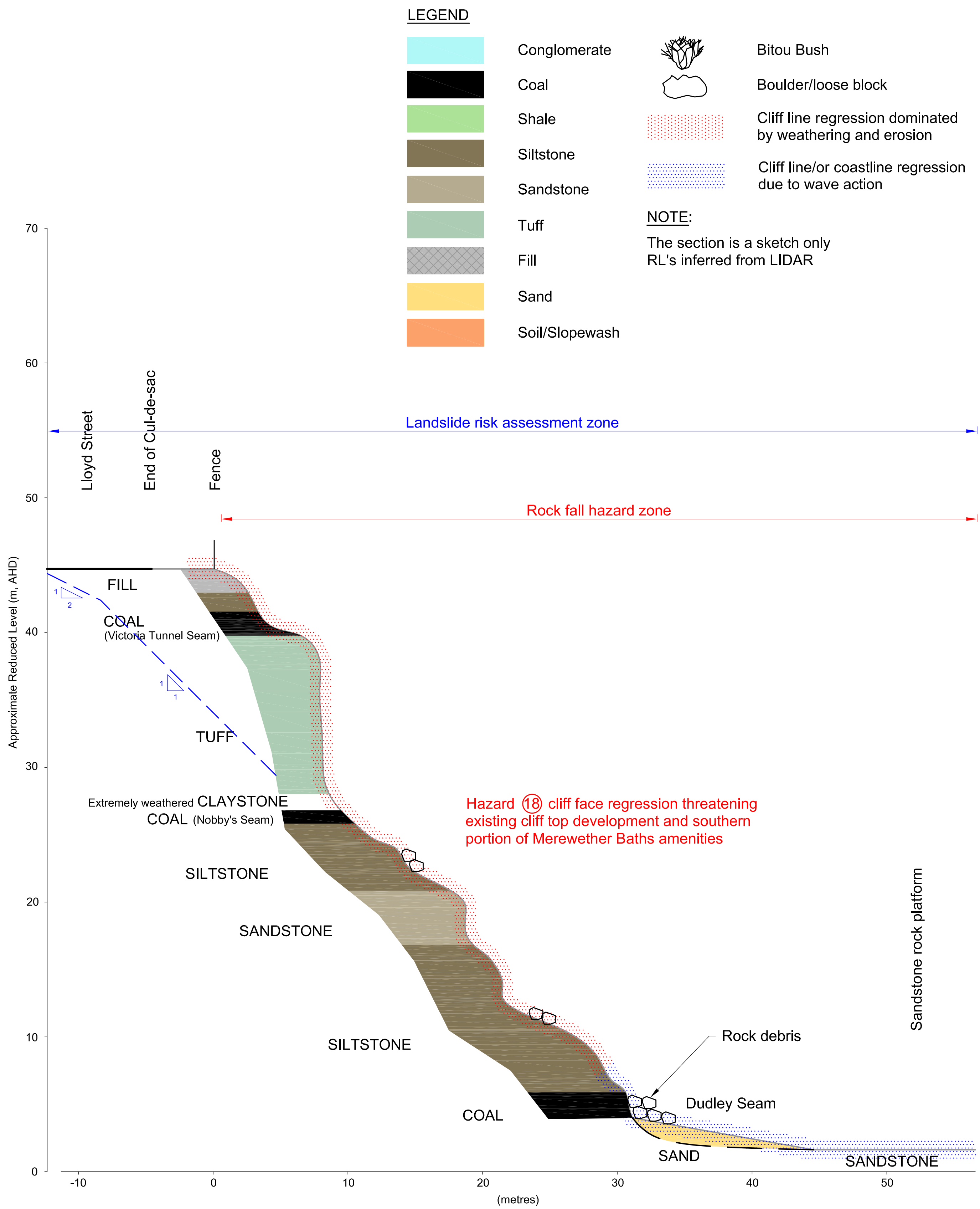


CROSS - SECTION SKETCH S17
NEWCASTLE COASTLINE GEOTECHNICAL ASSESSMENT
KILGOUR AVENUE
DIXON PARK (THE CLIFF)

CLIENT	BMT WBM Pty Ltd				
DRAWN BY	AG	SCALE	1:400 H=V	RCA Ref	8365-202/2
APPROVED BY	JE	DATE	18/12/2013	DRAWING No	S17 Rev 1

OFFICE NEWCASTLE

CDT-DWG-A4V-001/1



CROSS - SECTION SKETCH S18
NEWCASTLE COASTLINE GEOTECHNICAL ASSESSMENT
SECTION 15
LLOYD STREET
MEREWETHER

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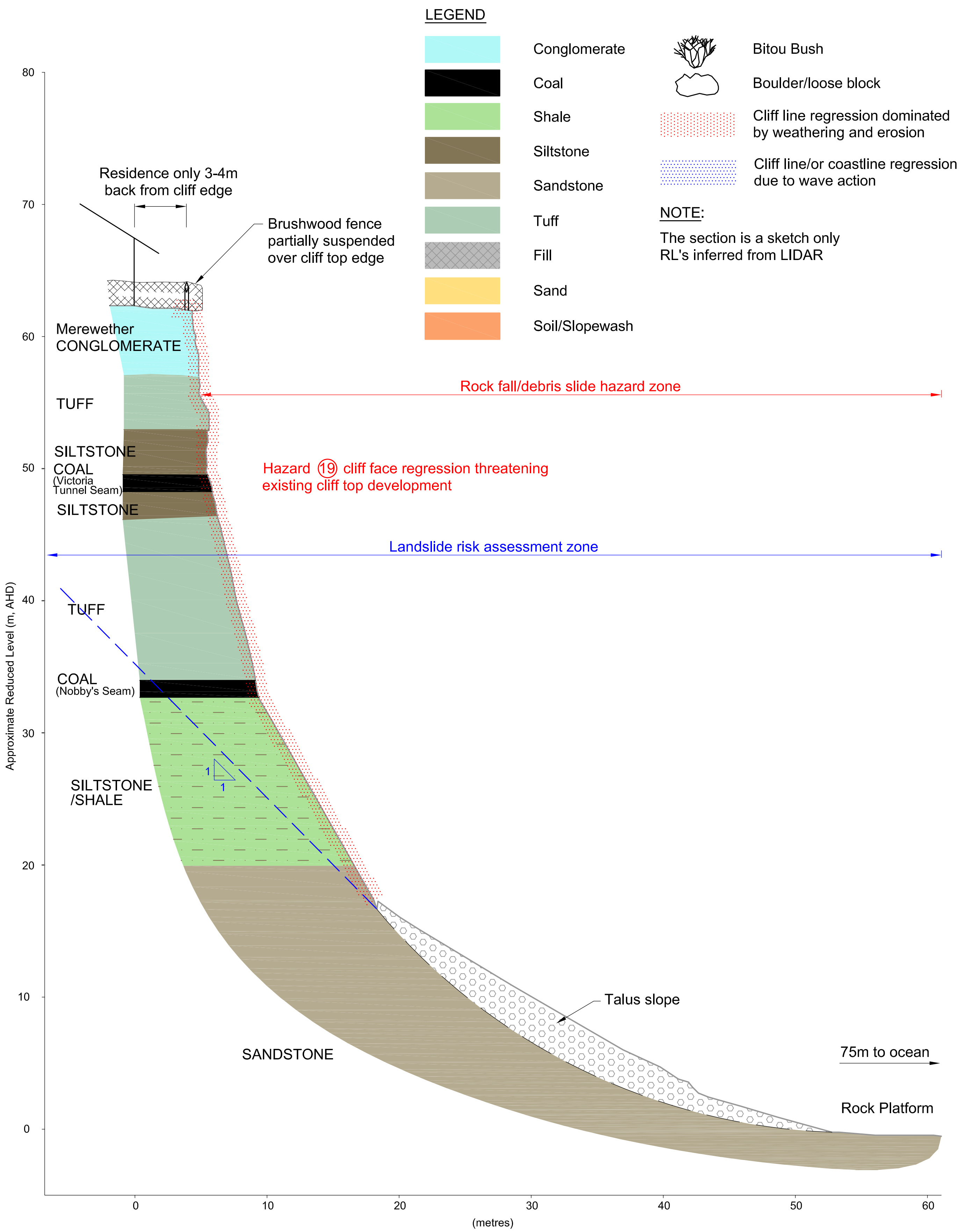
CLIENT	BMT WBM Pty Ltd				
DRAWN BY	JE	SCALE	1:400 H=V	RCA Ref	8365-202/2	OFFICE NEWCASTLE
APPROVED BY	JE	DATE	18/12/2013	DRAWING No	S18 Rev 1	

CDT-DWG-A4V-001/1



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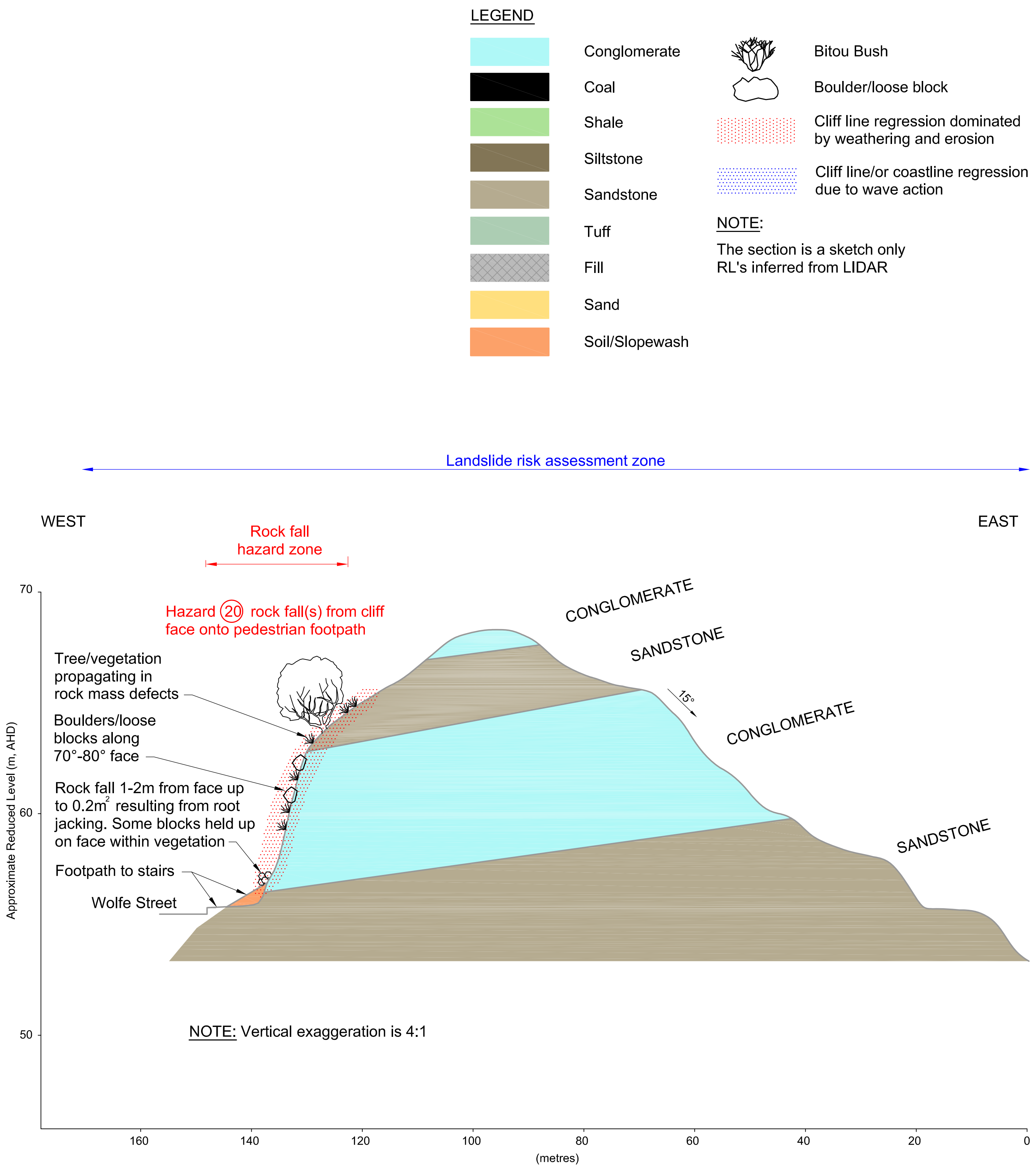
CROSS - SECTION SKETCH S19
NEWCASTLE COASTLINE GEOTECHNICAL ASSESSMENT
HICKSON STREET
MEREWETHER

CLIENT	BMT WBM Pty Ltd					
DRAWN BY	SC	SCALE	1:400 H=V	RCA Ref	8365-202/2	OFFICE NEWCASTLE
APPROVED BY	JE	DATE	18/12/2013	DRAWING No	S19 Rev 1	



Refer to figure 21 in Appendix B for photo of Hazard 20

CROSS - SECTION SKETCH S20
NEWCASTLE COASTLINE GEOTECHNICAL ASSESSMENT
OBELISK HILL - WEST TO EAST
WOLFE STREET, THE HILL, NEWCASTLE

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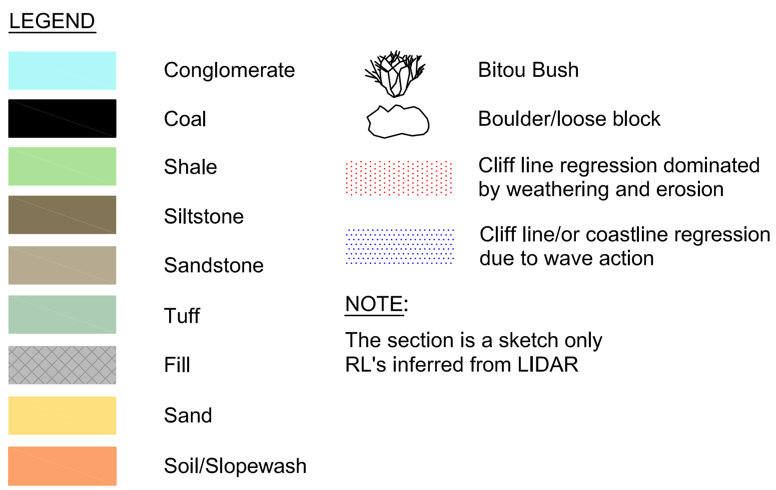
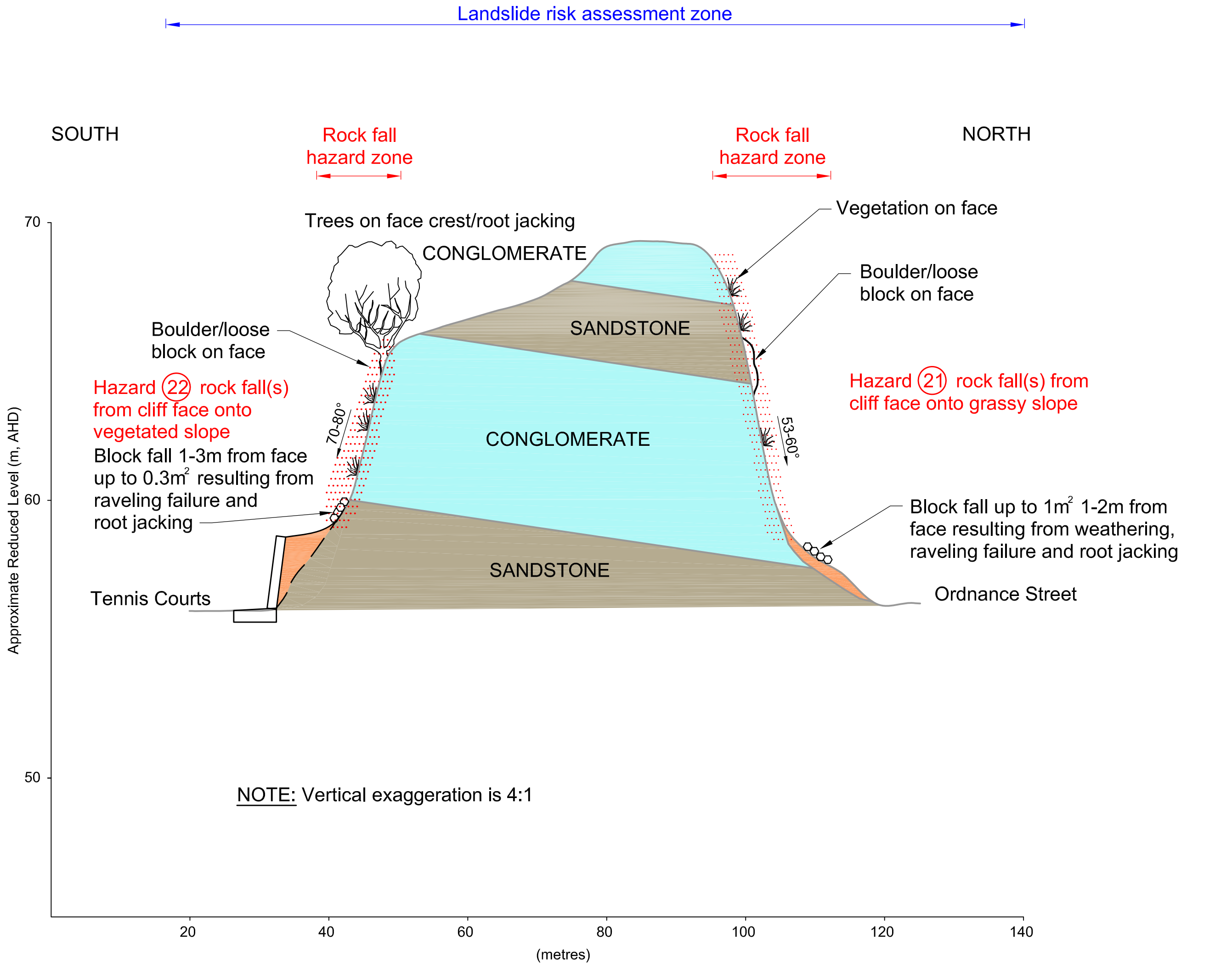
GEOTECHNICAL • ENVIRONMENTAL

CLIENT	BMT WBM Pty Ltd					
DRAWN BY	SC	SCALE	1:1000 H 1:250 V	RCA Ref	8365-202/2	OFFICE
APPROVED BY	JE	DATE	18/12/2013	DRAWING No	S20 Rev 1	NEWCASTLE

CDT-DWG-A4V-001/1





Refer to figure 22 in Appendix B for photo of Hazard 21

Refer to figure 23 in Appendix B for photo of Hazard 22

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CROSS - SECTION SKETCH S21
NEWCASTLE COASTLINE GEOTECHNICAL ASSESSMENT
OBELISK HILL - SOUTH TO NORTH
ORDNANCE STREET, THE HILL, NEWCASTLE

CLIENT	BMT WBM Pty Ltd					
DRAWN BY	SC	SCALE	1:1000 H 1:250 V	RCA Ref	8365-202/2	OFFICE NEWCASTLE
APPROVED BY	JE	DATE	18/12/2013	DRAWING No	S21 Rev 1	

CDT-DWG-A4V-001/1

Appendix B

Geo-hazard Figures 1 to 22

Table B1: Risk to Property Assessment Matrix

Table B2: Risk to Life Assessment Matrix

Table B3: Combined Risk Ranking Matrix

AGS LRM 2007 Landslide Qualitative Risk to Property Classification

AGS LRM 2007 Australian Geoguide LR8 - for Hillside Construction

AGS 2011 Development Approval Flow Chart

Figure 1 *Geo-hazard #1 – Rock fall(s) into vegetation, existing fence or onto Nobby's breakwater shared pathway. Pathway rock fall risk area shown in red. Past rock falls circled.*

Figure 2 *Geo-hazard #2 – rock fall(s) from cliff face onto beach. Warning signage (circled) provides visual warning; however ~ 10% of rock blocks have 'run out' past signs.*

Figure 3 *Geo-hazard #3 – Cliff top regression encroaching into existing development on the south side of Nobby's Headland. At risk structures (hi-lighted in red) are setback less than 3-5m from crest of weathering cliff face, with one corner of boundary fence 'suspended' over steep slope.*

Figure 4 *Geo-hazard #4a – Rock fall(s) onto Shortland Esplanade, hazard area outlined in red. Past rock fall debris, circled in black. Historical photos show rock debris on road.*

Figure 5 *Geo-hazard #4b – Rock fall(s) from blocky outcrop (shown in red) onto Fort Drive. Past sediment and rock falls circled. Note, crack (red line) in concrete wall; cracks were observed at several other locations along this wall.*

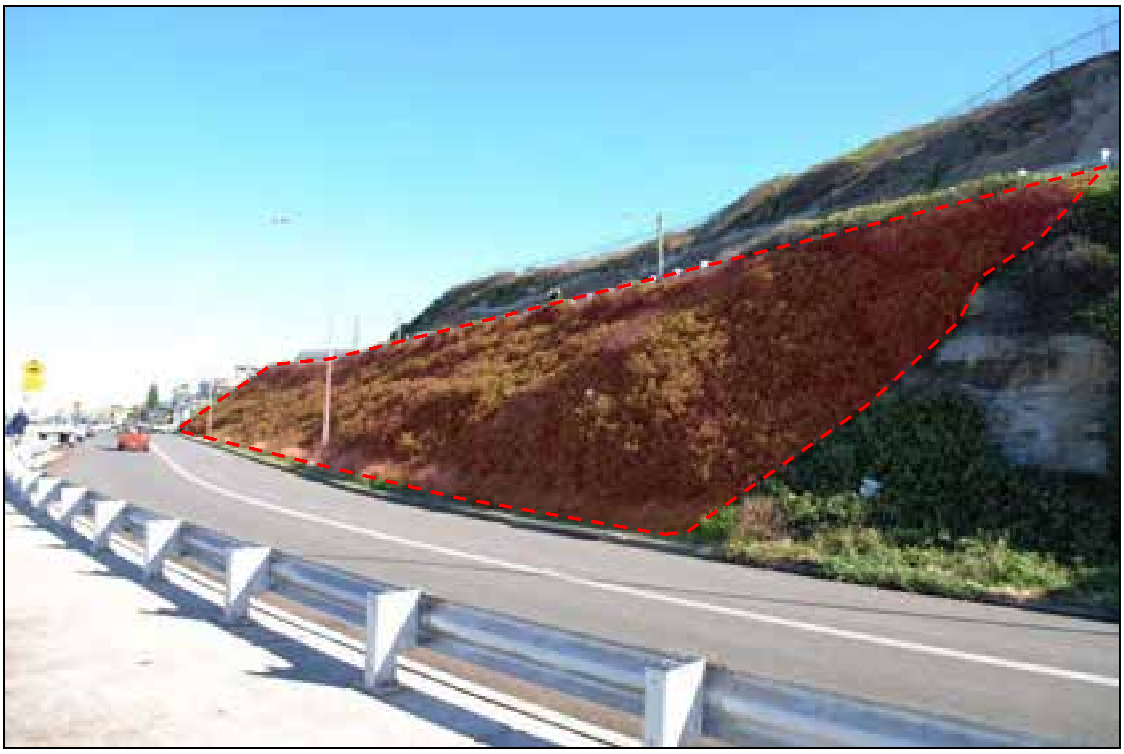


Figure 6 *Geo-hazard #5 – Vegetation covered fill batter/ shallow soil slope above road, shown in red. Potential for shallow failure of mixed debris onto Shortland Esplanade.*

Figure 7 *Geo-hazard #6 – Unsupported section of block wall (shown in red) falls onto Newcastle Beach footpath. At a meeting on 23/3/2012 CoN reported this section of wall had failed.*

Figure 8 *Geo-hazard#7 – Massive block(s) fall risk, shown in red. Rock fall analysis indicates it is unlikely to reach fence.*

Figure 9 *Geo-hazard #8– Rock falls from South Newcastle Cliff face.*

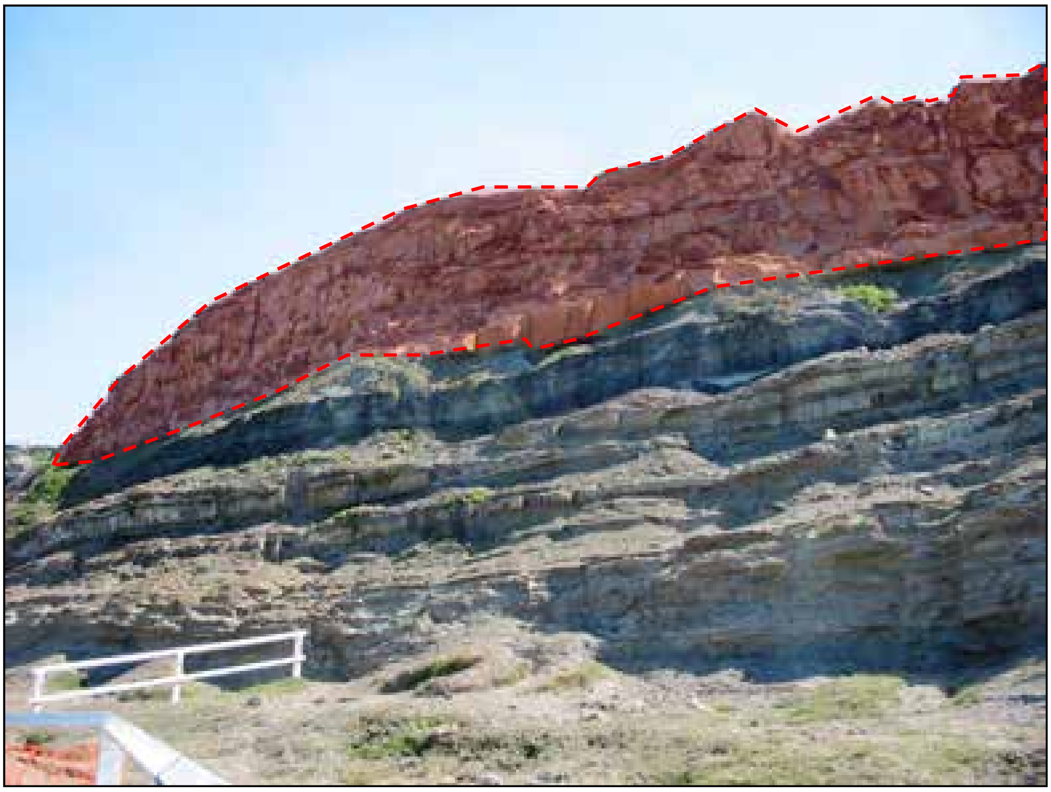
The cliff face was extensively re-shaped, 'groomed' and a rock fall barrier fence was installed in 2005 based on a detailed investigation & analysis by GHD Geotechnics. A review in 2011 by GHD Geotechnics indicates the rock fall barrier fence (see Figure 10 below) has stopped all rock falls to date. GHD noted no rock fall blocks in excess of 200mm diameter had occurred since the cliff/slope was re-shaped, 'groomed' and a rock fall barrier fence was installed.

Figure 10 *Geo-hazard #9– Tension crack/ differential settlement in recently sealed walkway. Hazard associated with deep fill behind sea wall at South Newcastle.*

Note rock fall hazard fence installed by GHD Geotechnics/ CoN to control geo-hazard #8 on right of picture.

Figure 11 *Geo-hazard #10 – Tension crack & settlement of coastal edge of Shortland Esplanade, shown in red. Hazard associated with deep fill supported by an old mortar block retaining wall.*

Figure 12 *Geo-hazard #11 - Creep movement of Shortland Esplanade fill embankment, shown in red, has resulted in stepped/ cracked pavement. Fill embankment creep & instability and sea cliff regression has resulted in loss of access to concrete footpath.*



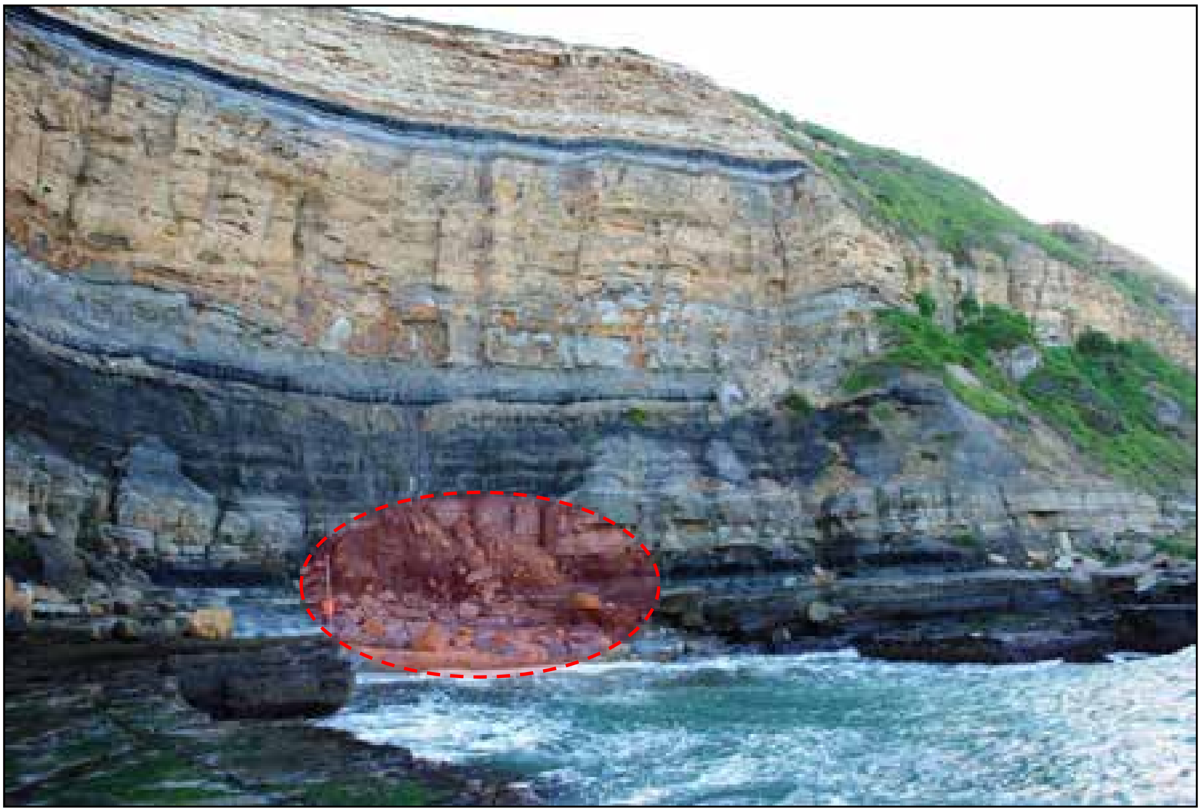
Geo-hazard #12a –Rock falls from cliff above Bogie Hole viewing area, due to erosion & weathering along open joints in a blocky sandstone unit, shown in red. This cliff/slope was 'groomed' after 2003 rock fall.

Figure 13 *Geo-hazard #12b – Increased frequency of rock falls due to increased wave attack on sea cliff adjacent to Bogie Hole rock platform.*

(Photo shows storm swells approximately 1¾ hours past a 1.3m high tide. Wave set up approximates BMT WBM modelled year 2100 mean sea level)

Geo-hazard #13– Cliff top erosion, northern 'neck' above & southern 'neck' below

Figure 14 *Geo-hazard #13 – Cliff top erosion resulting in 'necking' of cliff top from Strzelecki Lookout to Shepherds Hill along the proposed alignment of the Memorial Walk.*



Geo-hazard #14 – recent rock fall(s) and debris slide circled, covering narrow rock platform at toe of cliff face.

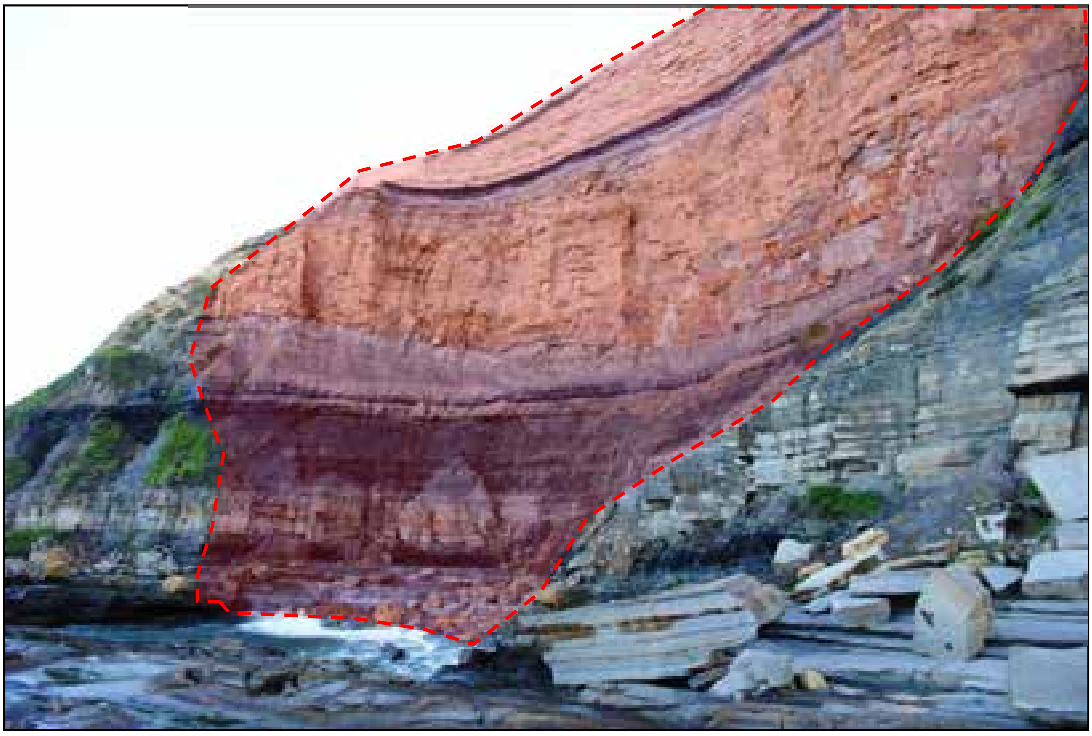


Figure 15 *Geo-hazard #14 – Accelerated cliff face retreat, shown in red. Hazard located below Shepherds Hill Trig Stn, adjacent to the proposed Memorial Walk alignment.*

Geo-hazard #15 – Landslide failure in May 2001 destroyed hillside staircase to Susan Gilmore Beach, circled.

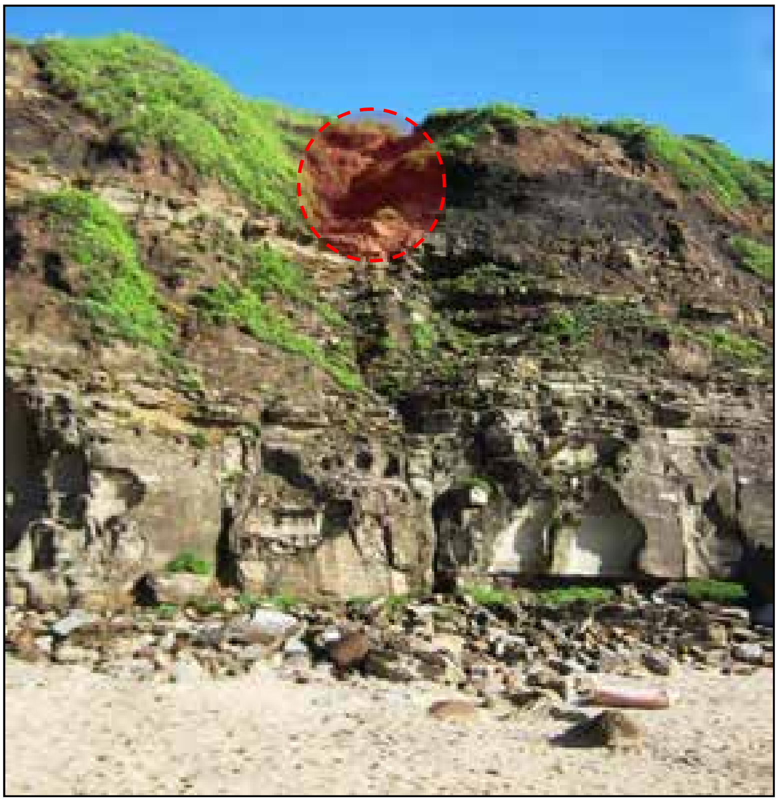
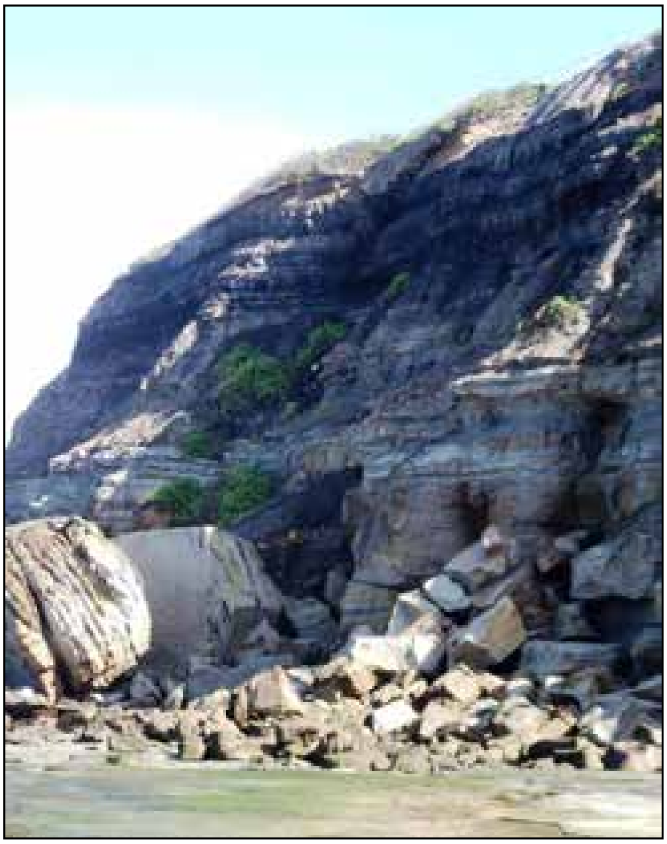


Figure 16 *Geo-hazard #15 – Cliff / slope deeply scoured by stormwater discharge onto upper and mid-slope areas. Soil/ extremely weathered rock and Dudley Seam almost completely eroded in circled area by stormwater discharge.*



Geo-hazard #16a – Yard Seam exposed to wave action at base of cliff leading to toppling of large (up to $4m^3$) blocks affecting the entire cliff face/ slope & threatening Bar Beach Car Park above.

Figure 17 *Geo-hazard #16b – Accelerated weathering/regression of the Dudley Seam & low strength rocks exposed mid-slope of cliff/slope are resulting in upper slope landslides threatening Bar Beach Car Park along crest of cliff/slope.*

Bathers Way above Geo- hazard # 17

Figure 18 *Geo-hazard #17– 'The Cliff' below Kilgour Avenue, past slide(s) debris and rock falls cover/ litter beach at toe of cliff/slope. Past instability has been associated with intense rainfall events and has resulted in sections of the beach being closed whilst slope stability has been re-assessed.*

Geo-hazard #18 – Lloyd Street cliff / slope erosion along crest is within 2-3m of the boundaries of cliff top development

Figure 19 *Geo-hazard #18 – Lloyd Street cliff face instability resulting in rock falls and mixed debris slide debris, shown in red. Hazard affects beach and southern end of Merewether Baths.*

View of cliff top development above Geo-hazard # 19. Right hand-side panel of Brushwood fence in centre of picture is 'suspended' over ragged bare rocky cliff edge.

Figure 20 *Geo-hazard #19 – Accelerated cliff face retreat along Fault line & cliff top, shown in red. Edge of cliff crest comes within 3-6m of existing cliff top residences.*

Geo-hazard #20 – Rock fall(s) from Obelisk cliff face onto pedestrian footpath.

Figure 21 *Geo-hazard #20 – close up of rock face & stairs, shows rock mass defects and vegetation growing in rock defects. Tree roots in rock face defects appear to be the cause of most rock falls. Observed rock fall blocks mostly ≤ 300mm in diameter and have come to rest within 2m of cliff face*

Figure 22 *Geo-hazard #21 – Rock falls from north face of Obelisk Hill. Fallen block ~1m in dimension circled. Observed rock falls have come to rest within 2m of rock face.*

Figure 23 *Geo-hazard #22 – Rock falls from south face of Obelisk Hill, due to tree root 'jacking' open and weathering of joints, as shown above. Observed rock falls have all come to rest within 3m of face.*

Table B1: *Assessed Landslide* ***Risk To Property*** *for Newcastle Coastal Study*

Location	Identified Hazards		Risk to Property in accordance with AGS LRM 2007				Comments	Risk Management Strategies
	No.	Description	Annual Likelihood of event	Consequence of event	Assessed Risk to Asset	Typical rate of failure (AGS velocities)		
Nobbys Headland	1	Rock-fall/ debris slide from north facing rock faces impacts and/or partially blocks Breakwater shared pathway.	Almost Certain	Insignificant	Low	Very Rapid (5m/sec to 3m/min)	Cliff face – undercut/erosion with potential block fall(s) up to 0.6m in dimension onto the 21m length of the Breakwater shared pathway closest to rock face	Install jersey kerb along the 21m long at risk section of pathway, plus 3m either end
Nobbys Headland	2	Rock-fall from near vertical face, with talus 'ramp' at toe falls/runs out onto beach below up to a distance of 16m from cliff face.	Almost Certain	Insignificant	Low	Extremely Rapid (≥ 5m/sec)	as above, except onto beach not footpath	Flatten the debris fan along the beach side of cliff to 'catch' rock falls rather than promote 'run out' or Move warning signs out to 20m from face.
Nobbys Headland	3	Cliff-top failure/ erosion/regression damages existing structures (historical and contemporary structures); assumed design life of 120 years	Unlikely	Minor	Low	Very Slow* (15mm-1.6m/yr)	*Individual rock falls are likely to fail very rapidly (5m/sec to 3m/min) Observations indicated cliff top/ slope crest regression due to erosion had reached the perimeter brick fence at two locations, still at least 2m from other structures	Relevant authority to monitor cliff top retreat. Conduct AGS LRM landslide risk assessment at least once every 10 years and/or Upgrade existing brick wall to protect buildings from cliff retreat.
Fort Scratchley Hill	4a	Rockfall from Sandstone outcrops impacts and/or partially blocks a 30m length of Shortland Esplanade adjacent to rock face	Almost Certain	Insignificant	Low	Very Rapid (5m/sec to 3m/min)	Cliff face – undercut/erosion with potential block fall(s) up to 0.6m in dimension into the path of northbound traffic on Shortland Esplanade	Remediate rock face
Fort Scratchley Hill	4b	Rockfall from Sandstone outcrops impacts and/or partially blocks Fort Drive for up to 60m length of roadway	Likely	Insignificant	Low	Very Rapid (5m/sec to 3m/min)	Rock outcrop – undercut/erosion with potential block fall(s) up to 0.6m in dimension into the path of westbound traffic on Fort Drive. Unmarked car parking area adjacent to Northbound lane is at risk.	Install 'No stopping rock fall hazard signs'. Prevent car parking along toe of slope, revetments and retaining walls
Fort Scratchley Hill	5	Landslip of vegetated shallow fill/ soil slope impacts and/ or partially blocks Fort Drive or Shortland Esplanade	Possible	Minor	Moderate	Rapid (3m/min to 1.8m/hr)	No such landslide has been recorded to date; however cracking of concrete retaining wall along toe of northern slopes above Fort Drive indicates potential for failure increasing as conditon of wall deteriorates.	Structural engineer to assess condition of the existing concrete revetments and retaining walls.
Newcastle Beach	6	Landslide/ block fall due to failure of a section of the old sandstone block wall without footing impacts and/ or partially blocks Bather's footpath	Almost Certain	Insignificant	Low	Rapid (3m/min to 1.8m/hr)	At meeting with CoN on the 23/3/2012, RCA was advised this failure had occurred and wall was to be demoilshed and slope re-graded. No loss of life, injury or damage to pavement was recorded.	Recommend soil slopes are battered at ≤ 2H: 1V; weathered rock cut at ≤ 1.5H: 1V; Fresh competent rock cut at ≤ 0.75H: 1V; or support steeper slopes with engineer designed retaining wall(s).
Cliff behind Newcastle Beach Skate Park	7	Rock fall/ landslide from cliff impacts talus slope and/or Shortland Esplanade pavement behind waratah mesh fence, with locked gate.	Almost Certain	Insignificant	Low	Very Rapid (5m/sec to 3m/min)	Rock fall analysis indicated rock fall hazard zone extends up to 11m from rock face. Access to rock fall zone is controlled by a 1.9m high waratah mesh fence, with locked gate.	Cliff/slope to be inspected for rock fall/landslide risks prior to any work being undertaken behind fence.
South Newcastle Cliff	8	Rock fall/ landslide from cliff/slope penetrates rock fall barrier fence and then impacts and/ or partially blocks Bathers Way / Shortland Esplanade pavement	Barely Credible	Minor	Very Low	Very Rapid (5m/sec to 3m/min)	Extensive cliff face re-grade and purpose built rock fall catch fence completed in 2005 to protect Bathers Way users. This section of Shortland Esplanade closed to vehicular traffic.	Maintain exisitng rock barrier fence and inspect cliff/slope rock fall/landslide risks prior to work being undertaken behind barrier fence.
Shortland Esplanade, South Newcastle Seawall	9	Loss of public access along bathers walk, due to stepped failure and/or voids in fill behind seawall failure.	Unlikely	Medium	Low	Extremely Slow* (<15mm/yr)	*If wall failed then fill could fail at a Rapid (3m/min to 1.8m/hr) rate, as defined in AGS LRM 2007 depending on mode of wall failure. 2011-12 inspections indicated a 3-4m long, up to 5mm wide crack exists in Bathers Walk pavement, offset some 1m and running parallel to sea/ retaining wall.	Re-seal pavement crack to prevent ingress of wate into fill behind sea wall. CoN to monitor pavement crack development.
Shortland Esplanade, King Edward Park	10	Loss of public access along Shortland Esplanade, due to stepped failure and/or voids in fill associated with seawall/ retaining wall failure.	Unlikely	Medium	Low	Extremely Slow* (<15mm/yr)	*If wall failed then fill could fail at a Rapid (3m/min to 1.8m/hr) rate, as defined in AGS LRM 2007 depending on mode of wall failure. Cracking and settlement of footpath and road pavement observed along coastal edge of Shortland Esplanade.	1. Remove broken footpath and cracked asphalt. 2. Re-grade and compact upper metre of fill. 3. Re-instate asphalt seal and concrete kerb & gutter. 4. Re-instate concrete footpath, optional.
Shortland Esplanade, access to Bogie Hole	11	Loss of public access along Shortland Esplanade, due to stepped failure and/or voids resulting from cliff top soil and/or fill embankment failure.	Likely	Medium	High	Very Slow* (15mm-1.6m/yr)	*Fill embankment could fail at a Rapid (3m/min to 1.8m/hr) rate, as defined in AGS LRM 2007 depending on mode of failure. Instability of fill embankment above sea cliff, with constant seeapge along fill/soil interface and bedding dipping out of cliff face. Pronounced step and tension cracks noted in Shortland Esplanade. Abandoned footpath due to erosion/instability of fill embankment.	Subsurface investigation required, install 2-3 inclinometers to determine rate of movement and depth of existing failure.
Bogie Hole	12	Rock fall from cliff impacts and/or partially blocks access to cliff top viewing area or pool area	Likely	Minor	Moderate	Very Rapid (5m/sec to 3m/min)	Rock fall in 2003 damaged cliff top outdoor furniture & timber fence, pool steps & railing and come to rest in pool. The rock face above the pool was cleared of unstable blocks after failure. 2011-12 inspections indicate erosion/weathering is producing more rock fall hazards.	Remove source unit for rock falls from crest of rock slope, or Construct rock fall catch fence along toe of rock slope.
Cliff Top Shepherds Hill-Strzelecki Lookout (Northern portion of the Proposed Memorial Walk)	13	Cliff top erosion/failure undermines/damages proposed raised walkway and/or viewing platform (Memorial Walk)	Unlikely	Minor	Low	Very Slow* (15mm-1.6m/yr)	*Individual rock falls are likely to fail very rapidly (5m/sec to 3m/min) Cliff top erosion/weathering of conglomerate crest has resulted in cliff top 'necks' less than 2m width at two locations along this section of cliff top.	Specific geotechnical investigation prior to development. Likley advice: 1. Found supports for cliff top walkway 600mm below G.L. and 2. Found supports for footbridges below the base of the 'friable' cliff top conglomerate unit; typically 7-10m thick
Cliff top Trig Stn, Shepherds Hill (Southern portion of the Proposed Memorial Walk)	14a	Cliff top erosion/failure undermines/damages proposed Cliff top saftey barrier (Memorial Walk)	Unlikely	Minor	Low	Very Slow* (15mm-1.6m/yr)	*Individual rock falls are likely to fail very rapidly (5m/sec to 3m/min) Cliff top erosion/weathering of conglomerate crest has resulted in cliff top 'necks' less than 2m width at two locations along this section of cliff top.	Specific geotechnical investigation prior to development. Likley advice: Found posts for cliff top safety fence 600mm below G.L.
Rock platfrom /Beach below Trig Stn, Shepherds Hill	14b	Rockfall/landslide impacts and/or partially blocks 'notch' in rock platform/ beach below	Almost Certain	Insignificant	Low	Extremely Rapid (≥ 5m/sec)	Existing rock fall debris actually facilitates access across 'notch' in rock platform at high tide	Access at own risk, beware of falling rocks warning sign
Susan Gilmore Beach	15	Cliff/slope erosion/failure impacts and/or partially blocks closed footpath and/or Susan Gilmore Beach	Almost Certain	Insignificant	Low	Rapid (3m/min to 1.8m/hr)	Debris slide in 2001 demolished a timber stairway that provided public access from the lower end of a concrete footpath down to the beach. On-going scour/erosion of cliff/ slope by uncontrolled stormwater discharge onto slope is contributing to slope instability.	Re-locate stormwater outlets to base of slope.

Table B1: *Assessed Landslide* ***Risk To Property*** *for Newcastle Coastal Study*

Location	Identified Hazards		Risk to Property in accordance with AGS LRM 2007				Comments	Risk Management Strategies
	No.	Description	Annual Likelihood of event	Consequence of event	Assessed Risk to Asset	Typical rate of failure (AGS velocities)		
Bar Beach Car Park	16a	Cliff/Slope failure damages/undermines easterly edge of Bar Beach Car Park (BBCP)	Almost Certain to Likely	Minor to Medium	Moderate to High	Rapid (3m/min to 1.8m/hr)	Upper slope landslide probably iniated in June 2007? had degraded/eroded by February 2012 to undermine a 10m long section of BBCP fence and re-activated slide debris had reached rock platform/beach below. Existing landslide threatens adjacent 2-3m for a length of some 30m of the BBCP coastal pathway.	April 2012 CoN removed cliff top row of car spaces. Recommend CON immediately re-instate barricades to keep BBCP pathway users out of at risk area. Recommend at risk section of BBCP is protected by a retaining structure founded below base of landslide. Large or long reach excavator working from BBCP to confirm base of slide prior to wall construction.
Bar Beach-Susan Gilmore Beach Rock Platfrom	16b	Cliff/Slope erosion/failure impacts and/or partially blocks access to beach/rock platform below	Almost Certain	Insignificant	Low	Rapid (3m/min to 1.8m/hr)	Coal seam (Yard Seam) is exposed near base of cliff. Retreat of the coal seam due to wave action is undercutting overlying blocky sandstone and opening rock defects resulting in wedge failures and toppling. Past block falls are not preventing coal seam retreat under current conditions and it is anticipated the increasing frequency of wave attack with rising water levels will increase rates of mass movement/ landslides. Expected to result in retreat of cliff top affecting Bar Beach car park eastern area (i.e., towards cliff edge).	CoN to monitor slope stability on an annual basis and/or after rainfall events ≥ 1 in 100yr. CoN to commission a detailed Landslide Risk Assessment if cliff top assets come under threat.
The Cliff Kilgour Avenue, Dixon Park	17	Rock fall/ landslide impacts and/or partially blocks public access to beach below	Almost Certain	Insignificant	Low	Rapid (3m/min to 1.8m/hr)	Landslide in June 2007 high rainfall event prevented access to 300m x 25m beach area until debris cleared away by CoN.	As above
Lloyd St Cliff/ Slope, Merewether	18	Rock fall/ landslide partially blocks public access to Merewether baths and/or beach below	Likely	Minor	Moderate	Rapid (3m/min to 1.8m/hr)	A landslide of over crest spoil during the June 2007 high rainfall event damaged three fixed outdoor dining fixtures at Merewether Baths. Still some 15m length of over crest spoil threatening Merewether Baths pinic area.	CoN to remove remaining over crest spoil on slope above Merewether Baths picnic area, then protect and re-vegetate as done after 2007 failure.
Hickson Street Cliff / Slope, Merewether	19a	Cliff top erosion/failure affects residential development	Likely	Minor to Medium	Moderate to High	Very Slow* (15mm-1.6m/yr)	*Individual rock falls are likely to fail very rapidly (5m/sec to 3m/min) Exisitng brushwood fence is currently 'suspended' over ragged bare rock face. The ragged edge of a 5m high bare rock face is only 3-6m from two existing residences No.34A and 38A Lloyd Street.	CoN to monitor cliff top regression on an annual basis and/or after rainfall eventsof ≥ 1 in 100yr intensity. CoN to commission a detailed Landslide Risk Assessment if cliff top residences come under threat.
Hickson Street Cliff / Slope, Merewether	19b	Landslide/rock fall impacts and/or partially blocks rock platform below	Almost Certain	Insignificant	Low	Rapid (3m/min to 1.8m/hr)	Previous rock falls and landslides onto rock platform have come to rest within 16m of the toe of slope. Rock platform is typically >30m wide.	Rock fall zone sign posted with 'Beware of Falling rocks'
Obelisk Hill, Wolfe Street	20	West Face: Rock fall from exposed rock outcrop, due to weathering and 'root jacking' impacts and/or partially blocks footpath from Wolfe street	Almost Certain	Insignificant	Low	Very Rapid (5m/sec to 3m/min)	Previous rock falls blocks up to 0.2m in dimension have typically come to rest within 1-2m of the rock face.	CoN to remove/poison trees growing in rock defects, monitor rock face condition adjacent to footpath and remove or support unstable blocks as needed.
Obelisk Hill, Ordance Street	21	North Face: Rock fall from rock face due to weathering and tree/Ficus vine roots 'jacking' open rock mass defects, impacts or partially blocks access to grassy slope adjacent to Ordance Street	Almost Certain	Insignificant	Low	Very Rapid (5m/sec to 3m/min)	Previous rock falls blocks up to 1m in dimension have typically come to rest within 1-2m of the rock face.	CoN to remove/poison trees & Ficus Vine growing in rock defects, monitor rock face condition and remove or support unstable blocks as needed.
Obelisk Hill, Tennis Courts	22	South Face: Rock fall/ debris slide due to weathering and 'root jacking' impacts or partially blocks access to Tennis Courts	Unlikely	Minor	Low	Very Rapid (5m/sec to 3m/min)	Previous rock falls blocks up to 0.3m in dimension have typically come to rest within 1-3m of the rock face. Tennis Court fence is at least 4m from toe of Obelisk rock face.	CoN to remove/poison trees growing in rock defects, monitor rock face condition and remove or support unstable blocks as needed.

Table B2: *Assessed Geotechncial Risk to* ***Loss of Life*** *for Newcastle Coastal Study*

Location	Identified Geo-Hazard		Risk of Loss of Life in accordance with AGS LRM 2007										
	No.	Description	Likelihood of failure	Indicative Annual Probability P(H)	Persons at risk	Probability Spatial Impact P(S:H) (1)	Assumed max. No. of people at risk/ event (2)	Annual spatial probability of persons being present (3)	Annual Probabilty of person not being able to avoid failure	Vulnerability to loss of life of persons from failure V(D:T) (4)	Annual Risk of Loss of life (person most at risk)	Total Annual Risk (for all persons at risk)	Comments/Notes
Nobbys Headland	1	Rock-fall/ debris slide from north facing rock faces impacts/ covers Breakwater shared pathway. Hazard poses a risk to pathway users witihn a specific 20m long section of the pathway on the west side of the closed gun emplacement building	Almost Certain	1.00E-01	People passing through rock fall zone	0.75	3	0.05	0.01	0.5	1.95E-05	5.86E-05	1. Prob Spatial impact estimated from rock fall analysis. 2. Annual temporal spatial probability based on 320 people/day on shared pathway with 20 sec exposure each to rock fall zone ≈ 105 mins per day for five days a week, every week of the year
Nobbys Headland	2	Rock-fall from near vertical face, with talus 'ramp' at toe falls/runs out onto beach below up to a distance of 16m from cliff face. Hazard poses a risk to persons sitting/ lying on beach within 16m of face	Almost Certain	1.00E-01	People within 16m of cliff face	1	3	0.18	0.05	0.5	4.46E-04	1.34E-03	1. Prob Spatial impact estimated from rock fall analysis. 2. Annual temporal spatial probability based on 12 people/day in rock fall zone, with up to 30 min exposure ≈ 360 mins per day for five days every week of the year
Nobbys Headland	3	Failure from cliff-top erosion/regression threatening existing structures (historical and contemporary structures);	Unlikely	5.00E-04	Visitors to Nobbys complex within cliff top risk zone	1	4	0.0015	0.05	0.1	3.72E-09	1.49E-08	1. Prob Spatial impact estimated from rock fall analysis. 2. Annual temporal spatial probability based on a maximum of 4 vistiors occupy an at risk section of the Nobbys complex for 30 minutes, 2 days a week, once a month each year.
Fort Scratchley Hill	4 a	Sandstone Cliff face – undercut/erosion with potential block fall(s) up to 0.6m in dimension onto Shortland Esplanade lane nearest cliff/slope. Hazard poses risk to vehicles and occupants, within rock fall zone.	Almost Certain	1.00E-01	Vehicle occupants	0.9	5	0.03	0.01	0.3	8.04E-06	4.02E-05	1. Prob Spatial impact estimated from rock fall analysis. 2. Spatial Probability calculated based on an average of 720 vehicles in rock fall zone for 5 sec ea. ≈ 60 mins per day for 5 out of 7 days a week all year.
Fort Scratchley Hill	4 b	Sandstone outcrop – undercut/erosion with potential block fall(s) up to 0.6m in dimension onto Fort Drive lane nearest outcrop/slope. Hazard poses risk to vehicles and occupants, within rock fall zone.	Likely	1.00E-02	Vehicle occupants	0.67	5	0.01	0.01	0.3	2.99E-07	1.50E-06	1. Prob Spatial impact estimated from rock fall analysis. 2. Spatial Probability calculated based on 360 vehicles day in rock fall zone for 5 sec ea. ≈ 30 mins per day for 5 out of 7 days a week all year.
Fort Scratchley Hill	5	Landslip of vegetated shallow fill/ soil slope onto Fort Drive or Shortland Esplanade. Hazard poses risk to vehicle occupants, within a typically 30-60m long landslide zone.	Possible	5.00E-03	Vehicle occupants	0.9	10	0.27	0.01	0.3	3.62E-06	3.62E-05	1. Prob Spatial impact estimated from rock fall analysis. 2. Spatial Probability calculated based on an average of 720 vehicles in rock fall zone for 45sec ea. ≈ 540 mins per day for 5 out of 7 days a week all year.
Newcastle Beach	6	Block fall from undercut section of masonry rock wall adjacent to Bather walk pathway. Hazard poses a risk to pathway users witihn block fall zone.	Almost Certain	1.00E-01	People passing through block fall zone	0.9	3	0.22	0.01	0.3	6.03E-05	1.81E-04	1. Prob Spatial impact estimated from rock fall analysis. 2. Annual temporal spatial probability based on 1/2 of 200 people/hr for 6hrs a day on shared pathway with 1 min exposure to wall failure zone = 600 mins/ day for five days a week, for 3/4 of the year
Cliff behind Newcastle Beach Skate Park	7	Massive block fall from cliff set back 3 to 11m from roadway. At present waratah mesh fence with locked gate prevents unauthorised people accessing cliff face. Maintenance workers clearing rock falls or carrying out slope maintenance and/or vegetation control are in rock fall zone.	Almost Certain	1.00E-01	Maintenance workers	0.9	4	0.04	0.01	0.5	1.65E-05	6.59E-05	Spatial Probability calculated based on maintenance crew of up to 4 persons spending up to 10 hrs a day for a total of 8 days over a year behind barrier fence clearing debris and controlling vegetation
Bathers Way, (Shortland Esplanade) below South Newcastle Cliff	8	Rock fall penetrates GHD Geotechnics designed rock fall barrier and impacts pedestrian on shared pathway	Barely Credible	1.00E-06	People using shared pathway	0.04	3	0.22	0.01	0.1	8.93E-12	2.68E-11	1. According to GHD geotechnics analysis the rock fall barrier prevents 96% of rock falls reaching the shared pathway. 2. Annual temporal spatial probability based on 1/2 of 200 people/hr for 6hrs a day on shared pathway with 1 min exposure to wall failure zone = 600 mins/ day for five days a week, for 3/4 of the year
Bathers Way, (Shortland Esplanade), South Newcastle Sea Wall	9	People using Bathers Way (Shortland Esplanade) can't avoid stepped pavement and/or voids in pavement due to sea wall rotation/ failure over a 15-60m length.	Unlikely	1.00E-04	People using shared pathway	1	3	0.45	0.05	0.1	2.23E-07	6.70E-07	1. Creep failure at present - persons likely to be warned of rapid wall failure 2. Vulnerability: given warning it is unlikley persons are buired by failure. 3. Annual temporal spatial probability based on 1/2 of 200 people/hr for 6hrs a day on shared pathway with 2 min exposure to wall failure zone = 1200 mins/ day for five days a week, for 3/4 of the year
Shortland Esplanade, King Edward Park (KEP)	10	Pedestrian(s) can't avoid stepped pavement and/or voids in pavement due to sea wall rotation/failure; likely failure length will correspond to wall length of 20m.	Unlikely	1.00E-04	People using shared pathway	1	3	0.18	0.05	0.1	8.93E-08	2.68E-07	1. Creep failure at present - persons likely to be warned of rapid wall failure 2. Vulnerability: given warning it is unlikley persons are buired by failure. 3. Annual temporal spatial probability based on 1/2 of 160 people/hr for 6hrs/day on shared pathway with 1 min exposure to fill failure = 480 mins per day for five days a week, for 3/4 of the year
Shortland Esplanade, KEP - Bogie Hole	11	Pedestrian(s) can't avoid stepped pavement and/or voids in pavement due to cliff top fill embankment failure. Exisitng pavement deformation some 40m long.	Likely	1.00E-02	People & vehicles using roadway	1	6	0.36	0.1	0.1	3.57E-05	2.14E-04	1. Creep failure at present - persons likely to be warned of rapid embankment failure 2. Vulnerability: given warning it is unlikley persons are buired by failure. 3. Annual temporal spatial probability based on 1/2 of 160 people/hr for 6hrs/day on shared pathway with 2 min exposure to fill failure = 960 mins per day for five days a week, for 3/4 of the year
Bogie Hole	12	Rock fall impacts pedestrians and/or bathers using veiwing area and/or ocean rock pool	Likely	1.00E-02	People using veiwing area, steps & rock pool	0.75	6	0.89	0.01	0.5	3.35E-05	2.01E-04	Annual temporal spatial probability based on 240 people/day in rock fall risk area with av. 10 min exposure each to rock fall zone = 2400 mins per day for five days a week, for 3/4 of the year
Cliff Top Shepherds Hill-Strzelecki Lookout (Northern Portion of the Proposed Memorial Walk)	13	Risk to pedestrians as a result of slope failure affecting walkway (Memorial Walk) over a 15-30m length	Unlikely	1.00E-04	People using proposed cliff top Memorial Walk	1	6	0.58	0.01	0.1	5.80E-08	3.48E-07	1. Very slow failure rate at present - persons likely to be aware of damage to walkway 2. Vulnerability: given warning it is unlikley persons are buired by failure. 3. Annual temporal spatial probability based on 260 people/hr for 6hrs/day on shared pathway with 1min exposure to slope failure = 1560 mins/ day for five days a week, for 3/4 of the year

Table B2: *Assessed Geotechncial Risk to* ***Loss of Life*** *for Newcastle Coastal Study*

Location	Identified Geo-Hazard		Risk of Loss of Life in accordance with AGS LRM 2007										
	No.	Description	Likelihood of failure	Indicative Annual Probability P(H)	Persons at risk	Probability Spatial Impact P(S:H) (1)	Assumed max. No. of people at risk/ event (2)	Annual spatial probability of persons being present (3)	Annual Probabilty of person not being able to avoid failure	Vulnerability to loss of life of persons from failure V(D:T) (4)	Annual Risk of Loss of life (person most at risk)	Total Annual Risk (for all persons at risk)	Comments/Notes
Cliff top Trig Stn, Shepherds Hill (Southern portion of the Proposed Memorial Walk)	14 a	Cliff top sightseers at proposed safty fence are caught in cliff top landslide	Unlikely	1.00E-04	People witihn 8m of cliff top fence	0.5	6	0.30	0.01	0.1	1.49E-08	8.93E-08	1. Very slow failure rate at present - persons likely to be aware of cliff top instability 2. Vulnerability: given warning it is unlikley persons are buired by failure. 3. Annual temporal spatial probability based on 60 people/day in risk area with av. 10 min exposure each = 600 mins per day for five days a week, every week of the year
Rock platfrom /Beach below Trig Stn, Shepherds Hill	14 b	Persons traversing 100m long 'notch' beach/platform are impacted by rockfall from cliff.	Almost Certain	1.00E-01	People 'clambering' over old rock fall and/or 'notch' beach	1	3	0.12	0.05	0.5	2.98E-04	8.93E-04	Annual temporal spatial probability based on 24 people/day in rock fall risk area with av. 10 min exposure each to rock fall zone = 240 mins per day for five days a week, every week of the year
Susan Gilmore Beach	15	Persons traversing old rock falls/ beach/platform witihin 16m of toe of cliff/slope are impacted by rockfall from cliff.	Almost Certain	1.00E-01	Persons within 16m of cliff/ slope toe	0.75	3	0.13	0.01	0.5	5.02E-05	1.51E-04	Annual temporal spatial probability based on 6 people/hr 6hrs/day in rock fall risk area with av. 10 min exposure each to rock fall zone = 360 mins per day for five days a week, for 3/4 of the year
Bathers Way, Bar Beach Car Park	16 a	Risk to persons walking along or stopped to view from eastern edge of Bar Beach car park, above clif/slope. Exisitng slope failures typically 15-30m in length.	Almost Certain to Likely	5.00E-02	People witihn 5m of cliff top fence	1	6	0.58	0.01	0.1	2.90E-05	1.74E-04	1. Creep failure at present - persons likely to be warned or not present when rapid slope failure occurs. 2. Vulnerability: given warning it is unlikley persons are caught in failure. 3.Annual temporal spatial probability based on 1/2 of 260 people/hr for 6hrs/day on shared pathway with 2 min exposure to slope failure = 1560 mins/ day for five days a week, for 3/4 of the year
Rock Platform/ Beach below Bar Beach Car Park	16 b	Risk to persons on beach/platform from landslide/ rockfall from cliff/slope below car park.	Almost Certain	1.00E-01	Persons within 16m of cliff/ slope toe	0.75	3	0.13	0.01	0.5	5.02E-05	1.51E-04	Annual temporal spatial probability based on 6 people/hr 6hrs/day in rock fall risk area with av. 10 min exposure each to rock fall zone = 360 mins per day for five days a week, for 3/4 of the year
The Cliff Kilgour Avenue, Dixon Park	17	Risk to beach users from mixed debris slides following high rainfall events, such as June 2007.	Almost Certain	1.00E-01	Persons within 16m of cliff/ slope toe	0.75	3	0.13	0.01	0.5	5.02E-05	1.51E-04	Annual temporal spatial probability based on 12 people/day in rock fall zone, with up to 30 min exposure = 360 mins per day for five days, for 3/4 of the year
Merewether Baths Picnic Tables, Rock platform & Beach below Lloyd St sea cliff/ slope	18	Rock fall/ landslide impacts walkers, picnickers @ Merewether Baths and/or beach/rock platform below cliff.	Likely	1.00E-02	Persons within 16m of cliff/ slope toe	0.9	5	0.13	0.01	0.5	6.03E-06	3.01E-05	Annual temporal spatial probability based on 6 people/hr 6hrs/day in rock fall risk area with av. 10 min exposure each to rock fall zone = 360 mins per day for five days a week, for 3/4 of the year
Hickson Street Cliff / Slope, Merewether	19 a	Residents affected by cliff top failure	Likely	1.00E-02	Persons within 6m of cliff edge	0.3	4	0.09	0.1	1	2.68E-05	1.07E-04	Annual temporal spatial probability based on a maximum of 4 residents in at risk section of residential development for 1hr/day = 240 mins/day, 5 days a week, for 3/4 of the year
Hickson Street Cliff / Slope, Merewether	19 b	Landslide/rock fall impacts person(s) on rock platform	Almost Certain	1.00E-01	Persons within 16m of cliff/ slope toe	0.75	6	0.13	0.01	0.5	5.02E-05	3.01E-04	Annual temporal spatial probability based on 6 people/hr 6hrs/day in rock fall risk area with av. 10 min exposure each to rock fall zone = 360 mins per day for five days a week, for 3/4 of the year
Obelisk Hill, Wolfe Street	20	Rock fall impacts pedestrian on steps/footpath from Wolfe Street to Obelisk	Almost Certain	1.00E-01	Persons within 3m of rock face	0.9	3	0.16	0.01	0.5	7.23E-05	2.17E-04	Annual temporal spatial probability based on 36 people/hr 6hrs/day in rock fall risk area with av. 2 min exposure each to rock fall zone = 432 mins per day for five days a week, for 3/4 of the year
Obelisk Hill, Ordance Street	21	Rock fall impacts person(s) sitting/walking along base of cliff	Almost Certain	1.00E-01	Persons within 3m of rock face	0.9	3	0.13	0.01	0.5	6.03E-05	1.81E-04	Annual temporal spatial probability based on 6 people/hr 6hrs/day in rock fall risk area with av. 10 min exposure each to rock fall zone = 360 mins per day for five days a week, for 3/4 of the year
Obelisk Hill, South Face	22	Rock fall impacts person(s) using nearby Tennis court	Unlikely	1.00E-04	Persons leaning against court fence nearest rock face	0.1	3	0.13	0.01	0.5	6.70E-09	2.01E-08	Annual temporal spatial probability based on 6 people/hr 6hrs/day in rock fall risk area with av. 10 min exposure each to rock fall zone = 360 mins per day for five days a week, for 3/4 of the year

Notes:

1 Probability of spatial impact P(S:H) was determined from rock fall analysis where appropriate or by estimating probability of hazard reaching impact zone.
2 Assumed maximum number of people at risk of loss of life per individual event
3 Annual spatial probabilities of person being present at failure based on observation or from CoN published maximum useage rates for Bathers Way from Nobby's to Merewether
4 Vulnerabilities taken from Appendix F of AGS LRM 2007

Table B3: *Combined Risk Ranking of Geo-hazards for Newcastle Coastal Study*

Identified Hazards			Risk to Property in accordance with AGS LRM 2007						
Location	**No.**	**Description**	**Annual Likelihood of event**	**Consequence of event**	**Assessed Risk to Asset**	**Typical rate of failure** (AGS velocities)	**Annual Risk of Loss of life (person most at risk)**	**Total Annual Risk (for all persons at risk)**	**Combined Risk Ranking**
Shortland Esplanade, access to Bogie Hole	11	Loss of public access along Shortland Esplanade, due to stepped failure and/or voids resulting from cliff top soil and/or fill embankment failure.	Likely	Medium	High	Very Slow* (15mm-1.6m/yr)	3.57E-05	2.14E-04	1
Bar Beach Car Park	16a	Cliff/Slope failure damages/undermines easterly edge of Bar Beach Car Park (BBCP)	Almost Certain to Likely	Minor to Medium	Moderate to High	Rapid (3m/min to 1.8m/hr)	2.90E-05	1.74E-04	2
Hickson Street Cliff / Slope, Merewether	19a	Cliff top erosion/failure affects residential development	Likely	Minor to Medium	Moderate to High	Very Slow* (15mm-1.6m/yr)	2.68E-05	1.07E-04	3
Bogie Hole	12	Rock fall from cliff impacts and/or partially blocks access to cliff top viewing area or pool area	Likely	Minor	Moderate	Very Rapid (5m/sec to 3m/min)	3.35E-05	2.01E-04	4
Lloyd St Cliff/ Slope, Merewether	18	Rock fall/ landslide partially blocks public access to Merewether baths and/or beach below	Likely	Minor	Moderate	Rapid (3m/min to 1.8m/hr)	6.03E-06	3.01E-05	5
Fort Scratchley Hill	5	Landslip of vegetated shallow fill/ soil slope impacts and/ or partially blocks Fort Drive or Shortland Esplanade	Possible	Minor	Moderate	Rapid (3m/min to 1.8m/hr)	3.62E-06	3.62E-05	6
Nobbys Headland	2	Rock-fall from near vertical face, with talus 'ramp' at toe falls/runs out onto beach below up to a distance of 16m from cliff face.	Almost Certain	Insignificant	Low	Extremely Rapid (≥ 5m/sec)	4.46E-04	1.34E-03	7
Rock platfrom /Beach below Trig Stn, Shepherds Hill	14b	Rockfall/landslide impacts and/or partially blocks 'notch' in rock platform/ beach below	Almost Certain	Insignificant	Low	Extremely Rapid (≥ 5m/sec)	2.98E-04	8.93E-04	8
Obelisk Hill, Wolfe Street	20	West Face: Rock fall from exposed rock outcrop, due to weathering and 'root jacking' impacts and/or partially blocks footpath from Wolfe street	Almost Certain	Insignificant	Low	Very Rapid (5m/sec to 3m/min)	7.23E-05	2.17E-04	9
Obelisk Hill, Ordance Street	21	North Face: Rock fall from rock face due to weathering and tree/Ficus vine roots 'jacking' open rock mass defects, impacts or partially blocks access to grassy slope adjacent to Ordance Street	Almost Certain	Insignificant	Low	Very Rapid (5m/sec to 3m/min)	6.03E-05	1.81E-04	10
Newcastle Beach	6	Landslide/ block fall due to failure of a section of the old sandstone block wall without footing impacts and/ or partially blocks Bather's footpath	Almost Certain	Insignificant	Low	Rapid (3m/min to 1.8m/hr)	6.03E-05	1.81E-04	11
Hickson Street Cliff / Slope, Merewether	19b	Landslide/rock fall impacts and/or partially blocks rock platform below	Almost Certain	Insignificant	Low	Rapid (3m/min to 1.8m/hr)	5.02E-05	3.01E-04	12
Susan Gilmore Beach	15	Cliff/slope erosion/failure impacts and/or partially blocks closed footpath and/or Susan Gilmore Beach	Almost Certain	Insignificant	Low	Rapid (3m/min to 1.8m/hr)	5.02E-05	1.51E-04	13
The Cliff Kilgour Avenue, Dixon Park	17	Rock fall/ landslide impacts and/or partially blocks public access to beach below	Almost Certain	Insignificant	Low	Rapid (3m/min to 1.8m/hr)	5.02E-05	1.51E-04	14
Bar Beach-Susan Gilmore Beach Rock Platfrom	16b	Cliff/Slope erosion/failure impacts and/or partially blocks access to beach/rock platform below	Almost Certain	Insignificant	Low	Rapid (3m/min to 1.8m/hr)	5.02E-05	1.51E-04	15
Nobbys Headland	1	Rock-fall/ debris slide from north facing rock faces impacts and/or partially blocks Breakwater shared pathway.	Almost Certain	Insignificant	Low	Very Rapid (5m/sec to 3m/min)	1.95E-05	5.86E-05	16
Cliff behind Newcastle Beach Skate Park	7	Rock fall/ landslide from cliff impacts talus slope and/or Shortland Esplanade pavement behind waratah mesh fence, with locked gate.	Almost Certain	Insignificant	Low	Very Rapid (5m/sec to 3m/min)	1.65E-05	6.59E-05	17
Fort Scratchley Hill	4a	Rockfall from Sandstone outcrops impacts and/or partially blocks a 30m length of Shortland Esplanade adjacent to rock face	Almost Certain	Insignificant	Low	Very Rapid (5m/sec to 3m/min)	8.04E-06	4.02E-05	18
Fort Scratchley Hill	4b	Rockfall from Sandstone outcrops impacts and/or partially blocks Fort Drive for up to 60m length of roadway	Likely	Insignificant	Low	Very Rapid (5m/sec to 3m/min)	2.99E-07	1.50E-06	19
Shortland Esplanade, South Newcastle Seawall	9	Loss of public access along bathers walk, due to stepped failure and/or voids in fill behind seawall failure.	Unlikely	Medium	Low	Extremely Slow* (<15mm/yr)	2.23E-07	6.70E-07	20
Shortland Esplanade, King Edward Park	10	Loss of public access along Shortland Esplanade, due to stepped failure and/or voids in fill associated with seawall/ retaining wall failure.	Unlikely	Medium	Low	Extremely Slow* (<15mm/yr)	8.93E-08	2.68E-07	21
Cliff Top Shepherds Hill-Strzelecki Lookout (Northern portion of the Proposed Memorial Walk)	13	Cliff top erosion/failure undermines/damages proposed raised walkway and/or viewing platform (Memorial Walk)	Unlikely	Minor	Low	Very Slow* (15mm-1.6m/yr)	5.80E-08	3.48E-07	22
Cliff top Trig Stn, Shepherds Hill (Southern portion of the Proposed Memorial Walk)	14a	Cliff top erosion/failure undermines/damages proposed Cliff top saftey barrier (Memorial Walk)	Unlikely	Minor	Low	Very Slow* (15mm-1.6m/yr)	1.49E-08	8.93E-08	23
Obelisk Hill, Tennis Courts	22	South Face: Rock fall/ debris slide due to weathering and 'root jacking' impacts or partially blocks access to Tennis Courts	Unlikely	Minor	Low	Very Rapid (5m/sec to 3m/min)	6.70E-09	2.01E-08	24
Nobbys Headland	3	Cliff-top failure/ erosion/regression damages existing structures (historical and contemporary structures); assumed design life of 120 years	Unlikely	Minor	Low	Very Slow* (15mm-1.6m/yr)	3.72E-09	1.49E-08	25
South Newcastle Cliff	8	Rock fall/ landslide from cliff/slope penetrates rock fall barrier fence and then impacts and/ or partially blocks Bathers Way / Shortland Esplanade pavement	Barely Credible	Minor	Very Low	Very Rapid (5m/sec to 3m/min)	8.93E-12	2.68E-11	26

APPENDIX C: LANDSLIDE RISK ASSESSMENT

QUALITATIVE TERMINOLOGY FOR USE IN ASSESSING RISK TO PROPERTY

QUALITATIVE MEASURES OF LIKELIHOOD

Approximate Annual Probability		**Implied Indicative Landslide Recurrence Interval**		**Description**	**Descriptor**	**Level**
Indicative Value	**Notional Boundary**					
10^{-1}	$5x10^{-2}$	10 years	20 years	The event is expected to occur over the design life.	ALMOST CERTAIN	A
10^{-2}	$5x10^{-3}$	100 years	200 years	The event will probably occur under adverse conditions over the design life.	LIKELY	B
10^{-3}	$5x10^{-4}$	1000 years	2000 years	The event could occur under adverse conditions over the design life.	POSSIBLE	C
10^{-4}	$5x10^{-5}$	10,000 years	20,000 years	The event might occur under very adverse circumstances over the design life.	UNLIKELY	D
10^{-5}	$5x10^{-6}$	100,000 years	200,000 years	The event is conceivable but only under exceptional circumstances over the design life.	RARE	E
10^{-6}		1,000,000 years		The event is inconceivable or fanciful over the design life.	BARELY CREDIBLE	F

Note: (1) The table should be used from left to right; use Approximate Annual Probability or Description to assign Descriptor, not *vice versa*.

QUALITATIVE MEASURES OF CONSEQUENCES TO PROPERTY

Approximate Cost of Damage		**Description**	**Descriptor**	**Level**
Indicative Value	**Notional Boundary**			
200%	100%	Structure(s) completely destroyed and/or large scale damage requiring major engineering works for stabilisation. Could cause at least one adjacent property major consequence damage.	CATASTROPHIC	1
60%	40%	Extensive damage to most of structure, and/or extending beyond site boundaries requiring significant stabilisation works. Could cause at least one adjacent property medium consequence damage.	MAJOR	2
20%	10%	Moderate damage to some of structure, and/or significant part of site requiring large stabilisation works. Could cause at least one adjacent property minor consequence damage.	MEDIUM	3
5%	1%	Limited damage to part of structure, and/or part of site requiring some reinstatement stabilisation works.	MINOR	4
0.5%		Little damage. (Note for high probability event (Almost Certain), this category may be subdivided at a notional boundary of 0.1%. See Risk Matrix.)	INSIGNIFICANT	5

Notes: (2) The Approximate Cost of Damage is expressed as a percentage of market value, being the cost of the improved value of the unaffected property which includes the land plus the unaffected structures.

(3) The Approximate Cost is to be an estimate of the direct cost of the damage, such as the cost of reinstatement of the damaged portion of the property (land plus structures), stabilisation works required to render the site to tolerable risk level for the landslide which has occurred and professional design fees, and consequential costs such as legal fees, temporary accommodation. It does not include additional stabilisation works to address other landslides which may affect the property.

(4) The table should be used from left to right; use Approximate Cost of Damage or Description to assign Descriptor, not vice versa

APPENDIX C: – QUALITATIVE TERMINOLOGY FOR USE IN ASSESSING RISK TO PROPERTY (CONTINUED)

QUALITATIVE RISK ANALYSIS MATRIX – LEVEL OF RISK TO PROPERTY

LIKELIHOOD		CONSEQUENCES TO PROPERTY (With Indicative Approximate Cost of Damage)				
	Indicative Value of Approximate Annual Probability	1: CATASTROPHIC 200%	2: MAJOR 60%	3: MEDIUM 20%	4: MINOR 5%	5: INSIGNIFICANT 0.5%
A – ALMOST CERTAIN	10^{-1}	VH	VH	VH	H	M or **L** (5)
B - LIKELY	10^{-2}	VH	VH	H	M	**L**
C - POSSIBLE	10^{-3}	VH	H	M	M	**VL**
D - UNLIKELY	10^{-4}	H	M	**L**	**L**	**VL**
E - RARE	10^{-5}	M	**L**	**L**	**VL**	**VL**
F - BARELY CREDIBLE	10^{-6}	**L**	**VL**	**VL**	**VL**	**VL**

Notes: (5) For Cell A5, may be subdivided such that a consequence of less than 0.1% is Low Risk.

(6) When considering a risk assessment it must be clearly stated whether it is for existing conditions or with risk control measures which may not be implemented at the current time.

RISK LEVEL IMPLICATIONS

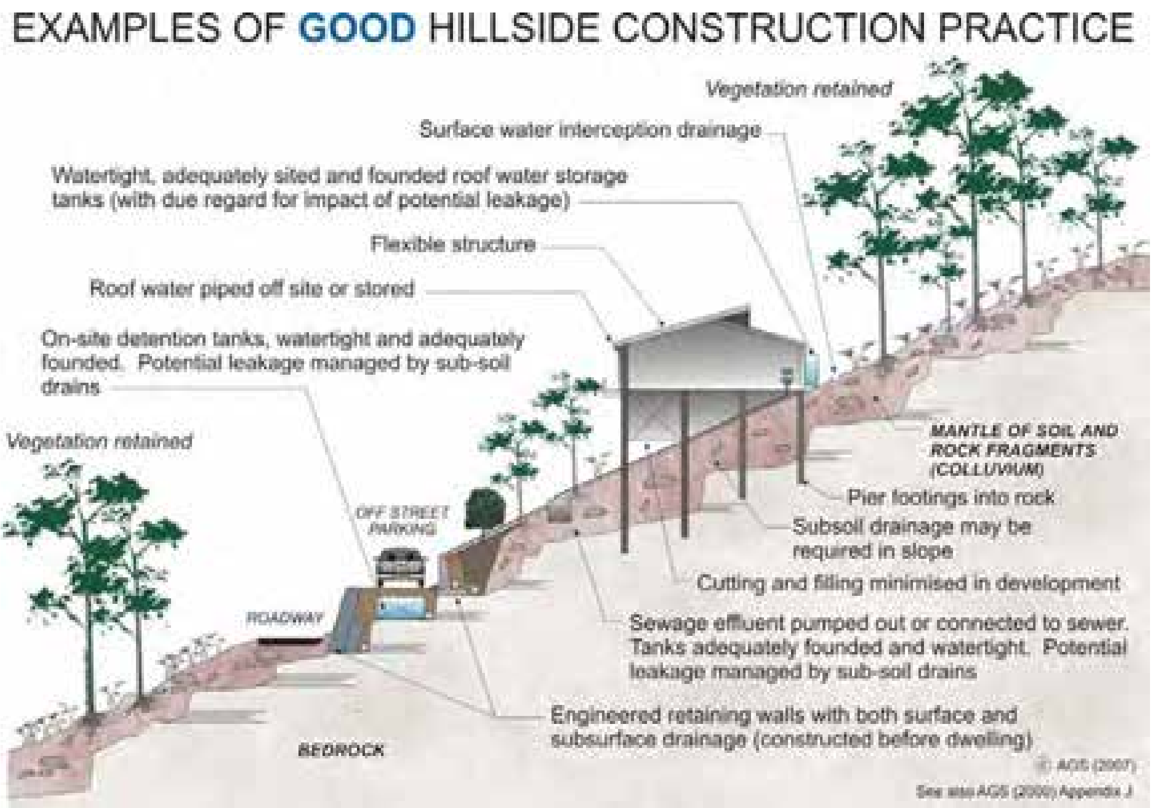
Risk Level		**Example Implications** (7)
VH	VERY HIGH RISK	Unacceptable without treatment. Extensive detailed investigation and research, planning and implementation of treatment options essential to reduce risk to Low; may be too expensive and not practical. Work likely to cost more than value of the property.
H	HIGH RISK	Unacceptable without treatment. Detailed investigation, planning and implementation of treatment options required to reduce risk to Low. Work would cost a substantial sum in relation to the value of the property.
M	MODERATE RISK	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. Treatment options to reduce to Low risk should be implemented as soon as practicable.
L	LOW RISK	Usually acceptable to regulators. Where treatment has been required to reduce the risk to this level, ongoing maintenance is required.
VL	VERY LOW RISK	Acceptable. Manage by normal slope maintenance procedures.

Note: (7) The implications for a particular situation are to be determined by all parties to the risk assessment and may depend on the nature of the property at risk; these are only given as a general guide.

AUSTRALIAN GEOGUIDE LR8 (CONSTRUCTION PRACTICE)

HILLSIDE CONSTRUCTION PRACTICE

Sensible development practices are required when building on hillsides, particularly if the hillside has more than a low risk of instability (GeoGuide LR7). Only building techniques intended to maintain, or reduce, the overall level of landslide risk should be considered. Examples of good hillside construction practice are illustrated below.



WHY ARE THESE PRACTICES GOOD?

Roadways and parking areas - are paved and incorporate kerbs which prevent water discharging straight into the hillside (GeoGuide LR5).

Cuttings - are supported by retaining walls (GeoGuide LR6).

Retaining walls - are engineer designed to withstand the lateral earth pressures and surcharges expected, and include drains to prevent water pressures developing in the backfill. Where the ground slopes steeply down towards the high side of a retaining wall, the disturbing force (see GeoGuide LR6) can be two or more times that in level ground. Retaining walls must be designed taking these forces into account.

Sewage - whether treated or not is either taken away in pipes or contained in properly founded tanks so it cannot soak into the ground.

Surface water - from roofs and other hard surfaces is piped away to a suitable discharge point rather than being allowed to infiltrate into the ground. Preferably, the discharge point will be in a natural creek where ground water exits, rather than enters, the ground. Shallow, lined, drains on the surface can fulfil the same purpose (GeoGuide LR5).

Surface loads - are minimised. No fill embankments have been built. The house is a lightweight structure. Foundation loads have been taken down below the level at which a landslide is likely to occur and, preferably, to rock. This sort of construction is probably not applicable to soil slopes (GeoGuide LR3). If you are uncertain whether your site has rock near the surface, or is essentially a soil slope, you should engage a geotechnical practitioner to find out.

Flexible structures - have been used because they can tolerate a certain amount of movement with minimal signs of distress and maintain their functionality.

Vegetation clearance - on soil slopes has been kept to a reasonable minimum. Trees, and to a lesser extent smaller vegetation, take large quantities of water out of the ground every day. This lowers the ground water table, which in turn helps to maintain the stability of the slope. Large scale clearing can result in a rise in water table with a consequent increase in the likelihood of a landslide (GeoGuide LR5). An exception may have to be made to this rule on steep rock slopes where trees have little effect on the water table, but their roots pose a landslide hazard by dislodging boulders.

Possible effects of ignoring good construction practices are illustrated on page 2. Unfortunately, these poor construction practices are not as unusual as you might think and are often chosen because, on the face of it, they will save the developer, or owner, money. You should not lose sight of the fact that the cost and anguish associated with any one of the disasters illustrated, is likely to more than wipe out any apparent savings at the outset.

ADOPT GOOD PRACTICE ON HILLSIDE SITES

AUSTRALIAN GEOGUIDE LR8 (CONSTRUCTION PRACTICE)

WHY ARE THESE PRACTICES POOR?

Roadways and parking areas - are unsurfaced and lack proper table drains (gutters) causing surface water to pond and soak into the ground.

Cut and fill - has been used to balance earthworks quantities and level the site leaving unstable cut faces and added large surface loads to the ground. Failure to compact the fill properly has led to settlement, which will probably continue for several years after completion. The house and pool have been built on the fill and have settled with it and cracked. Leakage from the cracked pool and the applied surface loads from the fill have combined to cause landslides.

Retaining walls - have been avoided, to minimise cost, and hand placed rock walls used instead. Without applying engineering design principles, the walls have failed to provide the required support to the ground and have failed, creating a very dangerous situation.

A heavy, rigid, house - has been built on shallow, conventional, footings. Not only has the brickwork cracked because of the resulting ground movements, but it has also become involved in a man-made landslide.

Soak-away drainage - has been used for sewage and surface water run-off from roofs and pavements. This water soaks into the ground and raises the water table (GeoGuide LR5). Subsoil drains that run along the contours should be avoided for the same reason. If felt necessary, subsoil drains should run steeply downhill in a chevron, or herring bone, pattern. This may conflict with the requirements for effluent and surface water disposal (GeoGuide LR9) and if so, you will need to seek professional advice.

Rock debris - from landslides higher up on the slope seems likely to pass through the site. Such locations are often referred to by geotechnical practitioners as "debris flow paths". Rock is normally even denser than ordinary fill, so even quite modest boulders are likely to weigh many tonnes and do a lot of damage once they start to roll. Boulders have been known to travel hundreds of metres downhill leaving behind a trail of destruction.

Vegetation - has been completely cleared, leading to a possible rise in the water table and increased landslide risk (GeoGuide LR5).

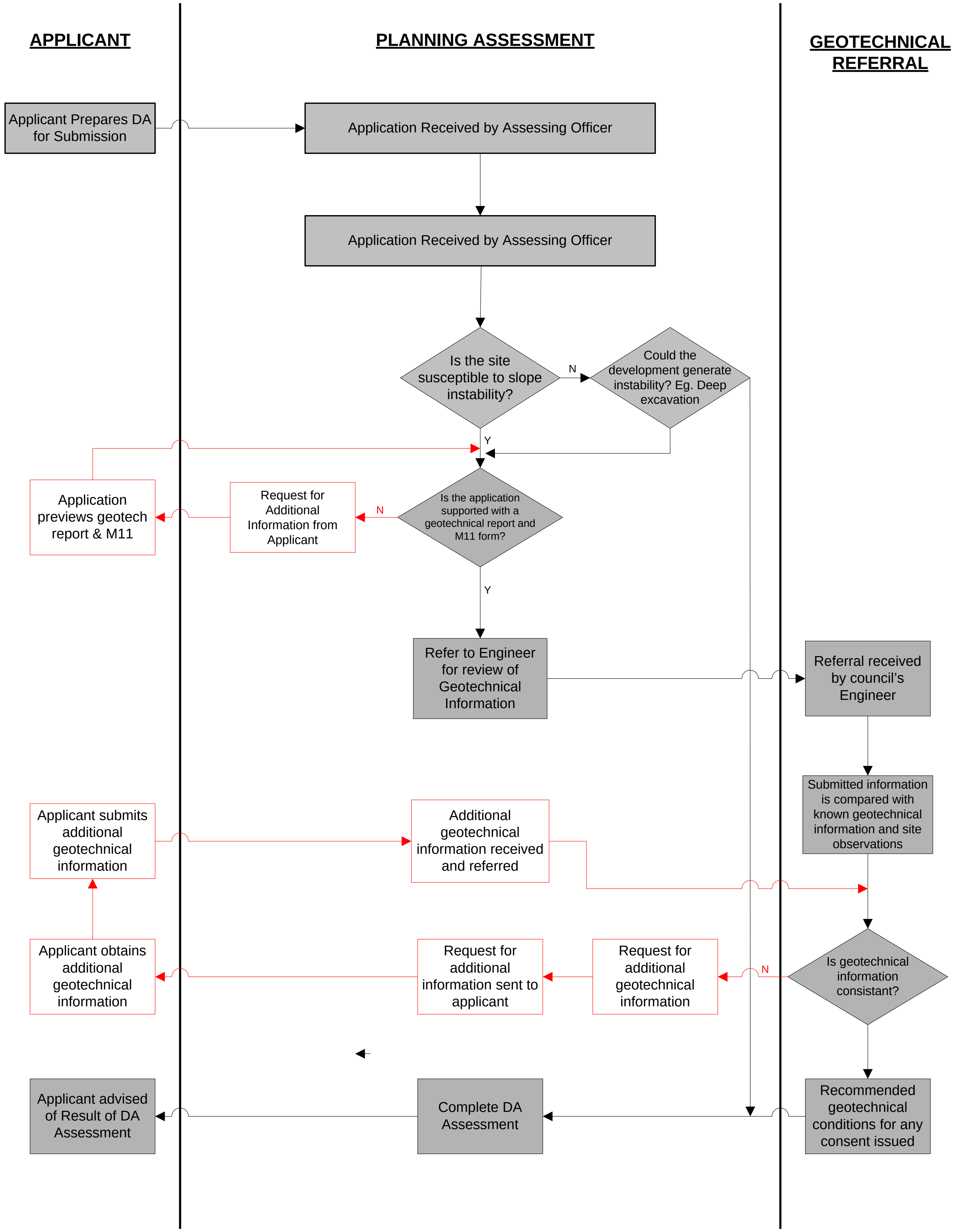
DON'T CUT CORNERS ON HILLSIDE SITES - OBTAIN ADVICE FROM A GEOTECHNICAL PRACTITIONER

More information relevant to your particular situation may be found in other Australian GeoGuides:

- GeoGuide LR1 - Introduction
- GeoGuide LR2 - Landslides
- GeoGuide LR3 - Landslides in Soil
- GeoGuide LR4 - Landslides in Rock
- GeoGuide LR5 - Water & Drainage
- GeoGuide LR6 - Retaining Walls
- GeoGuide LR7 - Landslide Risk
- GeoGuide LR9 - Effluent & Surface Water Disposal
- GeoGuide LR10 - Coastal Landslides
- GeoGuide LR11 - Record Keeping

The Australian GeoGuides (LR series) are a set of publications intended for property owners; local councils; planning authorities; developers; insurers; lawyers and, in fact, anyone who lives with, or has an interest in, a natural or engineered slope, a cutting, or an excavation. They are intended to help you understand why slopes and retaining structures can be a hazard and what can be done with appropriate professional advice and local council approval (if required) to remove, reduce, or minimise the risk they represent. The GeoGuides have been prepared by the Australian Geomechanics Society, a specialist technical society within Engineers Australia, the national peak body for all engineering disciplines in Australia, whose members are professional geotechnical engineers and engineering geologists with a particular interest in ground engineering. The GeoGuides have been funded under the Australian governments' National Disaster Mitigation Program.

AGS 2011 LANDSLIDE RISK MANAGEMENT - DEVELOPMENT ASSESSMENT FLOW CHART



Appendix C

Cliff Line Regression Photograph Sets

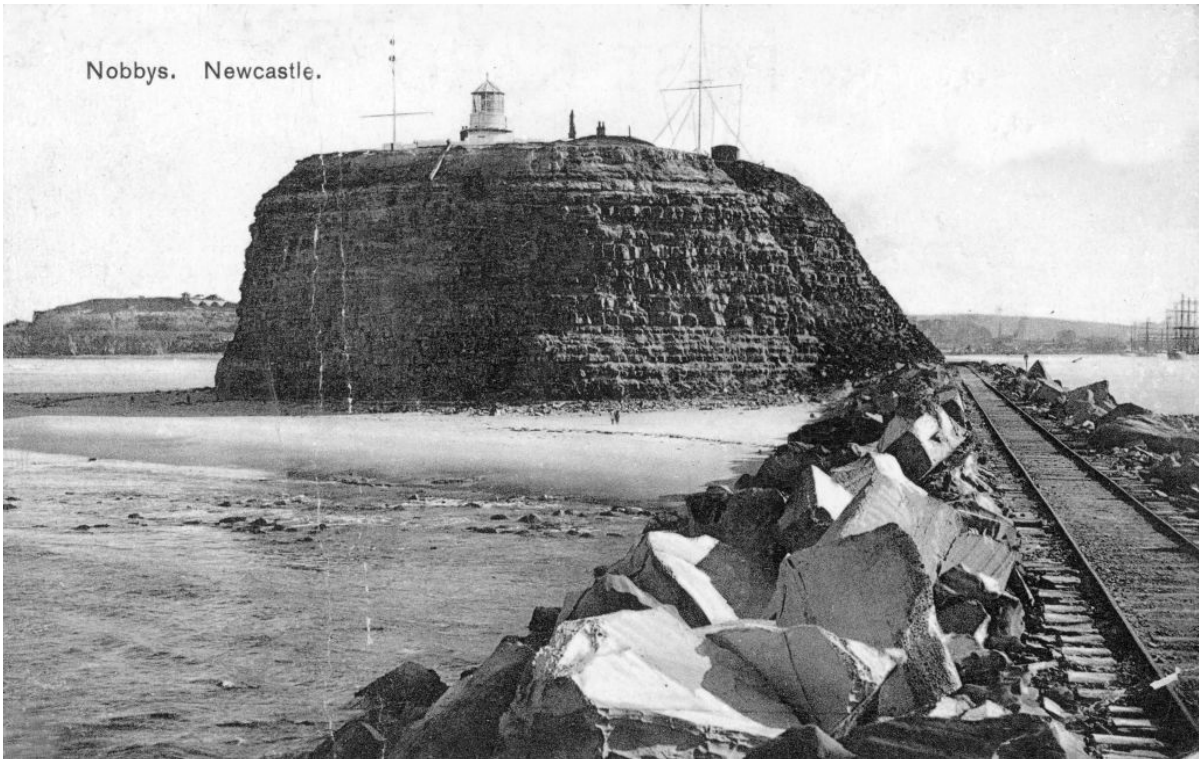


Figure 1 *Nobbys headland from the breakwater, approx 1900 and 2012. Areas of apparent cliff line regression circled.*

Figure 2 *Nobbys Headland from the south: 1887, 1998 and 2011 (from top). Evidence of apparent cliff line regression circled.*

Figure 3a *Signal Hill - South Newcastle 1907, cliff face pathway circled*

Figure 3b Signal Hill - South Newcastle 1998. Note the 1907 cliff face pathway is now barely discernible in the circled area.

Figure 3c *South Newcastle & Signal Hill headland: 1907, 1998, 2012 (from top).*
South Newcastle cliff face extensively re-shaped in 2005 as part of cliff stabilisation works.

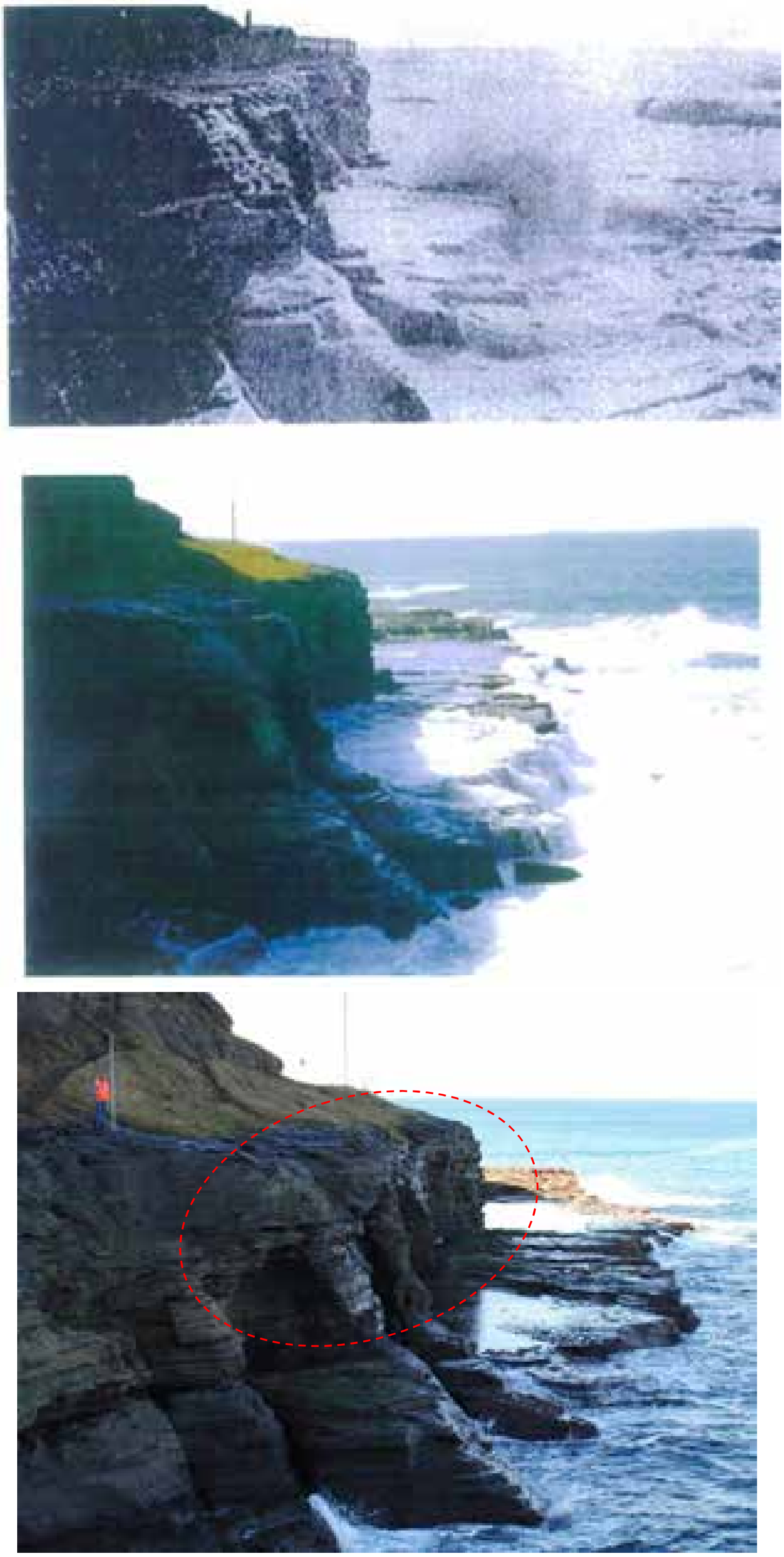


Figure 4 *Bogie Hole: 1908, 1998, 2011 looking north (from top). Area of apparent cliff line regression circled.*

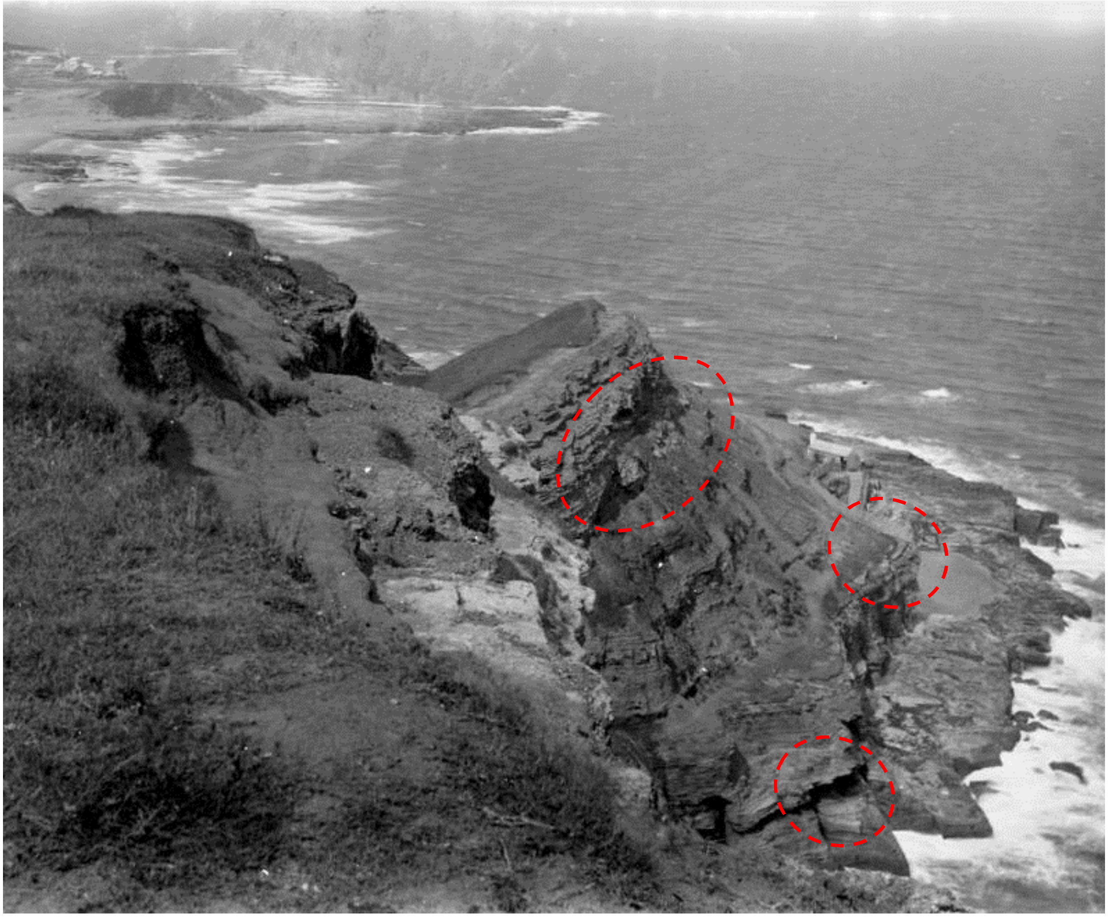


Figure 5a *Cliff/slope above Bogey Hole: 1896 looking north*

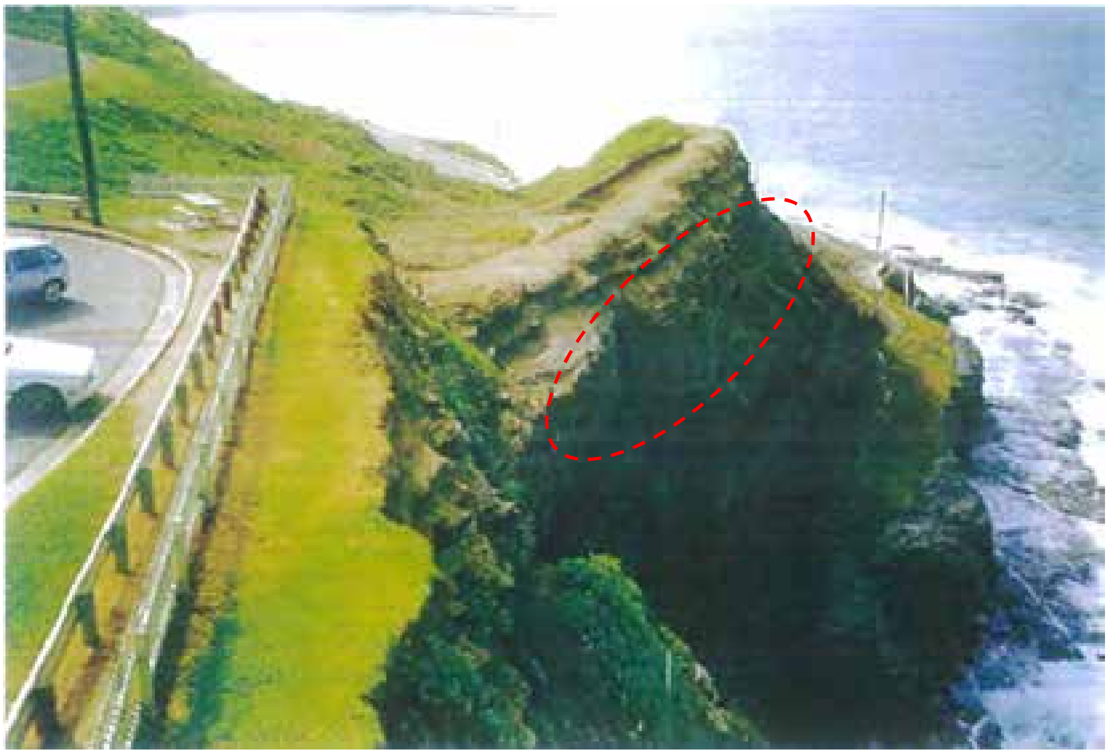


Figure 5b *Cliff/slope above Bogey Hole: 1998 looking north*

Figure 5c *Cliff/slope above Bogey Hole: 1896, 1998 & 2011 looking north. Areas of apparent cliff line regression circled.*

Figure 6 *Eroded ridge from Strezlecki to Shepherds Hill: 1900, 1998, 2012. Areas of apparent cliff top regression circled.*

Figure 7 *Shepherds Hill, south towards Bar Beach: 1998, 1900 & 2011 (clockwise from top left). Area of apparent cliff line regression, circled.*

Feb 1999 wooden steps down to SGB beach still intact,

August 2001 wooden stairs to SGB destroyed by a rock slide.

Figure 8 *Site of destroyed wooden steps (circled) above Susan Gilmore Beach in 2012*

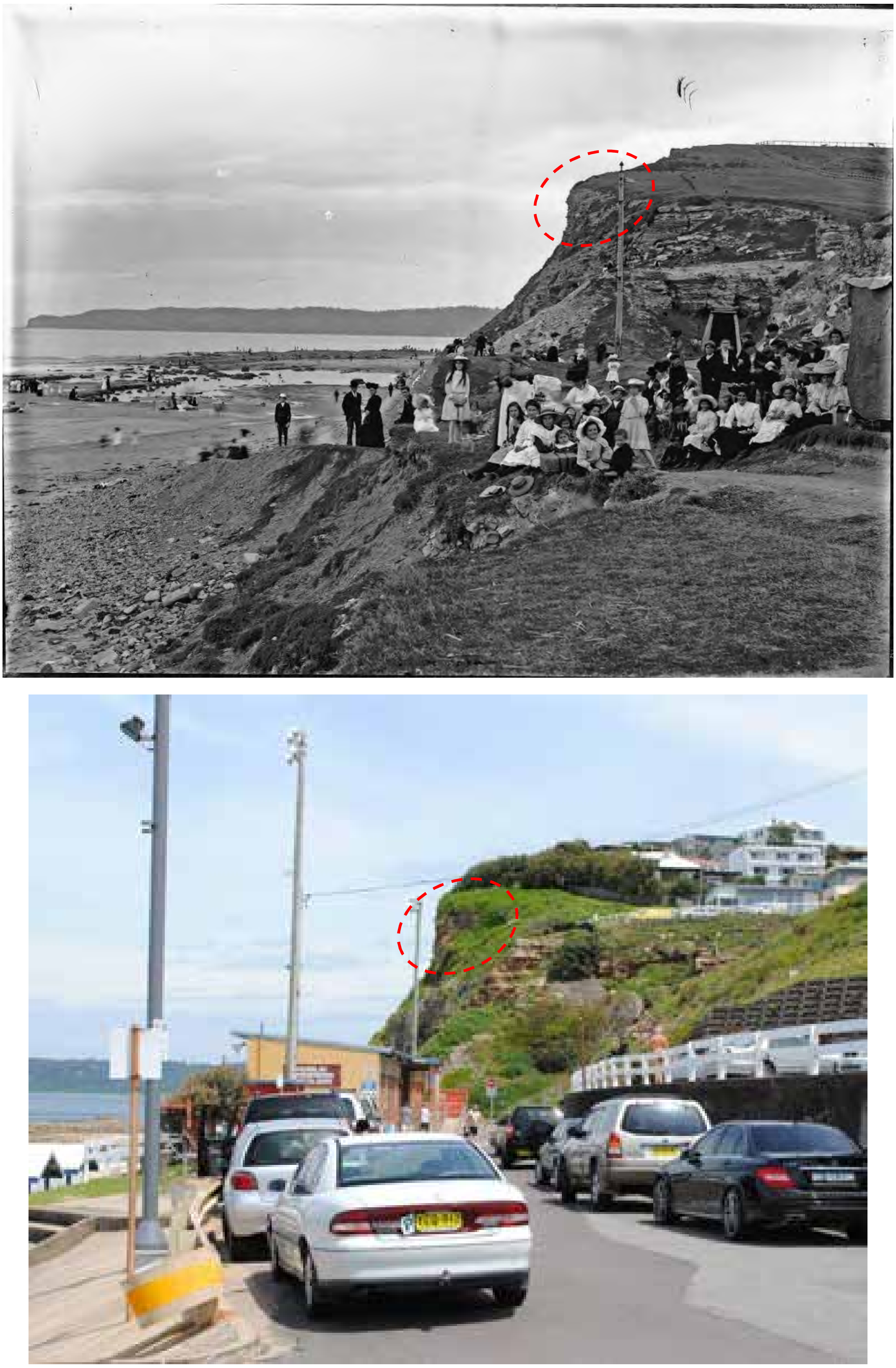


Figure 9 *Looking south at Lloyd St Merewether cliff, approx 1900 and 2012. Area of apparent cliff top regression circled.*

Appendix D

Photographs Illustrating Projected Sea Level Rise

Figure 1 *Fort Scratchley's Eastern Sea Wall will be exposed to increased wave action, as shown 1½ hours past a 1.3m high tide, approximating BMT WBM modelled year 2100 mean sea level.*

Figure 2 *Risk Site #4 – Newcastle Baths inundated approximately 1½ hours past a 1.3m high tide; , approximating BMT WBM modelled year 2100 mean sea level.*

Figure 3 *Bogie Hole & South Newcastle sea wall subject to constant wave action; approximately 1¾ hours past a 1.3m high tide, approximating BMT WBM modelled year 2100 mean sea level.*

Figure 4 *Bogie Hole inundated by wave action, with loss of amenity approximately 1¾ hours past a 1.3m high tide; approximating BMT WBM modelled year 2100 mean sea level.*

Figure 5 *Rock Platform below Bar Beach Car Park & lookout, inundated, approximately 1¾ hours past a 1.3m high tide; approximating BMT WBM modelled year 2100 mean sea level.*

Figure 6 *Merewether Baths inundated with loss of amenity, approximately 2 hours before a 1.9m high tide. Illustrates BMT WBM modelled year 2100 mean sea level.*

Figure 7 *HWC Sewer inundated at sea levels approximating BMT WBM modelled year 2100 mean sea level – some vents at sea level allow pipeline to be flooded with sea water.*

Appendix E

EJE Memorial Cliff Top Walk Conceptual Drawings

MEMORIAL WALK

A CLIFF TOP WALK FOR NEWCASTLE

A CONCEPT FOR THE ERECTION OF A CLIFF TOP WALK FROM THE BOGEY HOLE AND KING EDWARD PARK ALONG MEMORIAL DRIVE TO BAR BEACH

IN COMMEMORATING THE 100 YEAR
ANNIVERSARY OF WORLD WAR I

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VIEW OF BRIDGE AND VIEW AREA

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MEMORIAL WALK A CLIFF TOP WALK FOR NEWCASTLE

VIEW OF BRIDGE AND VIEW AREA

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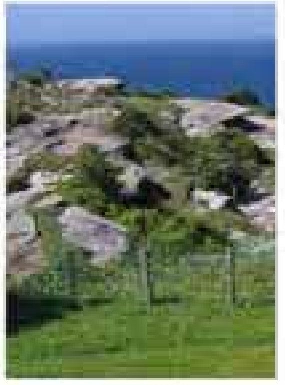
"FEDERATION WALK", SYDNEY

SYDNEY, AUSTRALIA'S LARGEST CITY AND ONLY A 100 KILOMETERS FROM NEWCASTLE IS WELL ENDOWED WITH NATURAL BEAUTY, NONE MORE SO THAN HER SPECTACULAR COAST LINE BOTH NORTH AND SOUTH OF THE HARBOUR.OVER THE YEARS THERE HAS BEEN A STEADY ADVANCEMENT AND IMPROVEMENT OF THIS GREAT SCENIC AMENITY, WITH THE CONSTRUCTION OF CLIFF AND BEACH HUGGING WALKS THAT PROVIDE THE VISITORS (BOTH LOCAL AND FROM ELSEWHERE) WITH SAFE AND EASY ACCESS.

THE COASTAL WALKS ON THE SOUTH SIDE OF SYDNEY EXTEND FROM BRONTE TO BONDI AND FROM NORTH BONDI TO VAUCLUSE.THE MORE SPECTACULAR OF THESE IS THE "FEDERATION WALK" WHICH WAS COMPLETED IN RECENT YEARS AND HAS SUCCESFULLY TACKLED THE ISSUES OF SAFETY AND COMFORT FOR THE USERS (PHOTOS ABOVE).

"In 1999 Waverley Council was successful in gaining a grant from the Commonwealth Government's Federation Community Projects Program, for a coastal walkway project marking Australia's Centenary of Federation.With Council funds and assistance from the State Government Metropolitan Greenspace Program (a Sydneycentric program), *the Walk was constructed over two stages, with an official opening in December 2004 by Premier Bob Carr. The walk links a series of previously undeveloped coastal clifftop reserves from Dover Heights to Vaucluse".* (FROM WAVERLEY COUNCIL WEB SITE).



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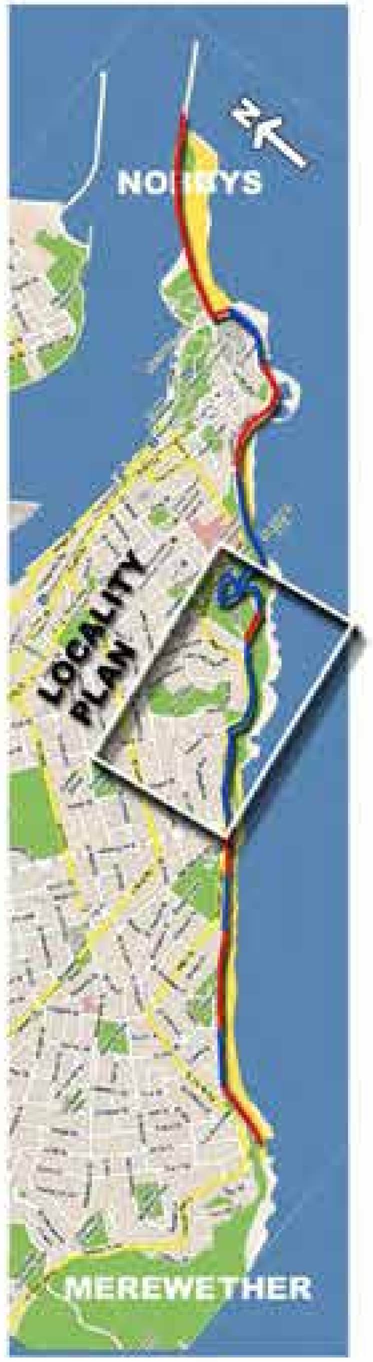
NEWCASTLE TOO, HAS SIMILAR COASTAL ATTRACTIONS, AND ARE IN PLACES WELL ACCESSED. RECENT EFFORTS HAVE BEEN MADE TO IMPROVE THE SAFETY AND AMENITY OF THE WALKS FROM SOUTH NEWCASTLE BEACH TO KING EDWARD PARK WITH PLANS FOR SAFE ACCESS TO THE BOGEY HOLE AT PRESENT UNDER CONSIDERATION.

ACCESS TO WW2 COASTAL DEFENCE AREAS AND SHEPHERD'S HILL COTTAGE ARE RESTRICTED OR ARE UNFORMED AND ARE UNSAFE.THE WALK ALONG THE TOP OF THE CLIFF FROM STRZELECKI LOOKOUT TO NORTH BAR BEACH ARE NOW IMPASSIBLE AND ARE EXTREMELY DANGEROUS (SOME BARRIERS ARE IN PLACE). THE PEDESTRIAN WAYS FROM BAR BEACH SOUTH TO MEREWETHER ARE IN GOOD ORDER AND ARE IN CONSTANT USE AT ALL HOURS AND IN ALL WEATHER CONDITIONS BY BOTH THE CASUAL WALKER AND BEACH GOER TO FITNESS ENTHUSIASTS.

SCENICALLY, THE MOST SPECTACULAR PORTION OF NEWCASTLE'S COAST WALK REMAINS CLOSED TO PUBLIC ACCESS. FROM THE CLIFF TOPS THE VIEWS OF NEWCASTLE ARE UNRIVALLED, THE VIEWS OF SELDOM VISITED AND MAINLY UNSEEN ROCK SHELVES AND INLETS AND STONEY BEACHES EASILY MATCH THOSE FOUND IN SYDNEY. THE PANORAMIC VIEWS OF SHIPS WAITING TO ENTER THE HARBOUR ARE UNIQUE TO NEWCASTLE.THE TRIG STATION IS HISTORICALLY IMPORTANT AS IT IS THE LOCATION WHERE NEWCASTLE ORIGINAL STREET LAYOUTS WERE REFERENCED.TO THE IMMEDIATE SOUTH ARE TWO GRASSED AREAS WHICH WOULD MAKE IDEAL PICNIC AREAS. THERE ARE AT PRESENT NO PICNIC OR TOILET AMENITIES AT ANY OF THESE LOCATIONS.

NEWCASTLE, AS THE STATE'S SECOND LARGEST CITY SHOULD BE ABLE TO BOAST WELL PRESENTED, ACCESSED AND SERVICED FACILITIES TO ITS NATURAL ASSETS INCLUDING THESE CLIFF WALKS WHICH ARE ONLY FIVE MINUTES DRIVE FROM THE CBD, ANOTHER ASPECT THAT IS UNIQUE TO NEWCASTLE.


FOOTPATHS ON ROAD
PATHWAYS



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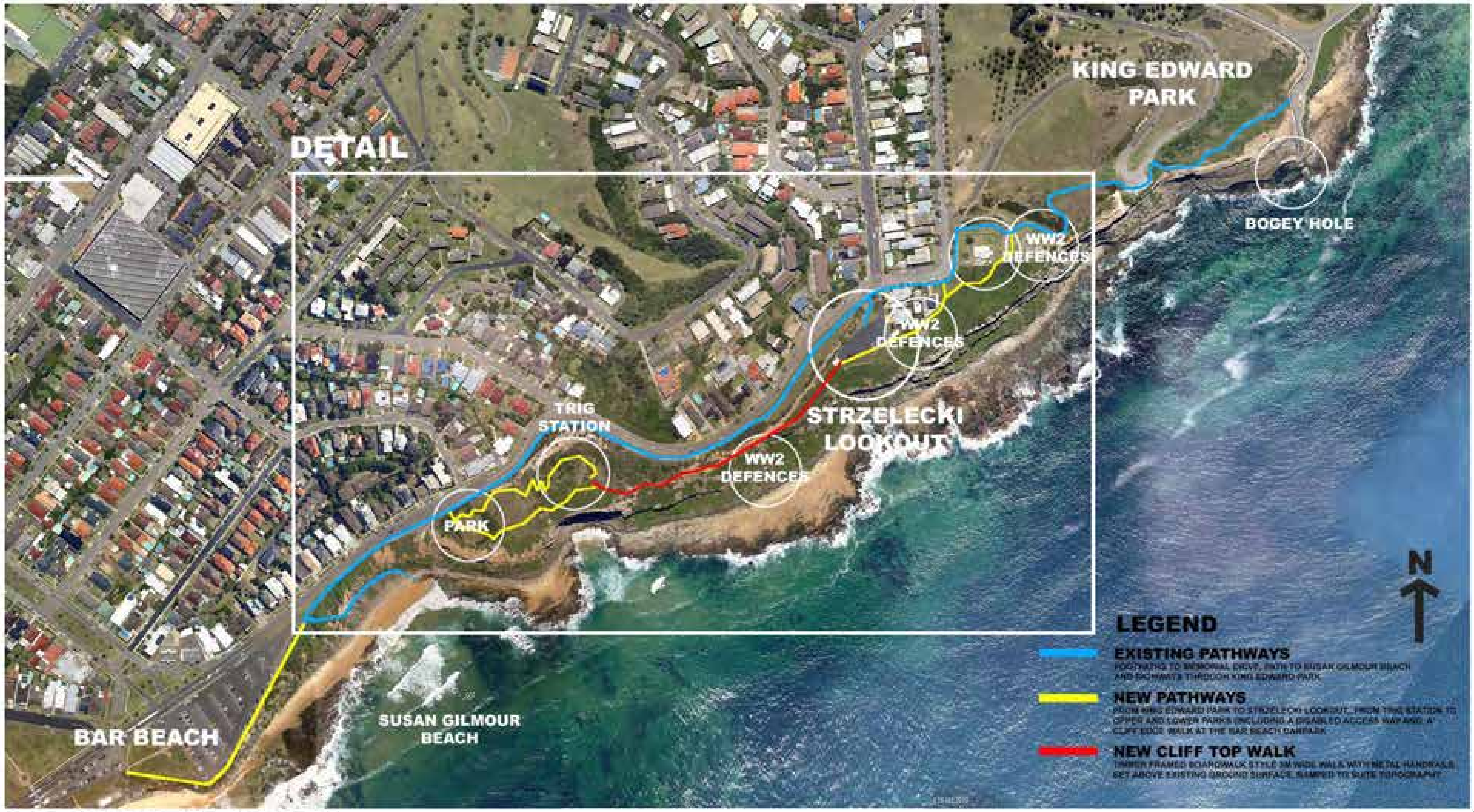
MEMORIAL WALK A CLIFF TOP WALK FOR NEWCASTLE



LOCALITY PLAN

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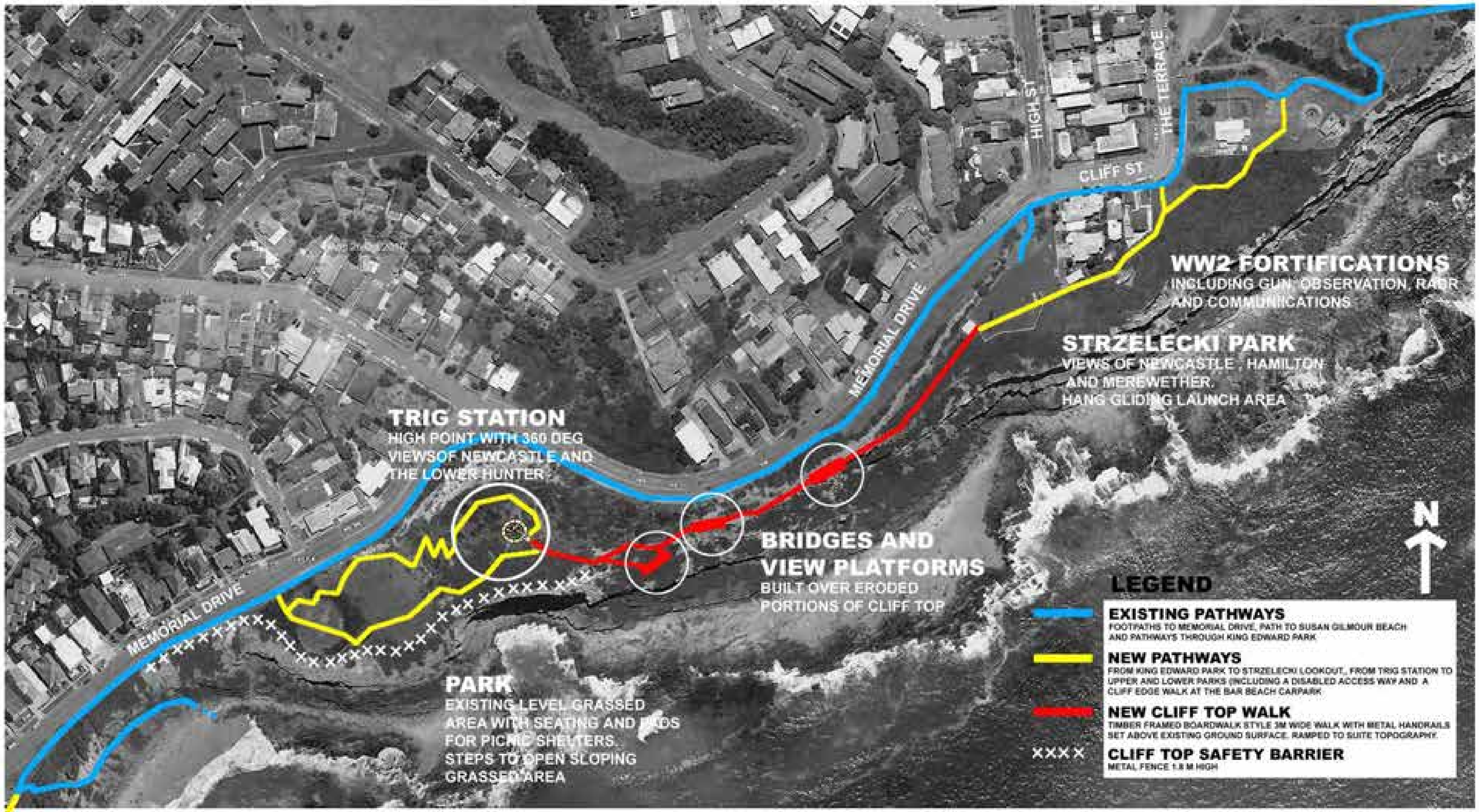
MEMORIAL WALK A CLIFF TOP WALK FOR NEWCASTLE



DETAIL

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MEMORIAL WALK A CLIFF TOP WALK FOR NEWCASTLE

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AERIAL VIEW

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MEMORIAL WALK A CLIFF TOP WALK FOR NEWCASTLE

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AERIAL FROM NORTH LOOKING TOWARD DUDLEY

MEMORIAL WALK A CLIFF TOP WALK FOR NEWCASTLE

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VIEW OF TYPICAL REST AREA

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MEMORIAL WALK A CLIFF TOP WALK FOR NEWCASTLE

VIEW FROM STRZELECKI LOOKOUT LOOKING SOUTH

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MEMORIAL WALK A CLIFF TOP WALK FOR NEWCASTLE

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BMT WBM Denver	**8200 S. Akron Street, Unit 120** **Centennial Denver Colorado 80112 USA** **Tel +1 303 792 9814 Fax +1 303 792 9742** **Email denver@bmtwbm.com** **Web www.bmtwbm.com.au**
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