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Kempsey Coastal Processes and Hazards Definition Study

Final Report June 2013

KEMPSEY
Shire Council

Kempsey Coastal Processes and Hazards Definition Study

Prepared For:	Kempsey Shire Council
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Title :	Kempsey Coastal Processes and Hazards Definition Study
Author :	Verity Rollason
Synopsis :	This Kempsey Coastal Processes and Hazards Definition Study Report presents a summary of coastal processes and then provides the methodology and outcomes for the definition of coastal hazards affecting the Kempsey LGA coastline. The likelihood ('almost certain', 'unlikely' and 'rare') of beach erosion and shoreline recession, and separately, coastal inundation have been mapped for the immediate, 2050 and 2100 horizons.

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1 INTRODUCTION

This report, the Kempsey Coastal Processes and Hazards Definition Study, describes the coastal processes and interactions operating on the Kempsey Local Government Area (LGA) coastline (the Kempsey coastline) and the extent of the coastal hazards arising from these processes. This report documents a summary of coastal processes, the methodology used to assess the coastal hazards, approach to hazards definition mapping, and a beach by beach summary of analyses and outcomes (focussing on the coastal villages of Kempsey).

The report was prepared in accordance with the former Coastline Management Manual (CMM) (NSW Government, 1990) and the new Guidelines for Preparing Coastal Zone Management Plans (DECCW, 2010). The report documents the coastline structure in terms of regional geology and geomorphology and coastal processes in terms of wave climate, water levels, wind processes, and projected climate change. The interactions between all of these factors governs waterborne longshore and cross shore sediment transport and windborne transport to shape the coastline evident today.

The report also outlines the methodology used to assess coastal hazards relevant to Kempsey's coastline. This includes our approach to beach erosion incorporating wave climate variability and the use of the "world's best practice" Shoreline Evolution Model to assess shoreline recession due to sea level rise and shoreline structures (e.g. headlands, river breakwaters, reefs).

In accordance with the NSW Government's Guidelines for Preparing Coastal Zone Management Plans, a risk based approach using the Australian Standard Risk Management Principles and Guidelines (AS/NZS ISO 31000:2009) has been adopted for defining hazards for this study. In order to transparently account for the uncertainty in hazards estimates, the likelihood of the beach erosion and recession and inundation hazards was defined. Following the Australian Standard Risk Management Principles and Guidelines (AS/NZS ISO 31000:2009), a likelihood scale of 'almost certain', 'likely', 'possible', 'unlikely' and 'rare' was adopted (although only 'almost certain', 'unlikely' as a best estimate and 'rare' as a worst case have been mapped).

As given in ISO 31000:2009, the level of risk is the combination of the 'likelihood' and 'consequence'. The Kempsey Coastal Processes and Hazards Definition study provides the essential information regarding coastal hazards and their current and future likelihood, for use in land use planning and preparation of a Coastal Zone Management Plan. Within the risk assessment framework, the definition of the 'consequences' of coastal hazards would be undertaken during the Coastal Zone Management Plan phase for the Kempsey coast. The outcomes of the risk approach may be used to guide land use planning as appropriate to the level of risk from coastal hazards in each beach compartment.

1.1 Study Area

The coastal zone of the Kempsey Local Government Area (LGA) extends from just north of Point Plomer in the south (including Big Hill) to just north of Middle Head in the north (including Middle Head Beach). The study area is illustrated in Figure 1-1 and Figure 1-2.

The width of the study area includes marine areas extending from offshore to the land and including beaches, dunes, headlands, bluffs, inside the coastal entrances and extending inland as far as applicable to determining coastal processes and hazards extents.

Key locations of interest for this Kempsey Coastal Processes and Hazards Definition Study include:

- The beaches associated with the coastal villages of Crescent Head, Hat Head, South West Rocks, Stuarts Point (including agricultural lands to the south at Fishermans Reach on the Macleay Arm) and Grassy Head;
- Flood mitigation structures including Big Hill outlet, Ryan's Cut flood outlet and structures on Killick and Korogoro Creeks; and
- Trial Bay Breakwall and the Macleay River entrance and their interaction with coastal processes.

1.2 The Coastal Zone Management Process in NSW

Coastal management in New South Wales is directly guided by the NSW *Coastal Protection Act 1979* (including 2002, 2010 and 2012 amendments), with further guidance from *NSW Coastal Policy* (1997), , *State Environment Planning Policy No. 71 – Coastal Protection*, and the *Environmental Planning and Assessment Act 1979* (including 2010 amendments). 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) and the *Coastal Design Guidelines for NSW* (2003).

Requirements for the preparation of coastal zone management plans are outlined within the *Guidelines for Preparing Coastal Zone Management Plans* (DECCW, 2010) (CZMP Guidelines), which replace the former Coastline Management Manual (NSW Government, 1990). At the time of the project commencement, the Coastline Management Manual was the guideline document and as such, this Coastal Hazards Definition Study has been formulated in accordance with both manuals. The key change in the CZMP Guidelines (and supported by other NSW guideline documents) is the direction to adopt a risk-based approach to coastal management. A risk-based approach incorporates the uncertainty in hazards definition and provides for prioritisation of management resources towards the greatest risks in the coastal zone.

The process to be followed in preparing Coastal Zone Management Plans is given below. This study forms Step 2 in the process, being the preparation of a Coastal Processes and Hazards Definition Study for the Kempsey LGA coastline.

1. Establish a Coastline Management Committee;
2. **Conduct a Coastal Processes and Hazards Definition Study to specifically identify and quantify hazards affecting the coastal area**;
3. Prepare a Coastal Zone Management Study to consider all feasible management options whilst also assessing the social, economic, aesthetic, recreational and ecological issues associated with land use of the area;
4. Prepare a Coastal Zone Management Plan consisting of the best combination of options for reducing the risks from coastal hazards, including the preparation of a strategy to implement the Plan and review the Plan through public exhibition and consultation,

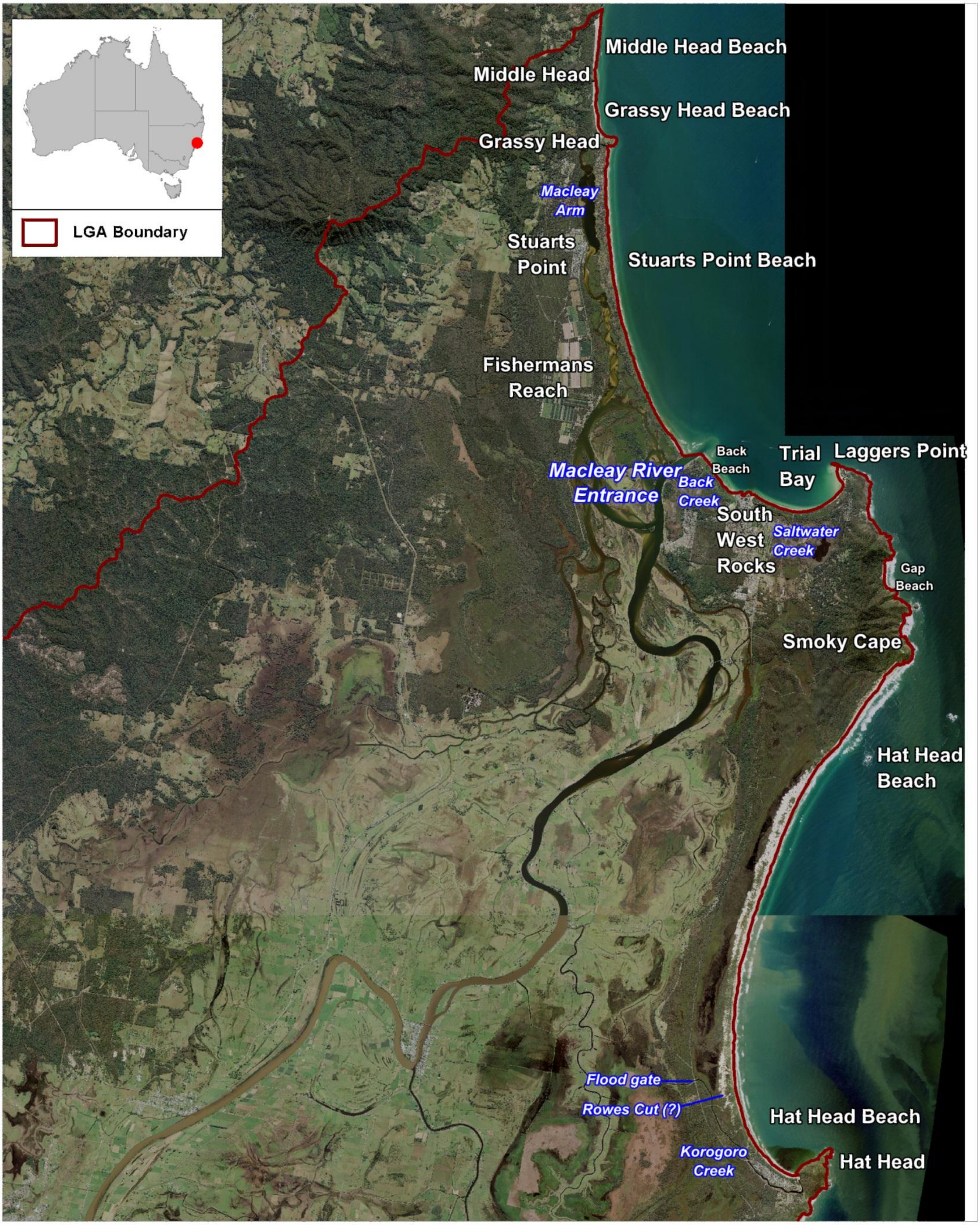
5. Council to adopt the Plan (noting that approval of CZMPs by the Minister for the Environment in accordance with Part 4A of the *Coastal Protection Act 1979* has been put on hold awaiting changes to the coastal management process by the NSW Government);
6. Implement the approved Coastal Zone Management Plan; and
7. Review the Coastal Zone Management Plan on a regular basis (5-10 years), to enable continued update and review of coastal risks and management measures (e.g. such as incorporating the latest sea level rise projections).

1.3 Project Objectives

The key objective of this study is to provide definition of likely hazards impacts relating to coastal processes, which shall inform the preparation of a Coastal Zone Management Plan for the Kempsey LGA coastline. The Coastal Zone Management Plan shall provide appropriate guidance on managing existing and future risks from coastal hazards. Therefore, this Coastal Processes and Hazards Definition study provides the technical information on hazard likelihood from which management actions can be formed, within a risk-based approach.

Objectives specific to the Kempsey LGA coastline also include:

- **To describe the coastal processes and interactions acting along Kempsey's coastline**, which shall include description and mapping of beaches, dunes and headlands, the geology and geomorphology of the coastline including the location of coastal protection and other man-made structures, and interactions between river and creek entrances and flood mitigation outlets with open coastal processes;
- **Identify and map the potential extent of coastal hazards for the current year, 2050 and 2100 timeframes**, focusing on the coastal villages (Crescent Head, Hat Head, South West Rocks, Stuarts Point, Grassy Head) and flood protection structures, and accounting for the performance and interaction of coastal processes with man-made protection and other structures (Macleay River Entrance, Trial Bay Breakwall);
- **Map the properties (including residential and commercial) and infrastructure within each hazard area**; and
- **Identify areas that may be subject to cliff instability for further investigation**.



Title:
Kempsey Coastline Study Area - North

Figure: 1-1

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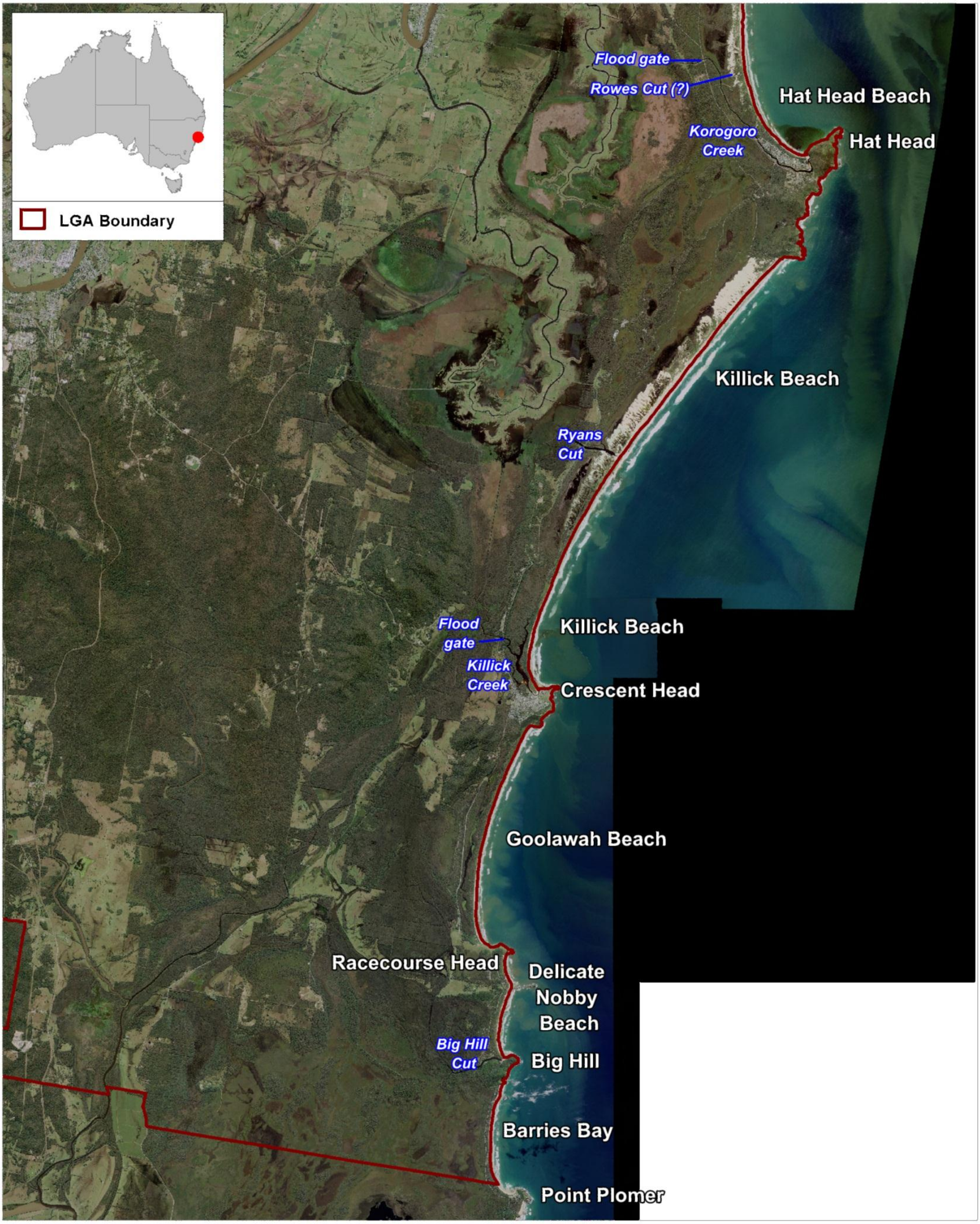

Title:

Kempsey Coastline Study Area - South

Figure: 1-2

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Approx. Scale

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2 SUMMARY OF COASTAL PROCESSES

2.1 Introduction

The geologic framework and coastal processes that have interacted to shape the morphology of the Kempsey regional coastline are described in this chapter. All of the coastal processes are related to or interact with each other to some degree and such interactions are described as required.

2.2 Regional Geology and Geomorphology

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 waves, tides and sea level changes with regional geology determines the shape of past, present and future shorelines and coastal barriers.

Broadly, the NSW coast is described as being strongly controlled by bedrock, which outcrops as headlands, rock platforms and cliffs. From south to north along the NSW coastline there is a general increase in the embayment length as there are fewer bedrock outcrops / headlands, and so, an increase in the length and width of Quaternary barrier deposits (that is, beaches and dunes) (Troedson *et al.,*2004).

The Kempsey coastline lies within the New England Fold Belt. Bedrock along the coastal zone forming headlands, reefs and other rock outcrops includes: lithic sandstones, mudstone, pebbly sandstone and minor conglomerate of the Kempsey Beds forming Middle Head, Grassy Head and part of Smokey Cape: an outcrop on New England granites (Smokey Cape Adamellite) at Laggers Point extending around 2.5 km south; massive conglomerate (Hat Head sediments) at Hat Head; massive and laminated sandstones, siltstone and conglomerate at Crescent Head; and Touchwood Formation siltstone, sandstone, paraconglomerates and basaltic breccia at Racecourse Head, Delicate Nobby, Big Hill and Point Plomer. All of these rock types are of Permian Age (250 – 300 million years ago), except for the Touchwood Formation at the southern boundary of the LGA, of Devonian Age (370 – 415 million years ago) (Troedson *et al.,* 2004).

The age and extent of coastal barrier formation reflects sea level rise from the past to present. A prior sea level high stand occurred during the Pleistocene around 120,000 years ago (the Last Interglacial period, 117,000 to 133,000 yr BP). At this time, sea levels were around 5 m above their present levels (Troedson *et al.*,2004). The last glacial period between 25,000 and 15,000 years ago saw sea levels around 110-130 m below their present level. After this, sea levels rose rapidly and reached the present level around 6,500 years ago, in the Holocene period. Sea levels have remained within 1 to 2 m of their present levels since this time (Troedson *et al.,*2004).

Coastal sediment barriers evident on the NSW coast today have formed in response to both the Pleistocene and Holocene sea level high stands. Barriers formed during the Pleistocene are termed inner barrier deposits, having formed during higher sea levels than present, and are still evident in some locations along the NSW coast, particularly towards the north. The more recent Holocene beach barriers systems are typically termed the outer barrier (Troedson *et al.,*2004).

Troedson *et al*. (2004) note there are generally extensive dune fields and beach ridge plains of Pleistocene age, particularly south of South West Rocks (some of which mantles bedrock) and some areas north of the Macleay River.

PWD (1980) describe two barriers (presumably of different age), separated by swamp deposits north of the Macleay River. This demonstrates that during the Pleistocene, large quantities of marine sand accumulated in the Trial Bay embayment to form wide beach ridge barriers. Seaward of the Pleistocene barriers on the Kempsey coastline, the Holocene barriers forming the present shoreline are described as narrow (typically less than 500 m in width, although wider areas are evident particularly at the northern ends of Hat Head, Killick and Stuarts Point Beaches). The barriers exhibit beach and foredune deposits, but not extensive beach ridges that would suggest a period of progradation during the Holocene (PWD, 1980).

2.2.1 Shelf Profile and Nearshore Sediments

The width and slope of the continental shelf affects the dissipation and shoaling of waves as they are transformed from deep water into the nearshore zone. The continental shelf of NSW is the narrowest continental margin along the entire Australian coast (Short, 2007). The width of the continental shelf in NSW typically ranges between 25 to 50 km and tends to increase in width from south to north (Roy, 2001).

For the Kempsey coastline, the only available bathymetric data is available from Australian hydrographic survey charts (AusChart 811 Crowdy to Nambucca Heads). From this data, the slope of the continental slope is found to be 1:140 on average in the study area. The width of the continental shelf (from 20 – 100 m water depth) is on average ~ 15 km from the coastline. In terms of the NSW Coast, Smoky Cape is relatively prominent as one of the more easterly headland features, and the width of the continental shelf is relatively narrow around this point. The nearshore slope between 0 and 20 m water depths, again using the AusChart data, is on average 1:70. The nearshore slope is consistent with the Nambucca region to the north of Kempsey, which is typically reported to have nearshore profiles of 1:60 to 1:70 slope (SMEC, 2009).

Along the NSW coast, marine sediments are predominantly quartzose sands, rounded in shape, with a variable content of shell material. The quartzose sands were originally derived from the erosion of bedrock on land, which has subsequently experienced prolonged reworking in the marine environment during previous glacial and inter-glacial periods (Troedson *et al.,*2004). That is, rather than being supplied from the land, the marine sediments evident on the coast today were derived from the continental shelf, as sea levels rose during marine transgressions and coastal barriers migrated landwards into their present embayments, a process termed shoreface retreat (Roy, 2001).

The nearshore or shoreface refers to the region extending from the beach barrier out to around 20 to 30 m water depth. There are marked difference in sand types and bed morphology at this water depth that indicate the boundary between the nearshore zone and the inner continental shelf sediments (Roy, 2001).

The inner continental shelf sand unit extends from 20 to 60 m water depth, and is particularly recognisable as iron-stained sand. The inner continental shelf sands can be mobilised in large quantities during large coastal storm events, however, net sediment movement is small, roughly estimated at 1-4 m^3/year onshore per metre length of beach (Roy, 2001). Over geologic timescales (thousands of years) these residual movements have contributed sediment into the nearshore zone where it has been reworked shoreward to assist in the progradation (seaward growth) of coastal barriers since sea level stabilised 6,000 years ago (Roy, 2001). These rates of onshore supply are very much dependent upon local offshore sand reserves on the continental shelf and onshore barrier morphology. Given the ample sand reserves onshore at the longer embayments such as Hat Head and Crescent Head, it is reasonable to assume a small rate of onshore supply.

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.

In some field areas (for example, Coffs Harbour and Byron Bay), two sand units corresponding to the inner and outer nearshore zones are evident, while in other areas, the different units are poorly developed or absent (Roy, 2001). Nearshore sediment in the Trial Bay embayment is composed of very fine to medium grained marine sand (PWD, 1980). Seismic data from south of the Macleay River entrance in Trial Bay suggest nearshore sediment ranges in thickness from 6 to 18 m (PWD, 1980).

The boundary between inner and outer nearshore sands is commonly stated to be the “depth of closure” where the limit for the majority of sediment transport under wave action occurs. As noted above, wave action can mobilise sediment in water depths greater than this during large coastal storms, so often a second “depth of closure” to mark limit of nearshore sediment transport is also defined, typically taken to be the boundary of the nearshore zone (20-30 m water depth).

In general in NSW, fluvial sand from rivers and creeks is not presently reaching the coastal zone in sufficient quantity to contribute significantly to sediment supply (except from a few localised rivers on NSW’s south coast) (Roy, 2001). This is evidenced by an absence of fluvial sand in marine sediment samples from the nearshore zone. However, Roy (2001) suggests that for the very large rivers on the NSW North Coast, this may be in part due to the significant rates of longshore transport of marine sediments as much as low rates of fluvial supply.

There is evidence of a minor accumulation of fluvial sediment at the Macleay River entrance in the form of a river mouth bar (PWD, 1980). Sediment sampling from the Macleay River entrance indicated quartz grains that were fine to medium sized, well sorted and rounded to sub-rounded accounted for 82 – 96% of sediments. A minor amount (4 – 18 %) of lithic grains were present, but no silts or clays were present (WMAwater, 2009). This suggests entrance sediments are predominantly marine sands with a small amount of fluvial sands that would account for the lithic and less rounded grains in the sediment sample.

The river entrance will hold marine sediments during non-flood periods. During floods, fluvial sand and mud is expelled into the coastal zone via rivers and creeks, such as evident in the aerial photography of Killick, Korogoro Creeks and the Macleay River (Figure 1-1and Figure 1-2). The entrance marine sand and possibly an additional minor supply of fluvial sand are delivered back into the coastal system during floods from the Macleay.

The finer grained fluvial sediments (i.e. muds and silts) delivered by floods tend to remain in suspension and become “diffused” seaward across the inner shelf, to be deposited in the mid shelf region, rather than remaining in the nearshore zone to contribute significantly to sediment supply in the nearshore zone (Roy and Stephens, 1980).

Shelf sand bodies are said to occur off every prominent headland in NSW (Roy, 2001). The formation of these bodies relates to the narrow and steep inner shelf regions offshore of the prominent headlands, and the interruption of sediment transport by such prominent headlands as sea levels rose and stabilised to present. The shelf sand bodies are supplied by offshore sediment transport, relating to the steep slopes of their morphology and underlying shelf substrate (Roy, 2001).

There are believed to be shelf sand bodies off Smoky Cape and also Hat Head (Roy, 2001 quoting Ferland, 1990). The shelf sand body at Hat Head has been measured at up to 38 m thick occurring in water depths of 25 – 60 m, while the shelf sand body off Smoky Cape has not been measured. As noted above, the continental shelf is relatively narrow around Smoky Cape, suggesting steeper continental shelf slopes nearer to shore at this location that would support the formation of shelf sand bodies. Without further measurements, it is unknown what volume of sand is lost to these shelf sand bodies annually, which would subsequently affect the regional sediment transport rate and therefore, shoreline position to the north of Smoky Cape and Hat Head. Trial Bay has been experiencing ongoing accretion and long term recession was not evident at Stuarts Point Beach over the last 40 years (refer Section 2.6 and 3.3.1**Error! Reference source not found.**). Therefore the rate of ffshore sediment transport that has formed the shelf sand bodies at Smoky Cape and Hat Head is not considered to significantly affect Kempsey's sediment budget over contemporary timescales (~ 100 years) of relevance to this study, and has not been considered further in this report.

2.2.2 Coastline Structure (Headlands, Reefs, Coastal Structures) and Orientation

The orientation of the shoreline and protruding headlands, reefs and man-made structures are important as they affect how waves are refracted and dissipated and thus the wave energy arriving at the shoreline to transport sediment along and between embayments.

The Kempsey regional coastline has medium to large sized and broad coastal embayments (Troedson *et al*., 2004), with small and large estuaries in the back barrier region.

The Kempsey coastline has a number of significant headlands that have a strong control on sediment transport between embayments. Smoky Cape, a 5 km extent of rocky shore and protrusive headland, forms the most significant headland in the region, and is likely to affect wave patterns into beaches beyond Scotts Head (north of Kempsey LGA). Laggers Point, at the northern tip of the Smoky Cape expanse, has also been extended by a breakwater built off the point between 1889 and 1903. Hat Head is the next most significant headland, south of Smoky Cape and protruding around 1 km from the shoreline. Other notable headlands along the Kempsey shoreline include Crescent Head, Big Hill and Point Plomer (just outside the southern boundary of the LGA).

The beach embayments of Kempsey, separated by the above headlands, are typically oriented towards east. The Kempsey LGA has the only section of nearly westerly facing shoreline, at the extreme eastern end of Trial Bay. The shoreline north of Laggers Point including Trial Bay to north of Middle Head tends to be oriented north east to east, while the shoreline south of Smoky Cape is oriented towards east-south-east.

Between the headlands, Kempsey's beaches tend to be sandy. Rock reef is mostly limited to rock platforms and submarine rocky outcrops associated with the major headlands and the narrow sections of continental shelf beyond 20 – 50 m water depth. An exposed reef outcrop known as Delicate Nobby Island is located close to shore around the centre of Delicate Nobby Beach. A small outcrop of rock reef is also evident at the northern end of Barries Bay, near to Big Hill. Offshore rock reefs are also evident around 1 km offshore of Smoky Cape and the northern end of Hat Head Beach.

In addition to the breakwater at Laggers Point, other man-made structures affecting coastal processes at Kempsey include most notably the Macleay River Entrance Breakwaters, north of South West Rocks. Lesser man-made structures include the training walls on Back Creek, Ryans Cut through Killick Beach, and Big Hill Cut at the southern end of Delicate Nobby Beach.

The effect of headlands and man-made structures such as the Macleay entrance and Trial Bay Breakwater upon longshore sediment transport and beach character is discussed in Section 2.6.4.

2.2.3 Beach State Model

Wright and Short (1984) developed a beach classification system for micro-tidal wave-dominated coasts, based on wave energy exposure, beach and surf zone morphology and sediment grain size. The beach state classification model of Wright and Short is given in Table 2-1, along with listing of the Kempsey's beaches. The classification system is useful as it describes the exposure of beach embayments to the existing wave climate, particularly wave height, and the response of the beach embayment depending upon the existing beach sediments and geology.

Kempsey's Beaches are typically intermediate beaches, which are typified by one to two roughly parallel sand bars cut by beach rips at regular intervals, medium to fine grained sand, and experiencing lower to high wave conditions.

Table 2-1 Beach State Model and Kempsey Beaches

Beach State	Identifier	Description / typical conditions	Kempsey Beaches
Reflective	**R**	Steep upper beach face which reflects waves, no sand bars, deeper water immediately offshore, Low wave energy (0-1 m height), coarser grain sizes	None
Low Tide Terrace (Intermediate)	**LTT**	Single shallow bar or terrace exposed at low tide, Low wave energy (0.5 – 1 m height), possible weak rips at high tide	Trial Bay, Horseshoe Bay
Transverse Bar Rip (Intermediate)	**TBR**	Attached bars cut by frequent beach rip troughs/channels (150 – 300 m spacing) which can have strong currents, Moderate wave energy (1 – 1.5 m height)	Grassy Head Beach, Middle Head Beach, Back Beach, Gap Beach (Smoky Cape), Hat Head Beach (south), Killick Beach (south), Delicate Nobby Beach
Rhythmic Bar & Beach (Intermediate)	**RBB**	Undulating (rhythmic) sand bars separated by a trough from shoreline which feeds into strong rips, often heavy shore break due to	Stuarts Point Beach (north end), Hat Head Beach (north & centre), Killick Beach (north & centre), Goolawah Beach,

Beach State	Identifier	Description / typical conditions	Kempsey Beaches
		troughs, Moderate wave energy (1.5 – 2.0 m height)	Barries Bay (north end)
Longshore Bar & Trough (Intermediate)	**LBT**	Shore parallel sand bar(s) with deep trough inshore and moderately steep beach face causing heavy shore break. Typically strong currents in trough feeding widely spaced, strong rip currents. Moderate to High wave Energy (1.5 – 2.0 m height)	In high wave conditions, Killick, Hat Head and Stuarts Point Beaches (particularly northern end) will trend toward this state
Dissipative	**D**	Wide surf zone with multiple shore parallel bars and troughs, High wave energy (2 – 3 m) generating wave set up/set down and undertow currents	None

2.2.4 Sand Mining

Sand mining for mineral sands occurred extensively along the NSW coast at various times from around the 1950s to 1970s, with most mining ceasing by the 1980s, in part after the NSW Government decided to disallow further mining leases in National Parks in 1977. The CCA 03 Project Quaternary Geology mapping of NSW provides evidence of sand mining leases. Historical photographs have also been utilised to clarify the extent of mining in these areas. From these data sources, the following beach dune regions were mined for mineral sands in Kempsey LGA.

- Middle Head Beach, which commenced in 1980 (pers. comm., Terry Parkhouse, former Yarrahapinni Ecology Centre) and had ceased by 1981 (Macleay Argus, 1982), largely due to political pressure at local and state level regarding the damaging impact of mining on the coastal environment. Prior to mining, Middle Head Beach had been an undisturbed, pristine coastal dune environment (pers. comm.., Terry Parkhouse, former Yarrahapinni Ecology Centre). In fact, lobbying throughout 1978 and 1979 on behalf of local activists has ensured that Grassy Head was excluded from mining, which would have exposed the littoral rainforest that exists behind the dunes on this beach. Figure 2-1 clearly shows the revegetation works and location of the former mining lease, indicating mining had actually occurred at the southern end as well as northern end of the beach as identified by Troesdon et al. (2004), see Figure 2-3.
- Killick Beach, unknown commencement date, but likely ceased in the early 1980s (based on accounts of existing operations in Macleay Argus dated 1st April 1980), see Figure 2-3.
- Delicate Nobby Beach, which had ceased operation by 1974, see Figure 2-2, with extent of mining operation mapped in Figure 2-3.

The impacts of sand mining are very relevant to the interpretation of photogrammetric data because the removal of sand volume for mining can distort the evidence of beach volume change. For example, it is unknown if Hat Head Beach may also have been mined. The photogrammetric data shows difference in dune location and height between 1942 and 1974, suggesting the entire removal of the foredune. However, the older dates of photography often have a lower level of model control, which may produce inaccuracies that also explain the dramatic changes.

Figure 2-1 Middle Head Beach ~ 1980-81, showing reshaped foredune with brush matting to initiate revegetation after sand mining (photo courtesy of Terry Parkhouse)

Figure 2-2 Delicate Nobby Beach, 20/2/1974 showing rehabilitation after mining (photo courtesy of Jim Fuller)

Title:

Sand Mining Areas on the Kempsey Coastline - North

Figure: 2-3

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0 2.5 5km

Approx. Scale

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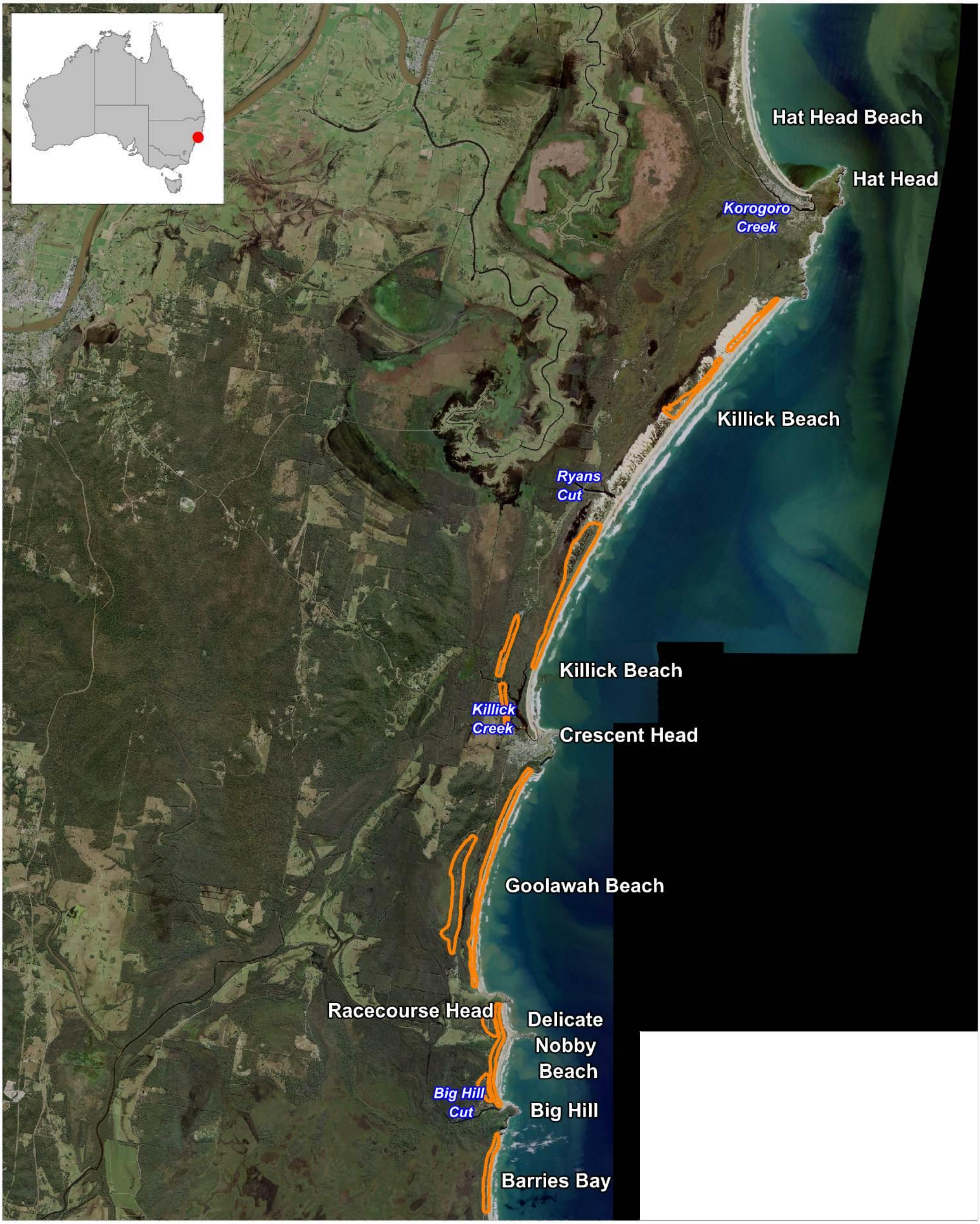

Title:

Sand Mining Areas on the Kempsey Coastline - South

Figure: 2-4

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Care was taken in interpreting the photogrammetry, to identify mining and thereby exclude any such areas in data analysis for beach erosion and long term recession. Discussion of the quality of photogrammetric data, including mining impacts, is given in Section 3.2.1.

2.3 Wave Climate

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 wave generation sources are outlined below (Short and Trenaman, 1992; Short, 2007, see Figure 2-5):

- Tropical cyclones (November to May), tracking towards the Tasman Sea (usually well offshore of the coast) may generate north easterly waves;
- East coast cyclones (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 waves;
- Mid-latitude cyclones (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;

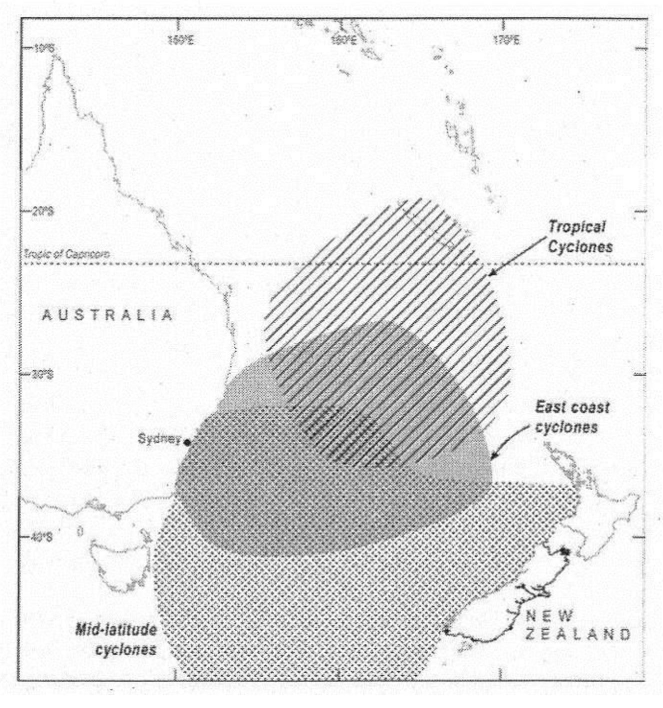

Figure 2-5 Wave generation sources on the South East Australian Coast (Short 2007)

- The subtropical anticyclone 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 Wave Climate

Wave data for Crowdy Head, Bryon Bay and Sydney was provided by the Department of Commerce Manly Hydraulics Laboratory (MHL), with data collection funded by OEH (then the Department of Environment, Climate Change and Water (DECCW)). The wave rider buoys are moored in around 85 m water depth, at around 10 km offshore.

The Crowdy Head site is the closest to the Kempsey coastline, and is also south of Kempsey, the direction from which the majority of waves arrive. However, the Crowdy Head wave rider buoy measures wave height and period, but not wave direction. Therefore, mean wave direction data for the Kempsey coastline has been interpreted from the Sydney and Byron Bay data, as Kempsey is mid way between the two sites.

The data recording period at Crowdy Head (85 km south of Crescent Head) spans 24 years from October 1985 to December 2009. The record length for wave direction at Sydney (~400 km south) spans 17.8 years from March 1992 to December 2009. At Byron Bay (~315 km north) the data record length is 8 years, from October 1999 to December 2007.The shorter record length for wave direction at Byron Bay may have impacted the statistical analysis. The Byron Bay directional buoy has also experienced occasional long periods of missing data, some of which occurred during storms. The missing data have been repaired and validated to some degree, for the purpose of statistical analyses (pers. comm., Mark Kulmar, MHL, 28/07/2008).

2.3.2.1 Significant Wave Height

The mean significant wave height (H_s) experienced at Crowdy Head is 1.61 m. This is similar to the mean for Bryon Bay of 1.65 m, and 1.62 m at Sydney, both north and south of Kempsey. Therefore, average H_s is expected to be in this range at Kempsey. Statistics for H_s percentage exceedence at Crowdy Head can be reviewed in Appendix A.

With regard to seasonality at the Kempsey coastline, information has inferred from the nearby Crowdy Head buoy. H_s is largest in autumn, then winter, summer and the lowest wave heights occur typically in spring. All of the major storm generation sources have the potential to occur in the autumn months, and this may explain the higher wave heights experienced over autumn. Tropical cyclones do not occur between May and October and mid latitude cyclones are more prevalent in winter than spring, thus the lowest wave heights would be expected during spring (although very high wave heights have been recorded in October at the Crowdy Head Buoy). The seasonality records at Crowdy Head are consistent with that at Sydney and Byron Bay.

The highest measured H_s of 7.35 m at Crowdy Head was recorded in March, during which east coast low cyclones, tropical cyclones and mid-latitude cyclones may occur.

The MHL analysis of storm wave height/duration return periods at Crowdy Head, illustrated in Figure 2-6, indicates a 1 in 100 year H_s of 8.6 m for a 1 hour duration storm. The Crowdy Head values are adopted for Kempsey as the closest wave recording site.

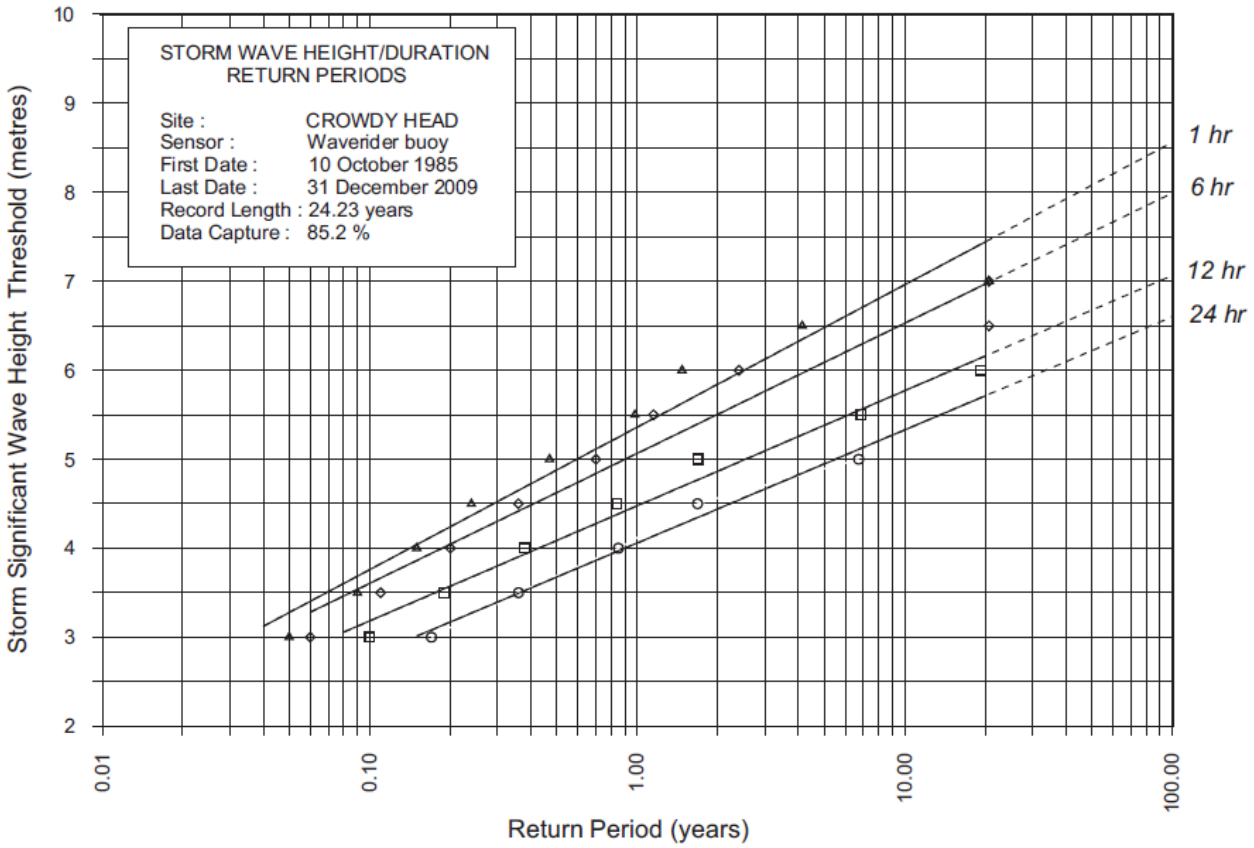

Figure 2-6 Storm Wave Height / Duration Curves for the Crowdy Head Waverider Data

2.3.2.2 Wave Direction

Wave direction statistics data from the directional buoy at Byron Bay and Sydney may be used to infer likely direction at Kempsey.

The mean annual wave direction is south east at both Byron Bay and Sydney, with 60% and 65% of waves arriving from the south east to south sector at the sites respectively, refer Appendix A. The single most dominant wave direction at both locations is south-south-east (SSE), with 27% and 30% of all waves arriving at Byron Bay and Sydney respectively from the SSE, refer Appendix A.

Average seasonal wave direction reflects the dominant wave generation mechanisms as discussed in Section 2.3.1. During winter and spring, south east sector waves are dominant at Sydney and Byron Bay, as consistent with the occurrence of mid-latitude cyclones during winter and spring when other generation sources are less prevalent. Thus, Kempsey is expected to demonstrate the same trends during winter and spring.

Over the summer to early autumn months in both Sydney and Byron Bay, wave direction shifts north slightly, being on average ~125 ° at both sites, refer Appendix A. At Byron Bay, east and east-south-east waves are the dominant wave directions during January to April. At Sydney, east-north-east directions are more prevalent than at Byron Bay, however south east sector waves remain the dominant wave direction over January to April. The shift in wave direction at both sites is consistent with occurrence of east coast low cyclones and tropical cyclones (which will be more evident in the record at Byron Bay) from summer through autumn. The wave record is also more easterly due to summer north-easterly sea breezes and associated wind waves on the coast. Thus, it is expected that wave direction at Kempsey shifts to more easterly waves during summer to autumn.

Percentage joint occurrence statistics for wave height and direction provide insight into the generation sources for storms. Based on data statistics provided by MHL, it is apparent that at both Sydney and Byron Bay, storm waves (i.e. H_s > 3 m) most commonly arrive from the south east sector (the SSE in particular). These wave directions are generated by both east coast low cyclones and mid-latitude cyclones. There is more prevalence of east-north-east to east-south-east storm waves at Byron Bay, as it is closer to the source of tropical cyclones that also generate storm waves that can affect the NSW coast.

Therefore, at Kempsey, storms are expected to arrive from the east-north-east to south, generated by east coast low cyclones, mid-latitude cyclones and occasionally tropical cyclones.

2.3.3 Storm History

For the period prior to 1977 when wave data measurements commenced, the storm history provided in sources such as BBW (1985, 1986) and in other hazard studies in the northern NSW region has been evaluated. The number of storms and some characteristics for each year taken from BBW (1985; 1986) prior to 1977 has been summarised, see Appendix A.

BBW (1986) found that most of the storm activity and the largest wave heights were produced by east coast low cyclones, then tropical cyclones to a lesser degree on the NSW north coast.

1967 was the stormiest single year in the historical data (BBW, 1985) with the highest number of storms and of the largest wave height. This included two category X storms in February and March 1967 (tropical cyclones), followed by a larger storm generated by an east coast low cyclone in June 1967. In addition to the extreme wave heights, the June storm is expected to have caused the greatest damage as it occurred in conjunction with spring high tides and when the beach was already in an eroded state. Other regional reports also note 1954 as a stormy year on the north coast (WBM, 2003). BBW (1985) have only limited data for 1954, however, one Category X storm during a tropical cyclone in February 1954 is reported.

The May-June period of 1974, during which numerous storms occurred and produced significant beach erosion particularly on the south, Sydney and central NSW coasts, was not reported by BBW (1985) to be as significant on the north coast of NSW, with only one event reported. However, this year is still thought to have been particularly erosive to the Kempsey coastline, due in part to the water levels associated with the May-June storms (Foster *et al.,* 1975) and due to the tropical cyclones that occurred earlier (Jan, Feb, Mar) in 1974 that would have left the beach in a relatively eroded state. Regional reports also describe 1974 to be a relatively stormy year (WBM, 2003: SMEC, 2009, L&T, 2003).

A number of the storm events are known to have coincided with high water levels on the NSW coast. While wave heights may have been 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 the occurrence 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 (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).

2.3.4 Variability in the Wave Climate

Throughout the wave record, the predominant wave direction has remained south east along the NSW coast. There may 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). The higher frequency of storms during this period suggests that the recovery of the beach between storms (or lack thereof) was 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). More recently, a series of damaging storms occurred in February, March, May and November of 2009. Significant beach erosion was recorded along the Kempsey coastline with in some locations such as Stuarts Point Beach erosion very near to the same extent as evident after the 1974 storms. Severe erosion was reported at Coffs Harbour, Bellingen and Nambucca Shire coastlines to the north of Kempsey during 2009 also.

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

2.4.1 Tides

Tides of the NSW coastline are classified as micro-tidal and semi diurnal with significant diurnal inequalities. This means that the tidal range is < 3.0 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).

The nearest permanent tidal measurement station to Kempsey is at Coffs Harbour. Coffs Harbour tidal water levels are given in Table-2-2, as provided by MHL using data from 1987 – 2007. Coffs Harbour has a maximum tidal range of 2.04 m. The highest predicted tidal level, or highest high water solstice spring tide (HHWSS), is 1.084 m AHD. Indian Spring Low Water tide (ISLW) is -0.955 m AHD, which is the lowest predicted tidal level. These values are suitable for use at Kempsey.

While there is some variation in tidal level along the NSW coast, of the order of 20 cm increase in tidal range from north to south (MHL, 2011), it is generally agreed that shore-parallel tidal currents along the coastline are negligible. Near the larger estuary entrances such as the Macleay 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-2-2 Coffs Harbour Tidal Levels*

	HHWSS	MHWS	MHW	MHWN	MSL	MLWN	MLW	MLWS	ISLW
Level (m AHD)	1.084	0.695	0.547	0.399	0.009	-0.381	-0.529	-0.677	-0.955
Level (m ISLW)	2.040	1.651	1.503	1.355	0.965	0.575	0.426	0.278	0.000

**Where: Highest High Water Solstice Spring (HHWSS); Mean High Water Spring (MHWS); Mean High Water (MHW); Mean High Water Neap (MHWN); Mean Sea Level (MSL); Mean Low Water Neap (MLWN); Mean Low Water (MLW); Mean Low Water Spring (MLWS); and Indian Spring Low Water (ISLW).*

2.4.2 Elevated Water Levels

Elevated water levels during a storm may comprise the following elements:

- **Barometric pressure set up** of the ocean surface due to the low atmospheric pressure of the storm;
- **Wind set up** due to strong winds during the storm “piling up” water onto the coastline;
- **Astronomical tide,** particularly the HHWSS;
- **Wave set up**, which is the super elevation of the water surface due to the release of energy by breaking waves. It is directly related to wave height, so will be greater during storm conditions; and
- **Wave run up**, which is the vertical distance of the uprush of water from a breaking wave on the shore.

It is generally considered that the highest elevated water levels would occur for a limited time only (several hours) around the high tide.

OEH (DECCW, 2010) advises that for coastal assessments the still water level return periods for Fort Denison in Sydney be used, until such time as location specific analyses are available. The Fort Denison values include barometric pressure set up, (some) wind set up and astronomical tide and tidal anomalies, but do not include wave set up. Extreme still water levels for Fort Denison are given in Table 2-3.

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).

The adopted 1 hour duration storm wave heights (refer Section 2.3.2.1) have been used to assess wave set up, because wave heights are greater over the shorter duration, giving the highest potential wave set up values that may occur at the coastline during a storm. The 1 hour storm duration wave heights and associated wave set up values at 15 % of wave height are given in Table 2-3, and have been summed with the extreme still water levels.

Future elevated water levels in 50 and 100 years will include the predicted increase in sea level. There may also be small changes in water levels in relation to the predicted minor changes to storm surge height and to the maximum (storm) wave height in the future due to climate change given by McInnes *et al.* (2007). Any reductions in storm surge and wave height predicted in the future have not been utilised because, from a risk perspective, increases in water level are of greater consequence. Potential future water levels including climate change factors for 2050 and 2100 are given in Table 2-4 and Table 2-5.

In considering risk, it is important to consider factors that may induce greater water levels than are predicted. Two components that may contribute to higher than predicted water levels have been considered in this study under an extreme or ‘rare’ scenario. First, there is the potential for a higher than predicted 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). This has been included in predicted water levels in Table 2-4 and Table 2-4.

Second, there is the potential for storm surge levels greater than predicted from the historical data, as a result of extreme climatic conditions (e.g. a tropical cyclone in closer proximity to the Kempsey coastline or more intense east coast low). In terms of risk, 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. It is also worth considering the potential for tropical cyclones or storms of greater intensity to occur at Kempsey under a hotter climate in the future.

To derive a sensible estimate for a potential extreme climate condition, cyclone storm surge values from south-east Queensland were reviewed. The 1 in 1000 year tropical cyclone storm surge plus tide water level at Surfers Paradise is the same as the 1 in 50 year water level at Fort Denison. For sites in southern Queensland (Rainbow Beach, Scarborough, Surfers Paradise) that have a similar highest astronomical tide to Coffs Harbour (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 2-4 to Table 2-5.

The final element of elevated water levels refers to the wave run up mechanism, being the uprush of water at (or over) a coastal barrier at the shoreline as waves break. Wave run up is highly variable between storms and locations, and will depend on factors including wave height, wave period, beach slope, shape and permeability, the roughness of the foreshore area and wave regularity. There are no measurements or assessments of wave run up specific to Kempsey's beaches. In this case, standard equations for run-up have been utilised, as discussed in Section 3.4.1.

The adopted likelihood of various water levels and resultant coastal inundation is discussed in Section 3.4.

Table 2-3 Elevated Water Levels for the Current Year Timeframe

Current Year				
Recurrence Interval (years)	**Still Water Level (Fort Denison) (m AHD)**	**1 hr duration wave height (m)**	**Wave Set up (m) (15% of wave ht)**	**Extreme Water Levels (m AHD)**
20	1.38	7.40	1.11	**2.5**
100	1.44	8.60	1.29	**2.7**
100 (extreme storm conditions)	1.64	8.60	1.29	**2.9**

Table 2-4 Elevated Water Levels for the 2050 Timeframe

2050						
Recurrence Interval (years)	**Still Water Level (Fort Denison) (m AHD)**	**Predicted increase in storm surge due to CC (m AHD)**	**1 hr duration wave height (m)***	**Wave Set up (m) (15% of wave ht)**	**Sea Level Rise****	**Extreme Water Levels (m AHD)**
20	1.38	0.01	7.84	1.18	0.34	**2.9**
100	1.44	0.01	9.12	1.37	0.34	**3.2**
100 (extreme storm conditions)	1.64	0.01	9.12	1.37	0.34	**3.4**
100 (extra SLR)	1.44	0.01	9.12	1.37	0.64	**3.5**

Table 2-5 Elevated Water Levels for the 2100 Timeframe

2100						
Recurrence Interval (years)	**Still Water Level (Fort Denison) (m AHD)**	**Predicted increase in storm surge due to CC (m AHD)**	**1 hr duration wave height (m)***	**Wave Set up (m) (15% of wave ht)**	**Sea Level Rise****	**Extreme Water Levels (m AHD)**
20	1.38	0.03	8.71	1.31	0.84	**3.6**
100	1.44	0.03	10.12	1.52	0.84	**3.8**
100 (extreme storm conditions)	1.64	0.03	10.12	1.52	0.84	**4.0**
100 (extra SLR)	1.44	0.03	10.12	1.52	1.34	**4.3**

**100 yr ARI wave heights only increase due to projected climate change (McInnes et al., 2007)*

*** SLR values account for 0.06 m rise in sea level between 1990 and 2010*

2.5 Wind Climate

In the coastal region, the prevailing winds are directly responsible for the general *sea* state, and in some instances may generate noticeable currents. More importantly, winds are responsible for the transport of sand from the sub-aerial beach face into incipient and foredunes, allowing for the growth of dunes and storage of sediment.

Assessment of 30 years of wind data from Coffs Harbour Airport north of the Kempsey region, indicated there to be a diurnal variation in wind direction during warmer months (November to March) (MHL, 1983). Winds are generally offshore in the morning (due to the cooler land mass relative to the sea), and onshore from the east to north east direction in the afternoon, as the land mass is heated during the day and the overlying air is heated and rises causing cool air to flow in from the sea to replace it. During the cooler months, winds tend to originate from the west to south directions. Occasional afternoon sea breezes occur during cooler months, however, these are of lesser strength than those in summer months (MHL, 1983; Binnie and Partners, 1987). These patterns are broadly true along the NSW east coast, and so may be applied to Kempsey.

2.6 Sediment Transport

2.6.1 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. On NSW beaches, the net longshore sediment transport is to the north, due to the predominant south east wave climate relative to the general north to south orientation of the coastline. The net northerly transport is considered to be more pronounced in northern NSW because the beach embayments are longer and headlands are less common, allowing for higher rates of longshore transport with relatively fewer structural constraints.

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). For the same wave height, the highest transport rates occur when the incoming wave is at an angle of 45° to the shoreline. Where the angle of wave attack is close to perpendicular to the shore, there is little to no generation of longshore current.

Where there is a longshore variation in the rate of longshore sand transport, there will be a net gain or loss of sand from the beach unit. That is, where more sand is transported out of a beach area than is being brought in over an extended period of time, the beach will erode. The erosion will occur initially in the surfzone where sand 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 more sand than is taken away.

Such differentials in the regional longshore transport rate can occur naturally along a coastline over the medium term (e.g. decades) in response to extended periods of wave climate (refer Section 2.3.4). Such periods of wave climate may enhance or reduce the longshore transport rate (due to slight shifts in wave direction) as well as sediment bypassing of headlands and other control features that 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. The regional longshore transport rate in Kempsey will increase or decrease around the average rate in any one year, or over years to decades depending upon the wave climate conditions.

The impact of headland and other controls on longshore and cross shore transport are discussed in greater detail in Section 2.6.4.

The average regional longshore transport rate at Kempsey estimated from the rate of accretion measured at Trial Bay was calculated to be 45,000 m^3/yr, (as Trial Bay is one of the few accreting beaches in NSW). The values at the shoreline given by the photogrammetry typically represent one-third of the transport occurring, as the photogrammetric measurements do not account for the changes in the surf zone profile occurring under water. The rates calculated above the water from photogrammetry were therefore scaled up to determine the average regional longshore transport rate given here.

Different regional transport rates were also applied within the Kempsey Shoreline Evolution Model to achieve a stable shoreline during 'warm-up' scenarios (refer Section 0). Sensible results were achieved using a regional longshore transport rate for Kempsey of 65,000 m^3/yr, which is somewhat higher than the measurements from Trial Bay, but is consistent with the regional transport rate at Scotts Head, Nambucca which is estimated to be 60,000 m^3/yr (pers. comm., Ian Goodwin, Macquarie University). Without a detailed study to measure actual rates of regional transport, clarification of the actual rate of transport is not possible. It is worth noting that the rate of transport may vary between years in response to natural variations in the wave climate (wave height, wave direction). A variation of some 20,000 m3/year is not unusual over inter-annual to decadal time scales, relating to wave climate variability.

2.6.1.1 Beach Rotation

The phenomenon of beach rotation forms a component of the observed extent of "erosion" on beaches. Beach rotation is the anti-clockwise to clockwise shift in beach orientation in response to shifts in wave direction and height over seasons and years (Short *et al.*, 2000; Ranasinghe *et al.* 2004). Beach rotation is essentially an increase in beach width at one end while the opposing end experiences a decrease in width. Rotation is particularly evident on embayed beaches where headlands constrain the transport of sediment within the embayment. For longer uninterrupted shorelines where headland bypassing occurs such as Kempsey, rotation is largely a longshore transport process, and is better explained by the shifts in the rate (and direction of longshore transport) that occurs in response to wave climate shifts over seasons to years and even decades. That is, rather than acting as a separate 'process', beach rotation is essentially part of the beach response to both storm events and regular swell waves arriving from different directions.

2.6.2 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. The severity of wave attack at the dune is dependent on wave height and 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.

During calmer weather, sand slowly moves onshore from the nearshore bars to the beach forming a wave-built berm and, subsequently, a wind-formed incipient foredune.

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.

2.6.2.1 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 the majority of the Kempsey coastline. 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. This can be seen in Figure 2-7, where tannin water exiting Ryan's Cut at low volume is taken both north and south by feeder currents into rips and offshore, to the north and south.

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

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 (see Section 2.6.4).

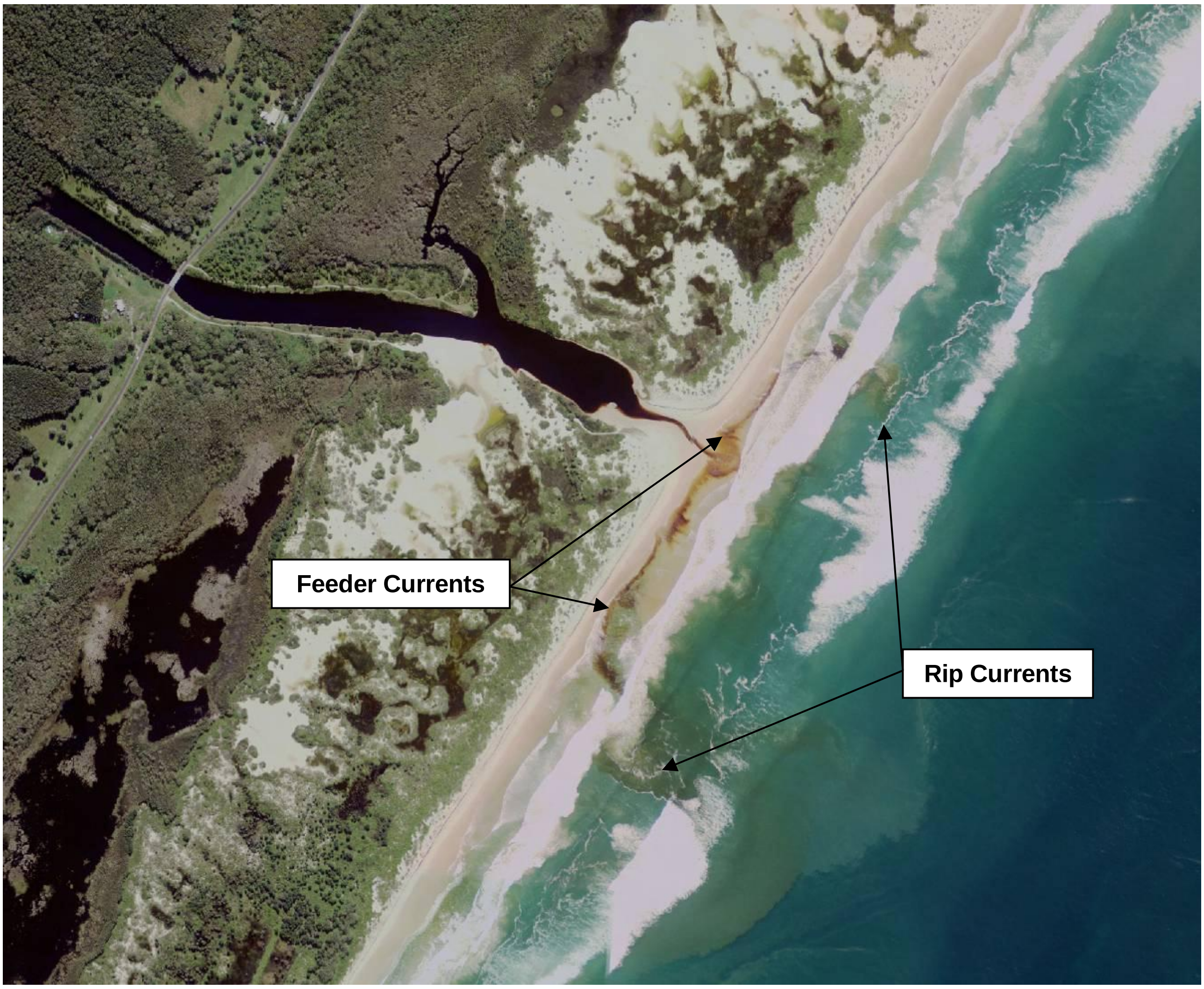

Figure 2-7 Rip Currents with Feeder Channels off Ryans Cut

2.6.3 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 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. Particularly the long, sandy stretches of coastline demonstrated the growth of incipient dune features particularly at their northern ends, which signals significant beach accretion. In northern NSW, accretion has been less extensive or not occurred at all on those beaches that are more east facing and / or affected by headland or other control features (e.g. where storms are required to initiate bypassing of the headlands and supply sediment into the beach, refer Section 2.6.4).

Throughout the first half of 2009, significant beach erosion was observed along the Kempsey and other adjacent coastlines to the north. Erosion escarpments were measured at or close to the erosion extents experienced during the highly stormy decade of the 1970s (after the 1974 storms in particular). In relation to the erosion observed in 2009, there was not one design storm (e.g. 1 in 100 year wave height) but instead there were a number of storm events during the January to November period, at least one of which coincided with a high spring high tidal phase. In this case, it was the close succession of the storm events coupled with high tide water levels that resulted in the significant extent of beach erosion observed.

For coastal planning purposes 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).

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

Longshore transport along beaches (particularly longer embayments) tends to be more continuous over the longer period (months, years). Sediment movement past headlands / structures 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.

The Kempsey region has both short embayments (such as Grassy and Middle Head, Delicate Nobby) and long embayments (Hat Head, Crescent Head, Trial Bay to Stuarts Point) with typically significant headland protrusions. Longshore transport occurs within the embayments relatively unimpeded, and must bypass the significant headlands to continue supply to beaches further north.

The most significant headland in the region, Smoky Cape to Laggers Point, does not constrain the northerly longshore transport, as evidenced by the shoal forming off Laggers Point and Breakwater. PWD (1980) concluded that the shape of the shoal extending north and west from the Laggers Point Breakwater, with a deeper area between the shoal and shoreline was evidence of sediment supply from the east (and south), and therefore bypassing of the extended rocky promontory of Smoky Cape to Laggers Point.

While the average net longshore flow of sand may bypass a headland over a period of years, thus maintaining beach stability, in the short term there is potential for temporary perturbations in the pattern of supply past natural headlands to downdrift beaches. The ‘slug’-like movement of sand past major headlands / structures is important for longshore transport, but may have short term erosion / accretion effects upon the shoreline, as follows (WBM, 2003):

- Periods of considerable temporary loss of sand from the updrift beach, after which there is slow accretion against the headland trapping longshore transport of sand;
- Large accumulations of sand to the immediate downdrift side of the headland during major storms, forming lobes at the shoreline, widening the beach and at time extending some distance seaward, beyond the normal surfzone;
- Extensive erosion upon the downdrift beach where there is a short term mis-match 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; and
- Erosion upon the beach may be further exacerbated if the downdrift beach has also lost sand via bypassing to its adjacent downdrift beach, or likewise if the updrift beach has not had sediment bypassing replaced by sediment bypassing from its adjacent updrift beach, in which case, there is a short term starvation of sediment from this beach, which may have short term effects upon the shoreline.

Headlands and rock reefs are structures around which the shoreline and natural sand bypassing has evolved over the geological time-frame (thousands of years). The natural coastal bedrock features have provided controlling influences on the movements of sand and the coastline shape throughout the past 10,000 years of Holocene shoreline evolution. Nearshore reef outcrops may shift shoreline position as they affect the dissipation and propagation of waves to the shore. Reefs act to attenuate and refract the waves, reducing wave energy at the shoreline behind. As such, accretion of shorelines in the lee of the reefs is often observed (e.g. tombolos and salients such as at Barries Bay, Figure 2-8). The reef and adjacent shoreline may act similarly to a groyne, with a more stable alignment updrift and shoreline retreat downdrift of the reef structure.

Artificial structures such as training walls / breakwaters, seawalls and groynes introduced into the natural system generally cause significant perturbations of beach processes. Most notably:

- Breakwaters and groynes act as shore-normal barriers to the longshore transport of sand, trapping sand and building out the beach/dune on the updrift (southern) side and eroding an equivalent quantity of sand from the downdrift (northern) side until a new dynamic equilibrium is established;
- Seawalls protect the land behind and detach the beach dunal system from active sub-aerial beach processes, which otherwise would contribute to the transport of sand both alongshore and cross-shore, hence seawalls may result in exacerbated erosion at adjacent shorelines (known as edge effects). On receding shorelines (and where seawalls have been built further seaward than the natural beach fluctuations), the sand in front of the seawall may be eroded, resulting in a loss of the sandy beach amenity (which is replaced with an exposed seawall).

The entrance to the Macleay River is now constrained by training walls. A breakwater was also constructed from Laggers Point at the turn of last century. Combined and separately, these features have affected the shoreline within the Stuarts Point to Trial Bay embayment.

Figure 2-8 Salient Formed Behind Rock Reef at Northern End of Barries Bay

2.6.4.1 Effects of the Construction of Macleay River Breakwaters

History of the Macleay River Breakwaters

Prior to 1893, the entrance to the Macleay River was adjacent to Grassy Head, at the northern end of Stuarts Point Beach, flowing through what is now known as the Macleay Arm. A proposal was prepared by Sir John Coode, a marine engineer from London, for training of the Macleay entrance. Coode investigated a number of alternatives (see Figure 2-9), including both the site of the entrance at Grassy Head, and the site of the present day entrance at around 1km north of South West Rocks. Coode's preferred entrance, with a detailed proposal for training walls along its banks, was the then entrance at Grassy Head (Macleay Argus, 30/09/1961).

In June 1893, a substantial flood caused the Macleay River to break across the dunes at what is now the present day "new entrance". For a time both the Grassy Head and new entrances were used by ships, however by 1895, the new entrance was continuing to deepen and indeed saved travellers 2 hours sailing time, while the Grassy Head entrance continued to shoal (Macleay Argus, 30/09/1961).

Between 1895 and 1902 the breakwaters were constructed, formalising the new entrance (although works to extend the walls westward inside the river mouth continued after this time) (Macleay Argus, 30/09/1961). One impact of the new entrance was an increase in the tidal limit for the Macleay River causing saltwater ingress and some inundation of agricultural lands near Clybucca Creek and Rainbow Reach. In addition, townships and businesses of Stuarts Point, Yarrahapinni, Eungai Creek and others largely faded, as the new entrance offered a direct trip to Jerseyville and the traders from these townships no longer had transport for their produce (Macleay Argus, 30/09/1961).

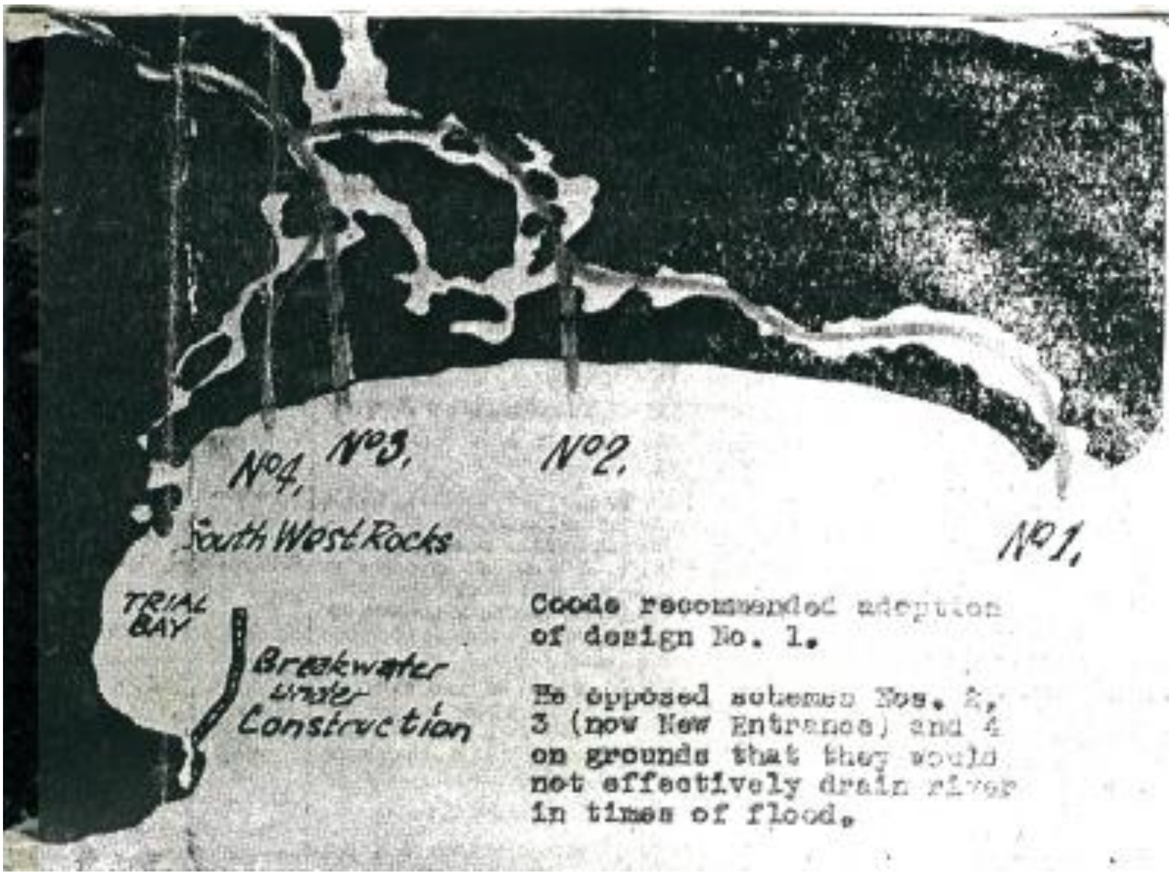

Figure 2-9 Coode's 1890 Scheme for Training the Macleay Entrance (Macleay Argus, 1961)

Effect of the Macleay Breakwaters on Beach Geomorphology

The Macleay River Entrance remains permanently open and in a permanent location due to the construction of two breakwaters. Historically, the entrance location would have migrated between the south and north ends of Stuarts Point Beach, from South West Rocks to Grassy Head (with Back Creek connected to the Macleay system). Large flood events would have caused the river to breakout at locations further south (such as occurred in 1893). During calmer weather, the entrance would migrate slowly north under the influence of typically south-easterly waves and northerly directed longshore transport.

In addition to the historical events of 1893 and the prior entrance position at Grassy Head, the low relief of Stuart Point Beach dunes and spit further support this concept. Higher dunes (above 5 m AHD) typically indicate shoreline stability over thousands of years, because as the shoreline remains in a steady location sand is blown into foredunes at the same location, allowing them to build higher. The low relief of the dunes along Stuarts Point Beach suggest the spit may have been reworked by the migration of the river entrance. The low relief of the dunes is also likely to be a result of a lack of vegetation combined with Aeolian transport that enabled sands to be transported inland (such as into the Macleay Arm), rather than to build upwards in dune height. And so, the Stuart Point dunes remained at low relief of 3-4 m AHD.

Based upon sketches of the Macleay River entrance prior to 1893 (see Figure 2-9), it appears that the embayment followed a smooth crescent-shaped alignment from South West Rocks (Back Creek entrance) to the then entrance at Grassy Head. Furthermore, mapping of the shoreline from 1910 parish maps by WMAwater (2009) suggests the shoreline along Stuarts Point to be further landward than present at the southern end of the beach adjacent to South West Rocks, further seaward along the central portion of the beach then becoming similar to present at the northern end adjacent to Grassy Head.

The present day aerial photography shows the coast around the Macleay Entrance to be out of alignment, with Back Beach around 400m further seaward than south Stuarts Point Beach (north of the breakwaters). The construction of shore-normal breakwaters at the Macleay entrance acted like a groyne to interrupt the northerly longshore sediment supply. The result was accretion of Back Beach and recession of south Stuarts Point Beach. Stuarts Point Beach is estimated to have retreated by around 180 m landward (WMAwater, 2009), and Back Beach accreted by a similar amount.

There is a displacement of the two entrance breakwaters of ~ 450 m. It is likely this was constructed to constrain longshore sediment transport and reduce the formation of shoals at the river mouth, however this would have led to further accretion on Back Beach and recession on Stuarts Point Beach.

The pattern of accretion on Back Beach and recession along Stuarts Point Beach will have continued until sediment accumulated against the Macleay Breakwaters to a point where bypassing commenced. Present day aerial photographs indicate sand bars extend from Back Beach around the river entrance (albeit deflected by river outflow) and into south Stuarts Point Beach, which provides evidence that bypassing of the Macleay Entrance is occurring at the present time. With a recommencement of sediment throughput, further recession of Stuarts Point Beach will have ceased.

The impact of river breakwaters to interrupt sediment transport causing erosion of downdrift (and accretion of updrift) coastlines is well documented at other locations in NSW (i.e. Coffs Harbour, Tweed River, Richmond River).

Within the entrance channel itself, the channel region is said to be characterised by net scour due to tidal inflow and outflow through the channel that has increased in efficiency with construction of the breakwaters (Cohen, 2005). The extent of marine sediments within the lower estuary is less than would typically be found for similar sized / type estuaries, with fluvial sediments extending to within a few kilometres of the ocean entrance. The limited marine flood tidal delta and relative proximity of fluvial sediment deposition to the entrance region suggests that a small supply of fluvial sediment into the open coastal zone may occur at times.

2.6.4.2 *Effect of the Construction of the Laggers Point (Trial Bay) Breakwater*

History of the Laggers Point (Trial Bay) Breakwater

The history of the construction of the Laggers Point Breakwater is closely linked with the construction of Trial Bay Gaol, which is sited above the Breakwater on the higher parts of the rocky Laggers Point granite outcrop.

A breakwater at Laggers Point was proposed to form a harbour for refuge for passing ships during storms. Ships were the main form of transport for goods and people in the late 19th century, prior to rail. However, the very high rates of loss of life, goods and ships to wreck led to the call for another harbour between Port Stephens and Moreton Bay. The use of prisoners to construct the breakwater was part of prison reform in the late 1800s, where it was hoped that the training provided to the prisoners in such public works schemes would provide rehabilitation for the prisoners upon discharge (Neil, 2006).

In 1870, the NSW government accepted the proposal to build a breakwater of 5,000 feet (1,524 m) off Laggers Point to form a harbour from Trial Bay. In conjunction with the prison reform, it was proposed to use prisoners to construct the breakwater, with a need to first build a gaol to house the prisoners. Construction of Trial Bay Gaol commenced in 1877 and was completed in 1886 (after various troubles with construction costs and funding).

The construction of the Breakwater commenced in 1889. The first year of construction proved very successful, with the structure extending 62.4 m. However, coastal storms soon became a problem, with sections of the breakwater destroyed, such as 30 m in 1892, 36 m in 1893 (the same storm which shifted the Macleay entrance), and another 30 m in 1897. By 1899, 10 years after construction had commenced, the breakwater measured just 220 m, with nearly as much stonework washed away by storms as constructed (Neil, 2006).

The construction of the breakwater ceased in 1903, in combination with closure of the Trial Bay Gaol. The cost of the doomed breakwater project and of running the gaol itself (which was also felt to be not in keeping with the ideas of penology of the day) was clearly no longer justifiable. In 1903 the breakwater reached just 303 m, only one fifth of its proposed length. At the present time, the breakwater extends to around 215 m, with dislodged rocks forming a fan shape (deflected towards the west) of approximately 80 m in diameter underwater at the end of the breakwater (see Figure 2-10).

Effect of the Laggers Point Breakwaters on Beach Geomorphology

Trial Bay is one of the only accreting beaches in NSW, with substantial seaward growth of incipient dunes particularly along the middle section of Trial Bay occurring over the last 100 years or more. That is, aside from natural fluctuations, the beach position is moving seaward over time. The shape of Trial Bay is also highly unusual as it faces true north, with the south eastern end of the embayment in fact facing west (one of the only west-facing beaches in NSW).

Figure 2-10 Morphology and Processes in Trial Bay

South easterly waves travelling past Smoky Cape and Laggers Point into Trial Bay prior to the breakwater construction would have refracted (bent) into the embayment, generating a current alongshore and transporting sediment, with the majority of longshore transport bypassing the extreme end of the embayment. Over geologic time, this will have eroded Trial Bay into its presently very “hooked” shape. The western end of Trial Bay is the rocky outcrop of South West Rocks. This feature has held the Trial Bay shoreline in position also.

The construction of the breakwater has modified wave refraction and sediment transport patterns into Trial Bay. Wave energy is somewhat reduced by the breakwater, and so the sand is dropped out of suspension behind the breakwater. The waves refracted by the breakwater, although reduced, will slowly transport the sediment onshore, rejoining the shoreline towards the middle of Trial Bay. This is supported by the shape and location of sand shoals off the tip of the breakwater and extending westward towards the shoreline, in Figure 2-10. The deflection of the tip of the Laggers Point breakwater (and its underwater rock lobe) towards the west as well as wave refraction patterns around the breakwater demonstrates the “bending” and reduction in height of waves from the south and east into Trial Bay, in Figure 2-10.

During the site inspection conducted for this study, some erosion of small Casuarina trees was evident in the soils and sand above the rock lined shoreline immediately in the lee of the breakwater. Likewise, the photogrammetry for this section of shoreline indicates that it has remained stable since the 1940s. However, accretion of the shoreline becomes increasingly evident in the photogrammetry from west of the lagoon (approximately 450 m west of the breakwater) along the shoreline towards the west. Across the length of the embayment, rates of accretion average 4 m^3/m/yr, although are as high as 11 m^3/m/yr in the middle of Trial Bay. This is consistent with shoal patterns noted above.

In addition to the reduction in wave energy from the south to east (the most common wave direction from offshore), the breakwater also blocks the transport of sediment out of the Trial Bay embayment under summer north to easterly waves. In effect, rather than a sediment throughput, sediment is captured within the embayment by the breakwater, as reduced energy at the breakwater causes sediment to be deposited and then slowly worked onshore by the refracted and reduced south east waves.

2.6.4.3 Ferry Wrecks and Other Man-made Structures

Ferry Wrecks in Trial Bay

Three car ferries were wrecked in Trial Bay in January of 1972. The ferries were being transported from Newcastle to Manila in the Philippines where they were to be used as scrap or barges. The three ferries were being moored in Trial Bay during the journey when on January 9, 1972, a storm commenced which snapped moorings of the Koondooloo (58 m long), which drifted ashore and became buried in the sand (see Figure 2-11). On January 12 1972, the Sydney Queen (57 m long) also broke free and ran aground 100 m north of the Koondooloo. The last ferry Lurgurena also ran aground on January 16 1972, around 50 m south of Koondooloo (Andrews, 1994).

The ferries were not able to be salvaged and have eventually sunk into the sand and been largely destroyed by saltwater. At the present time, NSW Maritime buoys mark the location of the ferries, which are only the top masts are visible at low tide and submerged at high tide. Both the Sydney Queen and Lurgurena are reported to have been at their most exposed in 10 years, after storms in 2009 (pers. comm., Rod McDonagh, NSW Maritime).

The wrecks are likely to have been quickly inundated by sand, located along the accreting coast of Trial Bay. The ships would have initially buffered the shoreline from waves to a small degree until they were buried, however, salients are not evident in the lee of the ships suggesting the vessels have not significantly protected the shoreline in the past. With sea level rise, the ships are likely to be further buried in sediment. The ships are unlikely to offer substantial protection to the shoreline (past or future) and so have not been included in the Shoreline Evolution Model (see Section 3.3.1).

Figure 2-11 Koondooloo Car Ferry Wreck in Trial Bay

Other Structures

The training walls at the entrance to Back Creek were constructed between 1961 and 1966, by drilling and blasting some of the small rock outcrops at the creeks entrance and channel, then using the dislodged rock to form a training wall on the eastern bank and part of the western bank (which was completed in 1966) (PWD, 1980).

Tied into and behind the existing rock outcrop of South West Rocks, it is unlikely that the training walls at Back Creek have significantly impeded open coastal processes. However, accretion on Back Beach due to the Macleay Entrance is very likely to have increased shoaling across Back Creek, particularly during low flow conditions. It is understood that Back Creek has been frequently dredged in the past. It is thought that a licence for dredging from Department of Primary Industries (Crown Lands) is still held by a private contractor (pers. comm., Rod McDonagh, NSW Maritime). The licence is based upon the contractors ability to sell the sand, however dredging has not occurred for some time (pers. comm., Ron Kemsley, Kempsey Shire Council).

There are numerous flood mitigation structures associated with the coastal creeks and Macleay River. These structures are typically located within the reaches of the creeks and therefore are not considered to significantly impact upon longshore or cross-shore transport processes. The flood mitigation works and their interaction with the coastal creeks and rivers are discussed in Section 2.7.1.1.

There do not appear to be any stormwater outlets directly onto the beach on the Kempsey coastline, which may affect erosion extents on the beach. This is discussed in relation to the Stormwater Erosion hazard in Section 3.7.

2.6.4.4 Sea Level Rise and Headlands, Coastal Structures and Reefs

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 occurs. 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.

The impacts of training walls, headlands and other features in relation to the long term recession hazard are discussed further in Section 3.3.

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 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. There are a number of small reefs along the Kempsey shoreline (acting as offshore breakwaters). The impact upon the shoreline alignment in the lee of nearshore reefs is discussed further as part of the long term recession hazard (Section 3.3).

2.6.5 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. At all beaches including those in Kempsey, aeolian transport typically contributes positively to the growth of incipient foredunes and storage of sediment in vegetated foredunes. For example, the accretion along the Trial Bay shoreline in incipient foredunes and active dune fields at Hat Head and Killick Beaches have formed largely from windblown sediments from the upper beach face.

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. These features are distinguished from prograded beach ridges which are shore parallel shoreline features formed under significant sediment supply and stable sea level (termed beach progradation, see Section 2.2).

The northern ends of Hat Head and Killick Beaches exhibit active dune fields, with low, unvegetated dunes up to 650 m metres in width. Without vegetation to capture the sediment, these active dunes have not built to significant height. The adjacent vegetated dunes at Hat Head and Killick Beach do not demonstrate shore-parallel beach ridges (which would have been preserved by the vegetation) that would suggest beach progradation. The wide expanse of the dune fields indicates a notable longshore sediment transport to deliver the sediments to the northern end of these long beaches, where it has then been transported landward by wind from the beach berm. PWD (1991) noted instabilities in the shape and height of dunes from the photogrammetry, which they attributed to Aeolian sediment transport forces.

Behind the active dune fields at Hat Head and Killick Beaches, a low-lying swale or backswamp area that may have acted as a former channel to nearby coastal creeks can be seen slowly infilling, such as in Figure 2-12. The process of infilling of backswamps is part of the natural geologic evolution of the coast. However, this process was considered a serious threat to the Macleay Arm behind dunes at Stuarts Point Beach. Rehabilitation of this site is discussed below (Section 2.6.5.1).

Figure 2-12 Sand Drift at Active Dunes Behind Hat Head Beach (photo courtesy of Jim Fuller)

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.

It is unknown what effect predicted changes to future wind regimes with climate change (refer Table 2-7) may have upon Aeolian transport volumes. However, while ever dunes are vegetated, windblown sediment is more likely to be captured and retained within the beach system.

2.6.5.1 Dune Rehabilitation Works on Kempsey's Beaches

By the 1970s, the dunes at Stuarts Point Beach were unvegetated and active across an area of 80 hectares, extending from Grassy Head south to the bridge walkway from Stuarts Point across the Macleay Arm to Stuarts Point Beach. A dunes stabilisation program was commenced in 1972 by the then NSW Soil Conservation Service (pers. comm., Jim Fuller, former NSW Soil Conservation Service).

Siltation of the channel by sand drift was a key reason for undertaking dune stabilisation works at Stuarts Point Beach, such as Figure 2-13. There were serious concerns that the channel would silt up completely, destroying the waterway access that was the main lifeblood of Stuarts Point village. It was noted that filling of the channel through river processes would be occurring naturally, and so the additional inputs of sediment from sand drift were considered a particular threat. In addition, the siltation and closure of the Macleay entrance at Grassy Head is believed to have allowed cattle to access the dunes at Stuarts Point Beach. Cattle grazing was believed to have been a key reason for the lack of vegetation on the dunes at Stuarts Point Beach by the 1970s, shown in Figure 2-14 prior to the revegetation work (pers. comm., Jim Fuller, former NSW Soil Conservation Service and Terry Parkhouse, former Yarrahapinni Ecology Centre).

A program of dune revegetation was commenced in 1972 and continued for approximately 13 years. By this time, dune vegetation extended across the 80 hectares of formerly active dune, as shown in Figure 2-15 (pers. comm., Jim Fuller, former NSW Soil Conservation Service). At the present day, dune vegetation is still extensive at Stuarts Point, however, there is notable infestation by Bitou Bush. In any case, the dune vegetation works allowed for the capture and stabilisation of windborne sediments at Stuarts Point.

The first Dune Care group in NSW began at Hat Head. The group still works within the dunes particularly around the village to remove Bitou Bush. Likewise, a Dune Care group at Crescent Head works predominantly at the Killick Creek entrance, mostly removing Bitou Bush and increasing vegetation coverage at the entrance. The entrance to Saltwater Creek at South West Rocks was revegetated around 20 years ago (pers. comm., Rod McDonagh, NSW Maritime), and is currently well vegetated.

During the 1970s and 1980s, a native plant centre was based at Grassy Head, and a nursery for Maram Grass (an initial species used in dune rehabilitation) in the foredunes approximately 2.5 km north of Hat Head village (pers. comm., Jim Fuller, former NSW Soil Conservation Service).

Dune revegetation works at other Kempsey Beaches typically occurred after sand mining, such as at Middle Beach, Delicate Nobby Beach and Crescent Head Beach.

Figure 2-13 Sand Drift into Macleay Arm, circa 1970s (photo courtesy Jim Fuller)

Figure 2-14 Stuarts Point Dunes in 1974 prior to revegetation (photo courtesy Jim Fuller)

Figure 2-15 Stuarts Point Dunes post revegetation, unknown date (photo courtesy Jim Fuller)

2.7 Coastal Creeks and Rivers

Coastal Creeks and Rivers on the Kempsey coastline (excluding flood mitigation works) include (from south to north):

- Killick Creek, at the southern end of Crescent Head Beach;
- Korogoro Creek, at the southern end of Hat Head Beach;
- Saltwater Creek, at the southern (western) end of Trial Bay Beach;
- Back Creek, adjacent to South West Rocks; and
- the Macleay River on Stuarts Point Beach.

There are also minor lagoons at the northern (eastern) end of Trial Bay and the centre of Grassy Head Beach.

Nearly all of the creeks and the Macleay River have estuary management plans, which outline in detail the complex tidal, fluvial and coastal processes that shape these systems, as well as providing management actions to manage the physical, chemical, ecological and anthropogenic issues associated with these systems.

For the purpose of preparing a Coastal Zone Management Plan, the focus of discussions given in the report will be upon the interaction of these systems with open coastal processes.

2.7.1 Coastal Entrance Sedimentation

River and creek entrances act as both a sink and a source for marine sediment along the coastline and are part of the natural sediment transport system.

Flood tidal delta shoals and entrance berms of the coastal creeks and rivers are a short term sink for marine sediment. Marine sediment is carried into the creek and river entrances on the incoming tide, which is typically greater than the outgoing tide, forming a flood tidal delta and shoal. When the creeks have minimal freshwater outflow for a period of time, the combination of tides and longshore transport processes act to close the entrance.

During flood conditions, the freshwater flows from the catchment will erode the entrance shoals, depositing the marine sediments back into the surf zone. In subsequent calm conditions, the marine sediments will be both reworked back into the entrance area to once again form shoals, as well as northwards by the net longshore currents.

Over the long term, these processes largely balance each other and the sediment budget may be considered to be in equilibrium. Any removal of sediment from the entrance region, for example through dredging, is thus a reduction in sediment supply to the coastal system.

Both Killick and Korogoro Creek remain typically open, located adjacent to a training wall (at Killick) and bedrock at the southern end of the beaches. In general, entrances to coastal creeks will tend to migrate towards the north, under the action of south east waves generating longshore transport. Saltwater Creek exhibits this behaviour, and closes frequently. However, located at the far southern end of the beach and in lee of prominent headlands, Killick and Korogoro entrances are partly shielded from longshore transport processes, reducing the likelihood of their closure. However entrance shoals are highly mobile in these systems, and at times the entrance can close, particularly during extended dry periods.

Closure of Back Creek may have increased as the Macleay Breakwaters promoted accretion on Back Beach, however a licence to dredge the creek periodically has likely reduced entrance closure in the past (refer Section 2.6.4.3).

The entrance to the Macleay River is one of the most difficult entrances to navigate in NSW due to shoaling and longshore bars in the surfzone, with more maritime incidents than elsewhere in the state (pers. comm., Rod McDonagh, NSW Maritime). The construction of entrance breakwaters, while stabilising the entrance position, did little to reduce longshore bars at the entrance (Section 2.6.4.1), which are also shaped by river outflow.

The Macleay entrance remains permanently open due to the freshwater flows through the system which counteract the forces of the open coast to close the system. Marine sediments will ingress into the entrance under tidal flows and be scoured by floods, which also affects the formation of shoals at the entrance.

The hazards associated with entrance processes are discussed in Section 3.5.

2.7.1.1 Flood Mitigation Works

The floodplain of the Macleay River is the most significant feature in the Kempsey LGA. The floodplain is low lying, typically only 1 -2 m above sea level.

In response to significant floods in 1949 and 1950, the NSW Government constructed a series of flood mitigation works, to ease flooding downstream of Kempsey. The works mentioned herein do not affect flood levels at Kempsey, however assist to drain Gladstone, Smithtown, parts of Clybucca and many hectares of surrounding agricultural land (pers. comm., Ron Kemsley, Kempsey Shire Council).

From south to north, the flood mitigation works are as follows, and are shown on Figure 1-1 and Figure 1-2.

- **Big Hill Cut Floodgates**, which consist of an excavated channel adjacent to Big Hill headland, with a flood gate at the ocean entrance on the southern end of Delicate Nobby Beach. The excavated channel follows a formerly minor creek line. The flood gates are used in events greater than a 1 in 10 year ARI, after other flood mitigation works have been utilised. The gates relieve flooding at around 30-40 properties and roads including Maria Road. Sand build up on the flood gate must be excavated prior to operating the gate.
- **Killick Creek Floodgates**, which are used to reduce flooding on the Belmore River, including when Connection Creek joins the Belmore River (Connection Creek connects the Macleay and Hastings River catchments in very large floods). A channel was cut between a freshwater stream and the saline Killick Creek estuary, with the flood gates used to separate the fresh and saline systems.
- **Ryans Cut**, essentially a channel cut directly through the sand dunes on Killick Beach, perpendicular to the beach. A floodgate on Loftus Road controls the use of the cut. Ryans Cut traverses a backswamp area between the flood gate and ocean, thus there are also flood gates on this backswamp, now operated by National Parks (and used infrequently). After flood waters are released from the Belmore River into Belmore Swamp, Ryans Cut is then used to drain the remainder of flood waters. These control structures are used to protect Smithtown, Gladstone, parts of Clybucca and many hectares of surrounding agricultural land by enabling the drainage of flood waters in 3-4 weeks rather than up to 8 months during floods bigger than a 1 in 10 year Average Recurrence Interval (ARI) event.

  As Ryans Cut is used infrequently, a sand berm readily forms across its ocean entrance. The water captured between the berm and the flood gate is typically higher than the landward side of the flood gate, resulting in pressure upon the structure. The beach berm is excavated prior to opening the flood gates.
- **‘The Choke’ Floodgates on Korogoro Creek**. The sluice flood gates are manually wound down, and are used to slow flood water down to minimise damage to the levees protecting the village of Hat Head as it outlets to the ocean, usually in a 100 year ARI event.
- **Rowes Cut**, a swale cut from Korogoro Creek through Hat Head dunes to the ocean. The swale is between ‘the Choke’ on Korogoro Creek and ‘the Choke’ sluice floodgates on Korogoro Creek to the south. Rowes Cut has not been used in a very long time, and it is uncertain if the channel would be usable at the present

The key aspect of interest for these flood mitigation structures is the ability for flood waters to drain to the ocean as sea level rises. The structures are all essentially at mean sea level or affected by mean sea level in their ability to drain floodwaters. The impact of sea level rise is discussed in Section 3.4.3. The impact of shoreline recession upon Ryans Cut and Big Hill Cut floodgates is discussed in Section 3.3.

2.8 Climate Change Parameters

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 2-6). 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), we have integrated the assessment of climate change into the analysis of the 2050 and 2100 extent of each coastal hazard, where possible. This is because climate change may affect all coastal processes and therefore hazards.

McInnes *et al* (2007) and Macadam *et al*. (2007) compiled various climate change predictions for Batemans Bay and Wooli Wooli Estuary. Predictions for Wooli Wooli Estuary have been used as this is the closer location to Kempsey. 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.

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, 2012).

The sea level rise benchmarks are based upon the most recent IPCC (2007) projections for sea level rise (0.18 – 0.59 m by 2090-99), the IPCC’s (2007) assumed linear trend in global ice melt causing 0.2 m sea level rise by 2100, plus up to 0.14 m regional sea level rise by 2100 associated with the East Australian Current on the NSW Coast (CSIRO, 2007; McInnes *et al.*, 2007), as described in DECCW (2009b). 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. The projections for 2100 were rounded (to 0.9 m and 0.4 m) to acknowledge the uncertainty in such estimates (DECCW, 2009a).

The NSW Chief Scientist and Engineer (2012) assessed the former NSW Sea Level Rise Policy Benchmark levels and advised that the science informing the policy levels is adequate. Therefore, the former NSW Sea Level Rise Policy Statement benchmarks were used to prepare this Kempsey Coastal Hazards Definition Study and hazard lines. Regardless of the repeal of the Policy Statement, the sea level rise values used in the Study remain the best available national and international projections for NSW. Until such time as new sea level rise projections are released (such as through the IPCC and / or CSIRO), there is no justifiable basis for using alternative estimates for planning and land management purposes.

From a risk perspective, it is important to consider changes beyond that given within the current predictions. Thus, in addition to the Policy Statement levels, we have analysed 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). The higher than predicted sea level rise also 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 scenario impact.

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.

McInnes *et al.* (2007) investigated future wave heights (mean and maximum) and future wave directions due to climate change for Wooli Wooli Estuary, which is the closest study site to Kempsey. The McInnes *et al.* (2007) projections for wave height are included in the coastal inundation hazard (Section 3.4), in lieu of better projections.

Predictions for future wave climate given by McInnes *et al.* (2007) are within the variability of the existing wave climate. That is, the historical shifts in wave climate that occur naturally are greater in range than the predicted shifts in the future wave climate. The resolution of the climate change models (CCM2 and CCM3) used to derive the predictions is not sufficiently fine scaled for example, these 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).

However, the sensitivity of shoreline response to an increase in wave height or 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 3.3.3). Wave directional change that can affect regional longshore sediment transport rates and therefore future shoreline recession has been assessed under a “worst case” or ‘rare’ scenario. An assumed linear increase in mean wave direction to 5° more easterly by 2100 has been assessed with the Shoreline Evolution Model as part of defining the shoreline recession hazard (Section 3.3)[1].

[1] Scenario testing of both an increase and decrease in mean wave direction by 5° was not conducted. The analysis of change in wave climate is still somewhat theoretical (there are no projections for such changes as yet, as described above). While a decrease in MWD was investigated as a worst case scenario, a greater

Table 2-6 Climate Change Projections of Interest for Coastal Hazards

Prediction	Year	2030	2050	2070	2100	Reference
Sea Level Rise			**0.40 m**		**0.90 m**	NSW Government (2009)
Storm Maximum Wave Height (Hmax)	S + SE direction	0% to +3%		-15% to +9%		McInnes *et al*. 2007. Ranges based upon output from CCM2 & CCM3 models
Storm Wave Frequency	S + SE direction	-8% to +13%		-20% to + 48%		McInnes *et al*. 2007. Ranges based upon output from CCM2 & CCM3 models
	NE Direction	-40% to +100%		-73.3% to 0%		
	E Direction	-49.5% to +2.7%		-54.5% to +35.1%		
	SE Direction	-35.6% to -23.6%		-34.4% to +50%		
	S Direction	+3.9% to +34.1%		-13.7% to +46.3%		
Swell Waves SSE direction (135-180 ° TN)	Mean Direction	158.6-159.6 ° TN		159.4-160.6 ° TN		McInnes *et al*. 2007. Ranges based upon output from CCM2 & CCM3 models
	Change in direction	-0.8 to +0.3 °		+0.1 to +1.2 °		
Swell Waves from 10-190 ° TN	Mean Direction	101.3-106.1 ° TN		99.4-105.9 ° TN		McInnes *et al*. 2007. Ranges based upon output from CCM2 & CCM3 models
	Change in Direction	-3.1 to +0.6 °		- 3.3 to -1.3 °		
Storm Surge	100 yr ARI	+/- 1%		-3% to +4%		McInnes *et al*. 2007. Actual change is 1 - 3 cm
Changes to percentage of wind direction days with average wind speed:	**4 - 8 m/s Annual** SE (112.5 – 157.5°)	-2 to +1 %		-1 to +2 %		Macadam *et al.* 2007 for ocean near Wooli, based on McInnes *et al*. 2007 output from CCM2 & CCM3 models
	8 - 12 m/s Annual SE (112.5 – 157.5°)	-1 to +2 %		-1 to +2 %		
	12 - 16 m/s Annual SE (112.5 – 157.5°)	0 to +1%		0 to +1%		
	>16 m/s Annual SE (112.5 – 157.5°)	*No change*		*No change*		
Extreme rainfall events		-10 % to 0 %		-10% to +10%		Macadam *et al*. 2007
Average total Rainfall		-6 % to 0 %		-19% to 0%		Macadam *et al*. 2007

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.

McInnes *et al* (2007) have provided predictions for the likely change in storm surge due to climate change. Projected sea level rise and wave set up change due to climate change impacts on wave

than predicted sea level rise produces far greater recession and provides the main element of the worst case scenario, as described in Section 3.3 of this report.

height (as given by McInnes et al., (2007) above) need also be added when assessing future elevated water level events, as has been done in Section 2.4.2 and Section 3.4.

Rainfall

Macadam *et al* (2007) have provided recommendations for percent changes in annual and extreme rainfall events for Wooli Wooli Estuary. The projections suggest that an increase in extreme rainfall in concurrence with an overall decrease in annual average rainfall may occur. This would impact upon the coastal entrance behaviour of coastal lagoons and intermittently opening coastal creeks.

There may also 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, there are no significant stormwater outlets upon Kempsey's beaches, although this may be relevant to the stormwater outlets that exist in Saltwater and Killick Creeks.

Wind

Macadam *et al.* (2007) have provided advice relating to future wind directions and speeds at Wooli Wooli Estuary. 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. The impact from predicted changes to wind regimes is discussed within the sand drift hazard (Section 3.6).

3 COASTAL HAZARDS METHODS AND ASSESSMENT

3.1 Hazard Probability 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, 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, etc.) and there are many different ways to assess the extent of hazards, which add to the uncertainty in estimating coastal hazards.

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.

The use of the risk assessment framework for managing coastal hazards is prescribed in the CZMP Guidelines, as well as the NSW Government's *NSW Sea Level Rise Policy Statement* and *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).

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, historical beach response, and likely future response. Based upon the Australian Standard for Risk Management (AS/NZS ISO 31000:2009) and its companion document (HB 436:2004), the scale of 'likelihood' or probability of occurrence for a hazard impact is given in Table 3-1. It is important to note that this is a qualitative scale, not a quantitative mathematical probability assessment. 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.

Ascribing likelihood to the hazard estimates provides transparency regarding the uncertainties, limitations and assumptions used to assess hazards. In addition, ascribing likelihood to coastal hazards can educate coastal planners and the wider community that hazard lines are estimates only and not precise predictions of future shoreline response.

The consequences of coastal hazards should be analysed as part of the Coastal Zone Management phase of the NSW coastal management framework, 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.

During this study, it has been found that the historical beach response and other data was not comprehensive or detailed enough to be able to differentiate between the five likelihood categories given in Table 3-1. Rationalisation of these categories has thus been required, 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.

Furthermore, to aid in the understanding of the hazard estimates by the community, we have updated the likelihood descriptors for the purpose of the hazards mapping, as shown in Table 3-1, and have assumed that:

- the '**almost certain**' descriptor is readily understandable, and remains as is;
- the 'unlikely' descriptor provides the **best estimate** for future hazard that should be expected to occur, albeit infrequently; and
- the 'rare' descriptor provides a **worst case** scenario of future hazard (similar to the "probable maximum flood" estimate provided for flood hazard mapping), which would not be expected to occur, but may occur in an extreme case.

The use of the above descriptors does not compromise Council's ability to apply a risk based approach to developing the Coastal Zone Management Plan (indeed, the equivalent likelihood descriptors remain available within this report for easy transition into a risk assessment). The above descriptors also enable Council to provide a 'best estimate' hazard line to the NSW Government (who are conducting state-wide collation of hazard mapping).

It is noted that the assessment technique undertaken to provide an analysis of likelihood to the beach erosion hazard estimates is necessarily qualitative. The assessment has been fully disclosed within this document to provide a justifiable and defensible explanation for the assigning of likelihoods to the various hazard extents derived. Irrespective of this being a qualitative assessment, the benefits to the community and Council from this risk based approach (such as the provision of sensitivities around the uncertainty of hazard assessment) remain. It is further noted that there is currently no available and reliable method for assessing a quantitative hazard probability.

Our understanding of coastal processes and potential for hazards impacts has improved and will continue to improve, allowing for improvements in determination of likelihood or probabilities in the future. Council is encouraged to continue to expand their data collection in order to have ongoing datasets with which to refine the coastal risk assessment into the future (e.g. conducting regular beach surveys, both on a periodic basis and following consequential storms. The surveys could be conducted along the existing photogrammetric cross-shore transects, or new transects at regular intervals (100m or so) that extend from the top of the dune to the water line or further where practicable. The surveys should be repeated across the same transects, and regular LiDAR surveys will add to the data collation exercise). The methodology adopted to define the hazards and their likelihood is outlined herein.

Table 3-1 Risk Likelihood / Probability

Likelihood	Description	Hazard Descriptor
Almost Certain	There is a high possibility the event will occur as there is a history of frequent occurrence.	**Almost Certain**
Likely	It is likely the event will occur as there is a history of casual occurrence.	
Possible	The event has occurred at least once in the past and may occur again.	
Unlikely	There is a low possibility that the event will occur, however, there is a history of infrequent or isolated occurrence.	**Best Estimate**
Rare	It is highly unlikely that the event will occur, except in extreme / exceptional circumstances, which have not been recorded historically.	**Worst Case**

Table 3-2 Timeframes for Coastal Planning

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

3.2 Beach Erosion

3.2.1 Photogrammetric Data

Photogrammetric data provides the only source of 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 data coverage for Kempsey includes:

- Grassy Head Beach (southern half, see Figure 3-1), with reliable data at 1967, 1973, 1996, 2000, 2010;
- Stuarts Point Beach (northern 4.7 km, see Figure 3-1) with reliable data at 1967, 1973 (except Block 1), 1979, 1988, 1996, 2000, 2006, 2010;
- Trial Bay (see Figure 3-2)with reliable data at 1966, 1972, 1974, 1980, 1988, 1993, 2000, 2010 and 1942 data used with caution; and
- Hat Head Beach (southern 2.6 km, see Figure 3-3) with reliable data at 1967, 1974, 1982, 1986, 1991, 1996, 2009;
- Crescent Head Beach (southern 3.6 km) and Goolawah (northern 200 m), in Figure 3-4, with partially reliable data at 1942 and reliable data at 1967, 1972, 1981, 1988, 1996, 2000, and 2009.

The accuracy of older data varies because of the altitude at which the aerial photography was flown, and for this reason, the 1942 photogrammetry at Grassy Head, Stuarts Point Beach, Hat Head Beach and most profiles at Goolawah and Crescent Head Beaches and 1956 data at Hat Head Beach was excluded from the analyses. Particularly for Hat Head, Aeolian transport processes across unvegetated dunal regions (sand blowouts) caused changes in dune vegetation shape and position particularly between the 1942, 1956 and later dates of photogrammetry (in addition to elevation inaccuracies inherent in the older photographic dates). Aeolian sand transport is a separate process from storm erosion, and so needs also be accounted for (or excluded) when assessing the photogrammetric data.

The occurrence of sand mining during the 1950s, 1960s and 1970s along the NSW coast can result in inaccuracies in photogrammetric data. Careful observation of photogrammetric cross sections in combination with sand mining lease mapping and other known observations of mining (as discussed in Section 2.2.4) was undertaken, and data excluded where appropriate.

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. For example, 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 elevation is also typically the region of active contemporary dune building processes during beach recovery. Therefore, at Hat Head and Grassy Head, the 4 m AHD contour is an appropriate bench mark to observe storm based fluctuations of the beach position.

At Stuarts Point Beach, dune heights within the active beach system were typically below 4 m AHD, and instead, the 3 m AHD position provided a far more reliable benchmark to assess storm fluctuations. Likewise at Trial Bay, the quick rate of accretion within the embayment has built incipient dunes of 2 – 3 m elevation as the shoreline position advances seaward, but not higher dunes (ie, > 4 m AHD). Therefore, the 2 m AHD elevation was used at Trial Bay to observe both the rate of accretion and storm driven fluctuations in shoreline position (which were certainly evident in addition to accretion of the shoreline).

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

The advantages and disadvantages of each of these calculations were reviewed by Hanslow (2007). 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 have been used to assess beach erosion and historical long term recession, in Section 3.2 and 3.3.1 below.

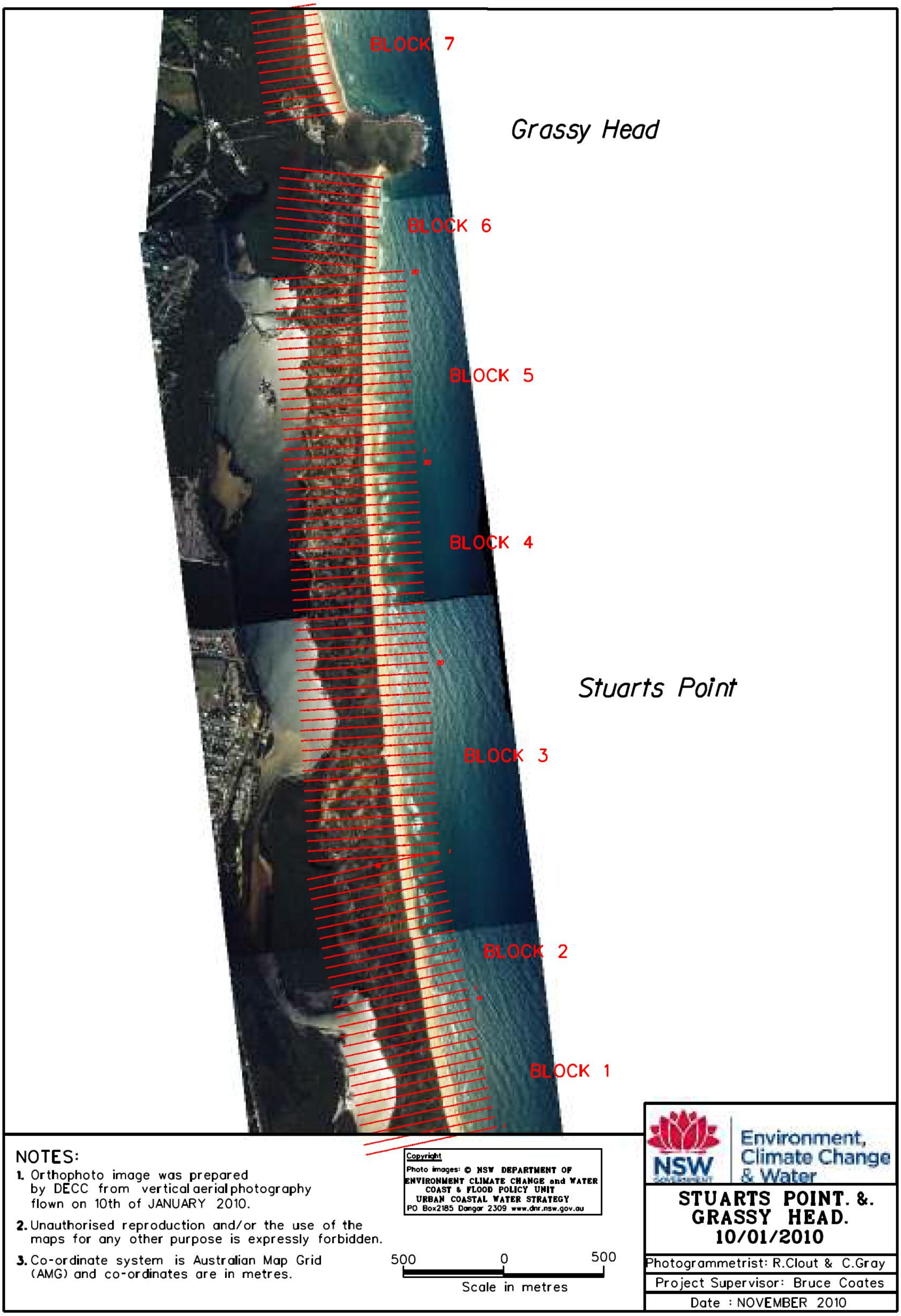

Figure 3-1 Photogrammetric Profiles Grassy Head / Stuarts Point Beach

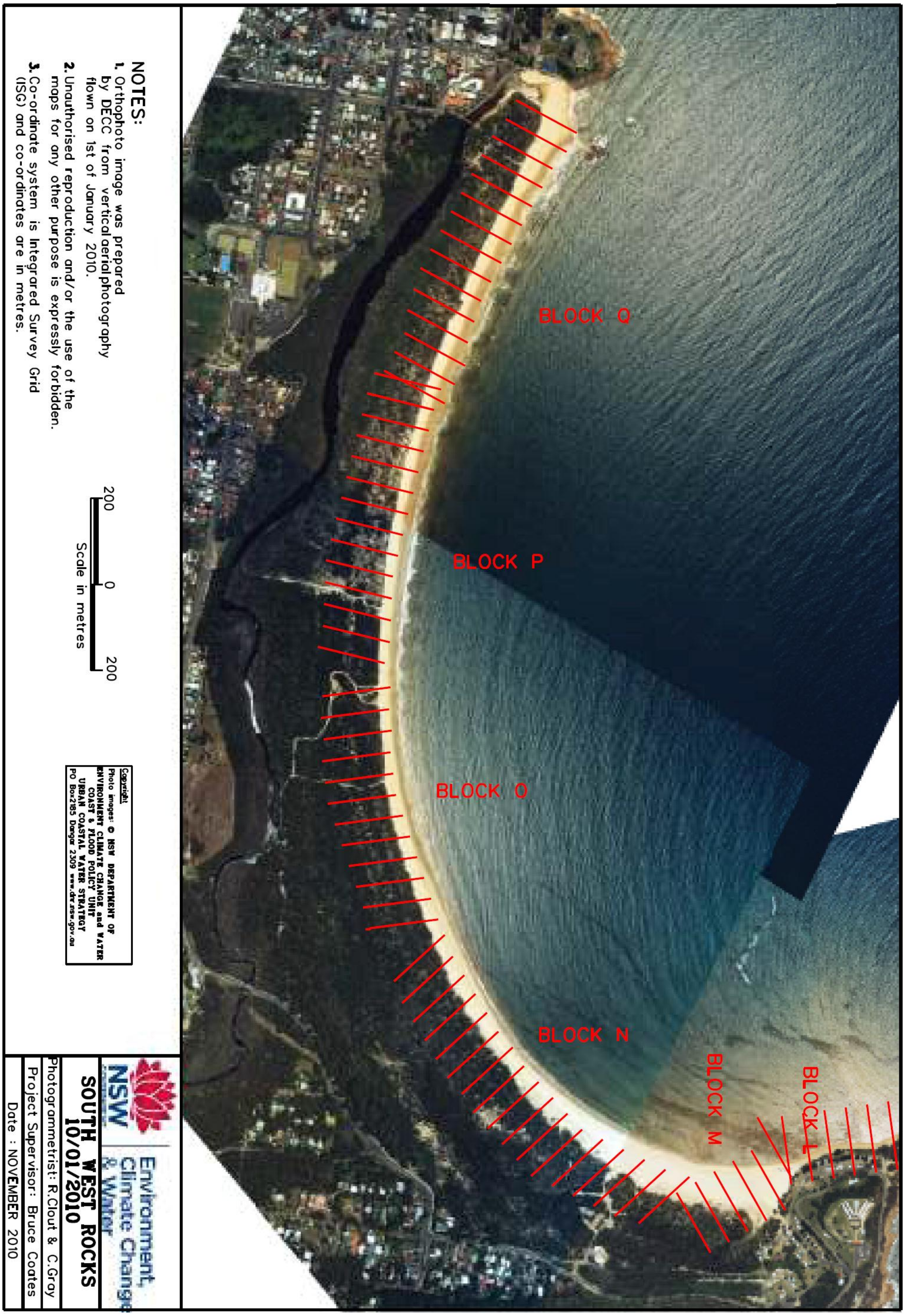

Figure 3-2 Photogrammetric Profiles Trial Bay

Figure 3-3 Photogrammetric Profiles Hat Head

NOTES:

1. Orthophoto image was prepared by OEH from vertical aerial photography flown on 12th of December 2009.
2. Unauthorised reproduction and/or the use of the maps for any other purpose is expressly forbidden.
3. Co-ordinate system is Map Grid of Australia (MGA) and co-ordinates are in metres.

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CRESCENT HEAD
12/12/2009

Photogrammetrist: R.Clout & C.Gray
Project Supervisor: Bruce Coates
Date : FEBRUARY 2012

150 0 150
Scale in metres

Figure 3-4 Photogrammetric Profiles Crescent Head

3.2.2 Beach Erosion Methodology

3.2.2.1 Discussion of the Approach

Beach erosion hazard extents have been defined based upon the most eroded profiles recorded in the photogrammetric data. It is important to understand that the analysis used here to define beach erosion is not equivalent to a 'storm demand' estimate (where 'storm demand' or 'storm bite' refer to the potential erosion caused by one or a series of closely spaced storms). The approach is based upon the historical data, and provides a different but defensible and justifiable hazard estimate for planning purposes. The hazard estimates are also provided within a qualitative risk-based context.

The beach erosion hazard lines are reflective of the most eroded (or landward) position of the dune escarpment. It may not be possible to describe the particular set of environmental conditions that produced the most eroded position in the measured data, but it can be expected that that set of environmental conditions – and beach erosion extent - will recur in the future (albeit infrequently). The beach erosion estimate is not equivalent to a design or single extreme event, or typical descriptions of storm demand. Importantly, the measurement of the most landward erosion position is taken relative to the present day shoreline position. This means the location of the hazard line is independent of the present day shoreline state (so for Kempsey, as the present day shoreline state is quite eroded, the hazard lines are thinner as they account for the erosion evident at the time that the topographic data was determined).

The approach captures the shoreline variability that is evident within reliable photogrammetric data, which demonstrates differences in shoreline position that may be larger than storm demand alone. This is because the shoreline variability is not related to storms alone, and is instead representative of a variety of long and short term environmental drivers and resultant processes.

Where local data is available, it is considered unwise to discount the measured data in favour of a storm demand estimate that was not derived from the local Kempsey area (storm demand in NSW is taken to be 250 m^3/m as a default estimate, which was derived from the Sydney region. Sydney beaches have little to no longshore drift between beaches, and are shorter and more heavily embayed, and so are expected to experience different coastal processes to Kempsey).

Regardless, the beach erosion hazard lines derived for Kempsey are not representative of storm demand alone, but the estimates do encompass the potential for beach erosion at each location that has been measured in the past and so should be expected to recur in the future.

This approach has distinct advantages for planning (as opposed to engineering) purposes[2]:

- The approach to hazard line estimation is independent of the environmental conditions that produced the resultant erosion. There is not sufficient climate data to understand the short to medium term (days to decades) wave climate and water level variability prior to the eroded

[2] It is important to distinguish the needs of an engineering assessment, where a structural design requires understanding of the erosive capacity of waves (or wave impacts, wave forces and so on); compared with planning purposes, where the aim is to provide land for development (be it residential, commercial or public open space uses) requiring definition of the boundary within which such development may be affected by a hazard. The approach provided here is suitable for planning purposes, defining the boundary where coastal processes have impacted in the past and so can be expected to recur in future.

beach condition recorded in the data. Regardless, the data measurement provides a valid hazard estimate for planning purposes.

- The environmental conditions that produce erosion are varied and complex, and increasingly it is evident that storms in isolation may not be the sole driver of shoreline variability. Medium term cycles in wave climate (which includes variability in the frequency of storms) and water levels may have an important impact on the shoreline position. A frequently discussed example of this is the phenomenon of beach rotation, which is driven by variability in longshore sediment transport within an embayment, in turn driven by wave climate variability.
- In Kempsey, net regional longshore sediment transport produces an enhanced potential for variability in the shoreline position. Wave climate variability over short to medium term scales drives variability in the strength and direction of longshore sediment transport, which may result in differentials in longshore transport between embayments (not just within embayments, as is the case for beach rotation). A standard 'storm demand' measurement may account for the influence of rips, but where there are substantial sediment bypassing episodes, or even more subtle medium term shifts in longshore transport processes, these episodes may be outside of the storm demand calculation.

Kempsey's beaches have experienced a number of storms over recent years, from at least 2009 to present. Unlike the decade prior to this, the beaches do not appear to be recovering fully after each storm episode, and so erosion is becoming more severe as time progresses. It is worth adding that none of the storms over the past four years have been considered to be 'design' storm events (e.g. 1 in 100 year waves or water levels etc), yet the erosion extents are greater than has been experienced for decades. The availability of sand for beach recovery appears to have been depleted and this suggests that longshore processes have been important in the extent of beach erosion evident.

For the purposes of defining the beach erosion hazard from the historical data, an 'almost certain', best estimate ('unlikely') and worst case ('rare') erosion extent have been determined. The most eroded profiles from the historical data were used in a number of ways to define the range of likely erosion extents. Defining a range of probable erosion extents rather than a single erosion line or 'storm bite' captures the uncertainty in beach erosion estimates due to climate variability, data limitations and assessment techniques. Potential, but unrecorded erosion events and their indicative likelihood were also estimated (as a worst case scenario). The details of the methodology adopted and advantages of this approach are detailed herein.

3.2.2.2 Estimation of Beach Erosion Likelihoods

The adopted approach to defining the extents of potential beach erosion was thus to consider the most eroded beach / 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.

For each photogrammetric profile along a beach, the most eroded (landward) position of the 2, 3, or 4 m AHD contour was measured from the latest date (2009 or 2010) position. Data was processed relative to the 2009 or 2010 position because aerial laser survey data and aerial photography is available for this date, from which hazard extents can be spatially measured and mapped.

It is important to note that there were a number of storms in 2009 prior to the photography and Lidar taken in 2009. Therefore, the 2009 baseline position is an eroded beach state and this must be accounted for when determining beach erosion extents landward of this baseline position. As noted above, the photogrammetric data was processed relative to the 2009 position (not a more seaward beach position) to ensure that the erosion that had occurred already prior to 2009 was not included in the beach erosion measurements. This ensures the erosion values adopted do not overestimate potential erosion extents. Council and other readers of this report should note that the values provided from this assessment are relative to an eroded beach position (ie, 2009), and so do not represent the extent of erosion should the beach be further seaward of the 2009 shoreline.

The subtraction between most eroded and 2009/2010 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. The data was cross checked with visual interrogation of profile cross sections to ensure profile data appeared reasonable and consistent with adjacent profiles and changes in morphology over time.

The average erosion value (in m movement from the dune position, i.e. 2, 3 or 4 m AHD) was adopted as the '**almost certain**' probability of occurrence of beach erosion, as shown in Figure 3-5 and Figure 3-6 at Hat Head and Stuarts Point Beaches respectively. 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. This includes further erosion beyond that which occurred in 2009 that has been recorded in the past.

The maximum erosion value (movement from dune position) at any point along the beach was considered to have an 'unlikely' probability of occurrence for the whole beach providing the **best estimate** for planning purposes, as shown in Figure 3-5 and Figure 3-6 at Hat Head and Stuarts Point Beaches respectively. This encompasses the possibility that rips (and their associated erosion scarps) may form at any location along a beach, that waves may affect any section of the beach, and that differentials in longshore sediment transport may propagate up- or down-coast depending on the short and medium term wave climate. Again, greater erosion than occurred in 2009 has been recorded at different sections of the beach in the past.

The potential erosion values at Hat Head Beach and Crescent Head Beach are slightly larger than Stuarts Point Beach, as Stuarts Point Beach is already in a relatively eroded state following storms in 2009 compared with these beaches (and so, the potential extent of further erosion is smaller at Stuarts Point Beach). The photogrammetric data from Crescent Head's southern end and the northern end of Goolawah Beach provide further insight into the impact of storms in 2009. Crescent Head demonstrated little of the impact to dunes from storms in 2009 than seen on Stuarts Point and Grassy Head Beaches. Goolawah Beach's northern end (immediately south of Crescent Head) did illustrate storm impacts from 2009, although the impact was not as severe as in 1972 for this location. This suggests that the southern ends of the beach were relatively protected from storms in 2009 compared with the northern ends of the beach, such as Stuarts Point Beach.

In deriving *almost certain* and *best estimate* (unlikely) hazard extents, it has been assumed that the conditions that produced the most eroded profiles in the past will occur again in the future. This is reasonable, as the 2009 and 2010 photogrammetric data provides similar erosion extents as events in the 1970s along some of beaches, with some profiles of the beach more and some less eroded. At

Hat Head and Crescent Head Beaches, the 2009 event was not as erosive, demonstrating the variable impact of different storms along a coastline.

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 data at each beach, and indeed, there is not photogrammetric data along the entire Kempsey coastline. The risk (likelihood) approach enables estimates of beach erosion that have not been captured in the historical record, but that may occur in a ‘rare’ scenario. The ‘rare’ or **worst case** erosion hazard provides 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 we presently have limited predictions (see Section 2.8).

To derive the *worst case* (rare) beach erosion scenario, the difference between the average and maximum beach erosion extent was added to the maximum eroded extent, as in Figure 3-5 and Figure 3-6. Once again, the *worst case* erosion extent accounted for the erosion that has occurred prior to 2009. Data from beaches in nearby Coffs Harbour with similar morphology support the *worst case* scenario values adopted.

For comparison, the extent of oscillation in the beach position was calculated, being the difference between the most eroded and most accreted profiles on all of the beaches. The oscillation of the shoreline position describes the envelope of beach change that occurs in relation to variability in the wave climate. This was calculated for both the movement of the contour position, and using individual profile volumes (m^3/m) converted to m movement. Both in terms of dune contour movement and profile movement, Hat Head exhibited slightly greater variability than the other beaches. This may in part relate to the photogrammetric data itself. However, it may also relate to the refraction and dissipation of wave energy by the prominent Smoky Cape to Laggers Point headland affecting beaches immediately to the north (Trial Bay, Stuarts Point Beach and Grassy and Middle Heads).

The *worst case* (rare) erosion value is slightly lower than the maximum oscillation in shoreline position (i.e. most accreted minus most eroded position in the historical record, see Figure 3-5 and Figure 3-6), which is expected given that the beach erosion measurements have accounted for the eroded state of the beaches after storms in 2009. However, the *worst case* values are still conservative enough to account for ‘rare’ events that are not in the data record and may occur in the future due to either existing climate variability or climate change.

The process utilised in deriving hazard probability zones from the historical data is summarised in Table 3-5. Definition of the probabilities is given in Table 3-1. The specific beach erosion hazard extents for beaches associated with Kempsey’s coastal villages is given in Table 3-3. Mapping of the beach erosion hazard is contained in Appendix B.

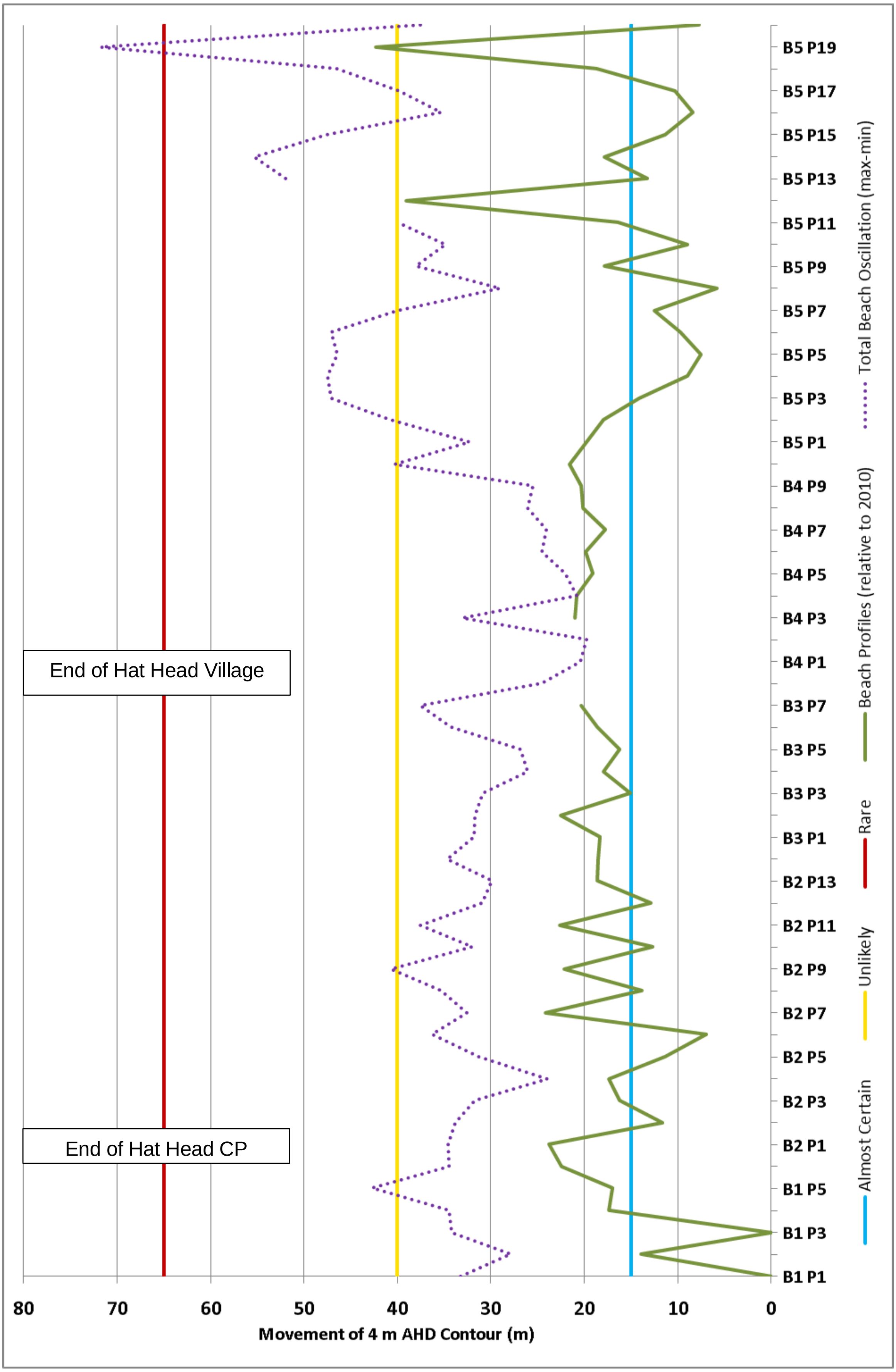


Figure 3-5 Beach Erosion Calculation, Hat Head Beach (with notation of photogrammetric block B and profile P)

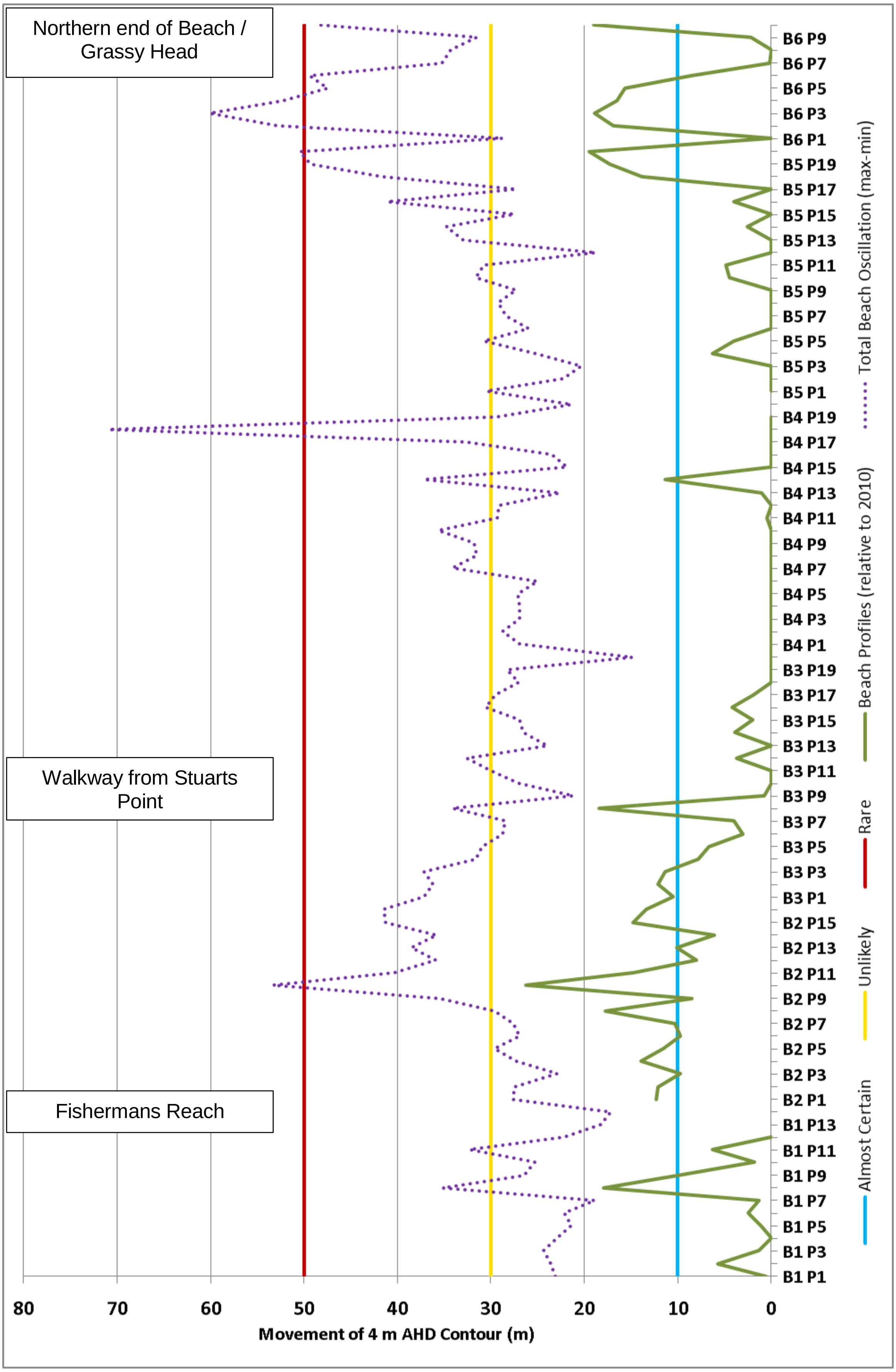


Figure 3-6 Beach Erosion Calculation, Stuarts Point Beach (with notation of photogrammetric block B and profile P)

Table 3-3 Adopted Beach Erosion Extents (relative to 2009 beach position)

Immediate Beach Erosion Hazard	**Dune contour height (m, baseline for measurement)**	**Almost Certain (m)**	**Best Estimate** (Unlikely) **(m)**	**Worst Case** (Rare) **(m)**
Middle Head	4	No photogrammetry, Grassy Head adopted		
Grassy Head	4	5.0	20.0	35.0
Stuarts Point Beach	3	10.0	30.0	50.0
Trial Bay	2	5.0	15.0	25.0
Hat Head	4	15.0	40.0	65.0
Crescent Head	4	15.0	40.0	65.0
Goolawah	4	15.0	40.0	65.0
Delicate Nobby	4	No photogrammetry, Stuarts Point adopted		
Big Hill	4	No photogrammetry, Stuarts Point adopted		

Further Details on Adoption of Beach Erosion Likelihoods

The values adopted for the beach erosion probabilities were rounded from the average and maximum values. 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*, *best estimate* (unlikely) and *worst case* (rare), have been adopted across the length of the beach embayment. All locations along a beach have the potential to be affected, depending upon the wave height, direction and water level of storms. Headland bypassing events occur during storms, resulting in episodic movement of slugs of sand around headlands. This can manifest as severe erosion of the updrift or downdrift coast, depending upon the timing of the bypassing. In addition, rip currents may potentially form at any location along the beach, and do also preferentially occur adjacent to headlands. The shoreline behind a rip current will typically experience greater erosion, due to the deeper water and outflowing current within the rip. In large storms, the number of rips reduces, but the size and strength of the individual rips increases, causing greater impact on the shoreline. For the Crescent Head photogrammetry, the data from Goolawah's northern end and Crescent Head's southern end were combined. Goolawah's northern end is considered representative of the northern end of Crescent Head and vice versa, and so, combining this data accounts for the possibility of a storm impact arriving into either the northern or southern ends of the beaches.

For beaches for which there was no photogrammetry (i.e. Delicate Nobby, Big Hill), the values from beaches with similar orientation and geomorphology were adopted (under the almost certain, best estimate and worst case scenarios). This also assumes that the beaches were equally affected by storms in 2009.

Photogrammetric data from profiles across creek mouths and drainage lines were not included in the assessment of beach erosion extents, because these areas are additionally affected by runoff and creek outflow which may enhance the extent of erosion. Including photogrammetric data from creek mouths would give an overestimate of beach erosion extents, which would be inappropriate along the remainder of the beach.

The mapping of beach erosion has included the extent of erosion at intermittently open creek mouths (e.g. Saltwater Creek) and drainage lines. The origin line from which beach erosion extents were measured was taken on the landward side of the creek entrance berms and drainage lines. In all cases, and as confirmed by the photogrammetric data, the entrance berms have been eroded away frequently in the past (such as at Saltwater Creek). Hence, it is reasonable to assume that the entire berm would potentially be eroded in the future. For drainage lines, waves may attack and cause erosion in the area adjacent and behind the drainage line. Hence, measurement of erosion extents from the drainage point ensures such erosion is captured within the Beach Erosion hazard mapping.

3.2.2.3 Future Beach Erosion Due to Climate Change

In the case of future wave climates (height, direction), the analysis in Section 2.8 indicated that any future change is within the existing variability that has occurred during the historical past. In particular, the period of enhanced storminess of 1970s is more extreme than that given in wave climate projections for the future.

In this case, we may consider the historical beach response, which represents the effects of wave climate of the past, to be representative of the potential impact of future wave climate variability. Utilising erosion profiles of the past is very likely to capture future erosion events, due to natural or climate change induced variability.

Modelling studies investigating the shoreline response to wave climate change based upon the McInnes *et al* (2007) projections have found that the response is minimal compared with the response of the shoreline to sea level rise (refer Huxley, 2009, 2011). Until such time as projections for wave climate change are more comprehensive, the assessment methodology for storm erosion utilised for this study is considered sufficient for planning purposes.

Change in the rate of longshore sediment transport due to an average shift in wave direction due to climate change has been investigated as part of the shoreline evolution modelling, in Section 3.3.

3.3 Shoreline Recession

Shoreline recession is defined as the long term trend of a shoreline to move landwards (permanently) (DECCW, 2010), which may occur due to a net loss in sediment supply over time, or in response to sea level rise. The net loss in sediment supply may be caused by shoreline structures such as river training walls or groynes that interrupt or block the natural transport of sediment between embayments or a natural alongshore gradient in the longshore sand transport.

The profile shape across the beach/dune and nearshore areas to the lower shore-face has an equilibrium form about which cross-shore storm erosion and accretion seabed changes fluctuate. In principle, that equilibrium shape tends to be maintained relative to sea level as the sea level changes. This two-dimensional concept is demonstrated by the Bruun Rule (1962) in Figure 3-7. As the sea level rises, wave, tide and wind related sand transport 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. There is an upward and landward translation of the profile to maintain equilibrium with the prevailing conditions at the new sea level position.

Future recession due to sea level rise has been assessed using the Shoreline Evolution Model (SEM), developed by BMT WBM's Dean Patterson (Patterson 2009; 2010; 2012; 2013). The SEM is capable of assessing the response of the shoreline to sea level change, and / or structural changes (e.g. the introduction of harbour breakwaters or groynes to the coastal system). The SEM offers a more comprehensive means of predicting future long term recession along coastline compartments compared with the Bruun Rule (1962), which has been the industry standard approach. For comparison, calculation of recession with the standard simplified Bruun Rule (1962) has also been conducted, the outputs from which provide further evidence of the improved calculation provided by the SEM.

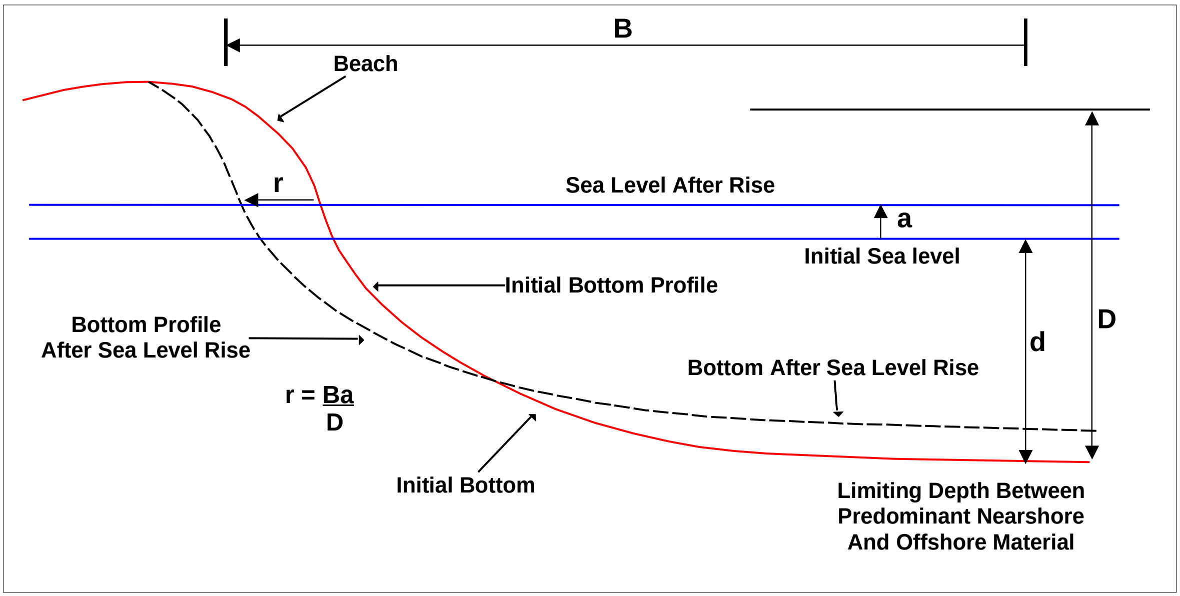


Figure 3-7 Bruun (1962) Concept of Recession due to Sea Level Rise

3.3.1 Historical Long Term Recession

The assessment of long term recession involved analysing the photogrammetric data to determine the rate of recession or accretion along the beach. Analysis of the photogrammetric data involved calculating cumulative block volumes and average dune position in blocks. Linear regression of volumes was conducted, and also converted (using dune height) into a metres per year (m/yr) movement of the shoreline position. For comparison, linear regression of the movement of the dune position was also conducted. Based upon the results, the rate of change representing either recession or accretion was determined within blocks and on average for Kempsey's beach.

The analysis carefully considered the quality of the photogrammetric data (as evident in profile cross section diagrams) such as for mining impacts or level inaccuracies in older photographs. Based upon this, data from certain older dates (typically 1942) for select blocks or the entire embayment were excluded.

Overall, the photogrammetry data indicates that Kempsey's beaches are not experiencing long term recession and in fact appear to be stable over the period of reliable photogrammetry (~ 1967 to present), except for Trial Bay. The cumulative volumes for each photogrammetric block of profiles for Hat Head over the data period (1967 to 2009) are illustrated as an example in Figure 3-8.

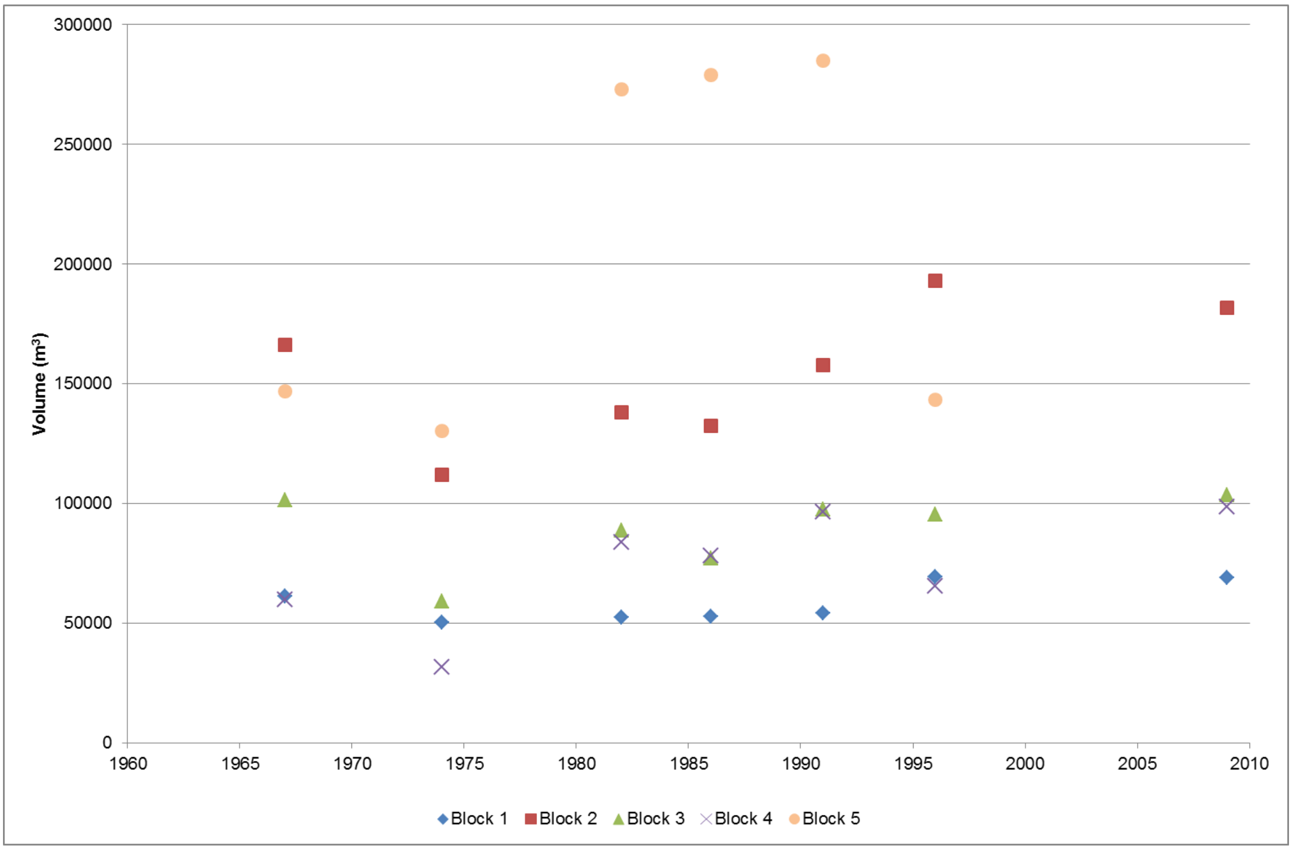


Figure 3-8 Cumulative Volumes for Photogrammetric Blocks on Hat Head Beach

Trial Bay Beach is exhibiting long term accretion, in the form of significant growth of incipient dunes and seaward advancement of the shoreline position, refer Section 2.6.4.2. Accretion appears to have been enhanced by the construction of the Laggers Point Breakwater, which has protected the typically north facing Trial Bay shoreline. The photogrammetry illustrates that accretion is occurring particularly from the middle of Trial Bay towards the west, with the southern (eastern) shoreline of Trial Bay remaining in a relatively stable position, as shown in Figure 3-9. This is consistent with the transport and shoaling of sediment from the end of the Breakwater to the west, meeting the shoreline around 450 m along the shoreline from Laggers Point.

Wave climate conditions may enhance or reduce the trends evident in the historical data, but do not represent a sediment deficit that is considered to be long term (permanent) recession. For example, the period of lower storminess and slightly enhanced southerly wave climate from the late 1970s to ~ 2007 has been observed to have promoted a period of accretion, particularly on beaches facing south-east to east-south-east, including beaches in the Kempsey LGA. In 2009, significant erosion occurred, due to a period of frequent storms throughout that year. The response to wave climate variability is not a long term permanent shift in shoreline position. This response to wave climate has however, been captured within the beach erosion hazard analysis.

As discussed in Section 2.6.4.1, the Macleay Breakwaters have modified the Back Beach to Stuarts Point Beach shoreline in the past. The breakwaters will have resulted in some accretion along Back Beach and slight setback of the entrance shoreline immediately north at Stuarts Point Beach around the time of their construction. However, the photogrammetry for Stuarts Point Beach does not demonstrate a long term recession trend, suggesting that the shoreline north and south of the breakwaters has adapted to the installation of breakwaters. Longshore sand bars across the Macleay entrance are evident, which represent a sediment transport pathway across the entrance, and this further supports this conclusion.

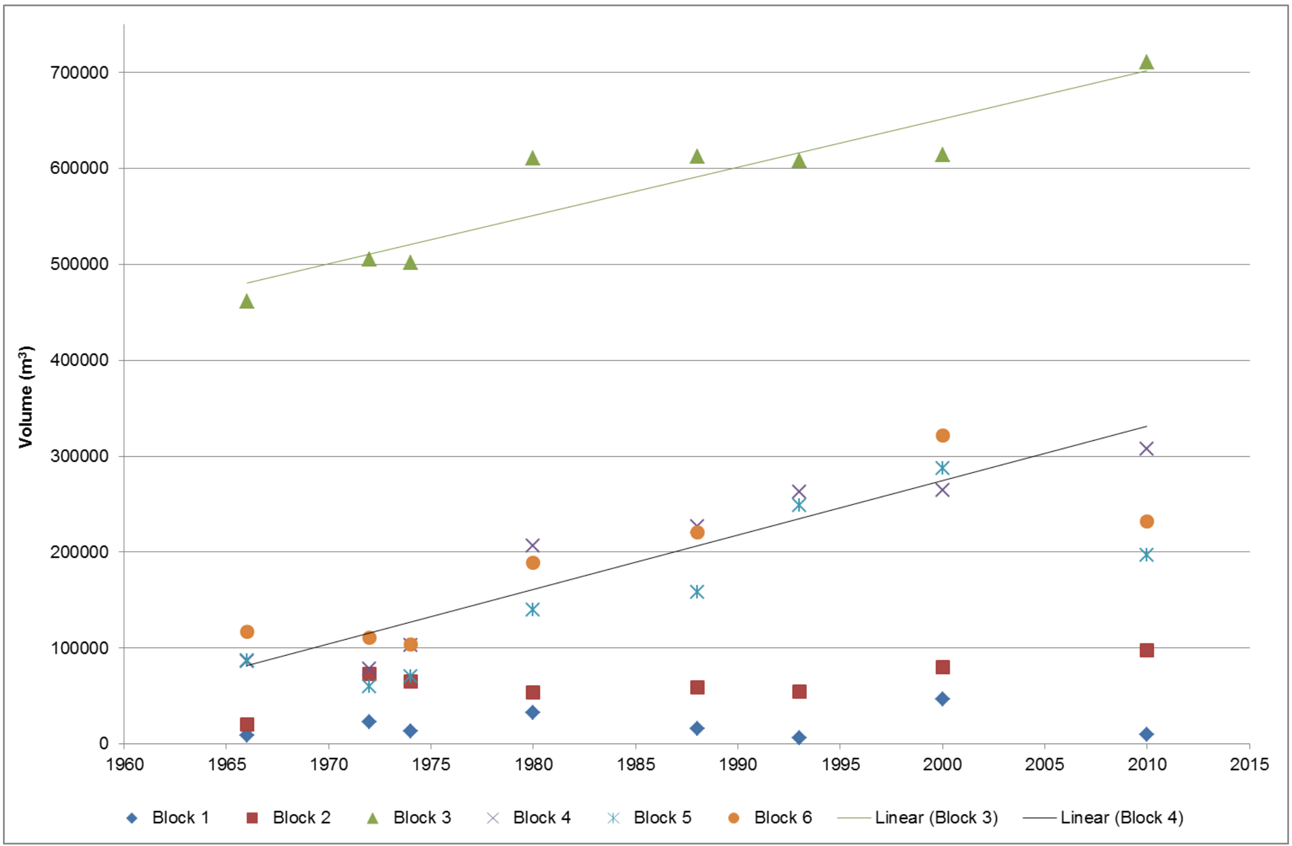


Figure 3-9 Cumulative Volumes for Photogrammetric Blocks at Trial Bay

3.3.2 Future Long Term Recession

3.3.2.1 The Shoreline Evolution Model

The Shoreline Evolution Model is able to predict shoreline evolution in response to changes in sea level at any scale (e.g. 0 to 100 m) as well as in response to other natural or anthropogenic factors. The model provides for the effects on the shoreline of gradients in alongshore transport driven by wave time series and time-dependent shoreface profile responses to cross shore sand movements. 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. The SEM caters for sea level rise factors that the Bruun Rule (1962) does not, 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 sections of coastline with headlands, reefs and structures such as groynes, harbour breakwaters and seawalls.

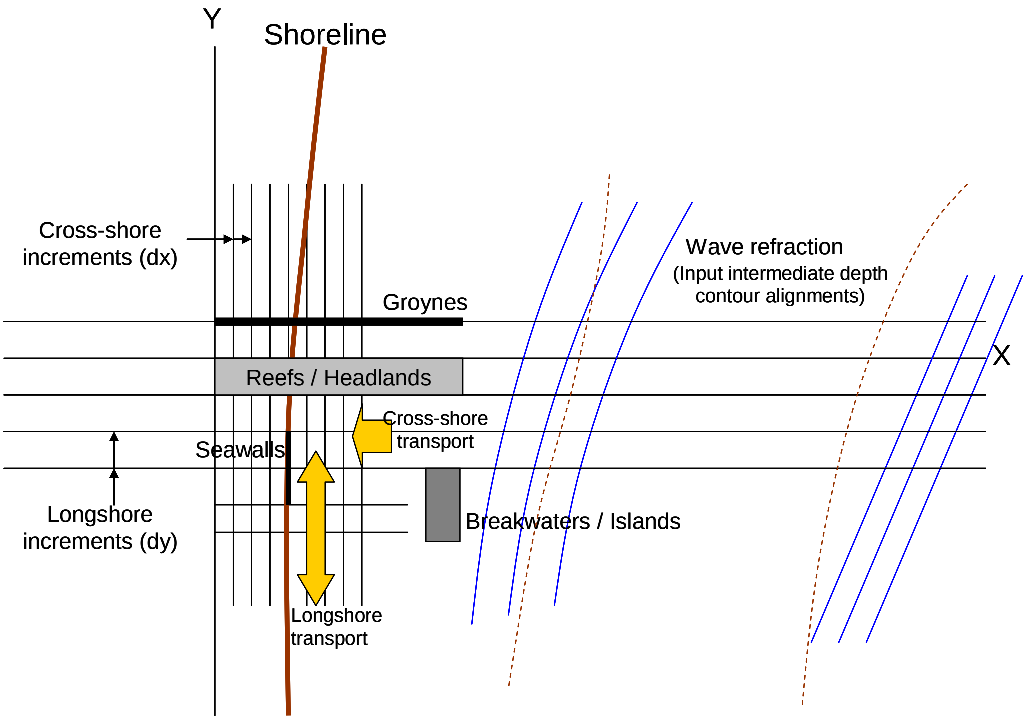


Figure 3-10 Plan view schematisation of SEM domain (Patterson, 2010)

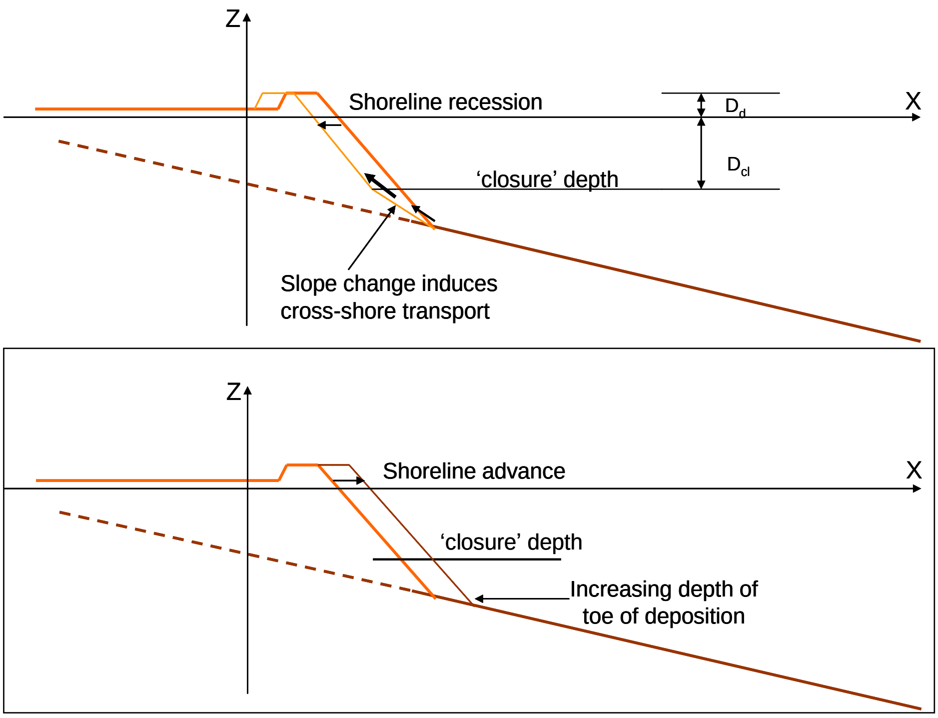


Figure 3-11 Cross shore schematisation of upper profile change for receding (top) and advancing (bottom) shoreline (Patterson, 2010)

Like the Bruun Rule, the SEM is based on the equilibrium profile principle. The SEM's main advantage is that it caters for the variation with depth of responses of the profile to changes induced by shoreline movements and sea level change (Patterson (2012; 2013). The Bruun Rule is based on the principle of geometric similarity of the entire shoreface equilibrium profile to the adopted closure depth. Thus, along sections of coastline that are not dominated by structural features such as headlands (such that a two-dimensional concept can be applied), both methods should achieve reasonably similar and acceptable results provided the closure depth adopted for the Bruun Rule is compatible with the profile response time inherent in the SEM.

3.3.2.2 Application of the Shoreline Evolution Model to Kempsey

For Kempsey, the assessment of shoreline response to the Laggers Point Breakwater, Macleay River Breakwaters and sea level rise utilised this modelling tool, with verification against available historical data.

The model domain was split into three modelling processes: a regional scale model of the entire Kempsey shoreline, then two finer grid models of the Trial Bay shoreline, and South West Rocks to Scotts Head shoreline. The regional model was used to define shoreline response for the shoreline south of South West Rocks, and also, to provide longshore transport rate inputs to the other two models. Trial Bay, which faces nearly west to north, was modelled separately to enable rotation of the model grid to capture the north to nearly western facing section of this shoreline. The outputs from this model were used to derive the shoreline response for Trial Bay. The South West Rocks to Scotts Head model provided better approximation of the response of the shoreline from the Macleay River entrance to the north, again by better incorporating the longshore transport rate around Smoky Cape into this section of shoreline than could be represented by the larger regional scale model.

For each of the three models, the following simulations were conducted:

- Modelling for a 'warm-up' case shoreline without sea level rise, but including all features such as headlands, reefs, offshore reefs, breakwaters and bedrock horizons further landward of the shoreline where known to occur from Quaternary Geological mapping (CCA Dataset, DPI 2004). 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 Kempsey coastline at present (prior to modifying sea level);
- 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 Macleay entrance, such as documented in Section 2.6.4.1, and the known long-term accretionary response in the Trial Bay compartment. 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 'base' case, simulated for 200 years from 1900 to 2100, without sea level rise. Changes to the shoreline from 1900 to 2010 were again verified against historical data and the present shoreline position. The model results were found to be generally consistent with anecdotal evidence and photogrammetric data for the shoreline and so, considered suitable for use in deriving the future shoreline response. The model results were used to compare with the

sea level rise and other scenarios, to ensure that potential changes in the shoreline without sea level rise were identified;

- Modelling of a 'sea level rise' case, simulated for 200 years from 1900 to 2100, using the projections given by the NSW Government (DECCW, 2009a). Based on the advice of DECCW (2010), 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 above present by 2100 was simulated[3];
- Modelling of a second theoretical 'sea level rise' case, to investigate the impact of a 0.5 m greater than projected rise in sea level by 2100. Again, the simulation was run for 200 years from 1900 to 2100, 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 projected 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 1900 to 2100, using the sea level rise benchmarks given by the NSW Government (DECCW, 2009a), described above plus and an average 5° more easterly wave climate.
- Where model results presented a geomorphologically reliable responses to sea level rise (e.g. beach response adjacent to headlands etc), the model results for sea level rise were adopted within the *best estimate* (unlikely) and *worst case* (rare) scenarios (with rounding to account for uncertainty), as explained in detail in Section 3.3.3; and
- In the case where model results were inconsistent with the response expected, the results were adjusted to better reflect the likely future impact, based upon our understanding of the standard Bruun Rule (1962) concept, and the expected geomorphologic response to sea level rise around coastline features such as headlands etc. This was typically of a minor nature, with gross changes demonstrated by the model used to derive the hazard estimates.

Discussion of the historical data, modelling results and verification for response to sea level rise in the future is given below.

3.3.2.3 Modelling of Future Long Term Recession

Model results for the base case scenario without sea level rise indicate the shoreline is unlikely to experience recession or progradation to 2100. There are evidently variations in the rate of longshore sediment transport from year to year (and decade to decade) as a result of natural variability in the wave climate (height and direction), but the shoreline overall remains stable. It is also noted that the base case did not illustrate any further response to structural features such as the Macleay entrance breakwaters or Laggers Point breakwater. This is to be expected given that the shoreline has adapted to these features.

Model results for the sea level rise scenario provide a very clear demonstration of the likely impact of the substantial headlands in the region to interrupt longshore sediment transport as sea level rises, as in Figure 3-12, Figure 3-13 and Figure 3-16 (Trial Bay). The modelling results demonstrate that the

[3] It is noted that the historical photogrammetry demonstrates relative stability of the beaches over the period of photography (around 40 years). Based upon this, the difference between modelling a very small rate of sea level rise between 1900 and 1990 (~1.5 mm/yr, equivalent to about 14 cm), and no sea level rise is considered negligible and is not expected to affect the calculation of future response to sea level rise given by the modelling.

extent of recession due to sea level rise is considerably greater at the southern end of the beach, while the northern end of the beach experiences considerably less recession.

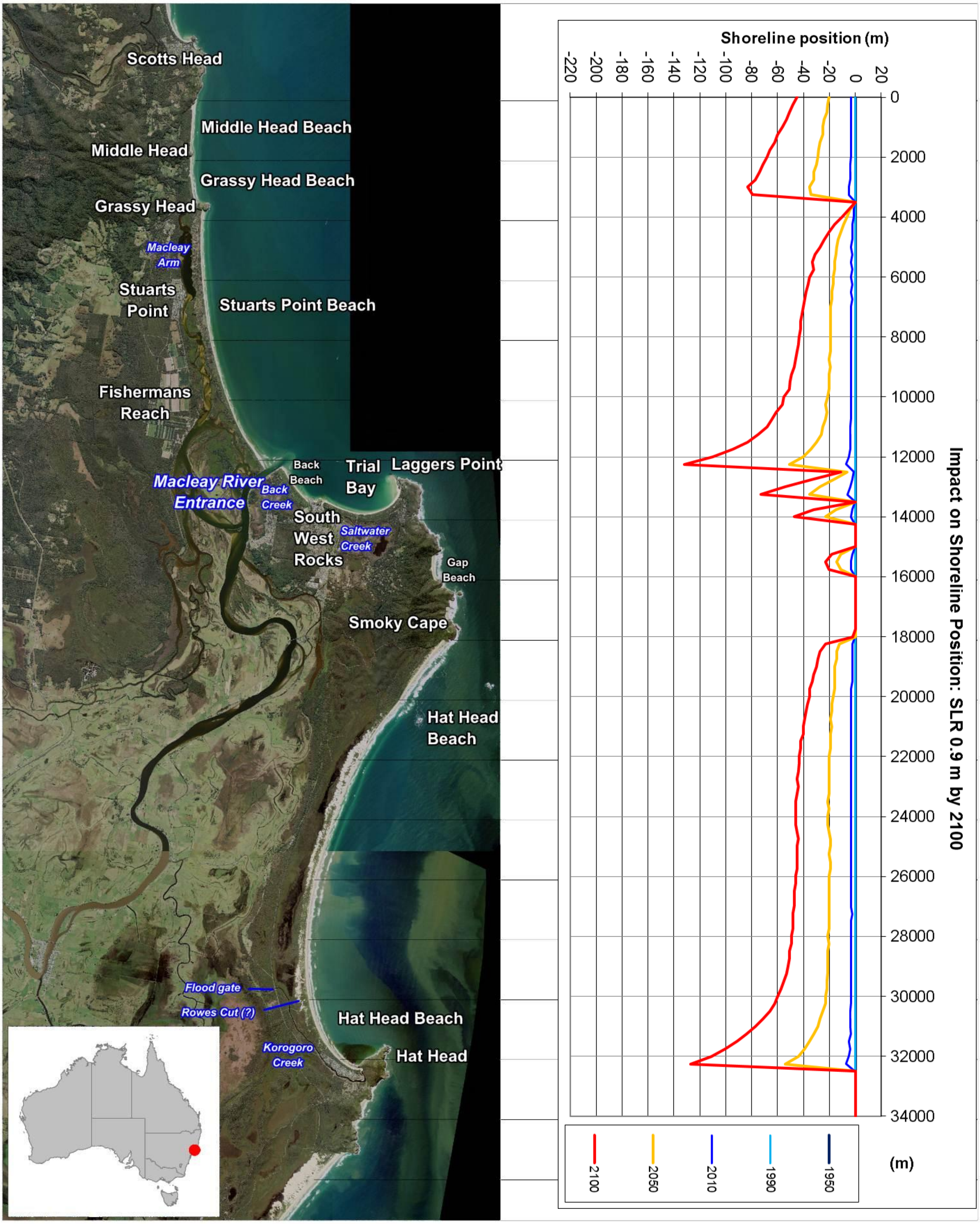
The typical south easterly wave climate in NSW generates northerly longshore sediment transport. As sea level rises, headlands constrain longshore sediment transport between beaches due to the increased water depths at the headland. Northerly directed longshore sediment transport continues within the embayment, mitigating recession at the northern end of the beach. The southern end of the beach is the source of supply to the northern end, but without supply from beaches further south into an embayment, the result is enhanced recession at the southern ends of beaches due to sea level rise. This outcome is very evident in the modelling for the southern ends of all the beaches in the Kempsey LGA (see Figure 3-12, Figure 3-13 and Figure), particularly at Hat Head, Crescent Head, and Trial Bay as the supply of sediment into these embayments is subdued by the large headlands to the south. Even within Delicate Nobby Beach, the central attached reef and island acts like a groyne to interrupt the transport of sediment to the north as sea level rises.

Figure 3-14, Figure 3-15 and Figure 3-17 (Trial Bay) demonstrate the change (reduction) in longshore transport rates as a result of sea level rise. Compared with 1900 and 1950 longshore transport rates, sea level rise increases the depth adjacent to headlands and therefore the rate of longshore sediment transport around the headlands. It is this process that results in the enhanced rates of recession at the southern end of the beach. Towards the centre of beach embayments, wave energy is not impeded by headlands or structures, and so the reduction in transport is not as significant.

The non-uniform recession estimates along the Kempsey shoreline from the SEM are considered to be a realistic assessment of the likely response to sea level rise. Compared with the Bruun Rule, the extent of recession at the southern ends is greater and at the northern ends of beaches is smaller from the SEM. This is an important difference between the SEM and the Bruun Rule, as the model differentiates alongshore response in relation to significant structural features (headlands, reefs or man-made features) and natural longshore transport in the Kempsey region that the Bruun Rule is incapable of illustrating. This response is considered representative of the pattern of longshore sediment transport at headlands in NSW, and thus the model results are considered reliable for use in deriving the recession hazard.

A higher than predicted sea level rise (of 1.4 m by 2100) scenario and a scenario including a 5 degree more easterly wave direction plus 0.9 m sea level rise by 2100 were also tested with the SEM. These scenarios were considered as part of the ‘rare’ (or worst case) likelihood recession estimates. It was found that in almost all locations, the higher than predicted sea level rise produced greater recession impacts than the small (5°) shift in wave direction. The scenario results demonstrate sea level rise to be the dominant driver of shoreline recession compared with slight shifts in wave direction.

While future changes in wave height and direction due to climate change are still being investigated by scientific bodies such as the CSIRO, the results from the SEM suggest that wave climate change will have a relatively minor impact on the shoreline compared with sea level rise. It would take an extreme change in wave climate (e.g. 20-30 degree permanent shift in wave direction or increase in wave height) for notable changes in the shoreline response to occur. At present, such extreme changes are considered highly unlikely (that is, less likely than the ‘rare’ likelihood defined for this project).



Title:

Impact of 0.9 m Sea Level Rise by 2100 on Shoreline - Kempsey North

Figure: **3-10**

Rev: **A**

N

0 3.75 7.5km

Approx. Scale

BMT WBM

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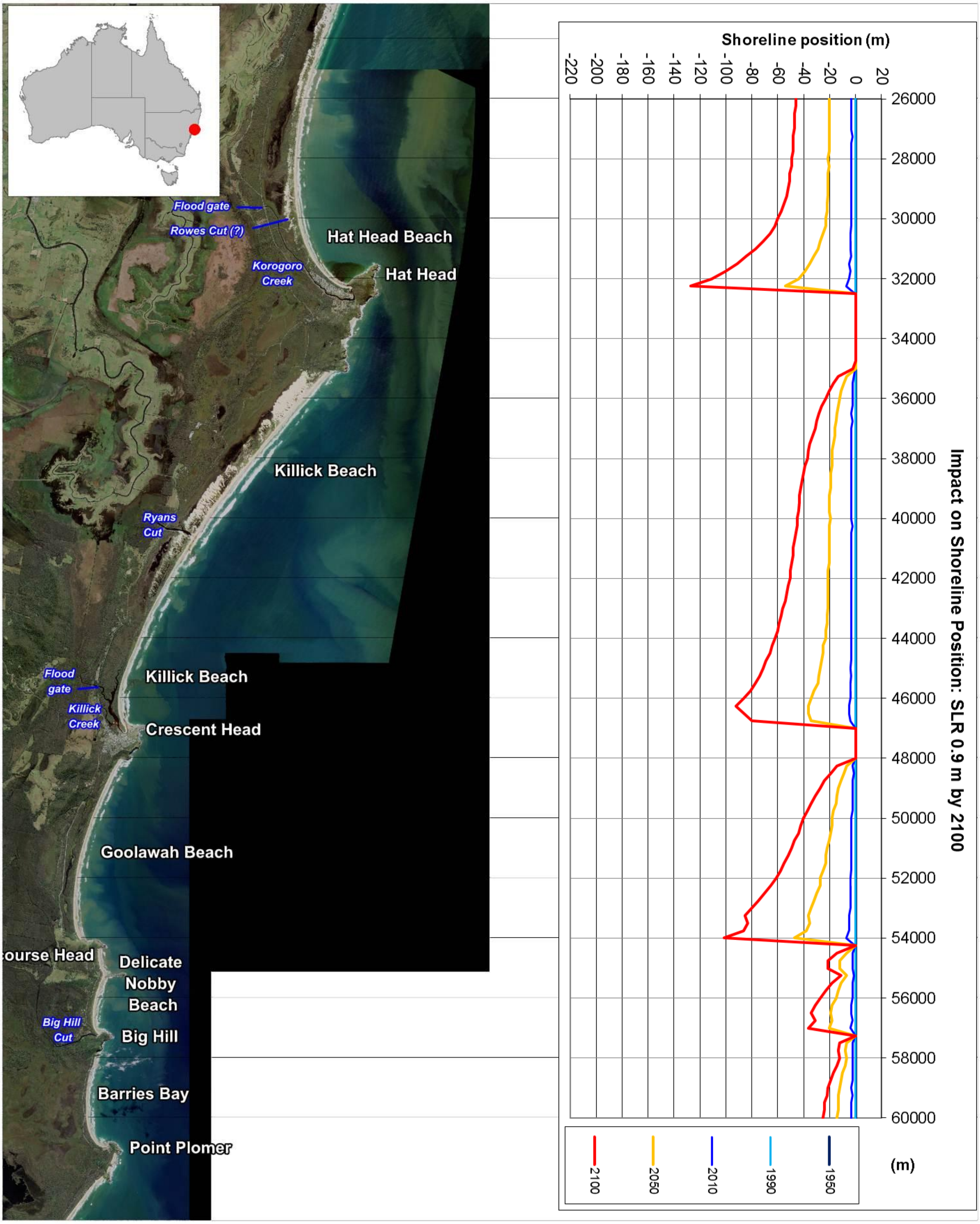

Title:

Impact of 0.9 m Sea Level Rise by 2100 on Shoreline-Kempsey South

Figure: 3-11

Rev: A

N

0 3.75 7.5km

Approx. Scale

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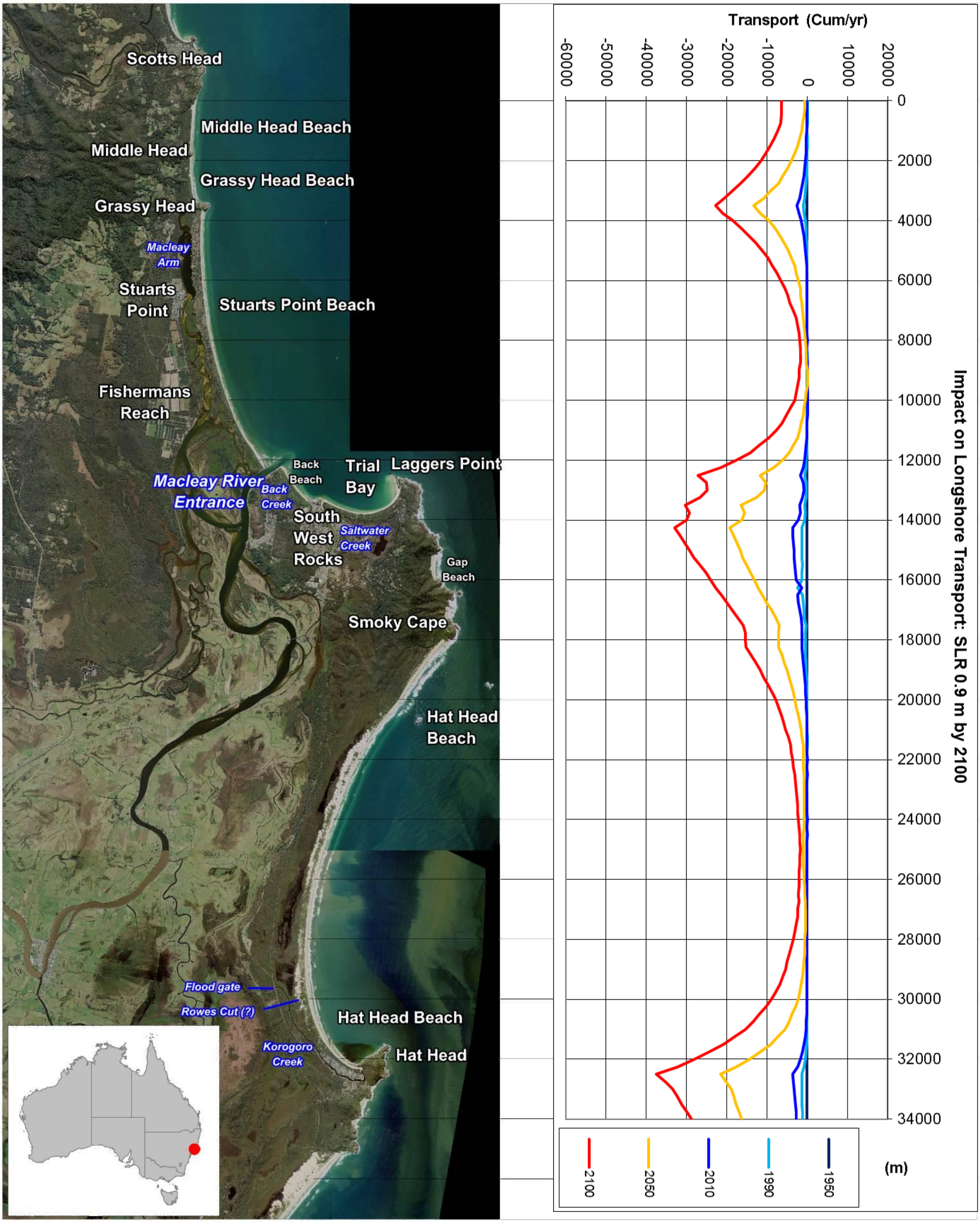

Title:

Impact of 0.9 m Sea Level Rise by 2100 on Longshore Sediment Transport - Kempsey North

Figure: **3-12**

Rev: **A**

N

0 3.75 7.5km

Approx. Scale

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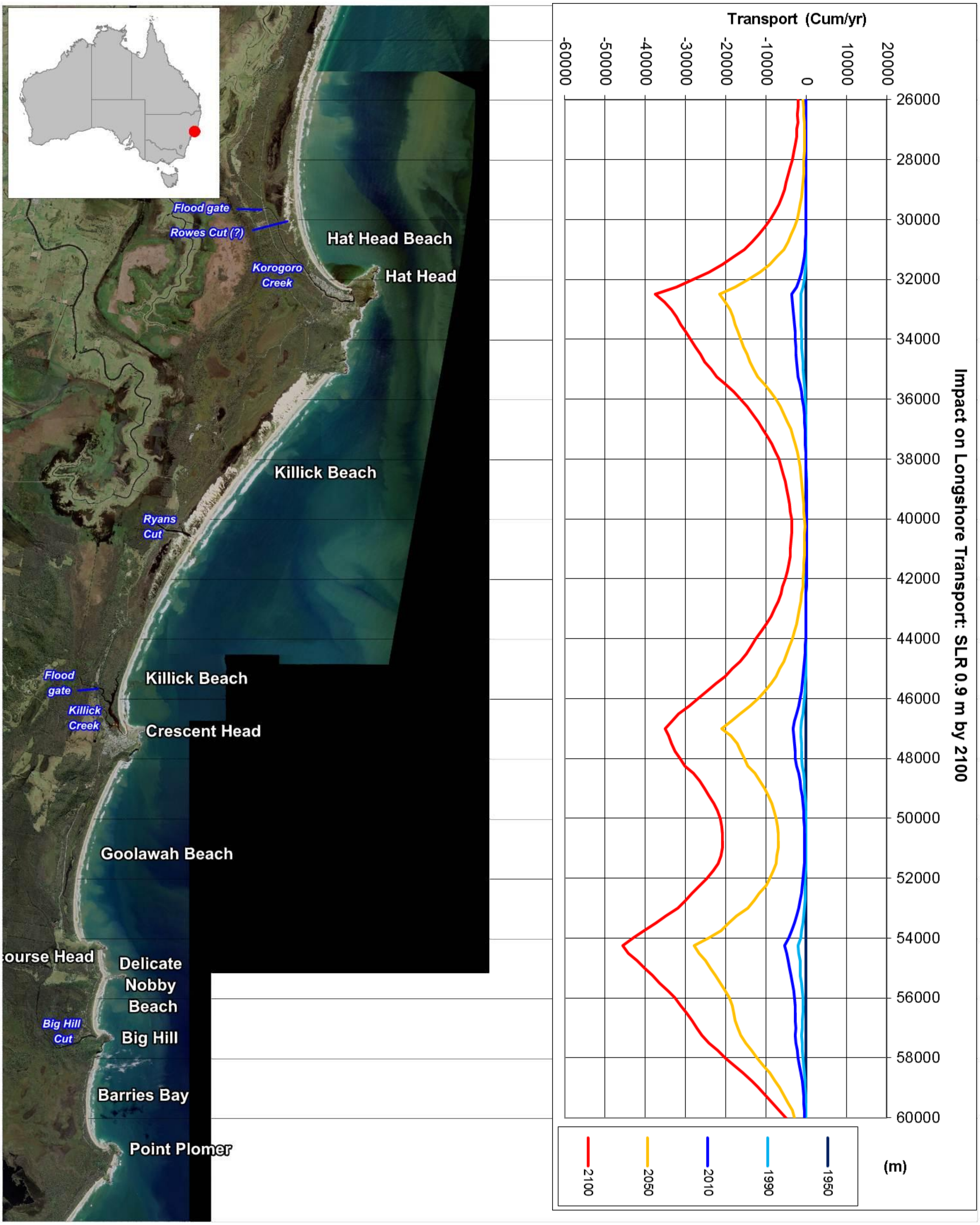

Title:

Impact of 0.9 m Sea Level Rise by 2100 on Longshore Sediment Transport - Kempsey South

Figure: 3-13

Rev: A

N

0 3.75 7.5km

Approx. Scale

BMT WBM

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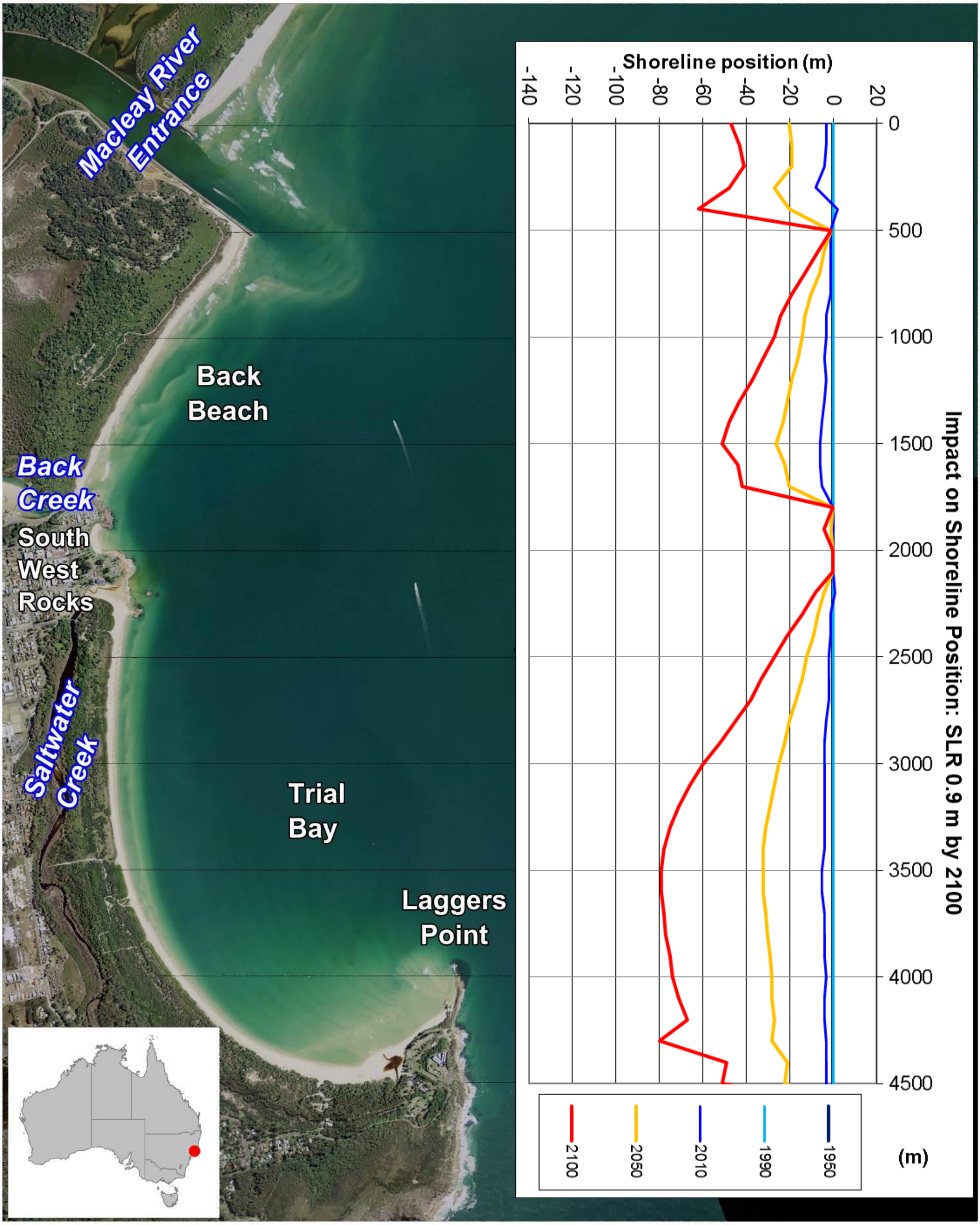

Title:

Impact of 0.9 m Sea Level Rise by 2100 on Shoreline - Trial Bay

Figure: **3-14**

Rev: **A**

N

0 0.5 1km

Approx. Scale

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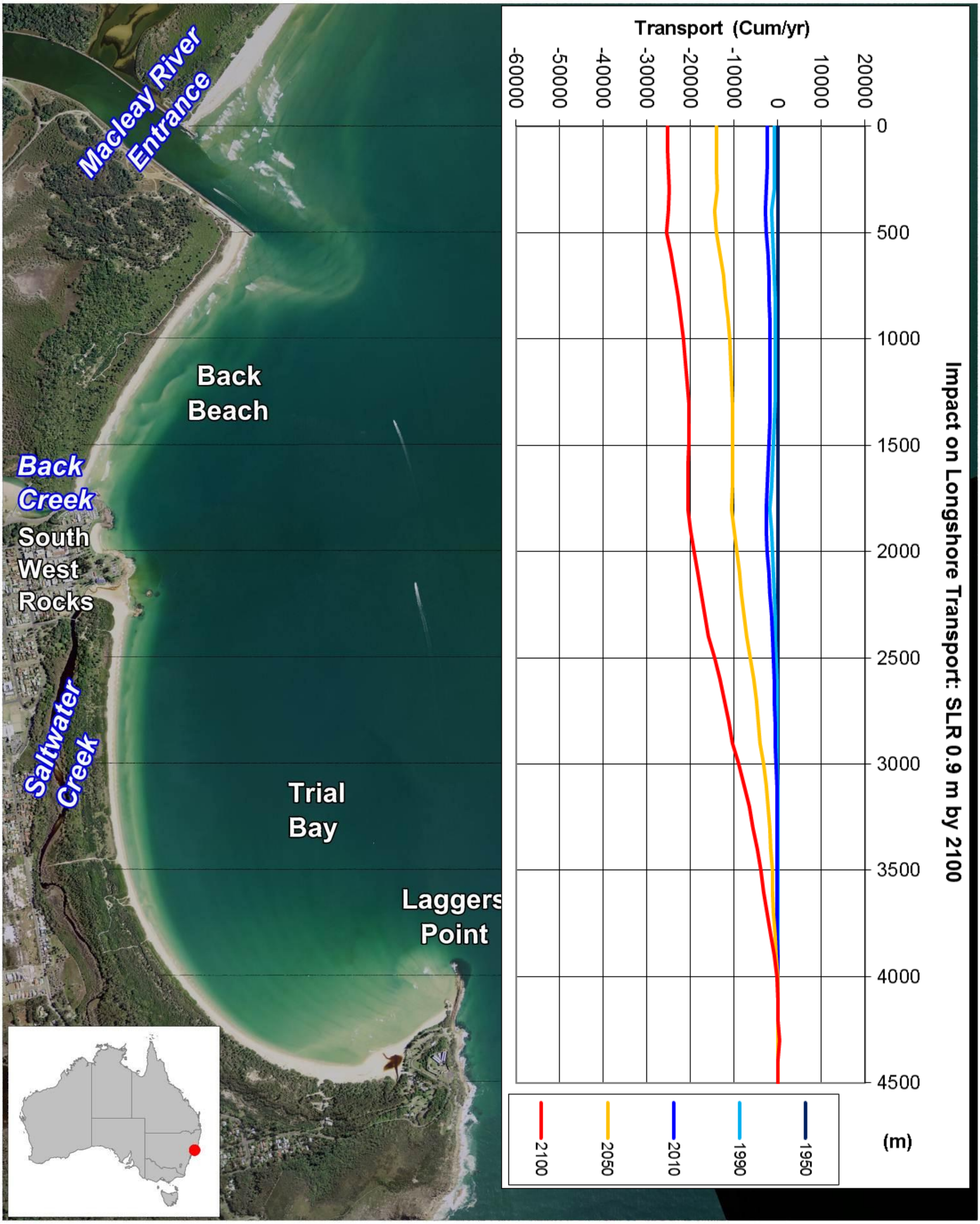

Title:

Impact of 0.9 m Sea Level Rise by 2100 on Longshore Sediment Transport - Trial Bay

Figure: **3-15**

Rev: **A**

N

0 0.5 1km

Approx. Scale

BMT WBM

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3.3.2.4 Comparison of SEM results with the Standard Bruun Rule

To provide a comparison with the SEM model results, calculation of recession on Kempsey's beaches with the standard Bruun Rule (1962) has been undertaken. This requires consideration of a range of factors, together with sensitivity considerations, that affect the Bruun Rule assessment in the context of the SEM approach, as described below.

The 'Standard' Bruun Rule Approach

The simplified Bruun Rule as shown in Figure 3-7 for the linear recession distance *r* (in metres) is:

$r = Ba/D$

Where: *B* = horizontal distance offshore from the top of the dune to the depth of closure (*d*); *a* = the rise in sea level, and *D* = the vertical distance (height) from the top of the dune to the depth of closure (*d*).

Application of a 'standard' Bruun Rule has been highly contested within the coastal science community (e.g. Ranasinghe *et al*., 2007), often relating to the depth of closure value applied within Bruun Rule. The depth of closure is generally adopted as the depth limit at which there is little or no potential for significant cross-shore exchanges of sand, but there has been conjecture surrounding what this depth may be. As shown in Figure 3-18, the depth of closure governs the vertical height component for determining the effective slope of the active nearshore profile used in the Bruun Rule. A more gentle slope will result in a greater horizontal distance of recession and vice versa.

The DECCW (2010) *Coastal Risk Management Guide: Incorporating sea level rise benchmarks in coastal risk assessments* indicates the appropriate calculation of the depth of closure (where suitable bathymetric data is not available) for use in the Bruun equation (noting that DECCW is now the NSW Office of Environment and Heritage, OEH) as follows: "*when using the 'Bruun Rule', use of the lower limit of profile closure (seaward limit of the Shoal Zone) as prescribed by Hallermeier (1981) is recommended in the absence of readily available information on active profile slopes at a location under consideration*". That depth is intended by Hallermeier to correspond to the seaward limit of seasonal net cross shore sand transport and is significantly greater (deeper) than the inner Hallermeir depth limit ($d_{l,t}$) that relates to measurable vertical profile changes, which is more consistent with the Bruun Rule (1962) concept.

It has been common practice along the NSW coastline to generically adopt active profile slopes in the range of 1:50 to 1:100; however, because of the intra-regional variability in slope that exists across the offshore NSW shelf, more rigorous site-specific analysis is recommended to justify the use of a selected active profile slope for use in a *'Bruun Rule'* assessment.

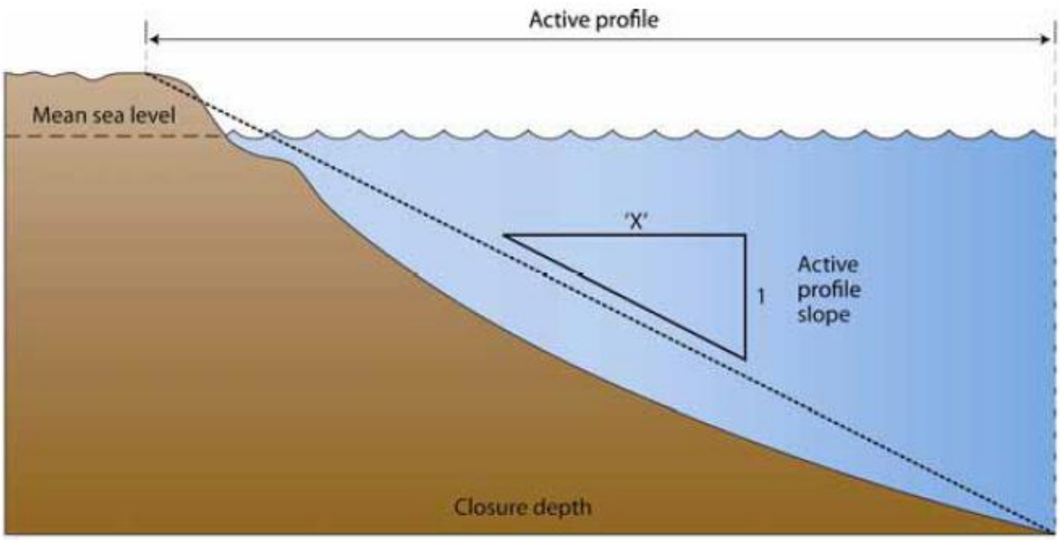

Figure 3-18 Idealised schematic of the active profile slope applicable in the 'Bruun Rule' (from DECCW, 2010)

Depth of Closure

Hallermeier (1981) divides the nearshore zone into three zones, namely:

- the littoral zone, which "extends to the seaward limit of intense bed activity";
- the shoal zone, which "extends from the seaward edge of the littoral zone to a water depth where expected surface waves are likely to cause little sand transport" and "waves have neither strong nor negligible effects on the sand bed"; and
- the offshore zone, which is seaward of the shoal zone and water depths are relatively deep with respect to surface wave effects on the sea bed.

Hallermeier (1981) stresses that sediment motion can and does occur seaward of the shoal zone, however the seaward boundary (d_i) defined by Hallermeier (1981) aims to provide "*a physically meaningful seaward limit to the usual wave-constructed shoreface*".

Hallermeier (1981) then identifies two depths that define the landward and seaward boundaries of the shoal zone:

- depth d_l which is the "*maximum water depth for sand erosion and seaward transport by an extreme yearly wave condition*"; and seaward of this,
- depth d_i which is the "*maximum water depth for sand motion by the median wave condition*", corresponding to the seaward limit of the usual wave-constructed profile.

Hallermeier (1981) proposes the relationship $H_{sm}T_{sm}(g/5000D_{50})^{0.5}$ to estimate d_i, where subscript *m* denotes the long term median value and H_s is the significant wave height, T_s is the significant wave period and D_{50} is the median grain size in metres (and assuming the equation applies to quartz sand in seawater, which is correct for the NSW coast). Conceptually, this depth corresponds to the depth to which storm-related seaward sand movement extends and from which return of sand to the littoral system occurs. The recorded wave data from Crowdy Head indicates approximate values for H_{sm}=1.45 m and T_{sm}=8.6 s, yielding a limiting depth (d_i) of about 35 m.

The Bruun Rule concept provides for complete filling to the closure depth of the 'accommodation space' made available at the outer (seaward) end of the profile with sand derived from the shore-face, as illustrated in Figure 3-6. Conceptually as illustrated, this has its maximum deposition depth at the deepest, most seaward end of the profile, implying a relatively short profile response time. However, there is no evidence that suggests such extensive response at 35m depth where suitable survey data is available along the east coast of Australia.

Cowell et al (2006) deal with this in a probabilistic manner, using a relatively deep closure depth, in which it is accepted that the toe of the profile may experience deposition in the range of 'full accommodation' (lower profile fully filled) or 'full dilation' (zero filling at the toe) with assigned probability. As such, sea level rise recession distances derived with their methodology range from those equivalent to the *Bruun Rule* over the range of Hallermeier closure depths from d_l to d_i.

Conceptually, depths in the range $d_{l,t}$ to d_i as prescribed by Hallermeier (1977; 1981) (i.e. depths within the shoal zone) represent the seaward limit of regular vertical profile changes ranging out to the seaward limit of significant net cross-shore sand transport respectively. Within that range, the limitation imposed by the time-scale of interest for the profile response needs to be considered in determining the appropriate closure depth. That is, the profile 'closure' occurs at greater depth as the time scale increases (for example, if we consider an extreme 100 yearly wave condition compared with the yearly wave condition originally proposed by Hallermeier (1981), the depth of 'closure' is deeper).

Nicholls *et al* (1996), Nicholls *et al* (1998) and Cowell *et al* (2000) refer to the closure depth in terms of the time scale considered. Nicholls *et al* (1998) adopt a version of the Hallermeier (1977; 1981) relationship for depth of closure of the form:

$$d_{l,t} = 2.28H_{e,t} - 68.5(H_{e,t}^2 / gT_{e,t}^2) \qquad (1)$$

Where:

$d_{l,t}$ = the predicted depth of closure over *t* years, referenced to Mean Low Water

$H_{e,t}$ = non-breaking significant wave height exceeded for 12 hours per *t* years

$T_{e,t}$ = associated wave period

Thus, their depth of closure to cater for sea level rise over a planning period of 100 years will be greater than that adopted for shorter durations (e.g. the one year extreme wave originally proposed by Hallermeier). Using recorded wave data from Crowdy Head and based upon a time period of 100 years, the applicable 12-hour wave height is 7 m (refer Figure 2-6), and corresponding wave period is about 12-14 seconds. This equates to a depth of closure of ~14 m. However, that depth relates to the limit of vertical profile change rather than the limit of potential shoreface profile evolution and a somewhat deeper closure depth is likely to be appropriate for the Bruun Rule, provided it is within the depth of feasible profile response.

Patterson (2012; 2013) has identified and quantified a profile response time scale which shows that the time required to achieve equilibrium increases with depth. The SEM model inherently caters for that response behaviour.

Patterson (2013) has determined profile response times for the exposed open coast at Tallow Beach from the adjacent recorded Byron data of 15 m for 200 years and 20 m for 500 years (Figure 3-19). The depth of 35 m corresponds to a response time in excess of 10,000 years.

Further, application of the Bruun Rule should incorporate translation of a representation of the equilibrium shore-face profile shape, not affected by the transition to the inner continental shelf (Figure 3-20). That is, where a deeper closure depth closer to d_i is adopted, its horizontal distance offshore should relate to the equilibrium profile shape, rather than that extending across the flatter inner shelf. The transition from shoreface to inner shelf itself is an indicator of the limiting depth of profile response. It is commonly evident at a depth of about 20-30m along the southeast coast of Australia (Thom 1984; Roy 2001; Cowell et al 2000). Indeed, the depth at the transition from the inner shelf to the shoreface represents the depth of closure with a response time of 5000 years, as this is the time over which the shoreface has been evolving since sea level reached its present level. This is further indication that 35m is too deep for application to the Bruun Rule with a planning response time of 100 years.

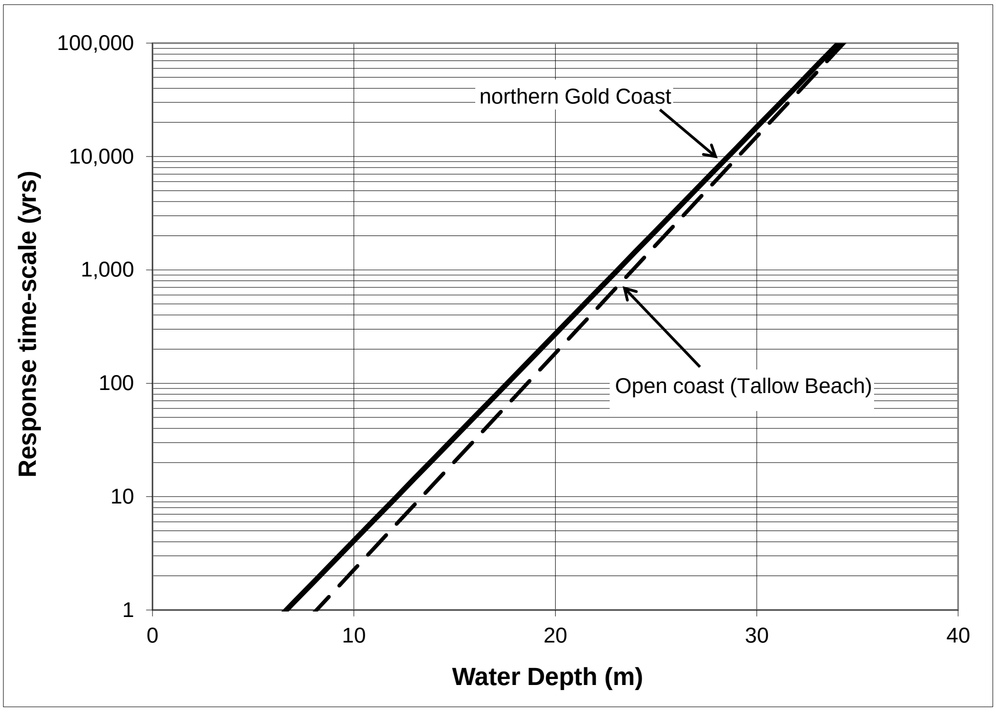

Figure 3-19 Profile response times for Gold Coast and open coasts in northern NSW (Patterson 2013)

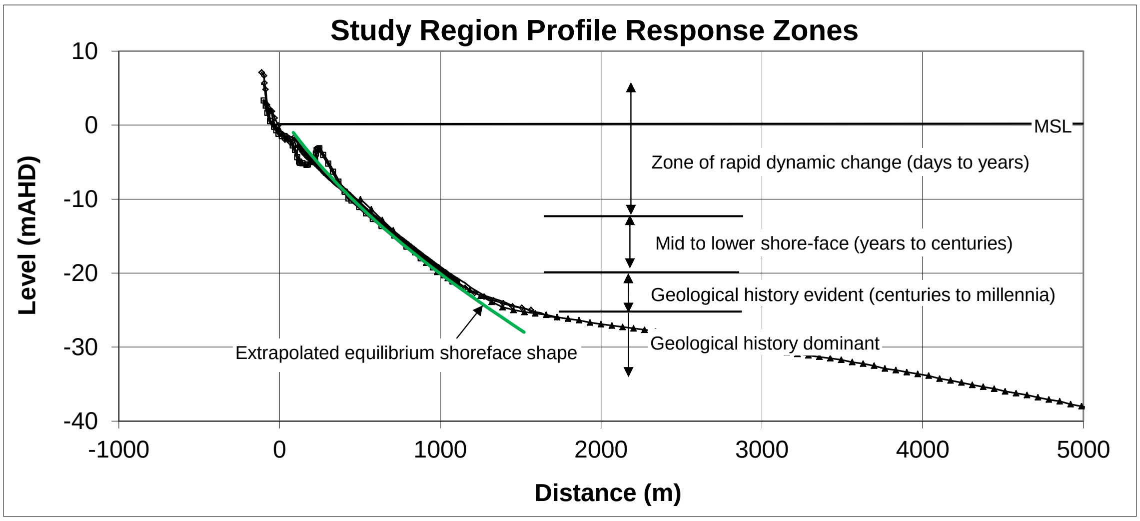

Figure 3-20 Profile response zones (adapted from Patterson 2013)

Results of Bruun (1962) compared with the SEM

For Kempsey, detailed bathymetric survey data is not available, and therefore the equilibrium profile shape cannot be reliably determined. In lieu of this, it is recommended to apply a Bruun Rule closure depth in the range 15 to 20 m, not deeper than the transition from the active lower shoreface slope to the inner shelf slope and not shallower than the depth with a response time scale of 200-500 years (Patterson 2013) as a conservative estimate. The sensitivity to adoption of that depth may be assessed by considering the effect of adopting a depth across that range of feasible depths. On that basis, a best estimate depth of 18m is adopted and sensitivity to a range from 14 m (corresponding to Hallermeir $d_{l,100}$) to 20m considered.

The nearshore slope applied in the Bruun Rule is affected by dune height, which when added with the depth of closure, provides the vertical component of the slope calculation. Higher dunes produce steeper slopes and vice versa with the Bruun Rule, which in turn affects the extent of recession. The hydrographic chart data available for Kempsey, while not sufficiently detailed to determine the equilibrium profile shape, can be used to determine the distance from the top of the dune offshore to the depth of closure, and therefore the slope of the nearshore profile.

In keeping with a 'standard' Bruun Rule application, the horizontal distance to the depth of closure (18 m) has been measured at each beach (including north, middle and south ends for the longer compartments), then averaged for the region. Based upon an average dune height of 5.6 m, depth of closure of 18 m and average offshore distance to the depth of closure of about 1425m for the Kempsey region, the active profile slope applied in the Bruun Rule is 60:1. Considering the adopted future sea level rise levels of 0.34 m at 2050 and 0.84 m 2100 (above 2010 sea level), the Bruun Rule approach would yield recession provisions of about 21 and 51 m respectively, which would then be applied along all beaches in the Kempsey region. A comparison of the Bruun Rule with the recession estimates from the SEM at each beach is given in Table 3-4.

For the larger depth of 20 m, the distance of 1600 m yields a slope factor of 62:1, while for a depth of 15 m, the factor is 57:1. If the Hallermeier depth $d_{l,100}$ of 14 m is applied, the slope factor is 55:1 with a resulting 19 m and 46 m of recession by 2050 and 2100 respectively. Thus, the resulting recession distances are fairly insensitive to the adopted depth, within this reasonable range.

It is clearly evident that a 'standard' Bruun Rule approach is unable to account for three-dimensional aspects of the coastline such as the structural features and wave driven longshore transport. The three-dimensional processes and structure of the coastline will most certainly influence the recessionary response along the shoreline due to sea level rise. As shown in Table 3-4, results of the SEM suggest that recession at the southern ends of the beaches is underestimated, while recession at the northern ends of beaches is similar or overestimated compared with the Bruun Rule calculation. The results of the SEM are physically reasonable, that is, it is reasonable to expect that net northerly littoral transport shall be increasingly trapped at the northern end of beach compartments as the sea level rises. The southern end of beach compartments then experience enhanced recession because the predominant wave climate continues to generate net northerly sediment transport yet the supply into the southern ends is cut off. Thus, the southern end of the beach supplies the northern end of the beach, tending to enhance recession at that end, and reduce recession extents at the northern end, where the sand is trapped.

It is interesting to note that the middle portion of the longer beaches demonstrate a similar recession result for both the SEM and the Bruun Rule approaches. Gross or net longshore sediment transport occurs through the centre of the beach. Even though sediment supply is constricted by the intervening headlands with sea level rise, the southern end of the beach continues to supply the northern end of the beach (under the predominant south-east wave climate), and so, the littoral transport rate through the central portion of the beach remains similar. In this case, longshore transport impacts on the shoreline can be ignored, such that a two-dimensional cross-shore concept such as Bruun Rule will provide reasonable results.

Table 3-4 Comparison of SEM results with Bruun Rule estimate

	Timeframe	2050		2100	
Beach		**SEM* (m)**	**Bruun (m)**	**SEM* (m)**	**Bruun (m)**
Middle Head	North End	20	21	45	51
	South End	25	21	60	51
Grassy Head	North End	30	21	65	51
	South End	35	21	80	51
Stuarts Point	North End	10	21	15	51
	Middle	20	21	45	51
	South End	45	21	100	51
Back Beach	North End	5	21	15	51
	Middle	15	21	30	51
	South End	25	21	50	51
South West Rocks		10	21	20	51
Trial Bay	North West End	10	21	25	51
	Middle	30	21	70	51
	South East End	25	21	65	51
Hat Head	North	15	21	30	51
	Middle	20	21	45	51
	South	35	21	90	51
Crescent Head	North	10	21	25	51
	Middle	20	21	50	51
	South	30	21	80	51
Goolawah	North	10	21	20	51
	Middle	25	21	50	51
	South	40	21	90	51
Delicate Nobby	North	10	21	20	51
	Middle	15	21	25	51
	South	20	21	35	51
Big Hill	North	5	21	10	51
	Middle	15	21	25	51

** SEM model results have been rounded to the nearest 5, to reflect the uncertainty in the calculation of recession (for which use of exact numbers belies a higher level of accuracy than appropriate to any of the available techniques).*

3.3.2.5 Model Assumptions and Limitations

For all models, there is a need to make assumptions, particularly where data is limited, and there are limitations that should be noted in order to correctly analyse and utilise the model output. BMT WBM recognises that modelling is a tool for understanding long term recession, rather than an absolute outcome. Model results provide an estimation of likely impact, but must be consistent and verifiable against the physical constraints of coastal processes and coastal geomorphology, as described in the historical record (e.g. photogrammetry) and geologic record.

For this project, careful analysis of photogrammetry data for long term beach trends and comparison with model outputs to verify results was conducted. Furthermore, to provide 'bounds of uncertainty' to the model results, the SEM output has been adopted within a qualitative probabilistic approach to hazards mapping. The approach to mapping of recession and erosion hazards in Kempsey is discussed in detail in Section 3.3.3.

Key assumptions and limitations in the application of the SEM to the Kempsey shoreline are outlined below. In spite of the limitations and assumptions, the SEM provides a significant advancement upon the existing standard practise for recession calculations that utilises the Bruun Rule (1962), as demonstrated in Section 3.3.2.4.

Equilibrium Profile and Cross shore Transport Potential

A major component of the SEM is the definition of the equilibrium nearshore profile (shape and slope), which extends from the seaward end of the surfzone out to the toe of the nearshore shoreface where it meets the continental shelf slope. This component of the model is an important differentiation from other shoreline response models and the Bruun Rule, as the model incorporates a capability to provide for cross shore transport from the lower shoreface to the littoral zone. The rate of this cross shore supply is dependent on the shape and slope of the existing nearshore profile relative to the equilibrium shape, and the depth-dependent potential for cross-shore transport.

The cross shore transport potential term used in the SEM is the depth and slope dependent factor that determines how the profile evolves. It is moderated by the extent that the existing profile is the same or is different from the equilibrium profile (i.e. how near the nearshore profile is to the equilibrium profile). While the high rates of onshore sand transport that occurred in the early part of the Holocene period have now essentially ceased, it is generally accepted within the coastal science profession that there is a small rate of residual supply to the shoreline, typically of the order of 0.5 to 4 m^3/m/year, as the shape of the nearshore profile continues to evolve towards an equilibrium shape, albeit as a very slow rate (Roy 2001; Cowell et al 2000; Goodwin et al 2005; Patterson 2013). Although the prevailing contemporary rate of supply is very low, over planning timescales and along substantial coastline lengths, this supply can be important in promoting the stability of many shorelines in NSW. To a large extent, the potential for ongoing shoreward supply is determined by the depth at which the inner continental shelf slope intersects the shoreface, with shallower depths indicating greater likely supply.

The equilibrium profile equation is not hard-wired into the SEM and the values for key coefficients of the equation can be input based upon the measured nearshore profile of the area being modelled. If changes to the coefficients for the equilibrium profile equation are to be made, this must be determined from accurate bathymetric data of the nearshore zone being modelled (hydrosurvey or marine LiDAR, preferably over numerous dates, to account for the variability of the upper littoral zone).

High resolution bathymetric data is not available for the nearshore zone out to 30-40 m in the Kempsey region. The only bathymetric data available is the Australian Hydrographic Chart No. 811 for Crowdy Head to Nambucca Heads (scale 1:150,000) and No. 220 for Trial Bay and South West Rocks. Depth soundings are limited in depths 0 to 40 m where the majority of sediment transport will take place. Without more reliable and detailed data, the equilibrium profile shape applied in the SEM for Kempsey is that from the Gold Coast in south east Queensland. The equilibrium profile was developed using the numerous nearshore profiles available at the Gold Coast, then confirmed for northern NSW by Patterson (2013).

Recession extents with sea level rise calculated with the Bruun Rule compared with the SEM results showed good agreement in the central portion of the beach where longshore processes are less important (and the cross-shore Bruun Rule approach is more reliably applied, see Section 3.3.2.4). This provides sound evidence that the equilibrium profile from the Gold Coast can be applied at Kempsey with reasonable confidence.

Longshore Sediment Transport

As discussed in Section 2.6.1, an average net sediment transport of 65,000 m^3/yr to the north has been assumed for the region, and applied in the SEM. As there is no existing measurement or calculated value for the Kempsey region, the regional net longshore sediment transport rate was estimated based upon the values for the regions north and south of Kempsey, then tested within the 'warm up' scenario model runs (in which the modelled shoreline is stabilised prior to introducing drivers such as sea level rise) in the SEM. A more detailed assessment of the actual rate of longshore transport may therefore vary from the value adopted in the SEM.

Within the SEM, the Shore Protection Manual (1984) equation for longshore sediment transport ('the CERC equation') is used to calculate longshore sediment transport. While the CERC equation is known to have limitations, in the context of the SEM simulations, it has been shown in a range of investigations to give reliable results when applied in time series form over years to decades. Further, it is the alongshore gradients of net transport and relative rates of change that most affect shoreline change, reducing the significance of limitations in the CERC equation.

Littoral Zone Beach Profile Change

The SEM is not a storm erosion model, and so the beach profile (between the top of the dune and the seaward limit of the surf zone) remains at an average set slope within the model (typically 1:30). This does not affect the ability of the SEM to determine longer term changes in shoreline position in response to net gains and losses of sand and/or sea level rise. Thus, it is important to understand that the change in shoreline position demonstrated by the SEM is not the result of storms, commonly termed storm demand or erosion. Therefore, beach erosion estimates must be added to the recession estimates from the SEM for future time periods.

3.3.3 Hazard Mapping for Beach Erosion and Long Term Recession

This section outlines how the modelling results for future long term recession have been combined with the future beach erosion hazard extents to derive the 2050 and 2100 hazard probability zones, as shown in figures in Appendix B.

The derivation of the beach erosion hazard accounts for the existing and future wave climate variability, for example an enhanced period of storminess such as observed during the 1970s and 2009. The 'immediate' beach erosion hazard is 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. 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 'almost certain' line at 2050 and 2100 accounts for 'almost certain' (average) beach erosion (refer Section 3.2) without sea level rise. There is no evidence of long term recession on Kempsey's beaches and data analysis plus the shoreline evolution modelling indicated that the shoreline has already stabilised in response to the Macleay Breakwaters. Therefore, no additional shoreline setback for long term recession has been included in the 'almost certain' hazard at 2050 and 2100. While it is noted that Trial Bay has experienced accretion in the past and this may well continue in the future, it is considered prudent to assume the Trial Bay shoreline remains in its present position, and as for the other beaches, the 'almost certain' hazard is carried on to 2050 and 2100.

The NSW Government (DP, 2010) guidance defines the coastal risk planning area as beginning from the immediate coastal erosion hazard line, which is effectively a zero sea level rise scenario. To represent this within the adopted hazard likelihood approach, the 'almost certain' beach erosion hazard line is continued for the future time periods of 2050 and 2100 without sea level rise. It is scientifically justifiable to assume that sea level rise will continue to occur at a rate that is at least the rate of rise over the 20th century prior to 1990 (of ~ 1.5 mm/year). It is also equally notable that the natural variability of the shoreline position is far greater than the potential impact of that rise, based upon the historical data for beaches (such as at Kempsey) throughout the 20th century with 1.5 mm/year rise that illustrates relative stability of the beaches within a highly variable beach position (i.e. the shoreline is highly variable shifting from eroded to accreted states). , The *almost certain* line is simply a planning benchmark irrespective of uncertainty associated with climate change and the potential rate of future sea level rise. The 'almost certain' hazard likelihood zones at all planning periods is summarised in Table 3-5.

The *best estimate* (unlikely) hazard likelihood zone 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 plus the *best estimate* (unlikely) beach erosion hazard extent (refer Section 3.2).

Incorporating the shoreline response to predicted sea level rise into the *best estimate* hazard zone is not intended to imply that sea level rise itself is 'unlikely'. In fact, the recession estimates are not given a likelihood, but are adopted directly into this hazard zone. The 'unlikely' likelihood of this hazard zone relates mostly to the beach erosion component. That is, while sea level rise and the resulting shoreline recession is considered likely, the subsequent occurrence of beach erosion to a maximum extent is unlikely. The *best estimate* (unlikely) zones at all planning periods are summarised in Table 3-5.

The *worst case* (rare) hazard probability zone was derived as the maximum extent of recession due to either:

- future long term recession due to a higher than predicted sea rise of 1.4 m by 2100 plus the immediate best estimate (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 and shift in mean wave direction to 5° more easterly by 2100 (2.5 ° by 2050), plus the immediate best estimate (maximum) beach erosion extent.

Table 3-5 Beach Erosion and Shoreline Recession Hazard Probability Zones

Probability	Immediate	2050	2100
Almost Certain	'average' beach erosion [1]	Immediate 'average' beach erosion	Immediate 'average' beach erosion
Likely	NM [2]	NM	NM
Possible	NM	NM	NM
Best Estimate (Unlikely)	'maximum' beach erosion at any position along the beach [1]	Immediate 'maximum' beach erosion + 0.4 m SLR	Immediate 'maximum' beach erosion + 0.9 m SLR
Worst Case (Rare)	'extreme' beach erosion [3]	**Worst Case of either**: Immediate 'maximum' beach erosion + 0.7 m SLR **OR** Immediate 'extreme' beach erosion + 0.4 m SLR **OR** Immediate 'maximum' beach erosion + 0.4 m SLR + 5 ° more easterly wave climate	**Worst Case of either**: Immediate 'maximum' beach erosion + 1.4 m SLR **OR** Immediate 'extreme' beach erosion + 0.9 m SLR **OR** Immediate 'maximum' beach erosion + 0.9 m SLR + 5 ° more easterly wave climate

[1] *as measured over the past 4 decades.*
[2] *NM = Not Mapped due to inadequate data to differentiate likelihoods between 'almost certain' and 'unlikely'.*
[3] *Assumed to be 'maximum' erosion plus the difference between 'maximum' and 'average' beach erosion.*

From a risk perspective, it is important to consider the impact of a higher rise in sea level than that currently prescribed by the NSW Government (DECCW, 2009a). 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 0). This also accounts for sea level rise occurring faster than predicted. The outcomes of this modelling for 2050 and 2100 have been combined with the *best estimate* (maximum) beach erosion extent, to form one of the scenarios for the *worst case* hazard probability zone.

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. However, from a risk perspective, 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.

Climate change projections for wave climate are still relatively coarse as described in Section 2.8, and uncertainty remains regarding how and to what extent climate change may affect our wave climate. The projections from McInnes *et al* (2007) are within the existing variability of the NSW wave climate, and suggest up to a 3.3° more easterly average (swell) wave direction by 2070. In lieu of more reliable projections, it was considered prudent to investigate a shift in the mean wave direction to 5° more easterly by 2100, as a worst case scenario.

Results from the Shoreline Evolution Model suggested that there was very little (~5 m at most) shift in the shoreline position with a 5° more easterly wave climate. Furthermore, the model results demonstrated that the effects of a greater than predicted sea level rise (to 1.4 m by 2100) or the addition of ‘rare’ beach erosion extents are far more significant in producing shoreline recession. While the shoreline is sensitive to shifts in wave climate (and particularly relating to beach erosion events), sea level rise is considered to be the dominant factor for long term shoreline recession. The outcomes of the Shoreline Evolution Model are supported by other modelling studies that have also demonstrated sea level rise to be far more dominant in generating shoreline recession compared with the changes to wave climate predicted by McInnes et al. (2007) at this time (Section 2.8).

For the *worst case* hazard likelihood zones, the maximum landward shift in shoreline position from any of the scenarios outlined above (at 2050 and 2100) was adopted as the final *worst case* hazard extent. In nearly all cases, the higher than predicted sea level rise provided the greatest potential for recession and thus this was the main scenario adopted as defining the *worst case* hazard.

3.3.3.1 Assumptions and Limitations in Hazards Mapping

For all scenarios, the results of the shoreline modelling have been used with caution. Model results and beach erosion estimates 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.

Areas of known bedrock identified by the Quaternary Geology mapping (DPI, 2004 as part of the Comprehensive Coastal Assessment Project 3 Dataset) have been incorporated when mapping the beach erosion and recession hazards, as described below. Areas of known bedrock were included in the hind dune region of the SEM also, to accurately constrain recession as required.

- Areas of assumed bedrock based on the Quaternary geology mapping (DPI, 2004) and verified by aerial photography and field observations (e.g. headlands, rock outcrops) are displayed on the hazard maps. It is noted that at Crescent Head, the area of assumed bedrock has been extended from the Quaternary Geology mapping to include Pebbly Beach, as field observations and aerial photography demonstrate this location to be entirely rock outcropping in the surfzone, as shown in Figure 3-21;

- 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 notably recede bedrock within the 100 year planning timeframe;
- Seawalls that are assumed to have been appropriately engineered for the coastal environment have also been included in the mapping, and assumed to constrain erosion and recession under the *almost certain* and *best estimate* scenarios, but not the *worst case* scenario. The *worst case* scenario aims to capture the potential for failure along sections of the wall, which may particularly be the case where a seawall is not maintained into the future;

  The key location of interest for this assumption for seawalls is Crescent Head. The rock wall along Killick Creek is assumed to be built to a suitable standard (or otherwise will be maintained into the future) and so expected to constrain erosion, except for the ‘rare’ scenario. The shoreline of Crescent Head is evidently a combination of natural bedrock and boulders with possibly some rock armouring above (see Figure 3-22). The natural line of bedrock included in the Quaternary Geology mapping does not extend to the surf club and Killick Creek mouth. Without detailed geological mapping of this section of shoreline, it is not certain if it is natural protection or rock armour in this location (see Figure 3-23). Therefore, it is assumed the natural rock and rock armour protection along the Crescent Head shoreline will constrain *almost certain* and *best estimate* erosion scenario, but the *worst case* erosion scenario assumes that there may be failure of the rock armour protection in front of the surf club. This should be certified through a site specific geotechnical investigation at this location; and
- Where the areas of high elevation were suggested in the geology mapping to be sediment, 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. Crescent Head).

It should also be noted that the erosion mapping does not incorporate wave overtopping, and so, the areas at Crescent Head may still be subject to overtopping, even where protected by natural rock and rock armouring.

Beach erosion and shoreline recession hazard maps for all sections of the Kempsey coastline for the immediate, 2050 and 2100 planning timeframes are given in Appendix B at the end of this report. It is noted that when viewing the mapped hazard lines, the lines do not represent the actual position of the shoreline at a particular timeframe. Instead, the lines represent the potential for any point along the beach to reach such a landward extent (ie, *almost certain*, *best estimate* (unlikely) or *worst case* (rare)) at that timeframe.

Figure 3-21 Pebbly Beach at Crescent Head with Rock Reef and Boulders and Gravel in the Surfzone and Beach

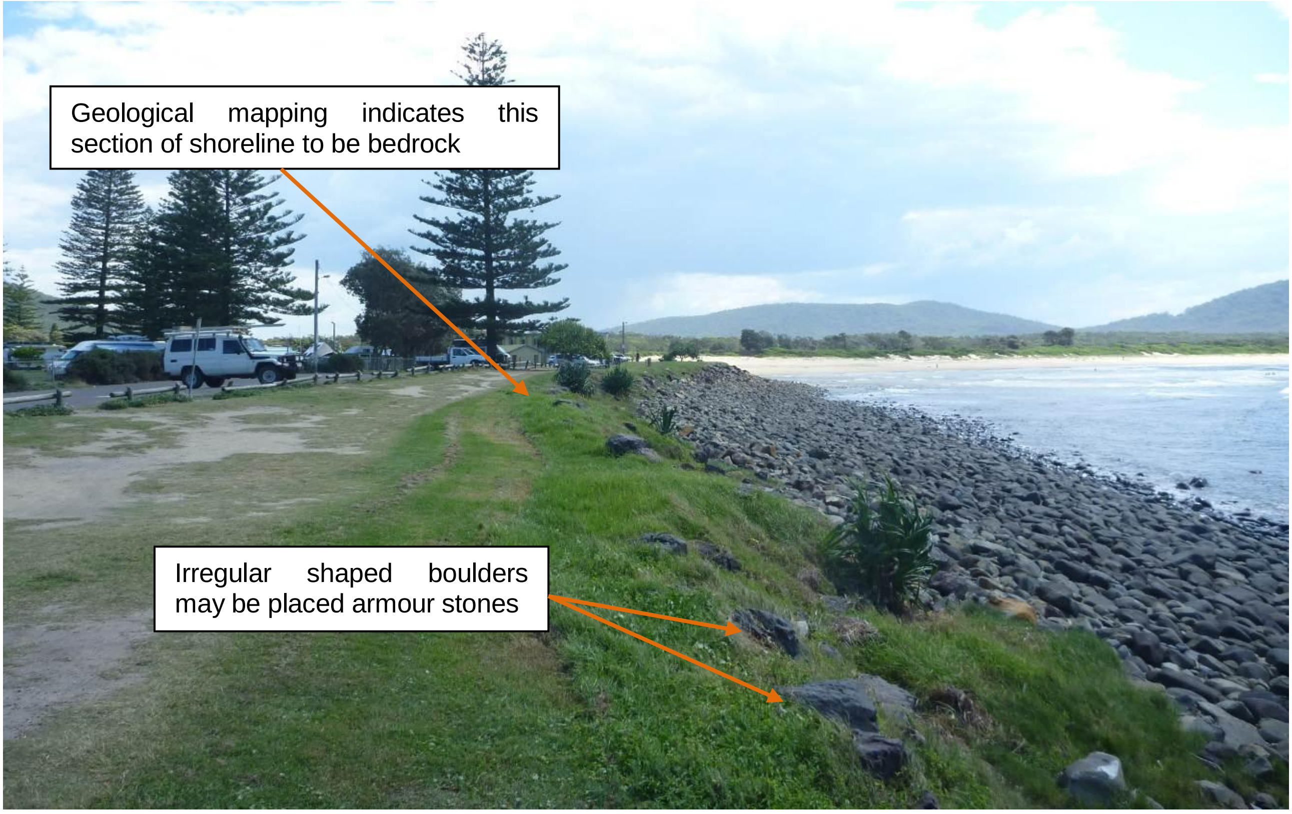

Figure 3-22 Crescent Head Shoreline Illustrating Bedrock, Boulders and Possible Rock Armour Stones

Figure 3-23 The Shoreline in front of Crescent Head SLSC illustrating Boulders and Potentially Unconsolidated (Erodible) Sediments

3.3.4 Dune Slope Adjustment and Reduced Foundation Capacity

Immediately following storm erosion events on sandy beaches, a near vertical erosion scarp of substantial height can be left in the dune or beach ridge. Over time this near vertical 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 3-24), 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.

The defined zones should 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.

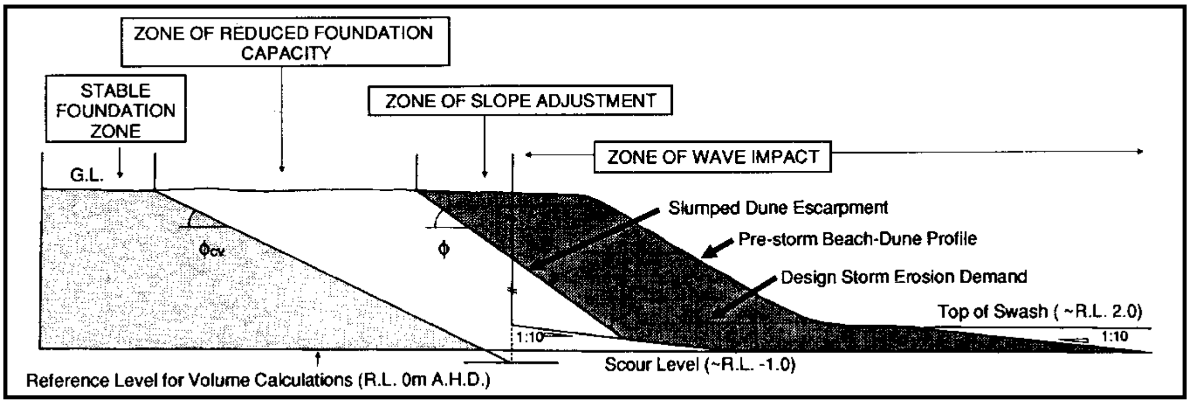

Figure 3-24 Design Profile and zones of instability for Storm Erosion (From Nielsen *et al.*, (1992)

Table 3-6 Width of Zone of Reduced Bearing Capacity

RL of Dunal System (m AHD) [1]	Indicative width of Zone of Reduced Bearing Capacity (m) [2]
4	9.3
5	10.7
6	12.2
7	13.6
8	15.0
9	16.4
10	17.9

1 Assumed that surface of dunal system is approximately level (see Figure 3-24).
2 Distance measured landward from the top of the erosion escarpment following slope readjustment (see Figure 3-24).

Amongst other factors, the width of the zone of reduced bearing capacity behind the top of an erosion escarpment is dependent upon the angle of repose of the dune sand and the height of the dune above mean sea level (refer Figure 3-24). Table 3-6 provides an indicative guide to the width of the zone of reduced bearing capacity measured landward from the top of the erosion escarpment for various dune heights.

The allowances in Table 3.4 are provided for indicative planning purposes only. These allowances 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.

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.

3.4 Coastal Inundation

The main impact of the coastal inundation hazard relates to the inundation of low-lying areas near and behind coastal barriers and coastal entrances during high ocean water levels. Elevated ocean water levels during a storm may result in the inundation of estuary foreshores, lake and lagoon foreshores (closed or open) and low lying back beach areas hydraulically connected to the ocean (NSW Government, 1990). The elevated ocean levels cause inundation by either propagating into entrances or acting as a tailwater level precluding flood outflow from the creeks and so elevating the water levels within the rivers / creeks /lagoons.

Elevated water levels during a storm, which may result in coastal inundation, comprise of: barometric pressure set up; wind set up; astronomical tide; and wave set up, as defined in Section 2.4.2. Table 2-3 to Table 2-5 provide elevated water level predictions for each of the immediate, 2050 and 2100 timeframes. A summary of the rationale behind the coastal inundation levels and their probability for all planning periods is given in Table 3-7, and explained below.

For the purpose of defining the likelihood of coastal inundation within the immediate timeframe, it was considered '**almost certain**' would be equivalent to a 1 in 20 return interval event, the **best estimate** (unlikely) would be equivalent to a 1 in 100 year event and **worst case** (rare) would be equivalent to a greater than 1 in 100 year event resulting from an extreme climatic condition. As detailed in Section 2.4.2, the extreme climatic condition represents the occurrence of an event of sufficient rarity, for example a tropical cyclone tracking further southwards along the NSW coast or extreme east coast low cyclone, resulting in still water levels (excluding wave set up) roughly equivalent to a 1 in 1000 year average recurrence. Such an event was estimated to add 0.2 m to the 1 in 100 year water level. 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 in the future. The adopted inundation levels for the immediate timeframe are given in Table 3-8.

For the 2050 planning period, as discussed in Section 2.4.2, extreme water levels will additionally include sea level rise, as well as minor projected changes to storm surge and wave height (as given by McInnes *et al*., 2007). The inundation levels are thus:

- an *almost certain* probability of a 1 in 20 return interval event, without sea level rise (to provide the boundary of the coastal risk planning area);
- a *best estimate* (unlikely) probability of experiencing a 1 in 100 yr event plus predicted sea level rise of 0.4m by 2050, and increased wave set up and increased storm surge due to climate change; and
- a *worst case* (rare) probability of a 1 in 100 yr event plus greater than predicted sea level rise of 0.7 m by 2050, or an extreme climatic condition (e.g. a 1 in 1000 year still water level event, excluding wave set up) plus predicted sea level rise of 0.4 m by 2050, whichever was the higher.

The adopted inundation levels for the 2050 timeframe are given in Table 3-8.

Similarly, the 2100 planning period coastal inundation extents will additionally include sea level rise and minor changes to wave set up and storm surge due to climate change. The *almost certain, best estimate* and *worst case* probability levels are thus the same as 2050, but with the additional sea level rise and wave height and storm surge change predicted by 2100. The adopted inundation levels for the 2100 timeframe are given in Table 3-8.

Table 3-7 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
Possible	NM	NM	NM
Best Estimate (Unlikely)	1 in 100 yr storm surge and wave set up	1 in 100 yr storm surge and wave set up + 0.4 m SLR and climate change impacts	1 in 100 yr storm surge and wave set up + 0.9 m SLR and climate change impacts
Worst Case (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 **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 **OR** 1 in 100 yr storm surge and wave set up + 1.4 m SLR and climate change impacts

[1] *NM = Not Mapped*

Table 3-8 Adopted Inundation Levels

Adopted Inundation Levels	Immediate (m AHD)	2050 (m AHD)	2100 (m AHD)
Almost Certain	2.5	2.5	2.5
Best Estimate (Unlikely)	2.7	3.2	3.8
Worst Case (Rare)	2.9	3.5	4.3

3.4.1 Wave Run Up

A small component of the inundation hazard refers to overtopping of dune barriers by wave run-up. Wave breaking processes on the shoreline will cause wave run-up onto the beach face and over dune crests during elevated water level events. Wave overtopping at an extreme level is likely to occur for a limited time (several hours) around the high tide. Typically once a dune or barrier has been breached, the waves spread out in the 10 – 30 m behind the barrier.

There are no measurements or assessments of wave run up specific to Kempsey's beaches. In this case, standard equations for run-up have been utilised. 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
β = slope of the beach face (assumed to be 0.10);
$H_{0_{RMS}}$ = deepwater RMS wave height $\approx H_s/\sqrt{2}$;
$L_{0_{TZ}}$ = 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. A 2% run up level is typically applied as the conservative estimate in engineering practise, which is the run-up level exceeded for 2% of the time.

For a 1 in 100 year ARI 6 hour duration wave height at Crowdy Head of 8.0 m with a wave period of 12 s, run-up of 6.4 m AHD may be assumed for the immediate timeframe. This run up height includes the 1 in 100 year water level of 1.44 m plus estimated wave set up of 1.2 m (assumed to be ~15% of the offshore wave height of 8 m). A 6 hour duration wave height is used as this is likely to coincide with a high tide. The run-up level would increase with sea level rise by an amount equivalent to the sea level rise (i.e. equating to 6.8 m by 2050 and 7.3 m by 2100 with projected sea level rise of 0.4 m by 2050 and 0.9 m by 2100 above the 1990 sea level).

The estimated 2% run-up level of 6.4 m at the current timeframe may overtop areas of low-lying dunes such as at Stuarts Point Beach and Trial Bay. These shorelines are undeveloped and backed by relatively wide barrier of dunes. Therefore, overtopping is expected to dissipate within 10 to 20 m of the dunal barrier and not present a significant hazard.

As it occurs during storm conditions, wave overtopping occurs in combination with the processes that cause beach erosion on sandy shorelines. In this case, overtopping is almost certainly of less consequence than the more hazardous impact of beach erosion during such a storm (and likely contributes to the erosion) on erodible dune barriers. Wave overtopping is of consequence at hard structural shoreline barriers such as seawalls, where the overtopping occurs without erosion and can cause minor inundation for back beach development.

Kempsey has a largely undeveloped coastline, without seawall or revetment type structures at which wave overtopping may be considered a hazard (at present and in the future). For dunes, which comprise the vast majority of Kempsey's coast, assessment of future run-up levels may be misleading. The shoreline is expected to respond to sea level rise, and therefore, it is not known what the exact height of dunes will be as shoreline recession proceeds. Without knowledge of the dune height, the overtopping volume from wave run up, and so the extent of the hazard, cannot be estimated. In most cases, the event causing wave run-up and overtopping at dunes would also be contributing to beach erosion. Therefore, it has been assumed that impacts of wave overtopping of dune barriers (i.e. wave run up) will be encompassed by the beach erosion hazard (refer Section 3.2). It is noted that inundation through creek and estuary entrances has been considered as part of the coastal inundation hazard analysis.

3.4.2 Limitations in Coastal Inundation Hazard Mapping

The analysis and mapping of coastal inundation of back beach areas, particularly lakes, lagoons and estuaries connected with the ocean, assumes that all components of the elevated water level (storm surge, sea level rise, tide, wave set up) are included when determining inundation extents using a ‘bath-tub’ approach. It is recognised that elevated ocean levels will not always penetrate into estuaries and lakes to the same maximum height, given attenuation through entrances and along channels. However, elevated ocean levels of this magnitude occur during storm conditions, and so it is probable that there would be rainfall on the catchments associated with the storm. In this case, the elevated water levels in the ocean acts as a barrier to water exiting the estuaries during catchment flooding, and thus has the potential to produce such elevated water levels within the estuaries, lakes and lagoon.

The impacts of elevated ocean levels on flooding extents associated with catchment runoff should be determined explicitly for each waterway using a hydraulic flood model. Prior to such assessments, it is reasonable to assume that flooding levels would reach a comparable level to ocean tailwater conditions within the estuaries. That is, inundation (be it from ocean or catchment) would be the higher of the coastal inundation extents or any flood modelling extents. Therefore, Council and others may use the coastal inundation extents as an interim flood level at the immediate, 2050 and 2100 timeframes, prior to completion of flood modelling that includes the coastal inundation extent as a tailwater ocean condition.

3.4.3 Performance of Flood Mitigation Structures with Sea Level Rise

There are a number of flood mitigation structures within the Kempsey LGA that will be affected by sea level rise. Flood gate structures on Killick Creek and Korogoro Creek, which essentially form the tidal limit of these creeks, are at present manually operated to let out floodwaters from the Macleay River and associated creeks. A rise in mean sea level of 0.9 m (or higher) by 2100 will reduce the hydraulic gradient between high flood waters and downstream water levels at the gates, and thereby slow the outflow of flood waters through these structures. For example, the present mean sea level will become the low tide water level by 2100, which would ultimately reduce the ability of the flood gates to promote draining of the land upstream, particularly for land that is less than 1 m above present sea level (i.e. ~ 1 m AHD).

Big Hill Cut flood gate is likely to be affected by recession due to sea level rise, which may outflank the structure some time after 2050. Until that time, it is possible that a higher sea level will result in more frequent wave attack at the structure and subsequent lowering of the bed level in front of the structure, similar to that seen in front of vertical seawalls at other locations on the open coast. Prior to opening the gates, Council is required to excavate sand that has built up against the structure in calmer conditions. Lowering of the bed suggests there would initially be a reduction in the need to excavate sand from in front of the structures during the storm conditions that would typically be associated with flooding. However, the same storm conditions are likely to be associated with high ocean water levels that form a tailwater “barrier” to the outflow of flood waters. This is likely to occur at present, with the flood gates opened at low tide to promote the outflow of flood waters. As sea level rises, the gradient between flood waters and ocean water levels will be reduced (as noted for Killick and Korogoro flood gates above), with the present sea level becoming approximately the low tide level by 2100.

Ryans Cut consists of a sandy entrance berm on the coast with a flood gate approximately 1km landward. The entrance berm will migrate landwards and upwards in line with recession of the shoreline at the open coastal barrier of Killick Beach, as determined in Section 3.3.2.3. The higher entrance berm will require greater excavation efforts by Council in the future (which is required when Council decides to open the Ryans Cut floodgates). Once the entrance berm is breached manually, the flood gate will experience the same impact noted for the flood gates above as sea level rises, that is, a reduced ability to drain floodwaters. The flood gate itself is not expected to be impacted directly by recession, as it much farther inland.

3.5 Coastal Entrances

The coastal entrance hazard refers to existing and future berm height and closure characteristics of coastal creeks, lagoons and estuaries, which may modify the extent of inundation in back beach areas during closed entrance conditions. Future berm heights and closure characteristics may be modified by sea level rise in particular. Future rainfall characteristics and their potential impact on entrance closure are also discussed.

The occurrence of back beach inundation through open / partially open coastal entrances is discussed within the coastal inundation hazard (Section 3.4), and erosion of coastal entrances is incorporated within the beach erosion and shoreline recession hazards (Section 3.2). As such, these aspects are not included in the definition of the coastal entrance hazard below.

The coastal entrance hazard for typically closed and typically open entrances is discussed separately. At the present time, Killick, Korogoro and Back Creeks and the Macleay River typically remain open to the ocean. Saltwater Creek and the minor unnamed lagoons on Trial Bay and Grassy Head Beaches are typically closed, with breakouts occurring during infrequent rainfall events. Killick Creek is known to have closed in the past and based on existing conditions, closure of Back Creek may occur in the future, thus these creeks have been included in the assessment of closed entrances.

3.5.1 Typically Closed Entrances

The potential extent of inundation is dependent upon the height of the entrance berm, as water is stored behind the closed entrance. For typically closed entrances, the probable inundation extents due to entrance closure may be derived from the measurement of berm heights in the past, given in the photogrammetric and other survey data.

Photogrammetric profiles covering the entrance berm region are available for Saltwater Creek and the unnamed Lagoon at Trial Bay, but not for the lagoon on Grassy Head Beach. Survey data provided by Council is additionally available for Saltwater Creek for nine months (April 2010 to January 2011).

For those locations with survey and or photogrammetric data, the berm height given in available profiles along an entrance berm was averaged, while the maximum value was also calculated over the years of available data. At Saltwater Creek, the more recent data would include artificial entrance openings that may skew the results to suggest lower berm heights on average. Further, the photogrammetric data provided snapshots of berm state, comprising eight dates over 68 years (1942 to 2010). This contrasts with 12 beach berm surveys over nine months (April 2010 to January 2011), diagonally across the entrance area provided by Council. The analysis was carefully compared with the profile cross sections from the photogrammetric data, to ensure the data was representative of the berm height as far as possible. The average berm height of 1.2 and maximum of 2.3 determined from the Saltwater Creek data appears reasonable, especially within the context of its use to derive a coastal entrance hazard, as explained below.

At the lagoon at Trial Bay, 8 dates of photogrammetry from 1966 to 2010 were available, from which an average berm height of 1.2 m and maximum of 2.0 m could be determined. The outcomes of the assessment are given in Table 3-10, and discussed further below.

Hanslow *et al.* (2000) suggested that the worst case (or extreme) scenario berm height at coastal entrances would occur during a prolonged period of little rainfall and runoff into the creeks / lagoons resulting in entrance closure. In this extreme scenario, the berm heights may reach the level of adjacent dunes. The incipient dunes formed by wind and wave processes over contemporary times typically reach a maximum height of 4 – 5 m AHD. The growth of dunes is assisted by vegetation that captures sediment within the dune. However, entrance berms are typically unvegetated, thus wind transports sediment off the top of the berm and into the creek / lagoon behind. This would limit the height of the entrance berm until such time as vegetation colonises the entrance, and which is unlikely to occur before a breakout occurred. Considering these factors, an extreme berm height of 3.5 m AHD has been adopted as a ‘rare’ probability at the coastal entrances. This is consistent with observations of low dune heights at Stuarts Point (of 3-4 m), an area that was frequently unvegetated in the past with sand drifting into the Macleay Arm behind. Likewise, incipient dune heights at Trial Bay reach only 2 -3 m before the shoreline advances seaward. The extreme berm height value is consistent with surrounding areas under similar processes.

For the typically closed entrance at Grassy Head Beach without data, the potential impacts of future sea level rise described below should be considered by Council in future planning and in flooding / inundation assessments. It is recommended that berm height measurements (e.g. from historical aerial photographs and / or future beach survey) be collected, to derive probable berm heights for planning and flood / inundation assessment purposes. The ‘rare’ scenario of 3.5 m AHD berm height may be adopted at this location.

For future planning periods of 2050 and 2100, sea level rise is an important consideration for the coastal entrance hazard. For typically closed entrances, it is widely reported (Hanslow *et al.*, 2000; Haines and Thom, 2007; Wainwright and Baldock, 2010) that berm heights will increase by a roughly equal amount as the rise in sea level. That is, it may be expected that berm heights will increase by 0.4 m by 2050 and 0.9 m by 2100. Similar to the Bruun Rule concept of the movement upward and landward of the beach profile, coastal entrances will also increase in height to reach equilibrium with the new mean sea level and wave processes. Wainwright (in prep.) has found that, with an increase in berm height at typically closed entrances, there is a corresponding increase in available storage volume within the lagoon or creek (behind the entrance). Entrance breakouts would thus become less frequent because more rainfall volume would be required to overtop the berm.

Table 3-9 Coastal Entrance Hazard Probability Zones

Probability	Immediate	2050	2100
Almost Certain	Average berm height[1]	As per immediate	As per immediate
Likely	NM[2]	NM	NM
Possible	NM	NM	NM
Best Estimate (Unlikely)	Maximum berm height	Maximum berm height + 0.4 m SLR	Maximum berm height + 0.9 m SLR
Worst Case (Rare)	Extreme berm height[3]	**Worst Case of either:** Extreme berm height + 0.4 m SLR **OR** Maximum berm height + 0.7 m SLR	**Worst Case of either:** Extreme berm height + 0.9 m SLR **OR** Maximum berm height + 1.4 m SLR

[1] *Measured over the past 3 - 5 decades*
[2] *NM = Not Mapped*
[3] *Taken to be 3.5 m AHD equivalent to incipient dunes, see text.*

Table 3-10 Coastal Entrance Hazard Berm Heights for Planning Purposes

			Immediate			2050			2100		
Creek / Lake / Lagoon	**Beach**	**Typical State**	*Almost Certain**	*Best estimate**	*Worst Case*	*Almost Certain**	*Best estimate**	*Worst Case*	*Almost Certain**	*Best estimate**	*Worst Case*
Killick Creek	**Crescent Head**	Open									
Ryans Cut*	**Killick**	Closed			**3.5**			**3.9**			**4.4**
Korogoro Creek	**Hat Head**	Open									
Unnamed Lagoon	**Trial Bay**	Closed	**1.2**	**2.0**	**3.5**	**1.2**	**2.4**	**3.9**	**1.2**	**2.9**	**4.4**
Saltwater Creek	**South West Rocks**	Closed	**1.2**	**2.3**	**3.5**	**1.2**	**2.7**	**3.9**	**1.2**	**3.1**	**4.5**
Back Creek	**Back**	Open									
Macleay River	**Back / Stuarts Point**	Open									
Unnamed Lagoon*	**Grassy Head**	Closed			**3.5**			**3.9**			**4.4**

***Insufficient berm height data to estimate an 'almost certain' or 'best estimate' berm height condition.*

From a risk perspective, it is also important to consider a higher than predicted increase, for example a 0.5 m higher than projected in sea level rise by 2100. For a 1.4 m rise by 2100 (0.7 m by 2050) berm heights may be expected to increase by close to an equal amount. Adopting the rationale used for the beach erosion hazard, the average berm height at a creek/lagoon over years was used to represent the '**almost certain**' entrance hazard and the maximum berm height to represent the **best estimate** (unlikely) entrance hazard at the immediate timeframe. The extreme case (3.5 m AHD) was adopted as the **worst case** (rare) entrance hazard at the immediate timeframe.

For the 2050 and 2100 planning horizons, there is an *almost certain* likelihood that berm heights will be at least as high as they are at present (i.e. regardless of sea level rise). There is an unlikely probability that berm heights will reach a maximum level plus an additional 0.4 m and 0.9 m in elevation in response to projected sea level rise by 2050 and 2100, respectively, and this provides a *best estimate* for future berm heights. The future *worst case* (rare) scenario berm height relates to either a higher than projected sea level rise, or an extreme entrance condition plus predicted sea level rise. For the worst case scenario then, the greater of the following two outcomes was adopted:

- The extreme berm height plus an increase in elevation due to sea level rise of 0.4 m by 2050 and 0.9 m by 2100; or
- A maximum berm height plus an increase in height equivalent to a higher sea level rise of 0.7 m by 2050 and 1.4 m by 2100.

The immediate, 2050 and 2100 coastal entrance hazard probability zones are summarised in Table 3-9 and values given for those entrances with data in Table 3-10. It should be noted that the values adopted for 2050 and 2100 are similar to the likely values adopted for the coastal inundation hazard, in Table 3-8.

3.5.2 Typically Open Entrances

For some typically open creeks or lakes, sea level rise may modify entrance dynamics such that they become more closed or more open in the future. For creeks such as Korogoro Creek that have a strong geomorphic control, that is, bedrock adjacent to and underlying the main entrance channel, sea level rise may impact upon water velocities through this channel. An increase in the water level due to sea level rise may reduce flow velocity through the channel, resulting in sediment deposition and thus entrance constriction and potentially even entrance closure.

For those entrances such as Killick Creek that are without bedrock beneath the main channel (even if bedrock or a rock wall is present at the sides of the channel) it is likely that the entrance area will move upward and landward in response to sea level rise, but remain similarly open as at present. The interaction of Killick Creek with the floodplain behind (connected through the Killick floodgates) under higher sea levels is uncertain.

Entrance areas at the southern ends of beaches will migrate further landward and change in shape and position, as the beach region is receded to a greater extent at the southern end (compared with the northern end) in response to sea level rise (refer Section 3.3.2.3). For entrances at the northern end (of which there are none in the Kempsey LGA), which will experience less landward recession, it is uncertain what impact the vertical accretion of the beach profile would have upon the frequency of entrance closure.

For the typically open Macleay River, the entrance does not appear to have any bedrock constraint within the entrance channel, therefore, it is likely that the entrance area will move upward and landward in response to sea level rise, but remain similarly open as at present.

Sea level rise will cause a corresponding increase in mean water levels within the Macleay estuary through the open entrance. As such, tidal water levels shall penetrate further into the estuary, and there may be changes to flow velocities and sediment transport within the river channels associated with this. There is likely to be an enhanced extent of inundation at foreshore edges, which will require the migration of plant species to their zone of tolerance to salinity and inundation levels.

3.5.3 Effects of Changes to Rainfall on Typically Open or Closed Entrances

At present, the predicted impacts on rainfall due to climate change are inconclusive. As outlined in Table 2-7, an increase or a decrease in annual rainfall is possible. Likewise, rainfall intensity could increase or decrease. In this case, only a brief qualitative discussion of impacts on coastal entrances is possible. The complexity of the response to rainfall at each entrance makes it difficult to generalise about the response to potentially changed rainfall with climate change.

For the smaller, mostly closed lagoons (e.g. unnamed lagoons on Grassy Head beach and Trial Bay), the lagoons responds quickly to rainfall and may break out frequently, but may remain open for only a short time. An increase in rainfall intensity may increase the frequency of breakouts, but in combination with higher berm heights due to sea level rise, there is potential that flooding under this scenario may actually be enhanced. In general, longer duration or higher intensity rainfall events allow for greater scouring of open entrances, and so, entrances may remain open for longer.

For Saltwater Creek which is larger but mostly closed, the frequency of breakout is more dependent upon annual rainfall as the waterway storage is greater and may need to be filled by events over time before overtopping will occur. Saltwater Creek is subject to artificial opening by Council at a water level of 1.8 – 2.0 m AHD (for September to end of Easter and Easter to September periods respectively). Water levels of around 2 m begin to threaten foreshore development (for example, the Trial Bay Tourist Park). The artificial breakout height of 1.8 – 2.0 m is said to be fairly close to the natural breakout level of the lagoon (WBM, 2006).

If annual rainfall were to decrease, prolonged entrance closure may ensue (as the reduced outflow cannot scour marine sediments delivered by waves that build an entrance berm). However, if there is less water stored within the lake with reduced rainfall, there is unlikely to be an increase in the inundation hazard to surrounding properties. If annual rainfall were to increase in combination with higher berm heights (due to sea level rise), there may be an increase in the extent of inundation held behind the higher berm and therefore flooding of development, until such time as a breakout occurs.

With respect to entrance management, if the same opening trigger levels are to be adopted in the future, then the frequency of opening will increase significantly as sea level rises. Ultimately it may be impractical to try and keep opening the entrance if the trigger level is only marginally above elevated tidal levels.

For the typically open creeks such as Killick, Korogoro and Back Creeks, the duration of rainfall events is important in maintaining a scoured and open entrance condition. An increase in rainfall intensity may allow for ongoing open conditions particularly where individual events are longer. A decrease in rainfall intensity may promote entrance constriction, particularly for Killick Creek which has closed (very infrequently) in the past, and at Back Creek, which is already relatively constricted by marine sand.

The volume of freshwater flows at the Macleay River and the constriction of the entrance channel between the breakwaters (which promotes scour of the entrance) indicate entrance closure would be extremely unlikely under present conditions. However, the conclusions above regarding rainfall may affect shoaling and constriction of the entrance channel in a similar manner. That is, an increase in rainfall intensity may allow for a more scoured entrance condition particularly where individual events are longer and a decrease in rainfall intensity may promote shoaling in the entrance.

It is apparent that without more detailed future rainfall predictions, it is not possible to determine more specific conclusions for the coastal entrance hazard. However, the concept for changes to berm heights with sea level rise at 2050 and 2100, and the available levels for particular creeks (Table 3-10) should be incorporated into any assessment or re-assessment of catchment flooding.

Erosion at coastal entrances has been encompassed within the beach erosion hazard. The photogrammetry data was analysed and it was found that in all cases, coastal entrance berms may be eroded out completely. This is due to a combination of creek outflow and beach processes, not beach erosion alone. To account for the potential erosion of the entire berm region, the origin line from which beach erosion was measured was placed behind the berm region. Careful analysis of the historical data and dune heights ensured that areas of former breakout that are now vegetated and seemingly stable were included in the beach erosion extents.

However, in order to avoid overestimating the potential for beach erosion caused by wave action upon sections of the beach that are not within an entrance, the photogrammetric data within creek regions was excluded from the assessment of beach erosion, as noted in Section 3.2.

3.6 Sand Drift

Windborne sediment transport is an important process in the building of sand dunes behind the active beach, as discussed in Section 2.6.5. Sand drift is a minor nuisance in most cases, but may present a notable hazard where coastal developments are being overwhelmed by windborne sediment, or significant volumes of sediment are being removed from the beach system.

In the case of Stuarts Point Beach and the Macleay Arm, sand drift was felt to pose a particular threat due to the infilling the Macleay Arm waterway upon which the township of Stuarts Point is dependant. The likely fate of the Macleay Arm following training of the river entrance can be seen behind the active dunes of Hat Head and Killick Beaches. In both locations, a low-lying swale or backswamp area that may have acted as a former channel to nearby coastal creeks can be seen slowly infilling, such as in Figure 2-12.

The process of infilling of backswamps is part of the natural geologic evolution of the coast. Further, the loss of sediment into the active dunes is a process to which the coastal system has been evolving. Therefore, sand drift at Hat Head and Killick Beaches is not considered to pose a serious risk to development or sediment supplies within the coastal system, and in fact may add to sediment supplies as sea level rises.

The remainder of dunes in the Kempsey region, including at Stuarts Point are largely vegetated. 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. Ongoing maintenance of existing dune vegetation will ensure the capture of windborne sediments to promote continued accretion and growth of dunes, which provides sediment stores to protect the beach during periods of erosion by waves and high water levels.

Bitou Bush commonly occurs within dune vegetation in Kempsey. When Bitou Bush perishes or is destabilised (such as by erosion), the root systems of the entire plant capture sediment, but can allow for destabilisation of sands around the plant, producing clumps or hummocks. The characteristics of Bitou Bush are not suitable for long term beach protection within dunes, and a program of bitou removal should be considered.

Uncontrolled access by the public, on foot or in four-wheel drive vehicles, can also destabilise protective dune vegetation. Proper management of access to the dunes is required to preserve the natural dune vegetation at Kempsey's beaches.

Changes to wind regimes under a future climate may present a change in Aeolian transport characteristics, such as wind direction, which may modify the direction of transport, and the duration of strong winds, which may modify transport volumes. However, the current predictions are not of sufficient detail to provide an accurate assessment. The predictions suggest that future wind patterns will be within the natural variability of wind patterns at present. Sand drift itself is not at present considered to pose a significant threat.

3.7 Stormwater Erosion

Stormwater outlets occur at (into) Killick, Korogoro and Saltwater Creeks, but not directly to the beach itself from the townships of Crescent Head, Hat Head and South West Rocks. While water quality and water volumes will be an issue within the creeks themselves, there is currently no threat to the open coast from erosion at stormwater outlets. Water quality and erosion issues from stormwater outlets in these creeks are already being managed through the creeks' Estuary Management Plans.

4 BEACH ACCESS AND AMENITY INFRASTRUCTURE

Access to Kempsey's beaches ranges from minimal, such as within the Hat Head National Park, to more extensive, such as at Crescent Head, based upon the visitation to these locations. Road access to the beaches also ranges from four-wheel drive only (such as the northern parts of Hat Head and Killick Beaches), to sections of dirt/gravel road, to fully signposted. Again this is commensurate with the level of use of the beaches. Patrolling of beaches for surf life safety is available at Grassy Head, South West Rocks, Hat Head and Crescent Head with the remainder of the beaches unpatrolled. Discussion of facilities at individual beaches is given below.

The current level of access and amenity is considered in keeping with the largely natural state of Kempsey's beaches. Large areas of Kempsey's beaches exist within national park, and the more low key access to these areas is in keeping with their protected status. Indeed, these beaches are also unpatrolled and have highly dangerous surf conditions, and so better access could increase the risks to public safety. Control of four wheel drive use within the undisturbed and natural beach sections is important to preserve dunal vegetation.

The high level of visitation from outside of Kempsey to places such as Crescent Head, South West Rocks and Hat Head particularly during summer does place a strain upon local services. In order to continue to maintain the natural and beautiful asset that is Kempsey's coastline, obtaining contributions from the visiting populations to assist funding should be considered, particularly as the impacts of sea level rise manifest and impact upon the beaches and other assets in the future.

4.1 Grassy Head and Middle Head Beaches

The main beach access for users of these beaches is to Grassy Head through the Grassy Head Caravan Park. A board walkway traverses the dunes, with a wooden viewing platform at the southern end of the beach. The wooden walkway and viewing platform were still intact during 2011, with some erosion affecting the fencing to the south of the walkway, see Figure 4-1. By 2013, erosion and dune slumping had undermined both the walkway and platform, and the dune fencing had been lost, see Figure 4-2. The walkway and platform require stabilisation and / or reconstruction in order to provide continued safe public access. This is the main accessway to Grassy Head beach. The existing scale of facilities (including life saving services in summer) is sufficient for the current demand.

In the parkland behind the southern end of Grassy Head there are beach showers, picnic tables and other amenities, adjacent to entry to the caravan park.

There are informal tracks across Grassy Head to Stuarts Point, and some informal tracks off Grassy Head Road provide access to Middle Head Beach and the northern end of Grassy Head Beach. In general, visiting populations utilise the facilities at Grassy Head., however, the walkway requires

Figure 4-1 Main Beach Access, Grassy Head, March, 2011

Figure 4-2 Main Beach Access, Grassy Head, March 2013 (photo courtesy John Schmidt)

Figure 4-3 Damage to Beach Access and Platform, 1st March, 2013 (photos: KCC)

4.2 Stuarts Point Beach

The main access to Stuarts Point Beach is via a footbridge across the Macleay Arm then a sandy track across the dunes onto Stuarts Point Beach, see Figure 4-4. As noted above, there is an informal track across Grassy Head which provides access to the northern end of Stuarts Point Beach, however this is not used frequently.

In general, visitors to Stuarts Point make use of the Macleay Arm for swimming or fishing (including off the bridge). At the Stuarts Point side of the bridge, there are beach showers, fish cleaning and boat launching facilities, parkland, car parking and amenities. However, the open coast beach itself is probably less frequented, as it typically has dangerous surf conditions (for swimming or surfing) and no life guard patrols. Once again, the level of access infrastructure is suitable to the level of usage, although the track from the bridge to beach should be reviewed for impacts upon dune vegetation, and stabilised as necessary.

The southern half of Stuarts Point Beach to the Macleay Entrance is far less accessible. This is likely suitable given the lack of beach patrolling and generally dangerous swimming conditions, particularly in close proximity to the entrance itself, which has fast flowing tidal currents and is well utilised by boat traffic, both unsafe for swimming.

Figure 4-4 Access to Stuarts Point Beach via Walkway over the Macleay Arm

4.3 Back Beach

Access to Back Beach is via a pedestrian bridge crossing Back Creek around 500 m downstream of the creek entrance. The bridge forms carriage for a pipeline to the dunal sewage disposal site in dunes behind Back Beach. A sandy track follows the creek edge to the trained entrance and onto Back Beach. The bridge is likely maintained largely as it provides a crossing for the sewage pipeline.

Car parking is available at the southern side of the bridge. There are no other beach facilities for Back Beach at the creek entrance or beach itself. The beach is not patrolled, and is likely to experience dangerous swimming conditions at times in proximity to both Back Creek entrance and the Macleay River entrance. The beach is popular for day visitors, including from boats.

The southern breakwater of the Macleay River Entrance forms the northern boundary of the beach. A tarred walkway is provided along the top of the breakwater and frequently used by visitors for walking and fishing. Access from the breakwater to the beach is relatively difficult, discouraging visitors from swimming in proximity to the breakwater and channel entrance as consistent with the dangerous swimming conditions at the river entrance.

Figure 4-5 Back Beach Pedestrian Walkway and Pipeline

4.4 Horseshoe Beach, South West Rocks

Horseshoe Beach is a very popular beach formed within South West Rocks, providing safe swimming for visitors and particularly children. Access is via either the Horseshoe Bay Beach Caravan Park immediately behind the beach, or the car park on top of South West Rocks adjacent to South West Rocks Surf Life Savings Club (SLSC). Facilities are provided within the caravan park or adjacent to the SLSC. South West Rocks SLSC provides surf life savings patrols for the beach.

Figure 4-6 Horseshoe Beach at South West Rocks

4.5 Trial Bay

Access to the southern end of Trial Bay is provided adjacent to the southern side of South West Rocks SLSC. When the creek is open, beach goers must cross Saltwater Creek to access the beach.

South West Rocks SLSC is founded on bedrock which provides suitable foundation capacity for the building. However, storms during May 2009 resulted in wave run up into the base of the building. Currently, the SLSC buggy is stored in the lower garage. There is currently erosion occurring along northern bank of Saltwater Creek that forms a thin strip of land in front of the SLSC, see Figure 4-7. Attempts to stabilise the bank with rocks and fill by the SLSC members have failed to stem the erosion. The erosion is a result of creek outflow and wave processes along the northern bank of the creek during storm conditions.

While the SLSC building is not at threat from erosion due to the shallow depth of bedrock, the erosion does pose an issue for safe public beach access. This bank is the main route of access for the public even when creek outflow is relatively deep and strong. In addition, the currently eroded bank is more difficult for surf life saving members to get equipment onto the beach, particularly in the case of an emergency.

Protection works for the bank could be considered in conjunction with an improvement to beach access safety for the public. The proximity of bedrock at the SLSC suggests the structure could be tied to rock relatively easily. The effect of protection works upon opening characteristics of Saltwater Creek, especially the opposite bank of the creek should also be considered as part of any impact assessment.

The northern end of Trial Bay is accessible from within Arakoon State Conservation Area and from Trial Bay Gaol itself. Suitable beach access, car parking and camping facilities are also available at the base of Trial Bay Gaol. Trial Bay Boat Ramp is a concrete structure located immediately behind (westward) the Laggers Point breakwater. There are competing use issues between boat users, nearby campers, and recreational users at the boat ramp at times. The Arakoon State Conservation Area and Trial Bay Gaol are managed by the National Parks & Wildlife Service (NPWS).

Figure 4-7 South West Rocks SLSC and Erosion of Creek Bank

4.6 Hat Head

The southern end of Hat Head Beach is very accessible via the Hat Head Caravan Park. This includes a number of fenced tracks across the dunes, and car parking and other facilities behind the beach and boat ramp. The bitumen boat ramp into Korogoro Creek has fish cleaning facilities, and the beach can be accessed along the southern creek bank also (see Figure 4-8). The boat ramp is potholed in some places and there has been request from locals to improve this facility.

The majority of Hat Head Beach lies within Hat Head National Park. Access to the northern part of Hat Head Beach is via four wheel drive only, either along Hat Head Beach or from the base of Smoky Cape. There are various four wheel drive beach access points at the southern end of the beach. A tarred road provides access to the Smoky Cape Lighthouse. Given the high energy wave conditions particularly towards the northern end of Hat Head Beach, limited access is appropriate. However, four wheel drive access along the beach may be impacting upon the dunal vegetation and should be monitored and controlled if required.

It has also been noted that signage for four wheel drivers and fishers at both Hat Head and Killick Beaches is at times excessive and confusing. The beach is managed both by Council and NPWS, however a rationalisation of signage is required to provide effective education and notification to beach users.

Figure 4-8 Korogoro Creek Boat Ramp Also Provides Access to Hat Head Beach

4.7 Crescent Head and Killick Beach

Crescent Head and Killick Beach are certainly one of the most heavily used locations in Kempsey's coastal zone. As such, Crescent Head has more extensive facilities, including amenities and cafes within the caravan park, car parking, a boat ramp accessing Killick Creek, access to Crescent Head adjacent to the golf course, a skate ramp and picnic and barbeque facilities.

Access to Killick Beach is safest via a wooden walkway across Killick Creek, around 200 m upstream from the SLSC. A set of stairs adjacent to the SLSC presumably provides access to the beach, however, the creek must be crossed before reaching the sand and this is likely to be unsafe during fast creek outflows, see Figure 4-9. Storms in early 2013 have caused erosion of the dune from around the end of the walkway to the end of the river mouth and along the beach front, as shown in Figure 4-10. While the current arrangements appear satisfactory, upgrade to the walkway and stairway are likely to be required soon, given both the high level of usage of this area and recent erosion, to maintain public safety.

Likewise, there is no formal access across the boulders to the famous Crescent Head surf break. This is particularly unwieldy for surfers (or swimmers) exiting the water, as they cross unstable rocks up the bank adjacent to the Crescent Head SLSC. A formal walkway would improve public safety and access in this location. Crescent Head SLSC provides surf life saving patrols. The building is likely to require upgrade fairly soon.

Figure 4-9 Access to Killick Beach showing Bridge in Background and Stairs into Creek in Foreground

Figure 4-10 Recent Erosion at the Walkway and Entrance to Killick Creek and Beach (photos: KCC)

4.8 Goolawah, Delicate Nobby and Big Hill

From Crescent Head, the roadway access to Goolawah, Delicate Nobby and Big Hill is unsealed in part, although still accessible by two wheel drive vehicle. The northern end of Goolawah Beach is accessed via an unsealed track across the dunes with an informal car park in the sand dunes. The track provides four wheel drive vehicle access to Goolawah Beach.

The remainder of beach access ways for the beaches tend to be tracks (typically unfenced and unboarded) across the dunes, signalled to passing traffic only by relatively informal “car parks” with little to no signage, for example . There are no other facilities for these beaches (eg, beach showers, amenities, picnic tables etc), and this is in keeping with the current character of these beaches. The area is largely natural and managed within Goolawah State Park and Limeburners Creek Nature Reserve by NPWS.

At Big Hill adjacent to Big Hill Floodgates there are more formal parking facilities above the rock wall adjacent to the flood gate and southern end of the beach.

Given the lower usage of these areas the current level of facilities is suitable, although fencing or boarding of the existing informal tracks may ensure beach access is controlled and vegetation protected across the dunes.

Figure 4-11 Typical Informal Track Access to Delicate Nobby Beach

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APPENDIX A: WAVE DATA

Table 5-1 Significant Wave Height Percentage Exceedance Statistics, Crowdy Head (1985 – 2007)

H_s (m)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
0 → 0.5	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
0.5 → 1	100.00	100.00	99.99	99.97	99.82	99.74	99.94	99.93	100.00	99.84	99.97	99.99	99.93
1 → 1.5	85.86	89.21	91.48	88.66	85.65	83.83	83.56	81.54	82.52	82.40	86.17	83.13	85.20
1.5 → 2	43.36	45.67	53.44	51.91	51.99	50.88	51.53	46.63	43.26	40.70	43.23	38.70	46.72
2 → 2.5	17.32	20.48	25.03	25.27	26.81	25.65	26.91	24.20	18.72	17.40	17.92	15.62	21.77
2.5 → 3	5.39	8.83	12.06	11.24	11.67	11.84	13.48	12.26	7.73	7.84	7.47	6.37	9.69
3 → 3.5	1.40	4.35	5.35	5.61	5.20	5.85	6.09	5.92	3.60	3.86	3.33	2.47	4.42
3.5 → 4	0.32	1.79	2.91	2.89	2.68	3.25	2.79	2.89	1.84	1.88	1.43	0.92	2.14
4 → 4.5	0.09	0.61	1.48	1.58	1.34	1.56	1.38	1.07	0.84	0.91	0.56	0.34	0.98
4.5 → 5	0.00	0.32	0.84	0.79	0.79	0.71	0.69	0.44	0.41	0.39	0.18	0.11	0.47
5 → 5.5	0.00	0.13	0.50	0.32	0.43	0.31	0.34	0.16	0.13	0.11	0.04	0.03	0.21
5.5 → 6	0.00	0.08	0.26	0.13	0.19	0.09	0.16	0.05	0.04	0.03	0.01	0.00	0.09
6 → 6.5	0.00	0.05	0.16	0.06	0.04	0.02	0.08	0.00	0.00	0.01	0.00	0.00	0.03
6.5 → 7	0.00	0.00	0.06	0.00	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.01
7 → 7.5	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Average	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Max	1.53	1.61	1.72	1.67	1.67	1.65	1.69	1.64	1.55	1.52	1.55	1.49	1.61
Min	4.48	6.48	7.35	6.46	6.66	6.28	6.78	5.89	5.82	6.42	5.86	5.23	7.35

Table 5-2 Percentage Occurrence Wave Direction, Byron Bay (1999 to 2007)

Dir'n	Degrees	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
N	348.75 - 11.24	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.000
NNE	11.25 - 33.74	1.82	0.07	0.10	0.40	0.97	0.85	0.17	1.49	6.71	5.48	3.78	6.16	2.603
NE	33.75 - 56.24	3.32	0.14	0.00	0.43	0.45	0.80	0.52	2.49	6.10	5.24	3.31	4.07	2.415
ENE	56.25 - 78.74	5.14	4.19	3.46	9.55	3.28	5.57	2.52	1.06	2.59	4.43	4.41	6.58	4.374
E	78.75 - 101.24	18.79	24.82	23.14	25.03	7.96	12.50	9.06	6.56	9.46	17.64	11.87	12.63	14.073
ESE	101.25 - 123.74	19.99	28.26	23.21	22.14	11.76	10.85	17.67	10.03	8.48	8.04	14.69	13.37	14.818
SE	123.75 - 146.24	15.56	17.02	15.97	15.98	19.45	23.30	25.02	18.52	14.70	12.52	22.74	17.53	18.493
SSE	146.25 - 168.74	19.20	15.53	23.35	17.64	34.76	31.51	32.75	41.75	32.96	24.90	22.09	25.39	27.402
S	168.75 - 191.24	15.44	9.33	10.05	8.09	20.61	13.73	11.58	15.94	17.11	19.56	15.32	13.05	14.579
SSW	191.25 - 213.74	0.56	0.58	0.62	0.43	0.52	0.39	0.54	1.01	0.71	1.54	1.42	0.88	0.791
SW	213.75 - 236.24	0.06	0.00	0.03	0.00	0.15	0.06	0.05	0.06	0.09	0.12	0.08	0.22	0.085
WSW	236.25 - 258.74	0.06	0.00	0.00	0.00	0.02	0.06	0.00	0.00	0.05	0.00	0.00	0.00	0.017
W	258.75 - 281.24	0.00	0.00	0.07	0.00	0.04	0.12	0.07	0.11	0.02	0.00	0.00	0.00	0.037
WNW	281.25 - 303.74	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.03	0.02	0.00	0.00	0.00	0.006
NW	303.75 - 326.24	0.00	0.07	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.006
NNW	326.25 - 348.74	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.000
Mean	Degrees	128.3	122.1	124.9	123.5	140.8	133.7	135.4	135.4	131.9	124.7	130.0	125.8	130.18

Table 5-3 Percentage Occurrence Wave Direction, Sydney (1992 – 2009)

Dir'n	Degrees	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
N	348.75 - 11.24	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
NNE	11.25 - 33.74	0.16	0.01	0.06	0.10	0.06	0.05	0.04	0.17	0.11	0.24	0.04	0.10	0.10
NE	33.75 - 56.24	4.40	2.87	2.66	2.06	1.37	1.07	0.82	1.66	4.99	5.49	4.46	5.45	3.08
ENE	56.25 - 78.74	16.62	14.07	9.77	6.51	6.33	3.54	3.41	4.62	10.04	10.55	14.24	11.80	9.02
E	78.75 - 101.24	18.83	17.68	16.74	11.56	9.67	8.60	9.46	6.05	7.72	9.08	10.23	10.37	11.04
ESE	101.25 - 123.74	11.05	13.32	12.73	13.68	10.25	9.98	12.72	7.81	6.80	7.77	8.95	9.08	10.26
SE	123.75 - 146.24	11.98	12.16	17.10	18.86	18.22	17.03	19.19	19.86	17.25	13.90	14.04	14.50	16.33
SSE	146.25 - 168.74	18.82	20.18	24.59	30.03	34.13	40.23	35.80	39.48	32.64	29.87	23.89	24.61	29.99
S	168.75 - 191.24	16.90	19.07	15.26	16.41	18.91	18.70	16.42	18.54	18.69	21.44	22.34	22.48	18.77
SSW	191.25 - 213.74	1.22	0.65	1.06	0.64	0.52	0.41	0.89	1.04	0.84	1.40	1.76	1.49	1.00
SW	213.75 - 236.24	0.00	0.00	0.03	0.10	0.11	0.05	0.29	0.08	0.15	0.06	0.00	0.02	0.08
WSW	236.25 - 258.74	0.00	0.00	0.00	0.00	0.03	0.03	0.14	0.10	0.20	0.04	0.03	0.01	0.05
W	258.75 - 281.24	0.01	0.00	0.00	0.04	0.05	0.12	0.29	0.14	0.19	0.04	0.01	0.02	0.08
WNW	281.25 - 303.74	0.00	0.00	0.00	0.00	0.10	0.07	0.27	0.15	0.23	0.10	0.01	0.03	0.09
NW	303.75 - 326.24	0.00	0.00	0.00	0.00	0.16	0.08	0.15	0.20	0.07	0.02	0.00	0.02	0.06
NNW	326.25 - 348.74	0.00	0.00	0.00	0.00	0.06	0.03	0.08	0.08	0.01	0.00	0.00	0.01	0.02
Mean	Degrees	120.37	123.60	128.12	135.53	138.79	144.56	142.89	144.74	136.46	134.74	131.41	132.74	134.89

Table 5-4 Storm History Prior to Wave Measurement

Year	Number storms	Largest storm descriptions North Coast Sector NSW	Reference
1921	5	Largest storms in April (5.5 m Hs, tropical cyclone) and July (5.1 m Hs, East Coast Low). No Category X storms	BBW 1985
1922	3	East coast low in Jan (4.1 m Hs) is largest storm	BBW 1985
1923	3	Largest storms in April (5.0 m Hs, tropical cyclone) and June (5.0 m Hs, continental low). No Category X storms	BBW 1985
1924	5	Storm wave heights generally smaller, with largest in April of 4.0 m (southern low)	BBW 1985
1925	5	Storm wave heights generally large,with three storms Hs > 5 m (east coast lows, STAC)	BBW 1985
1926	2	Category X east coast low in May producing 7.8m Hs	BBW 1985
1927	2	East coast low in April produces 5.3 m Hs	BBW 1985
1928	3	Tropical cyclone in Feb produces 4.9 m Hs, other storms relatively small	BBW 1985
1929	5	Large category X east coast low in June of 7.1 m Hs	BBW 1985
1930	0	Storm elsewhere on NSW coast are relatively small	BBW 1985
1931	1	Tropical cyclone in Feb produces 5.0 m Hs, other storms on NSW coast are small	BBW 1985
1932	2	Largest is 4.0 m Hs from a continental low	BBW 1985

1933	6	Two of the storms had Hs > 5 m, in March (tropical cyclone), and July (east coast low cyclone).	BBW 1985
1935	4	Low storm wave heights, maximum of 4.2 m due to intensification of the STAC, March	BBW 1985
1936	2	Moderate strength, 4.6 m Hs due to tropical cyclone in Marh	BBW 1985
1937	3	Category X tropical cyclone in Feb producing 8.1 m Hs	BBW 1985
1938	5	Lower Hs in storms, with maximum of 4.6 m in April (east coast low cyclone)	BBW 1985
1939	2	Maximum of 4.8 m in March, tropical cyclone	BBW 1985
1940	2	East coast low producing 5.2 m maximum in March	BBW 1985
1941	1	East coast low producing 5.3 m maximum in May	BBW 1985
1942	5	Category X east coast low in October producing 9.1 m Hs	BBW 1985
1943	1	STAC intensification producing 4.2 m Hs in May	BBW 1985
1944	0		BBW 1985
1950	1	Inland trough low produces Category X storm of 6.6 m in January	Only selected storms listed for 1945 to 1966 in BBW (1985)
1952	1	Continental low produces 4.8 m in June	Only selected storms listed for 1945 to 1966 in BBW (1985)
1954	1	Category X tropical cyclone in Feb producing 9.1 m Hs	Only selected storms listed for 1945 to 1966 in BBW (1985)
1955	5	Category X tropical cyclone producing 7.5 m in January	Only selected storms listed for 1945 to 1966 in BBW (1985)
1960	5	Hs in March up to 5.0 m	BBW 1985 + 1986
1961	4	Hs of storms are < 5.0 m	BBW 1985 + 1986
1962	3	Two of the storms had Hs > 5 m (April and July)	BBW 1985 + 1986
1963	5	Most storms < 5.0 m Hs	BBW 1985 + 1986
1964	5	Hs of storms are < 3.5 m	BBW 1985 + 1986
1965	3	Category X storm in July with Hs > 7.5 m	BBW 1985 + 1986
1966	1	June storm up to 5.0 m Hs	BBW 1985 + 1986
1967	13	Three Category X storms, of 9.9 m Hs in January and 6.1 m in February (both tropical cyclones) and 10.1 m Hs in June (east coast low cyclone)	BBW 1985 + 1986
1968	3	Largest wave height of 5.2 m in August	BBW 1985 + 1986
1969	3	Lower Hs in storms, with maximum of 4.2 m in February (tropical cyclone)	BBW 1985 + 1986
1970	1	Southern low producing 5.3 m Hs in Mar-Apr	BBW 1985 + 1986
1971	6	Category X of 6.1 m Hs in July from continental low	BBW 1985 + 1986
1972	6	Up to 5.3 m Hs in April tropical cyclone	BBW 1985 + 1986
1973	5	Up to 5.8 m in July east coast low cyclone	BBW 1985 + 1986
1974	6	Tropical cyclones in Jan, Feb and Mar (Hs 5.3 - 5.4m). Only 1 listing in May-June period, of 4.4 m on 3-5 June	BBW 1985 + 1986
1975	7	Storm wave height generally lower (< 4.0 m Hs)	BBW 1985 + 1986
1976	11	Storms generally lower (< 4.5 m), largest Hs of 5.5 m in January (tropical cyclone)	BBW 1985 + 1986

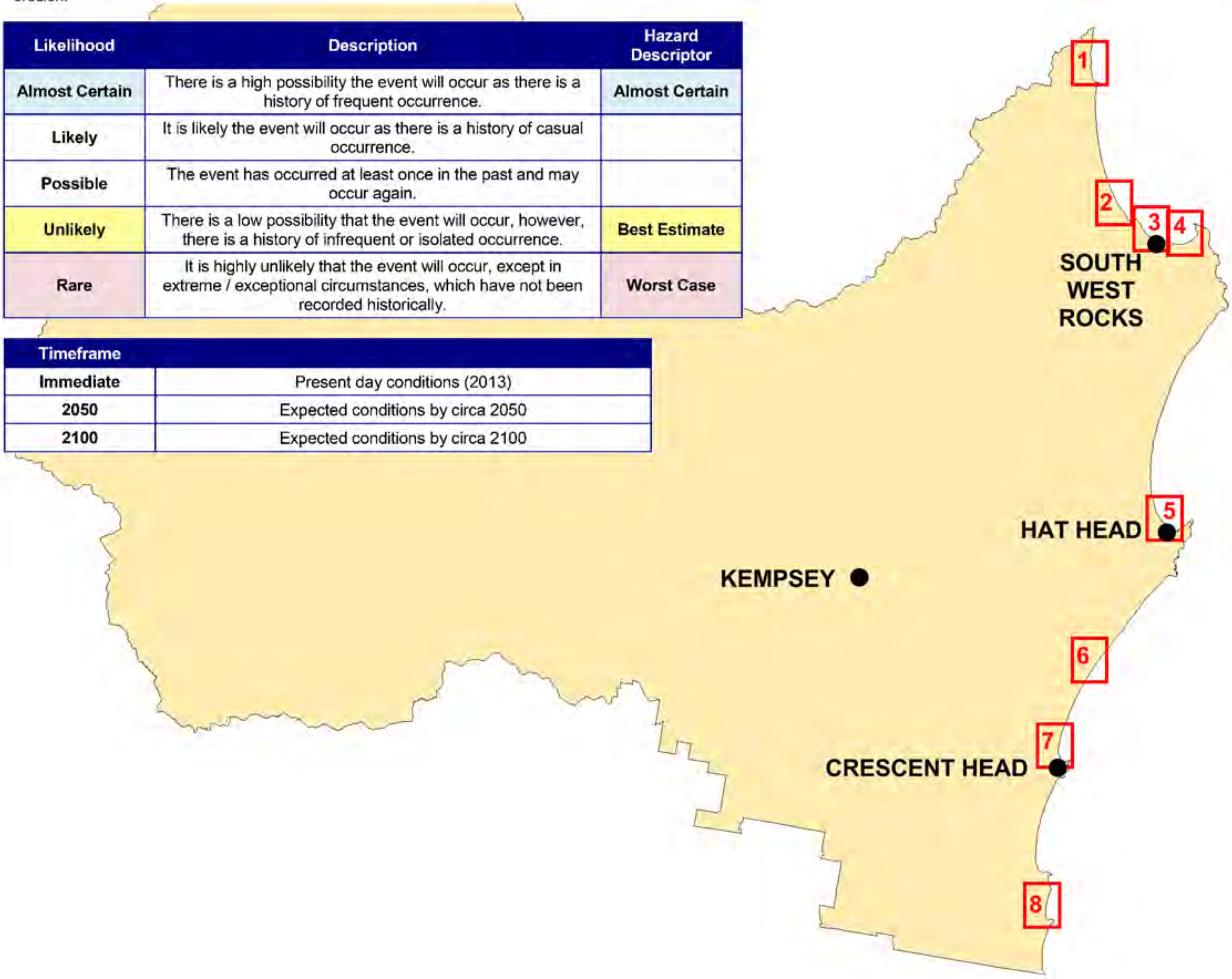
APPENDIX B: HAZARD MAPS

Probability	Immediate	2050	2100
Almost Certain	'average' beach erosion [1]	Immediate 'average' beach erosion	Immediate 'average' beach erosion
Likely	NM [2]	NM	NM
Possible	NM	NM	NM
Best Estimate (Unlikely)	'maximum' beach erosion at any position along the beach [1]	Immediate 'maximum' beach erosion + 0.4 m SLR	Immediate 'maximum' beach erosion + 0.9 m SLR
Worst Case (Rare)	'extreme' beach erosion [3]	**Worst Case of either:** Immediate 'maximum' beach erosion + 0.7 m SLR **OR** Immediate 'extreme' beach erosion + 0.4 m SLR **OR** Immediate 'maximum' beach erosion + 0.4 m SLR + 5 ° more easterly wave climate	**Worst Case of either:** Immediate 'maximum' beach erosion + 1.4 m SLR **OR** Immediate 'extreme' beach erosion + 0.9 m SLR **OR** Immediate 'maximum' beach erosion + 0.9 m SLR + 5 ° more easterly wave climate

[1] as measured over the past 4 decades.
[2] NM = Not Mapped due to inadequate data to differentiate likelihoods between 'almost certain' and 'unlikely'.
[3] Assumed to be 'maximum' erosion plus the difference between 'maximum' and 'average' beach erosion.

Likelihood	Description	Hazard Descriptor
Almost Certain	There is a high possibility the event will occur as there is a history of frequent occurrence.	**Almost Certain**
Likely	It is likely the event will occur as there is a history of casual occurrence.	
Possible	The event has occurred at least once in the past and may occur again.	
Unlikely	There is a low possibility that the event will occur, however, there is a history of infrequent or isolated occurrence.	**Best Estimate**
Rare	It is highly unlikely that the event will occur, except in extreme / exceptional circumstances, which have not been recorded historically.	**Worst Case**

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



Title:

Index to Erosion and Recession Hazard Maps

Figure: **A-0**

Rev: **A**

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N

0 10 20km

Approx. Scale

BMT WBM
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Filepath : K:\N2028_Kempsey_CoastalHazStudy\MapInfo\Workspaces\DRG_000_120809_Drawing_A-0.WOR

Title:

Erosion and Recession Hazard Definition
Immediate Planning Horizon - Grassy Head Beach

Figure: **A-1**

Rev: **A**

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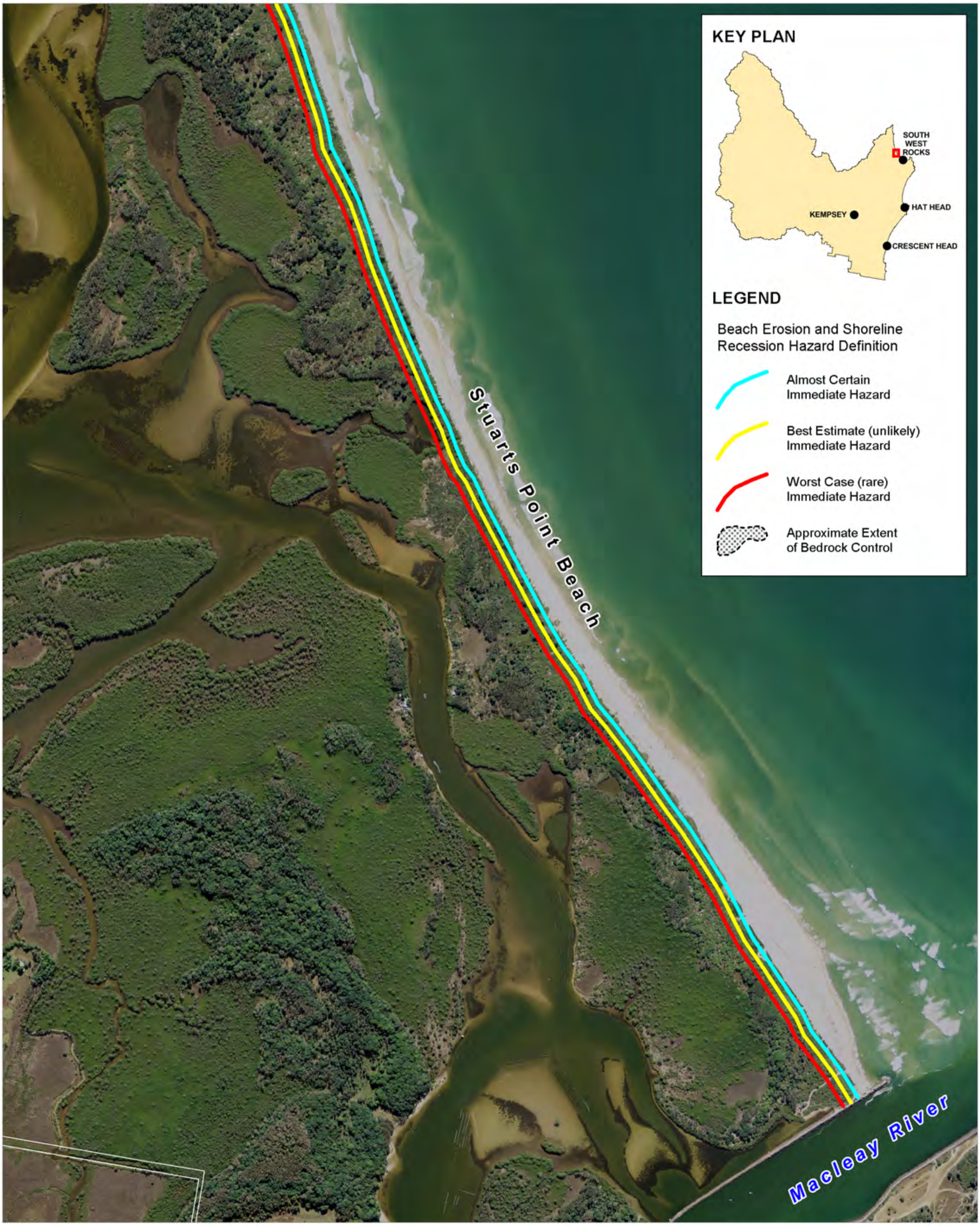

Title:

Erosion and Recession Hazard Definition
Immediate Planning Horizon - Stuarts Point Beach

Figure: **A-2**

Rev: **A**

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Approx. Scale

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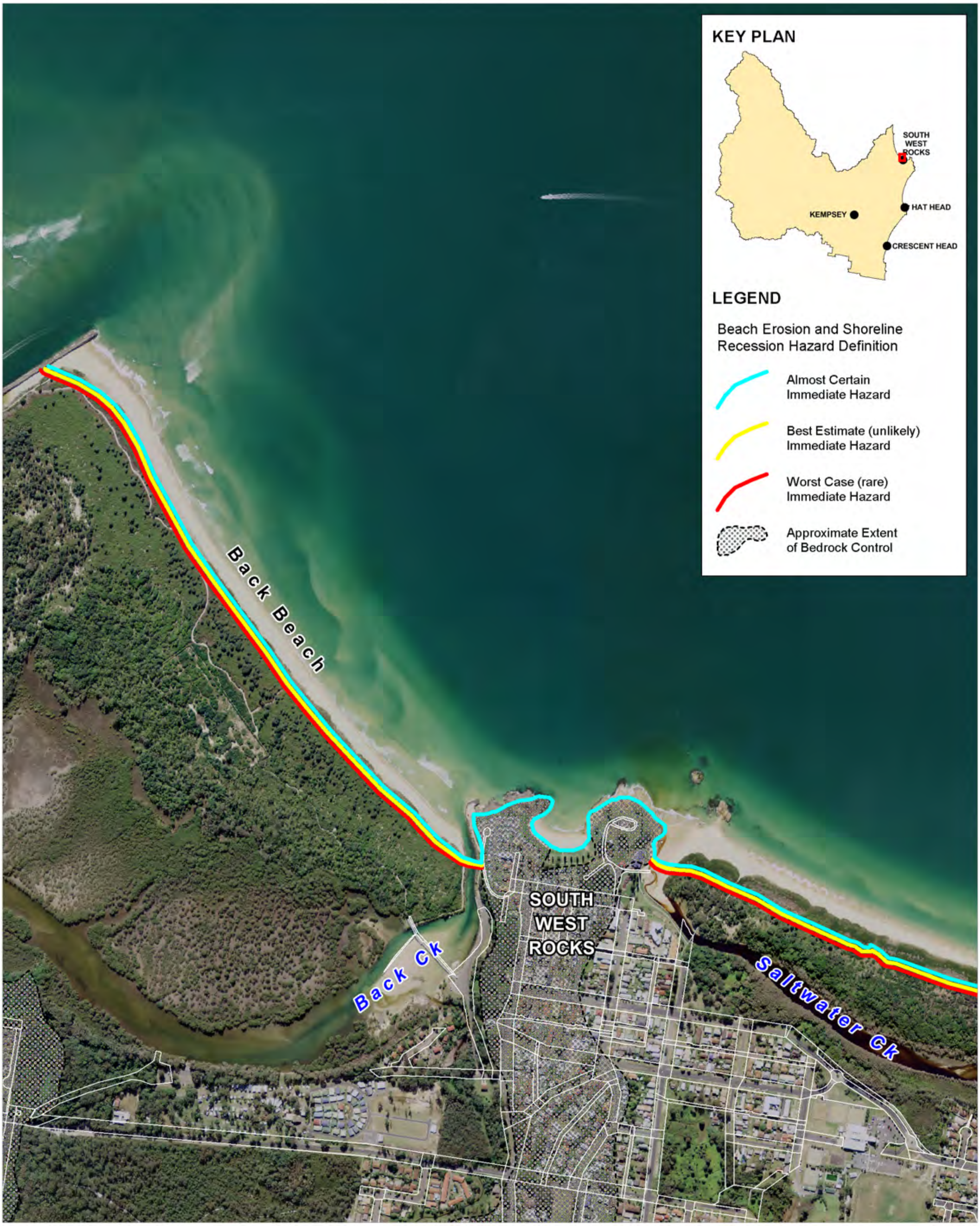

Title:

Erosion and Recession Hazard Definition
Immediate Planning Horizon - South West Rocks

Figure: **A-3**

Rev: **A**

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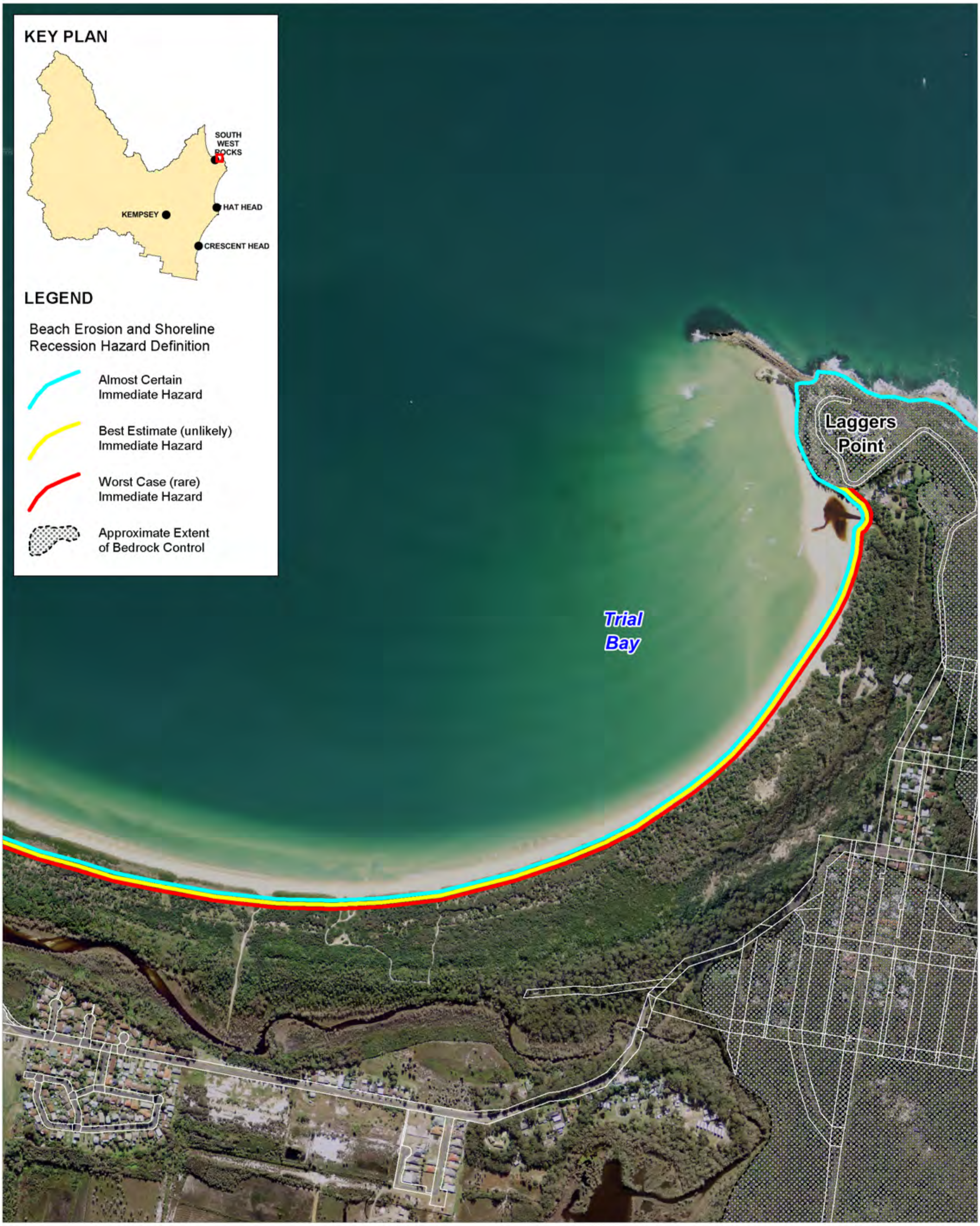

Title:

Erosion and Recession Hazard Definition Immediate Planning Horizon - Trial Bay

Figure: **A-4**

Rev: **A**

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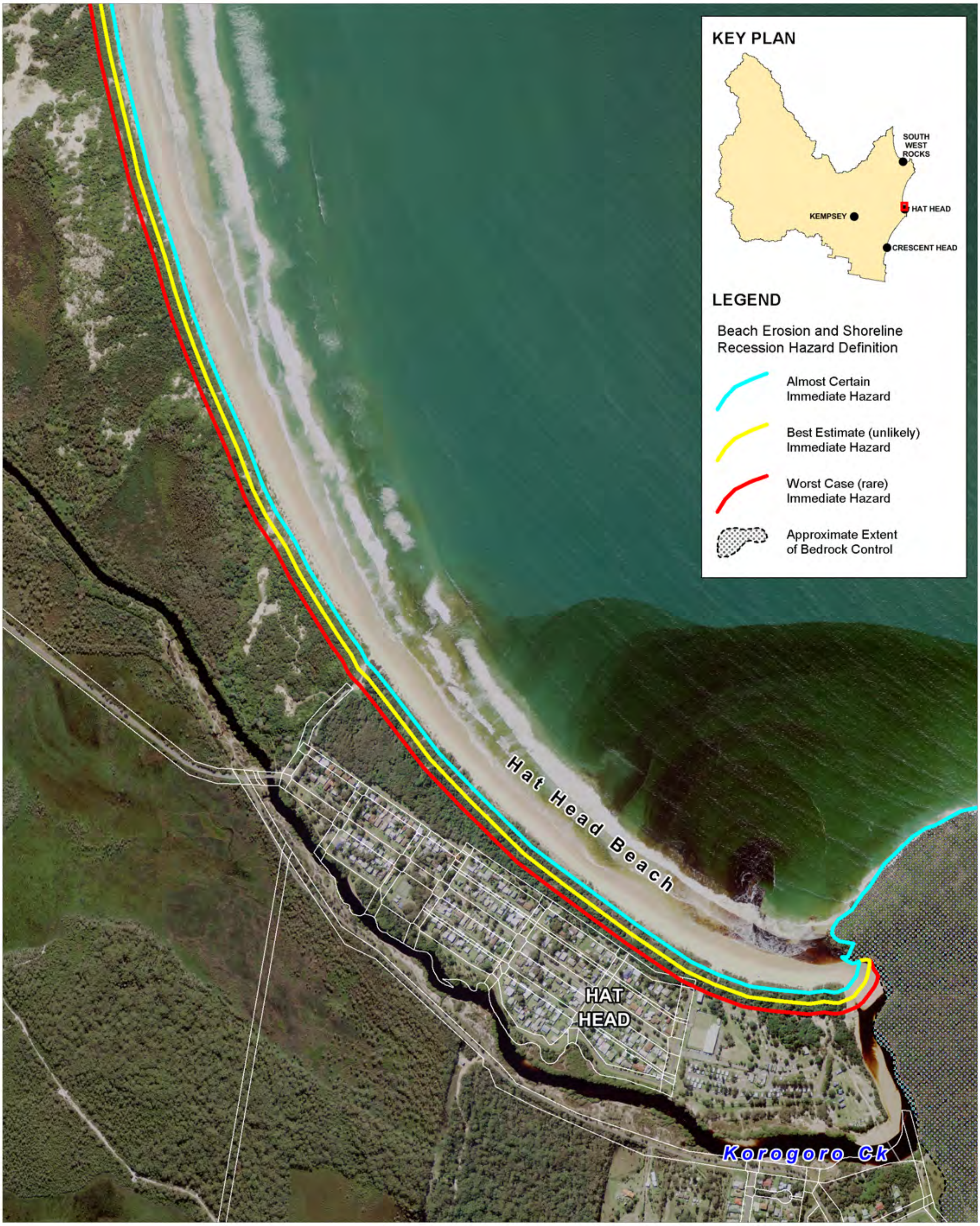

Title:

Erosion and Recession Hazard Definition Immediate Planning Horizon - Hat Head

Figure: **A-5**

Rev: **A**

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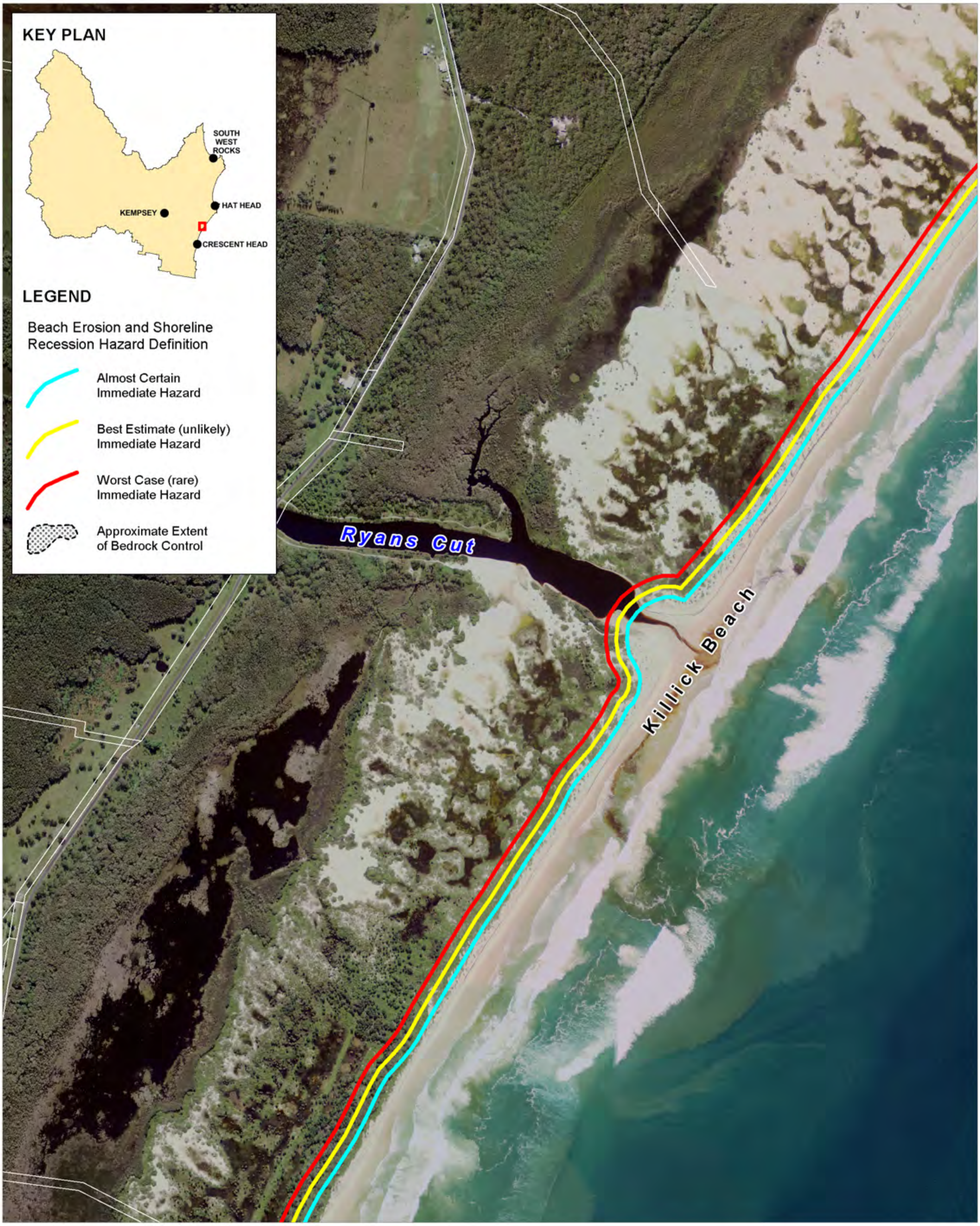

Title:

Erosion and Recession Hazard Definition Immediate Planning Horizon - Ryans Cut

Figure: A-6

Rev: A

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Approx. Scale

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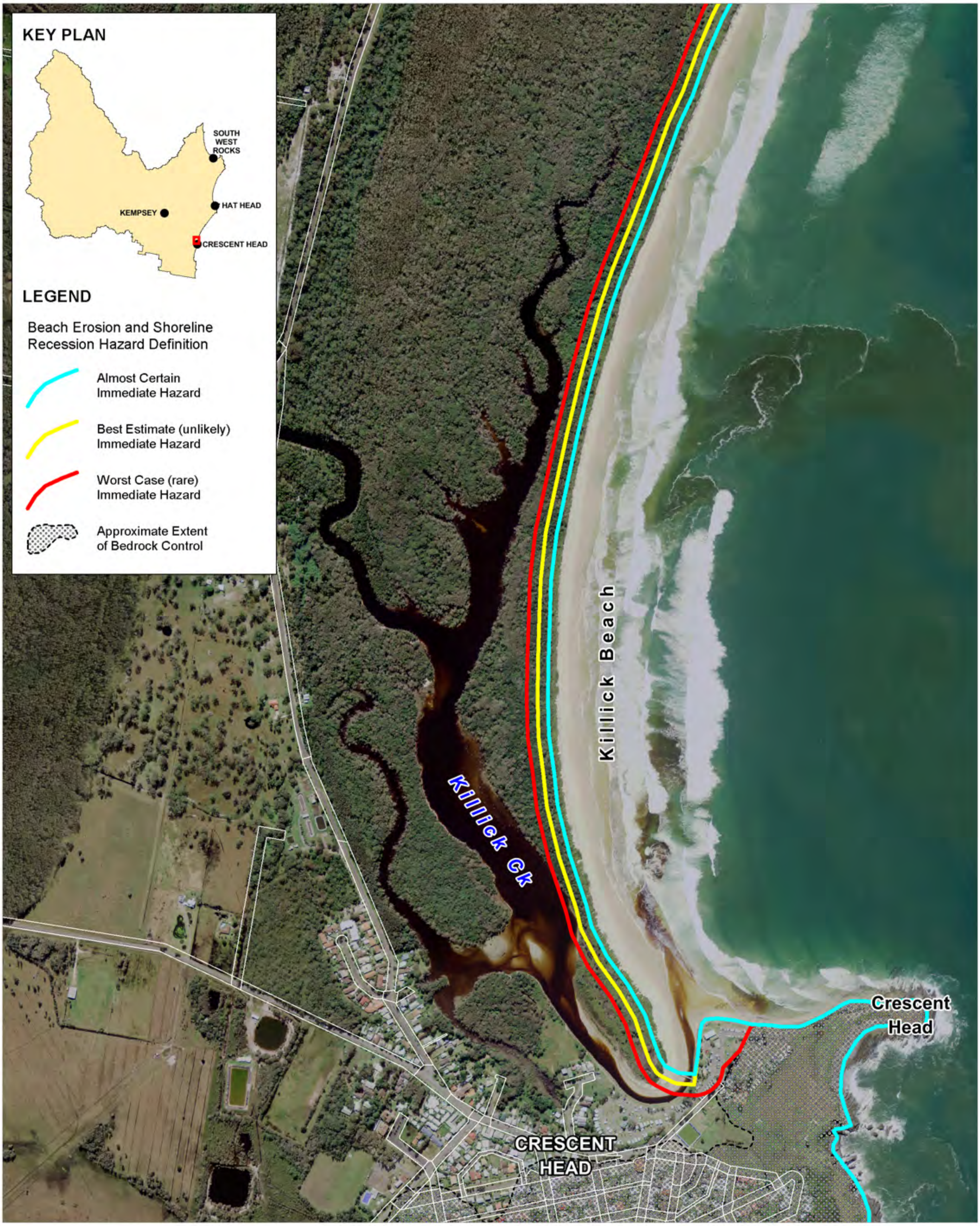

Title:

Erosion and Recession Hazard Definition Immediate Planning Horizon - Crescent Head

Figure: A-7

Rev: A

N

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Approx. Scale

BMT WBM

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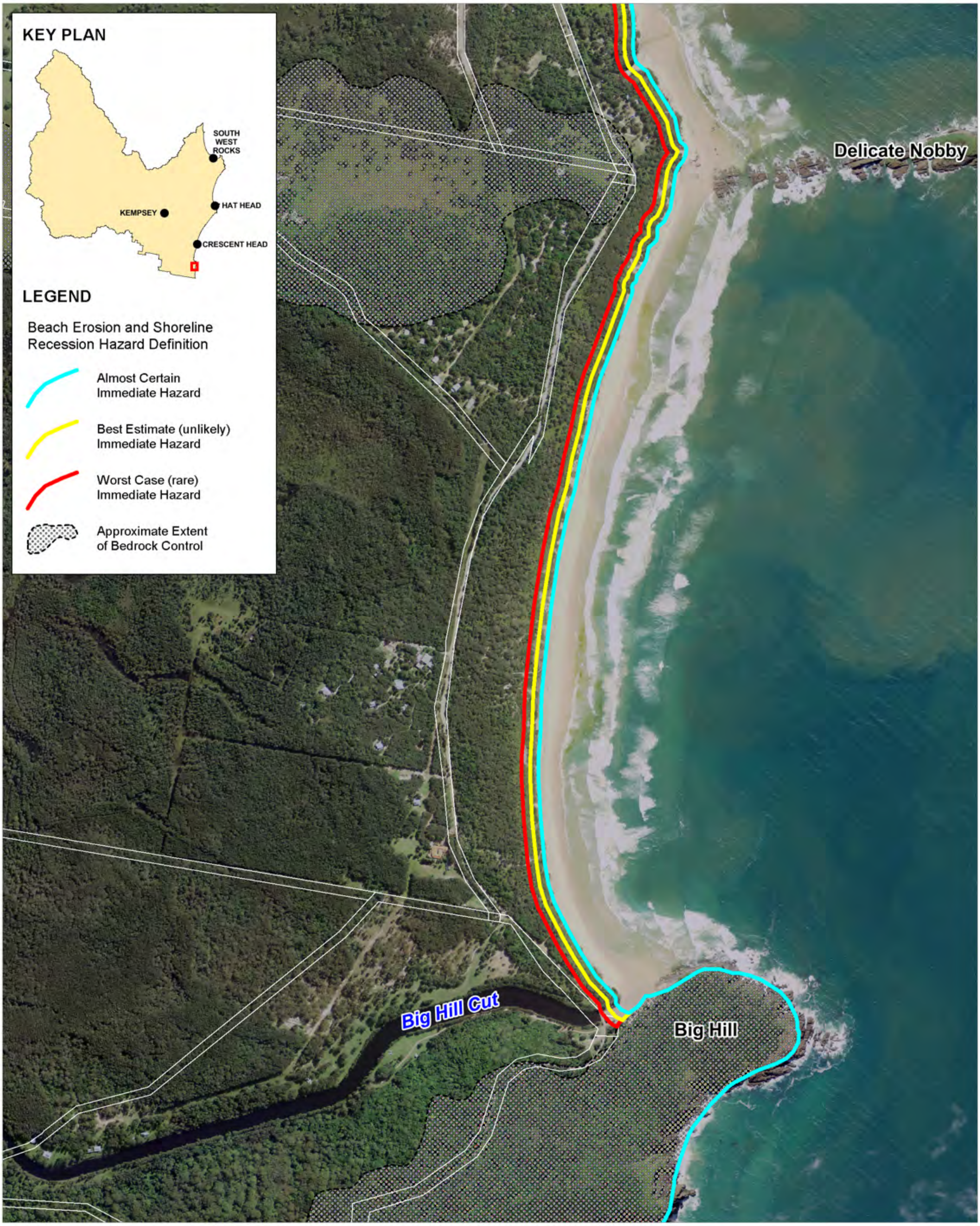
Filepath : K:\N2028_Kempsey_CoastalHazStudy\MapInfo\Workspaces\DRG_007_120809_Drawing_A-7.WOR



Title:

Erosion and Recession Hazard Definition Immediate Planning Horizon - Big Hill Cut

Figure: A-8

Rev: A

N

0 250 500m

Approx. Scale

BMT WBM

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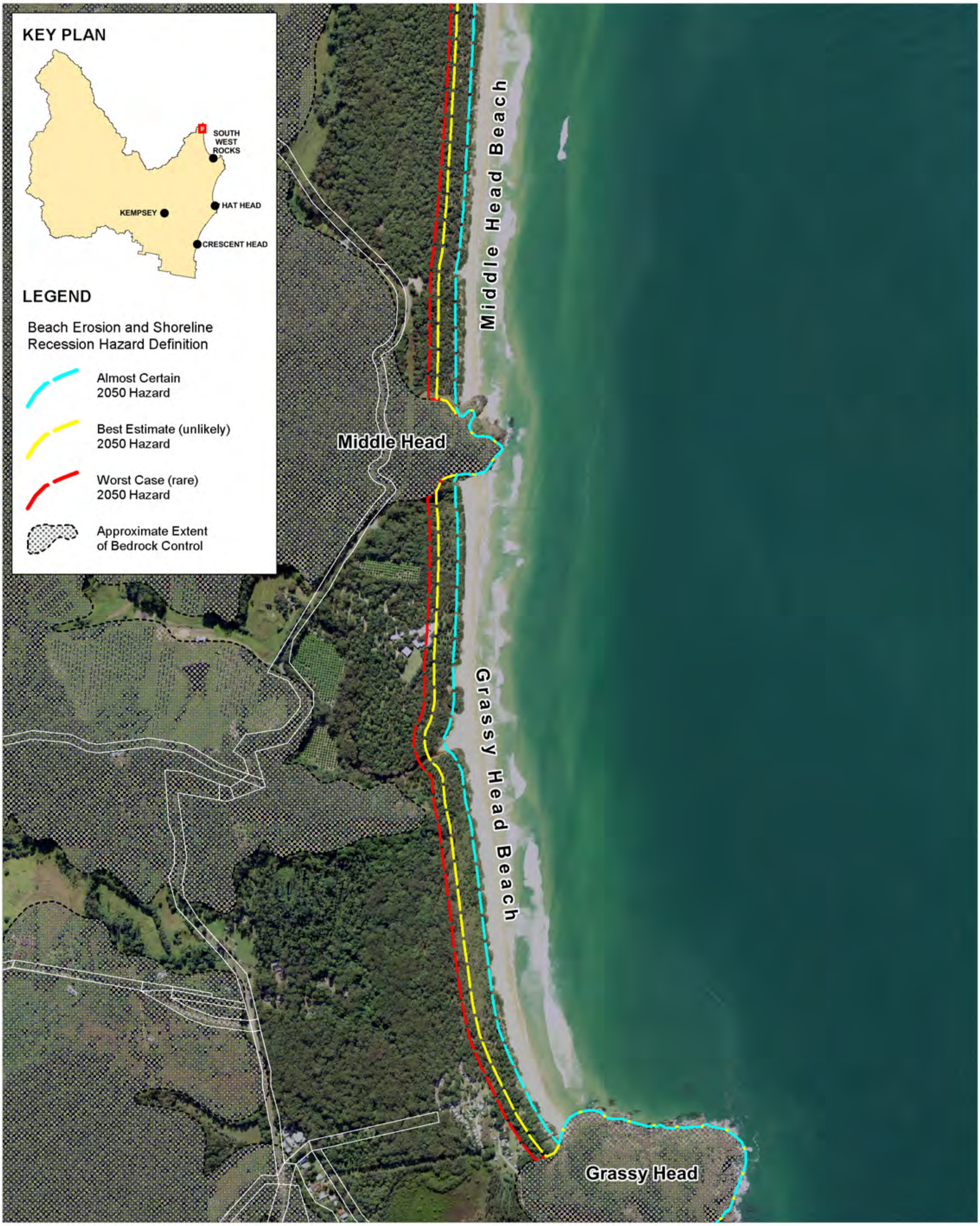
Filepath : K:\N2028_Kempsey_CoastalHazStudy\MapInfo\Workspaces\DRG_008_120809_Drawing_A-8.WOR



Title:

Erosion and Recession Hazard Definition 2050 Planning Horizon - Grassy Head Beach

Figure: B-1

Rev: A

BMT WBM
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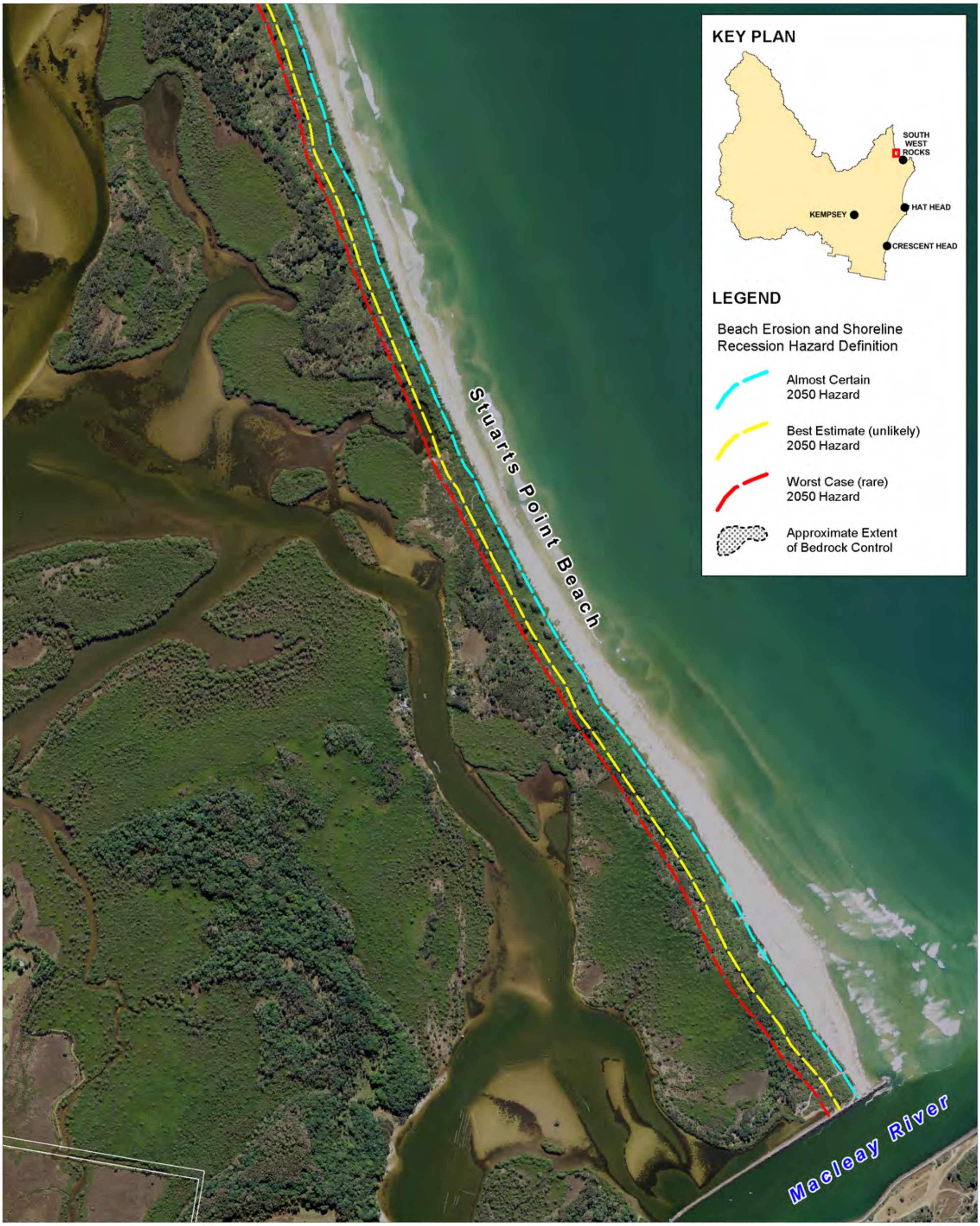
Filepath : K:\N2028_Kempsey_CoastalHazStudy\MapInfo\Workspaces\DRG_101_120809_Drawing_B-1.WOR



Title:

Erosion and Recession Hazard Definition 2050 Planning Horizon - Stuarts Point Beach

Figure: B-2

Rev: A

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N

0 250 500m

Approx. Scale

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Filepath : K:\N2028_Kempsey_CoastalHazStudy\MapInfo\Workspaces\DRG_102_120809_Drawing_B-2.WOR

Title:

Erosion and Recession Hazard Definition 2050 Planning Horizon - South West Rocks

Figure: B-3

Rev: A

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Filepath : K:\N2028_Kempsey_CoastalHazStudy\MapInfo\Workspaces\DRG_103_120809_Drawing_B-3.WOR

Title:

Erosion and Recession Hazard Definition 2050 Planning Horizon - Trial Bay

Figure: **B-4**

Rev: **A**

N

0 250 500m

Approx. Scale

BMT WBM

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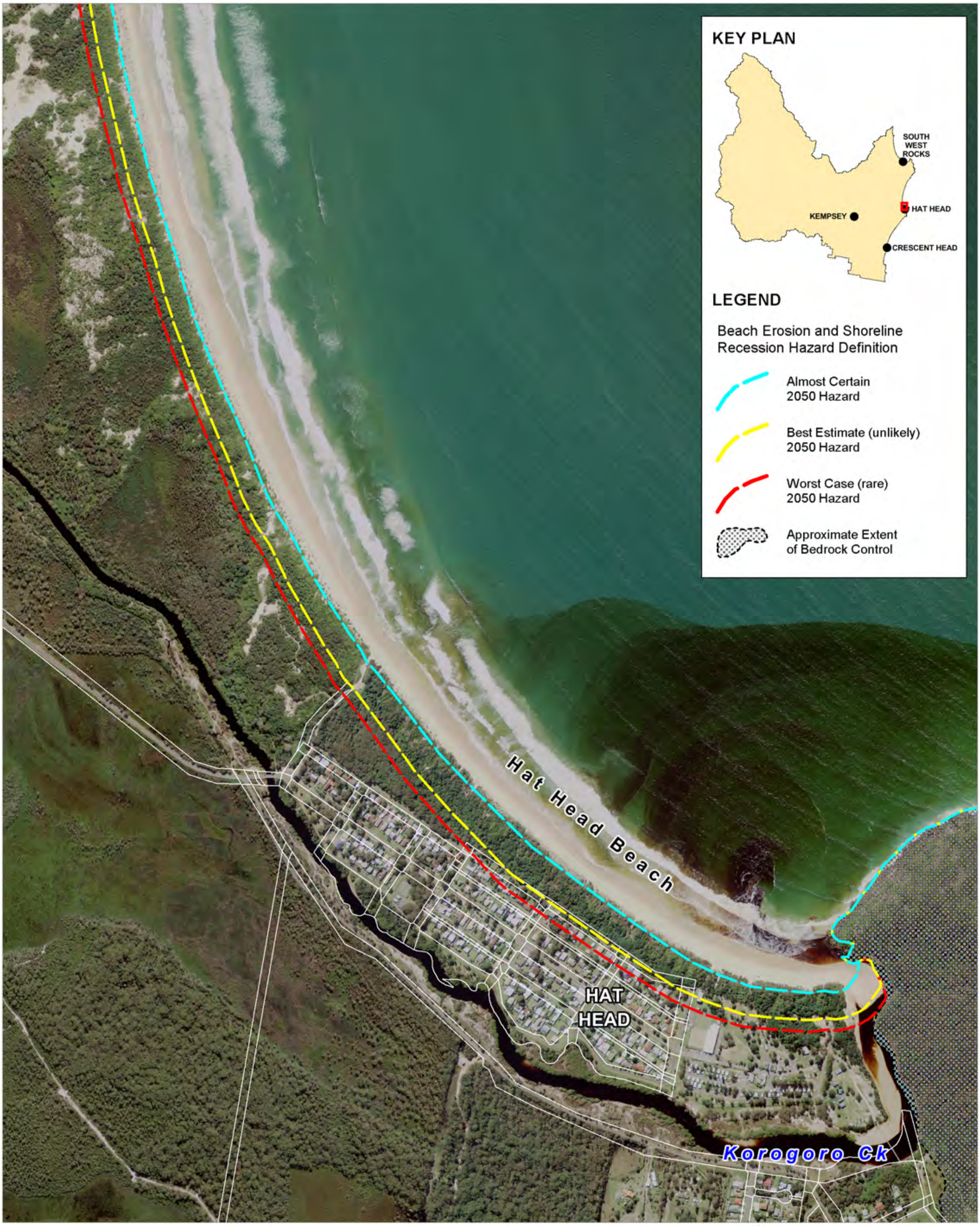
Filepath : K:\N2028_Kempsey_CoastalHazStudy\MapInfo\Workspaces\DRG_104_120809_Drawing_B-4.WOR



Title:

Erosion and Recession Hazard Definition 2050 Planning Horizon - Hat Head

Figure: **B-5**

Rev: **A**

N

0 250 500m

Approx. Scale

BMT WBM

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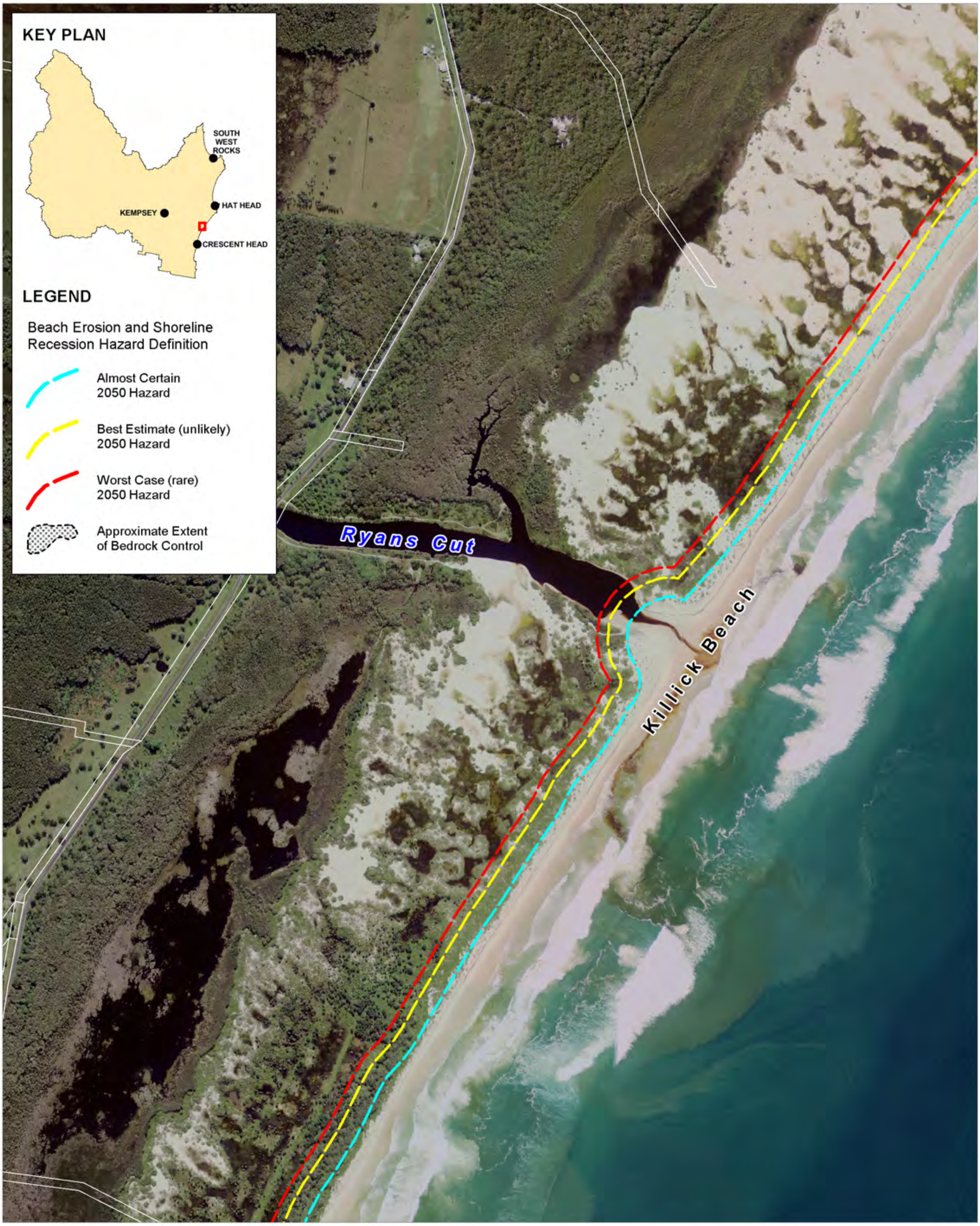
Filepath : K:\N2028_Kempsey_CoastalHazStudy\MapInfo\Workspaces\DRG_105_120809_Drawing_B-5.WOR



Title:

Erosion and Recession Hazard Definition 2050 Planning Horizon - Ryans Cut

Figure: **B-6**

Rev: **A**

N

0 250 500m

Approx. Scale

BMT WBM

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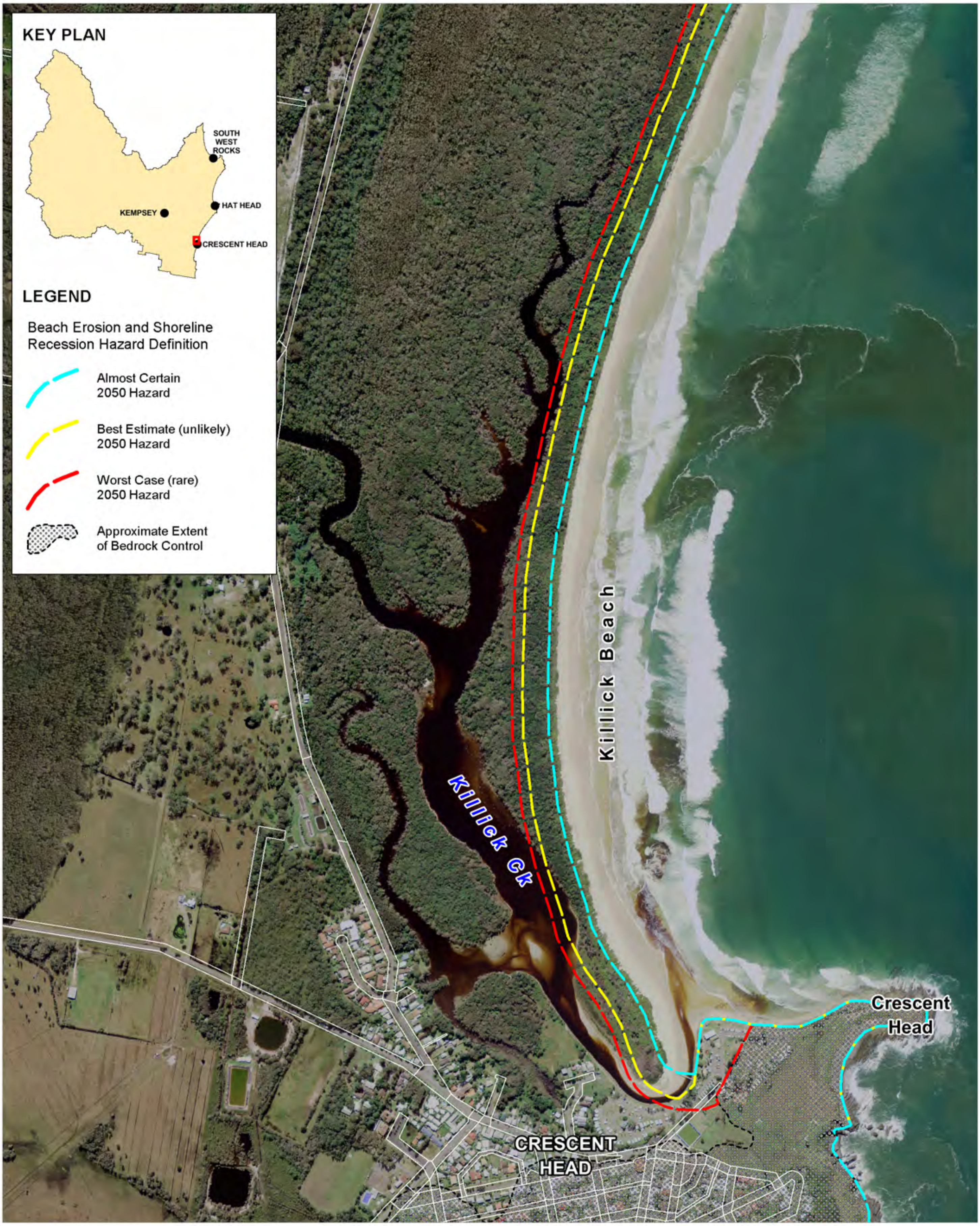
Filepath : K:\N2028_Kempsey_CoastalHazStudy\MapInfo\Workspaces\DRG_106_120809_Drawing_B-6.WOR



Title:

Erosion and Recession Hazard Definition
2050 Planning Horizon - Crescent Head

Figure: **B-7**

Rev: **A**

N

0 250 500m
Approx. Scale

BMT WBM
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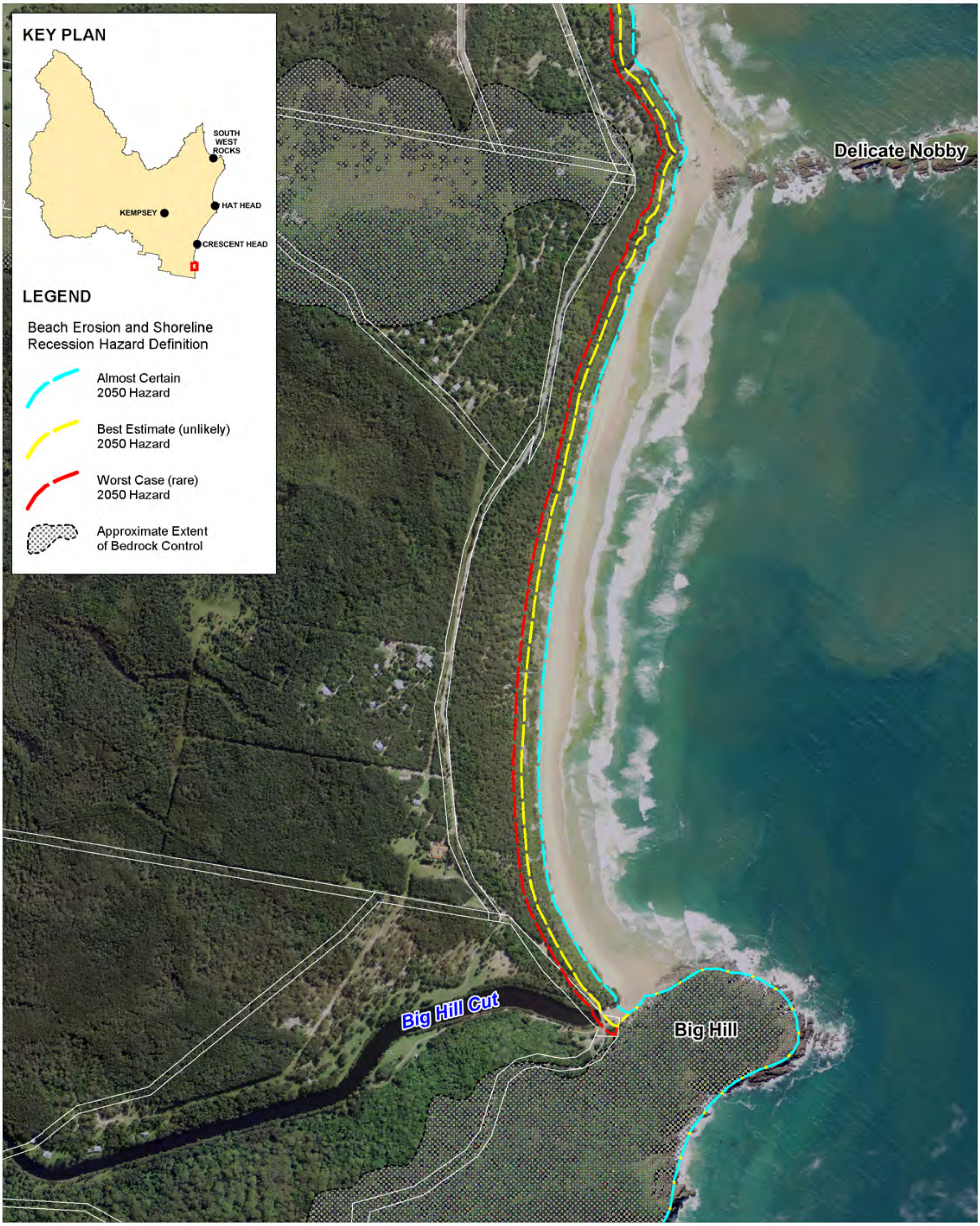
Filepath : K:\N2028_Kempsey_CoastalHazStudy\MapInfo\Workspaces\DRG_107_120809_Drawing_B-7.WOR



Title:

Erosion and Recession Hazard Definition 2050 Planning Horizon - Big Hill Cut

Figure: B-8

Rev: A

N

0 250 500m

Approx. Scale

BMT WBM

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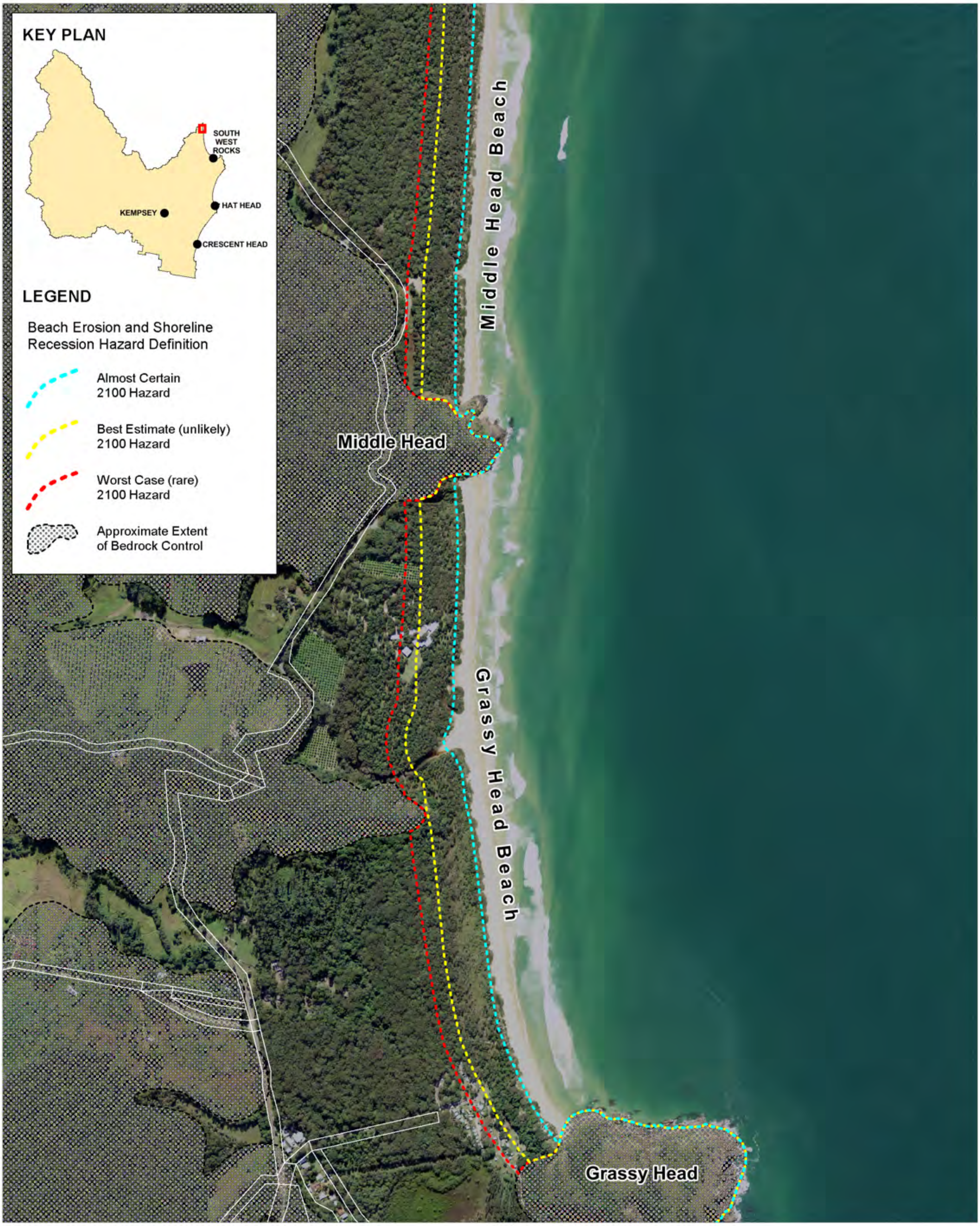
Filepath : K:\N2028_Kempsey_CoastalHazStudy\MapInfo\Workspaces\DRG_108_120809_Drawing_B-8.WOR



Title:

Erosion and Recession Hazard Definition
2100 Planning Horizon - Grassy Head Beach

Figure: C-1

Rev: A

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N

0 250 500m

Approx. Scale

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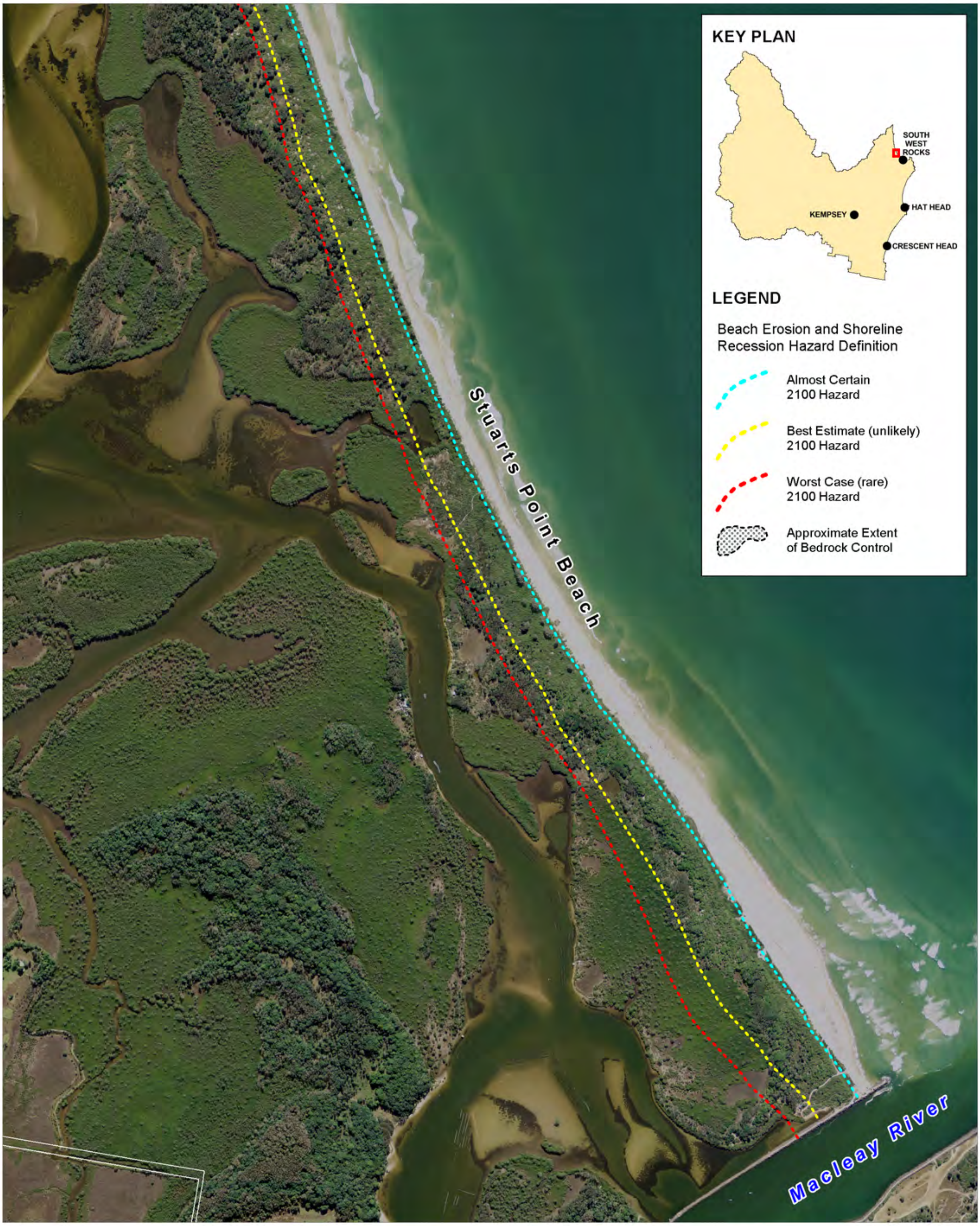
Filepath : K:\N2028_Kempsey_CoastalHazStudy\MapInfo\Workspaces\DRG_201_120809_Drawing_C-1.WOR



Title:

Erosion and Recession Hazard Definition 2100 Planning Horizon - Stuarts Point Beach

Figure: C-2

Rev: A

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N

0 250 500m

Approx. Scale

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Filepath : K:\N2028_Kempsey_CoastalHazStudy\MapInfo\Workspaces\DRG_202_120809_Drawing_C-2.WOR

Title:

Erosion and Recession Hazard Definition
2100 Planning Horizon - South West Rocks

Figure: C-3

Rev: A

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Filepath : K:\N2028_Kempsey_CoastalHazStudy\MapInfo\Workspaces\DRG_203_120809_Drawing_C-3.WOR

Title:

Erosion and Recession Hazard Definition
2100 Planning Horizon - Trial Bay

Figure: C-4

Rev: A

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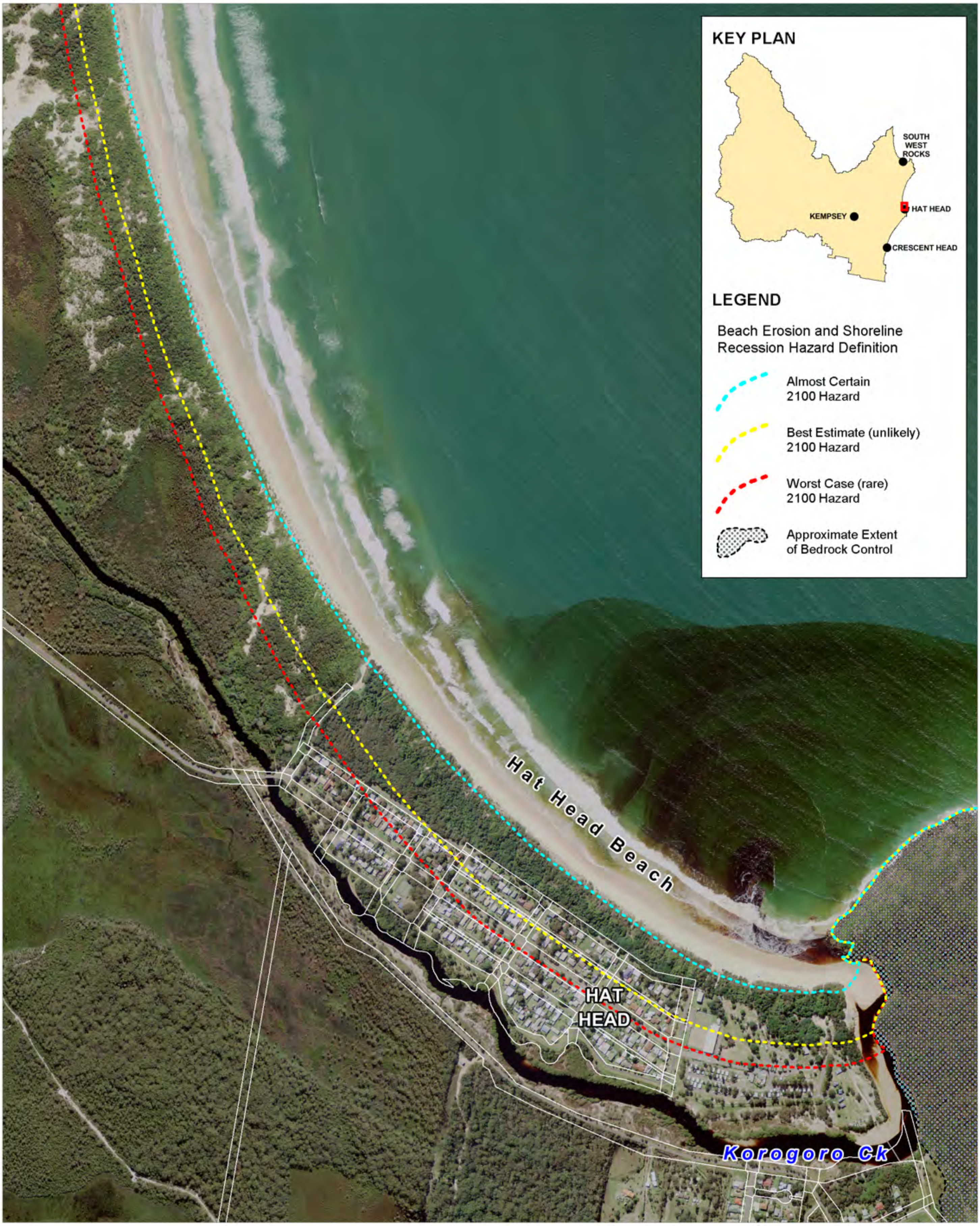

Title:

Erosion and Recession Hazard Definition 2100 Planning Horizon - Hat Head

Figure: C-5

Rev: A

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N

0 250 500m

Approx. Scale

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Filepath : K:\N2028_Kempsey_CoastalHazStudy\MapInfo\Workspaces\DRG_205_120809_Drawing_C-5.WOR

Title:

Erosion and Recession Hazard Definition
2100 Planning Horizon - Ryans Cut

Figure: C-6

Rev: A

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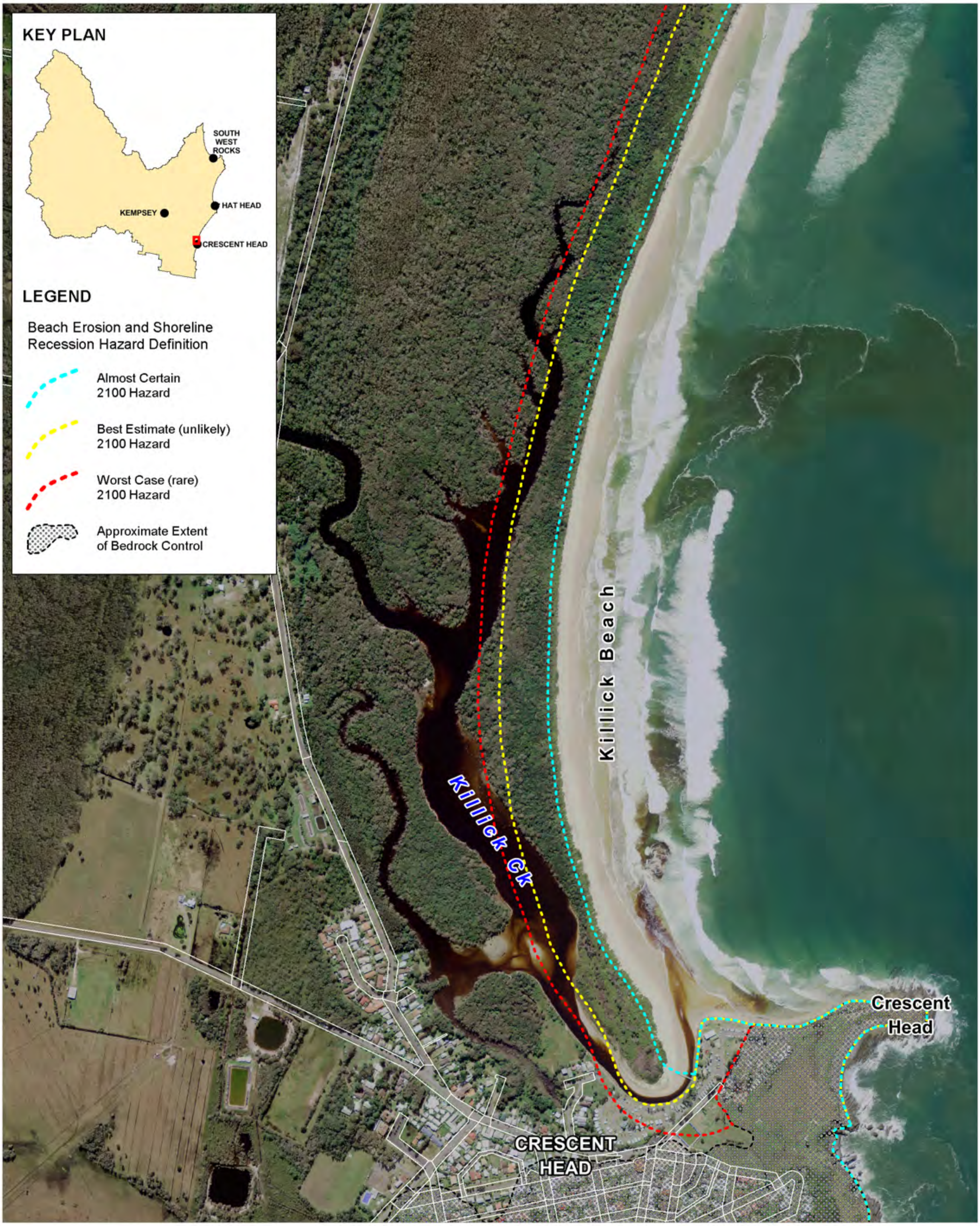

Title:

Erosion and Recession Hazard Definition 2100 Planning Horizon - Crescent Head

Figure: C-7

Rev: A

N

0 250 500m

Approx. Scale

BMT WBM

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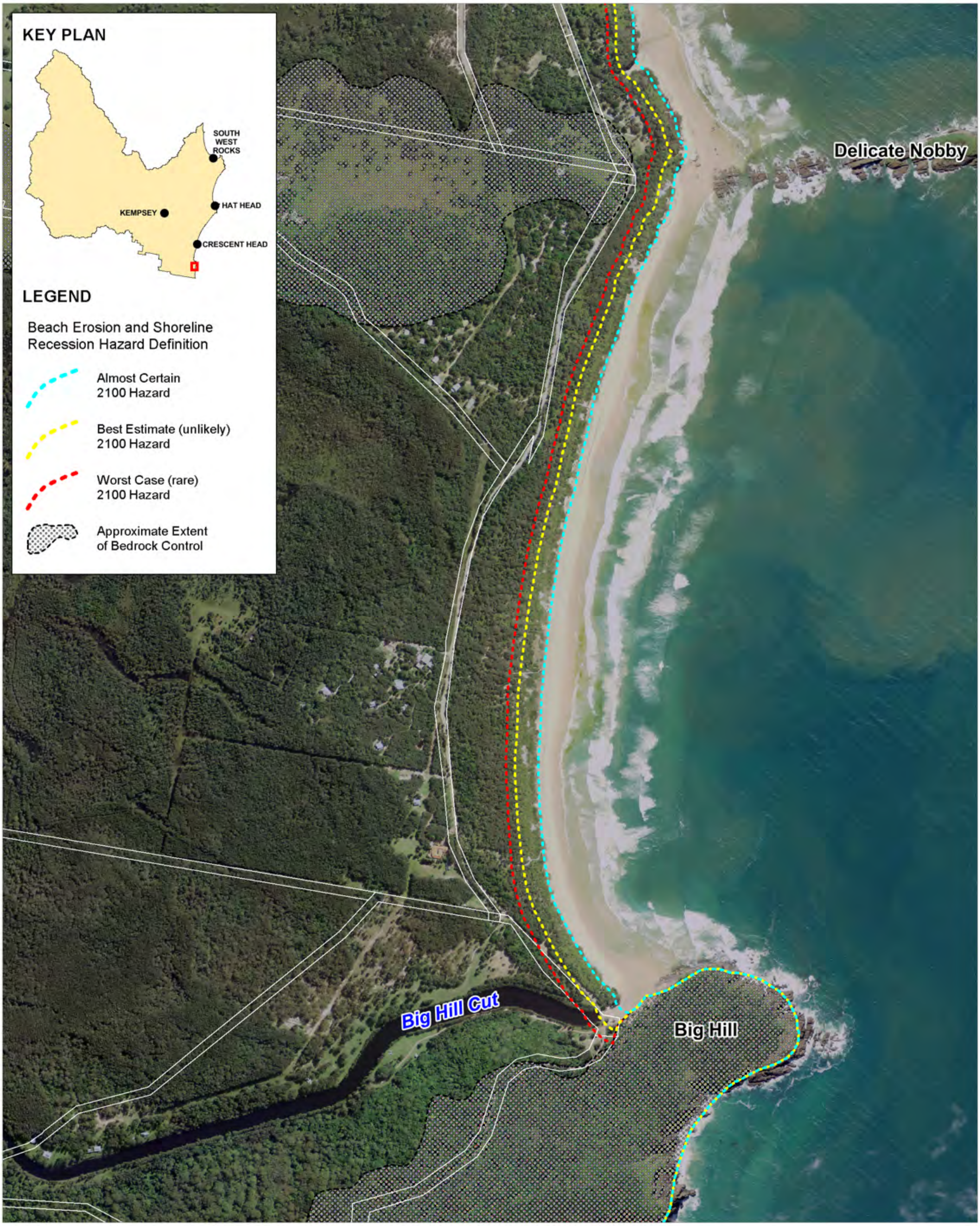
Filepath : K:\N2028_Kempsey_CoastalHazStudy\MapInfo\Workspaces\DRG_207_120809_Drawing_C-7.WOR



Title:
Erosion and Recession Hazard Definition 2100 Planning Horizon - Big Hill Cut

Figure: C-8

Rev: A

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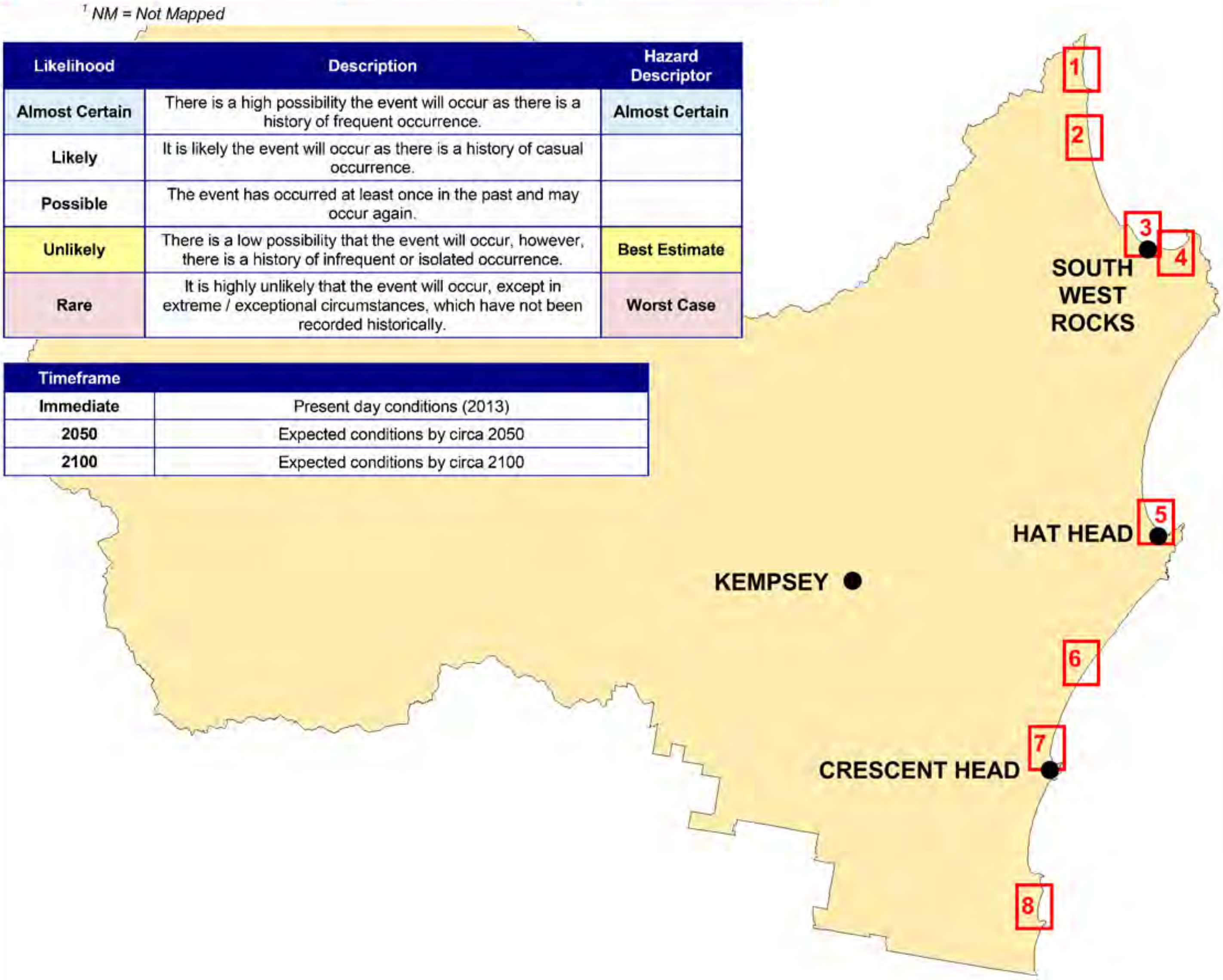
Filepath : K:\N2028_Kempsey_CoastalHazStudy\MapInfo\Workspaces\DRG_208_120809_Drawing_C-8.WOR

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
Possible	NM	NM	NM
Best Estimate (Unlikely)	1 in 100 yr storm surge and wave set up	1 in 100 yr storm surge and wave set up + 0.4 m SLR and climate change impacts	1 in 100 yr storm surge and wave set up + 0.9 m SLR and climate change impacts
Worst Case (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 **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 **OR** 1 in 100 yr storm surge and wave set up + 1.4 m SLR and climate change impacts

[1] NM = Not Mapped

Likelihood	Description	Hazard Descriptor
Almost Certain	There is a high possibility the event will occur as there is a history of frequent occurrence.	**Almost Certain**
Likely	It is likely the event will occur as there is a history of casual occurrence.	
Possible	The event has occurred at least once in the past and may occur again.	
Unlikely	There is a low possibility that the event will occur, however, there is a history of infrequent or isolated occurrence.	**Best Estimate**
Rare	It is highly unlikely that the event will occur, except in extreme / exceptional circumstances, which have not been recorded historically.	**Worst Case**

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



Title:

Index to Coastal Inundation Hazard Maps

Figure: **D-0**

Rev: **A**

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N

0 10 20km

Approx. Scale

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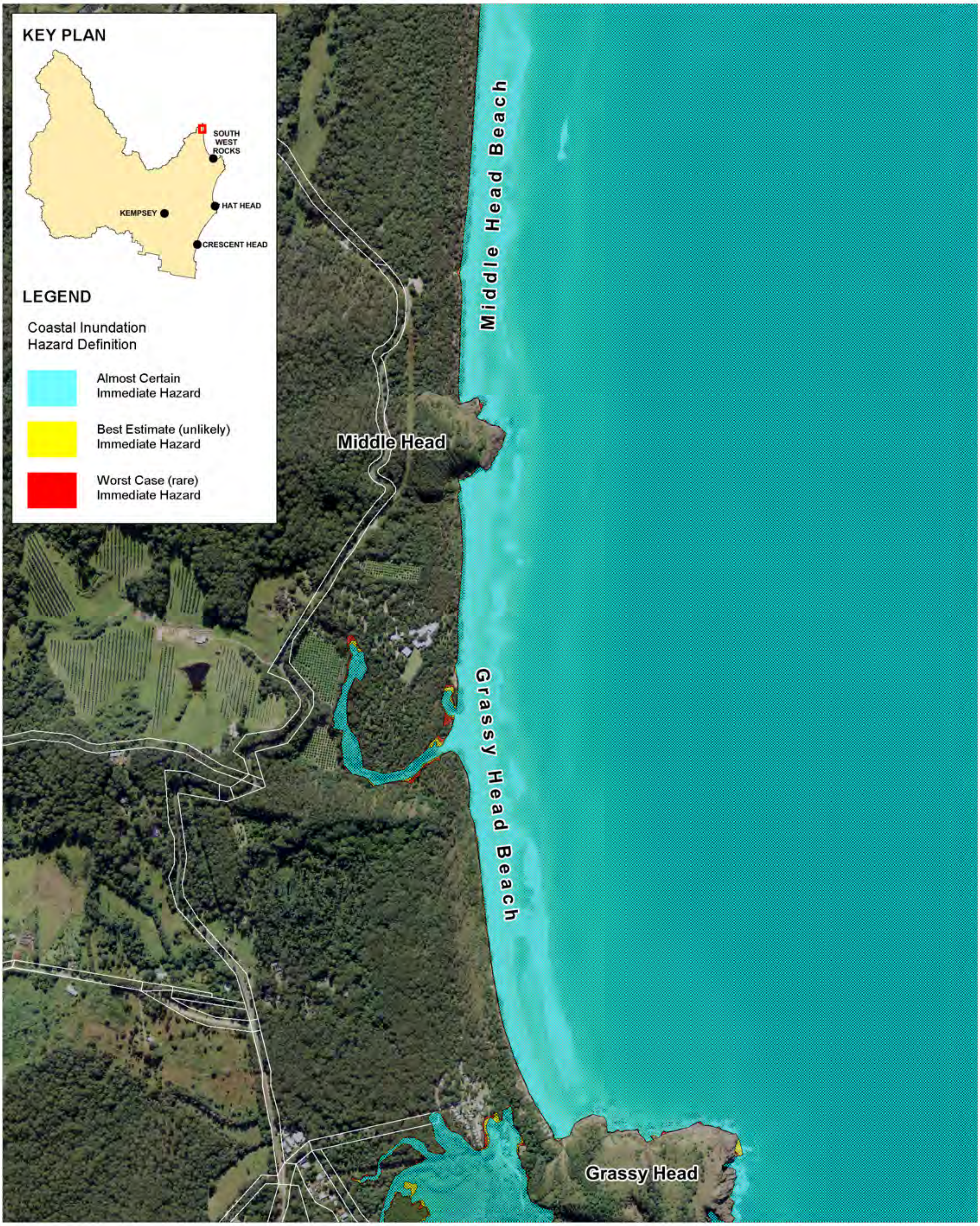

Title:

Coastal Inundation Hazard Definition
Immediate Planning Horizon - Grassy Head Beach

Figure: **D-1**

Rev: **A**

N

0 250 500m

Approx. Scale

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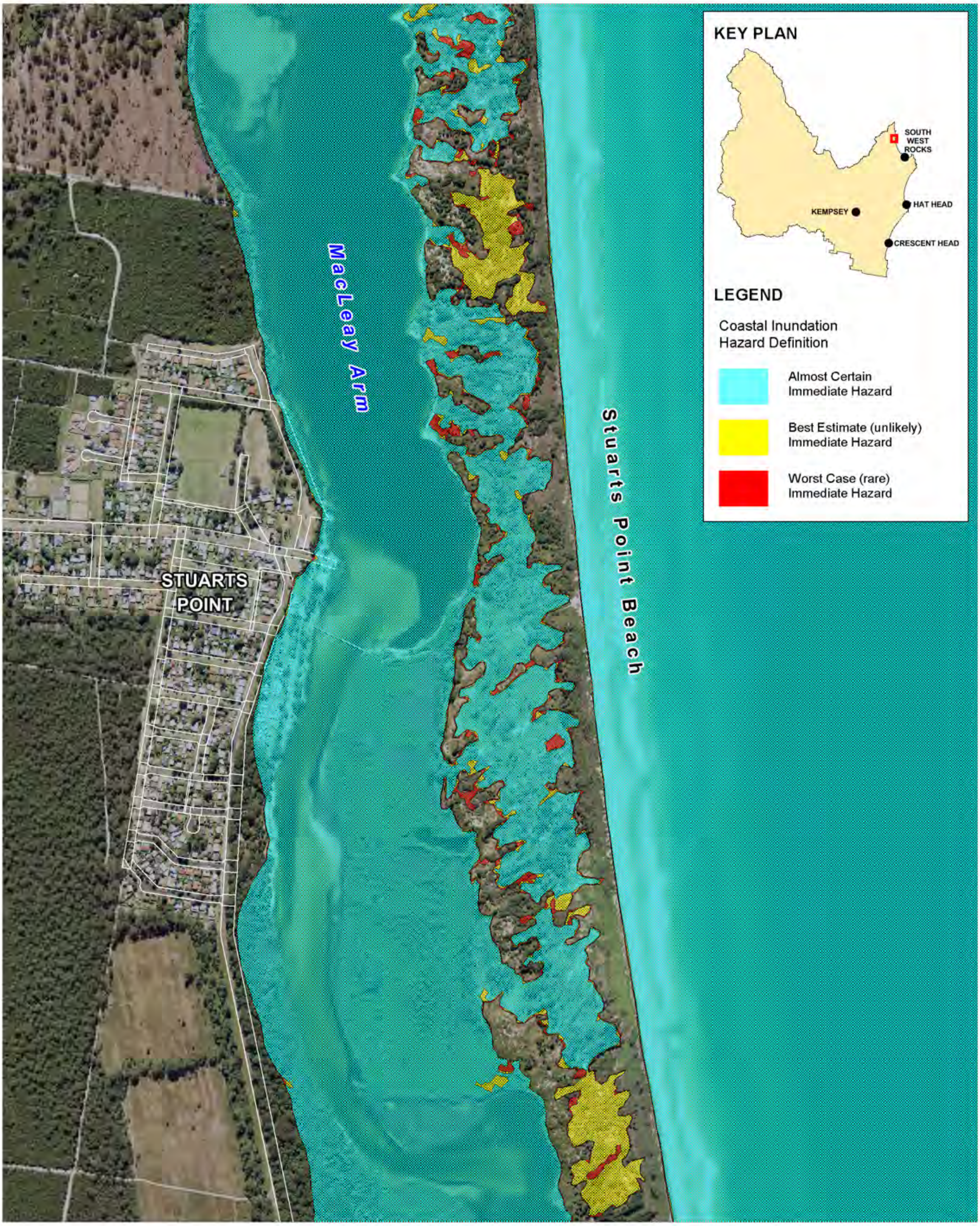
Filepath : K:\N2028_Kempsey_CoastalHazStudy\MapInfo\Workspaces\DRG_301_120912_Drawing_D-1.WOR



Title:

Coastal Inundation Hazard Definition
Immediate Planning Horizon - Stuarts Point Beach

Figure: **D-2**

Rev: **A**

N

0 250 500m
Approx. Scale

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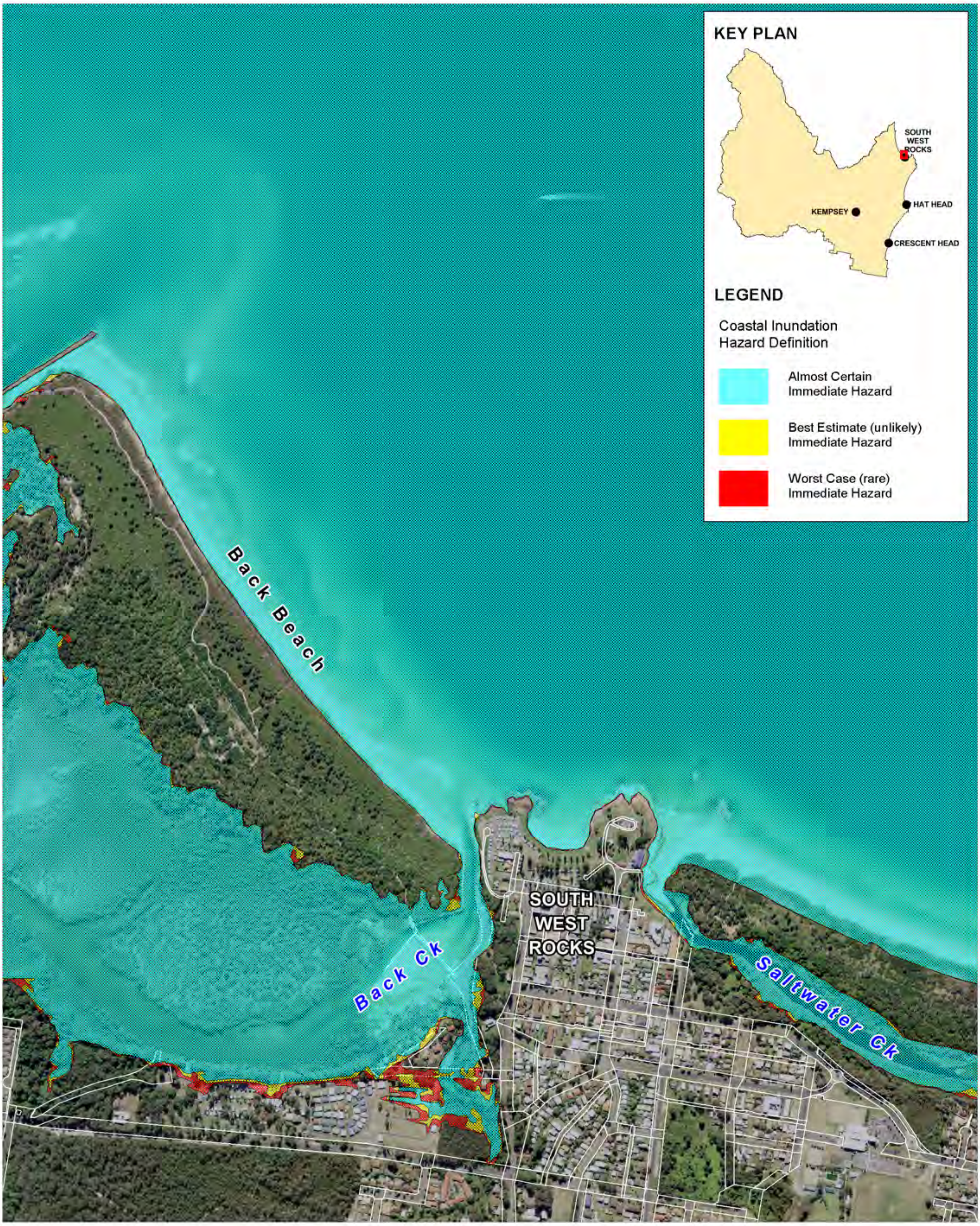
Filepath : K:\N2028_Kempsey_CoastalHazStudy\MapInfo\Workspaces\DRG_302_120912_Drawing_D-2.WOR



Title:

Coastal Inundation Hazard Definition
Immediate Planning Horizon - South West Rocks

Figure: D-3

Rev: A

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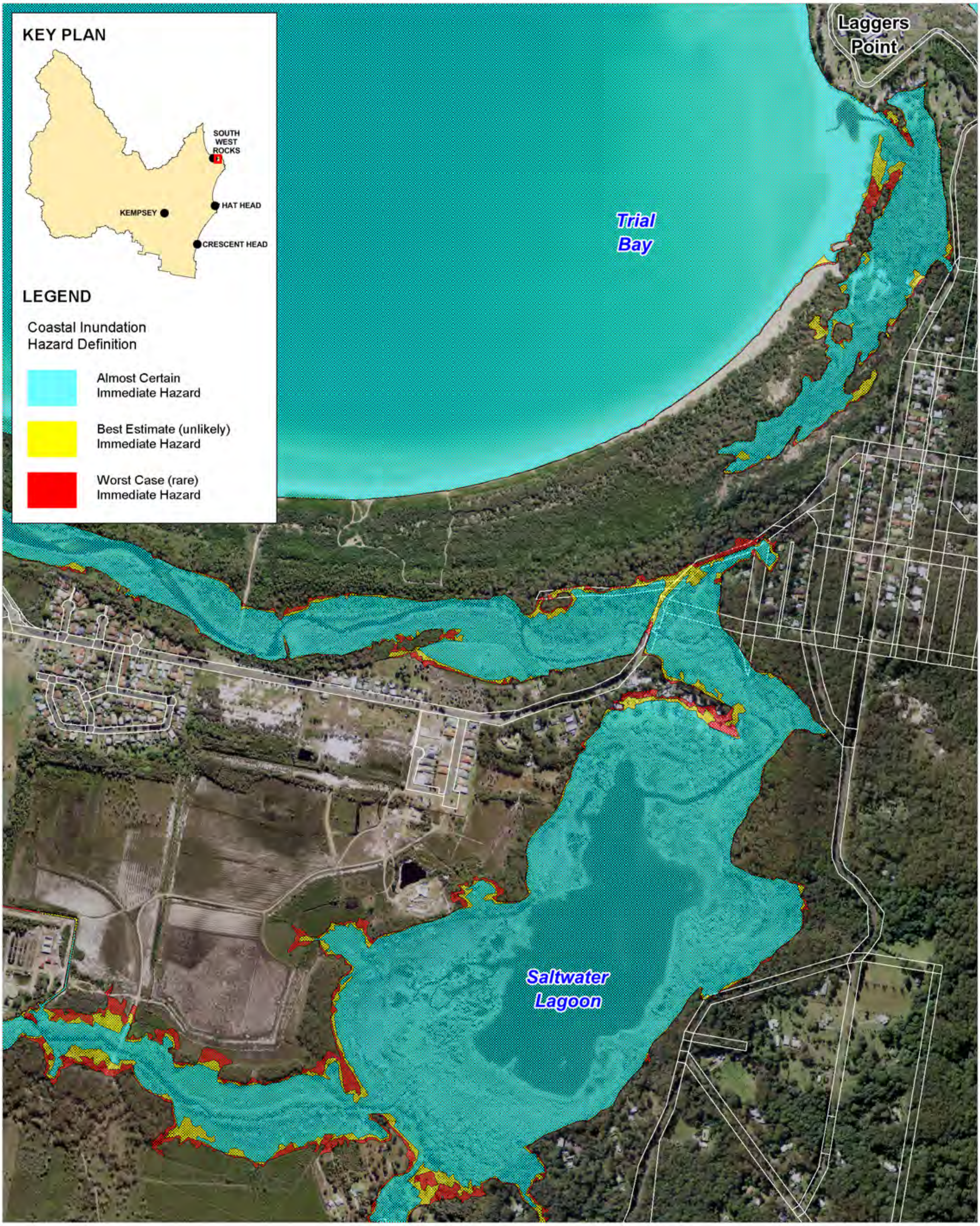

Title:

Coastal Inundation Hazard Definition
Immediate Planning Horizon - Trial Bay

Figure: **D-4**

Rev: **A**

N

0 250 500m

Approx. Scale

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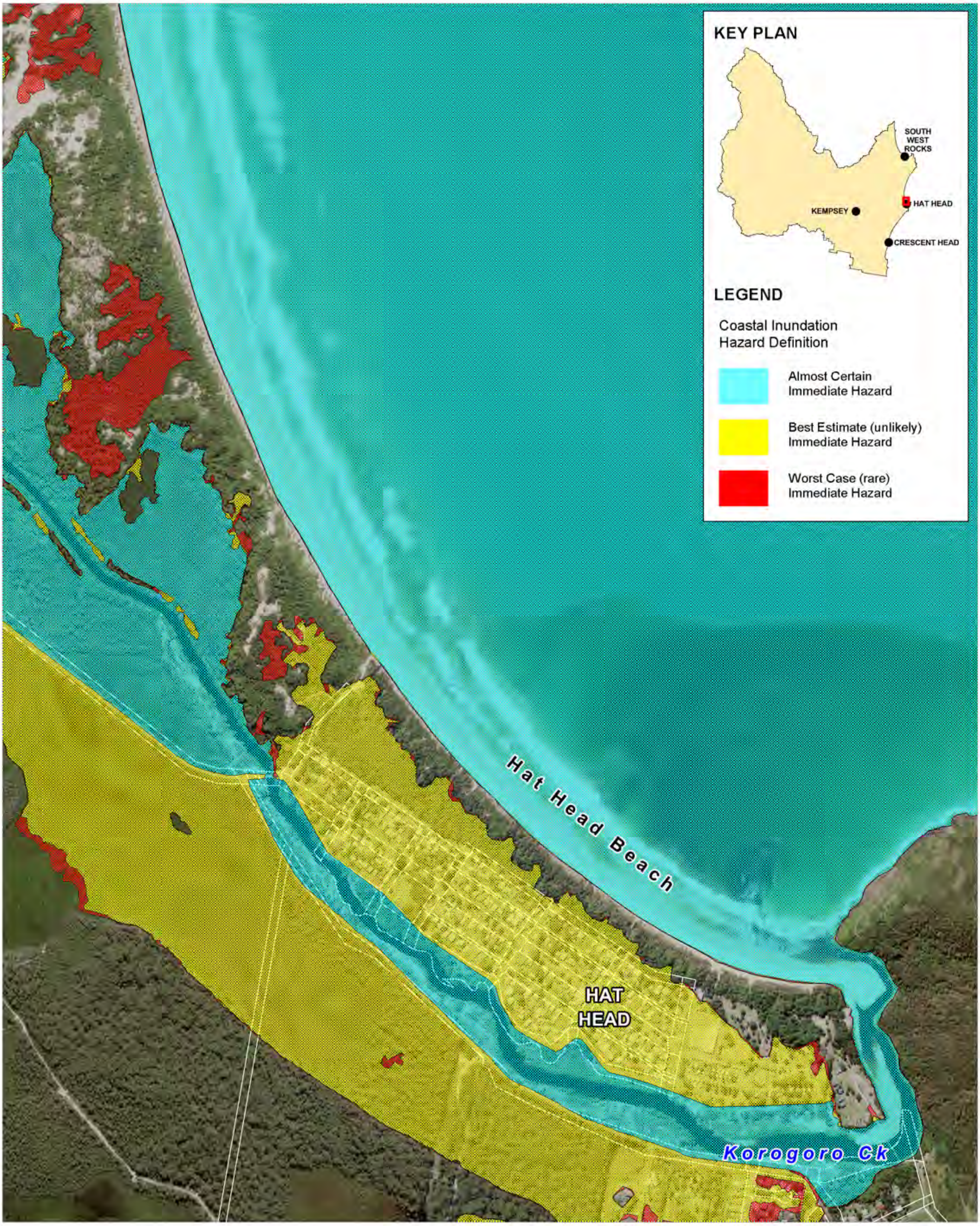
Filepath : K:\N2028_Kempsey_CoastalHazStudy\MapInfo\Workspaces\DRG_304_120912_Drawing_D-4.WOR



Title:

Coastal Inundation Hazard Definition
Immediate Planning Horizon - Hat Head

Figure: D-5

Rev: A

N

0 250 500m

Approx. Scale

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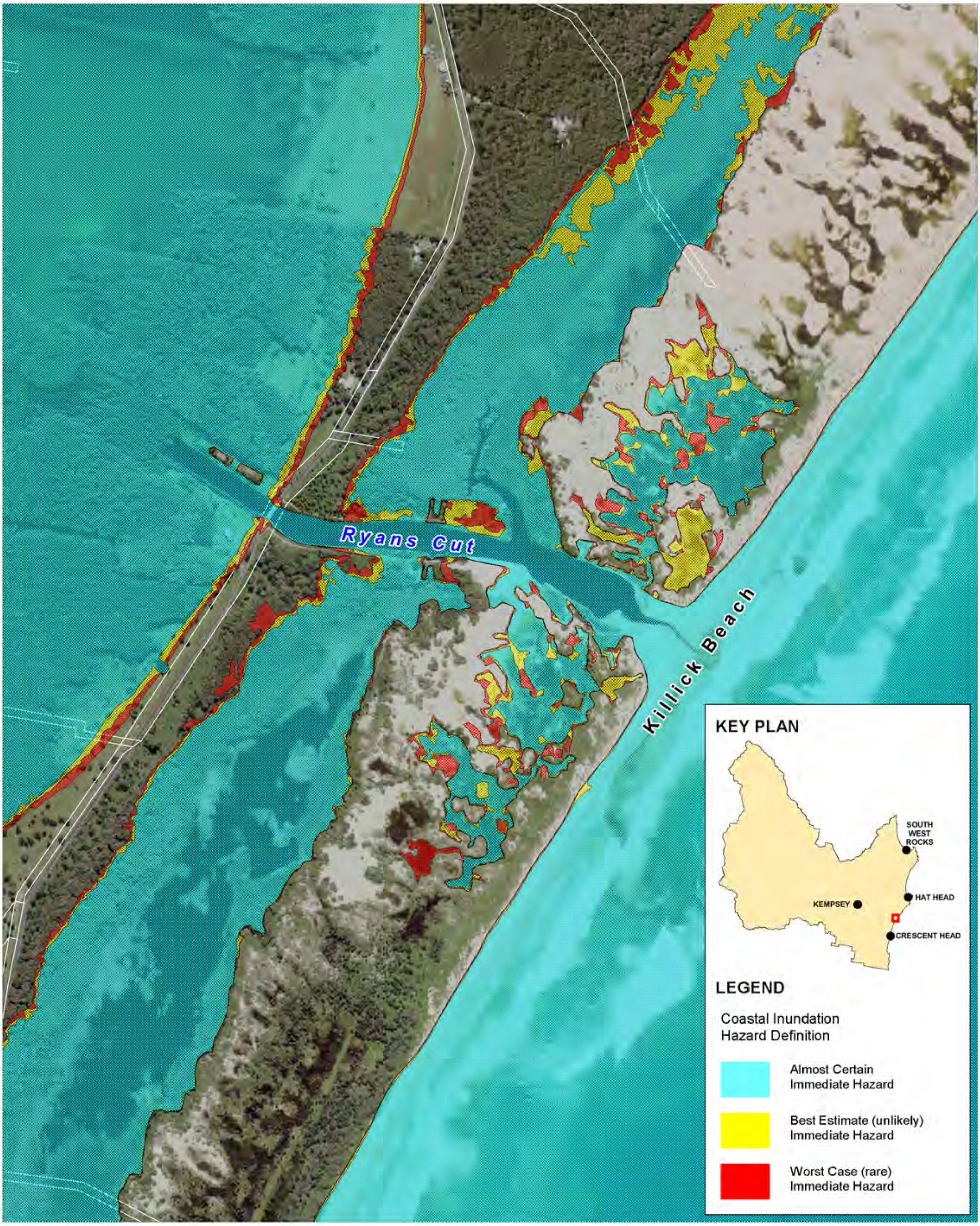
Filepath : K:\N2028_Kempsey_CoastalHazStudy\MapInfo\Workspaces\DRG_305_120912_Drawing_D-5.WOR



Title:
Coastal Inundation Hazard Definition
Immediate Planning Horizon - Ryans Cut

Figure: D-6

Rev: A

N

0 250 500m
Approx. Scale

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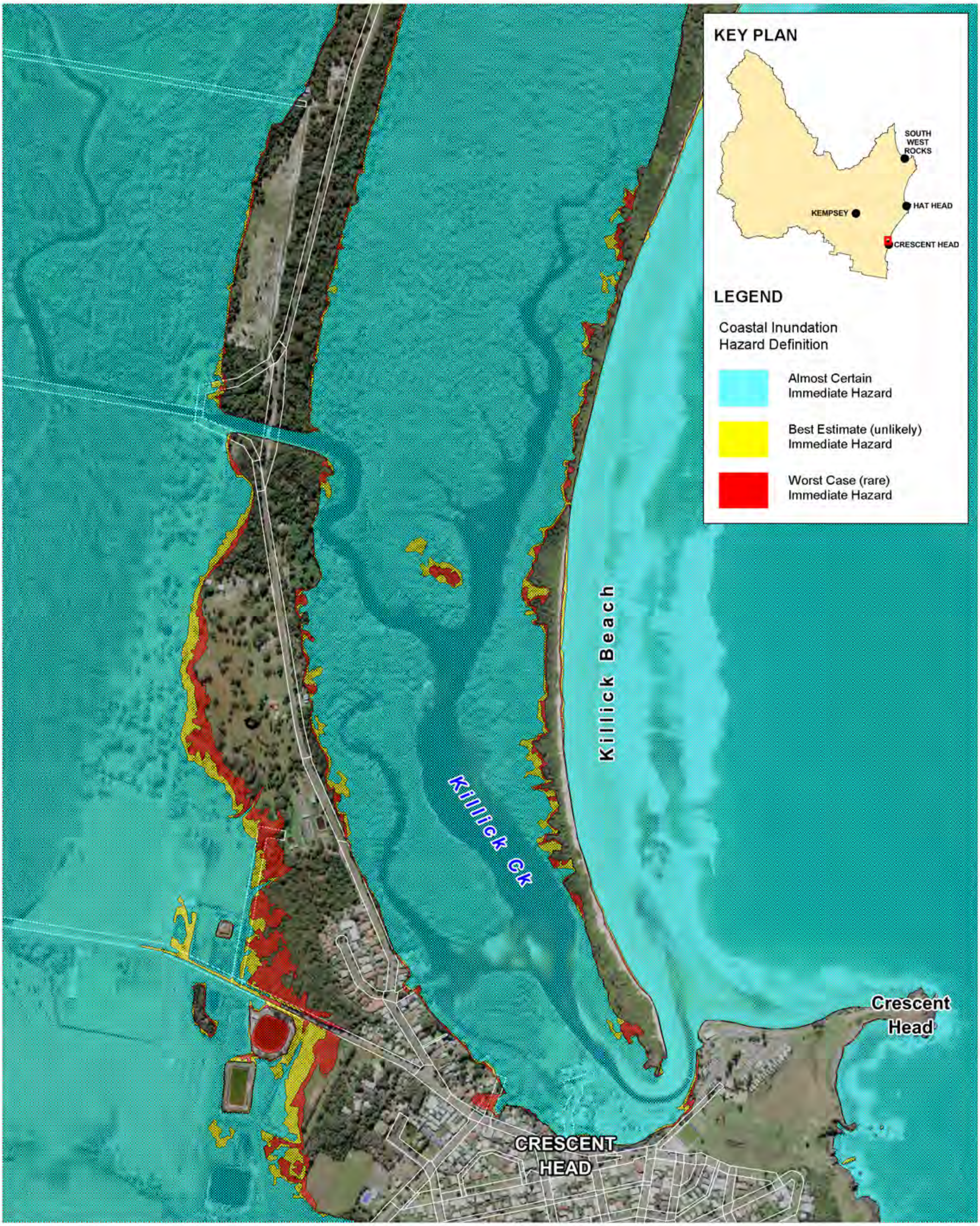
Filepath : K:\N2028_Kempsey_CoastalHazStudy\MapInfo\Workspaces\DRG_306_120912_Drawing_D-6.WOR



Title:

Coastal Inundation Hazard Definition
Immediate Planning Horizon - Crescent Head

Figure: **D-7**

Rev: **A**

N

0 250 500m
Approx. Scale

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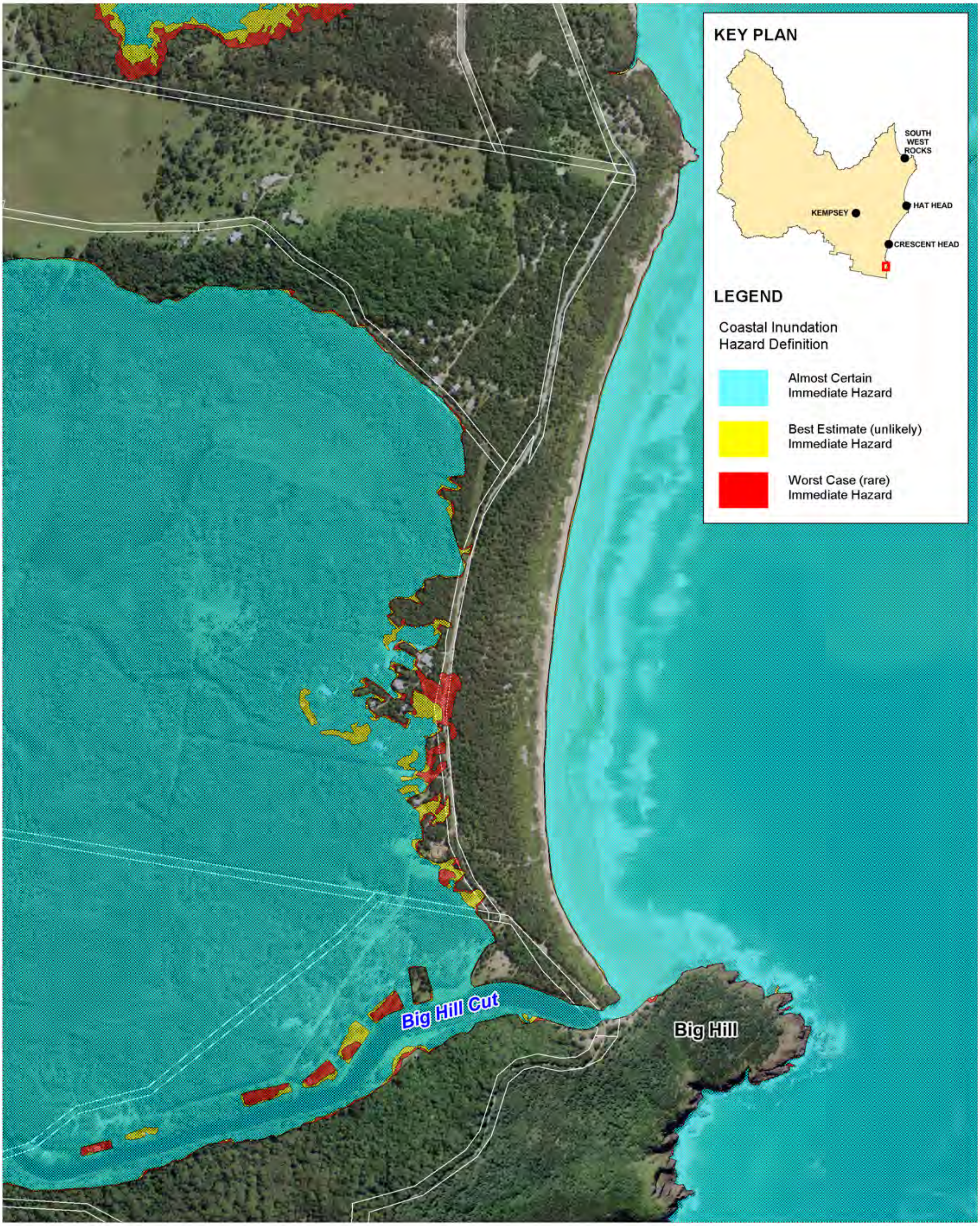
Filepath : K:\N2028_Kempsey_CoastalHazStudy\MapInfo\Workspaces\DRG_307_120912_Drawing_D-7.WOR



Title:

Coastal Inundation Hazard Definition
Immediate Planning Horizon - Big Hill Cut

Figure: D-8

Rev: A

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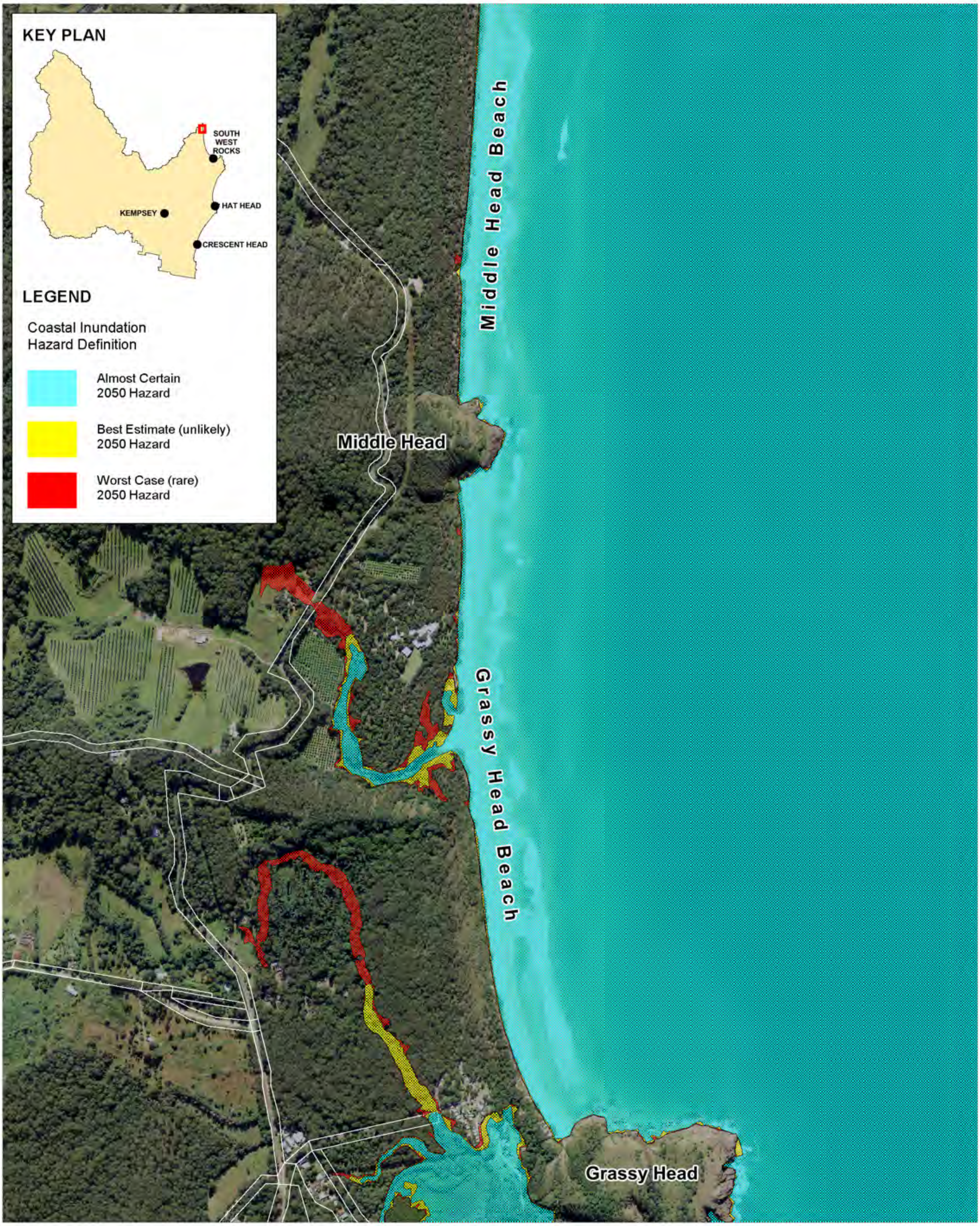

Title:

Coastal Inundation Hazard Definition 2050 Planning Horizon - Grassy Head Beach

Figure: E-1

Rev: A

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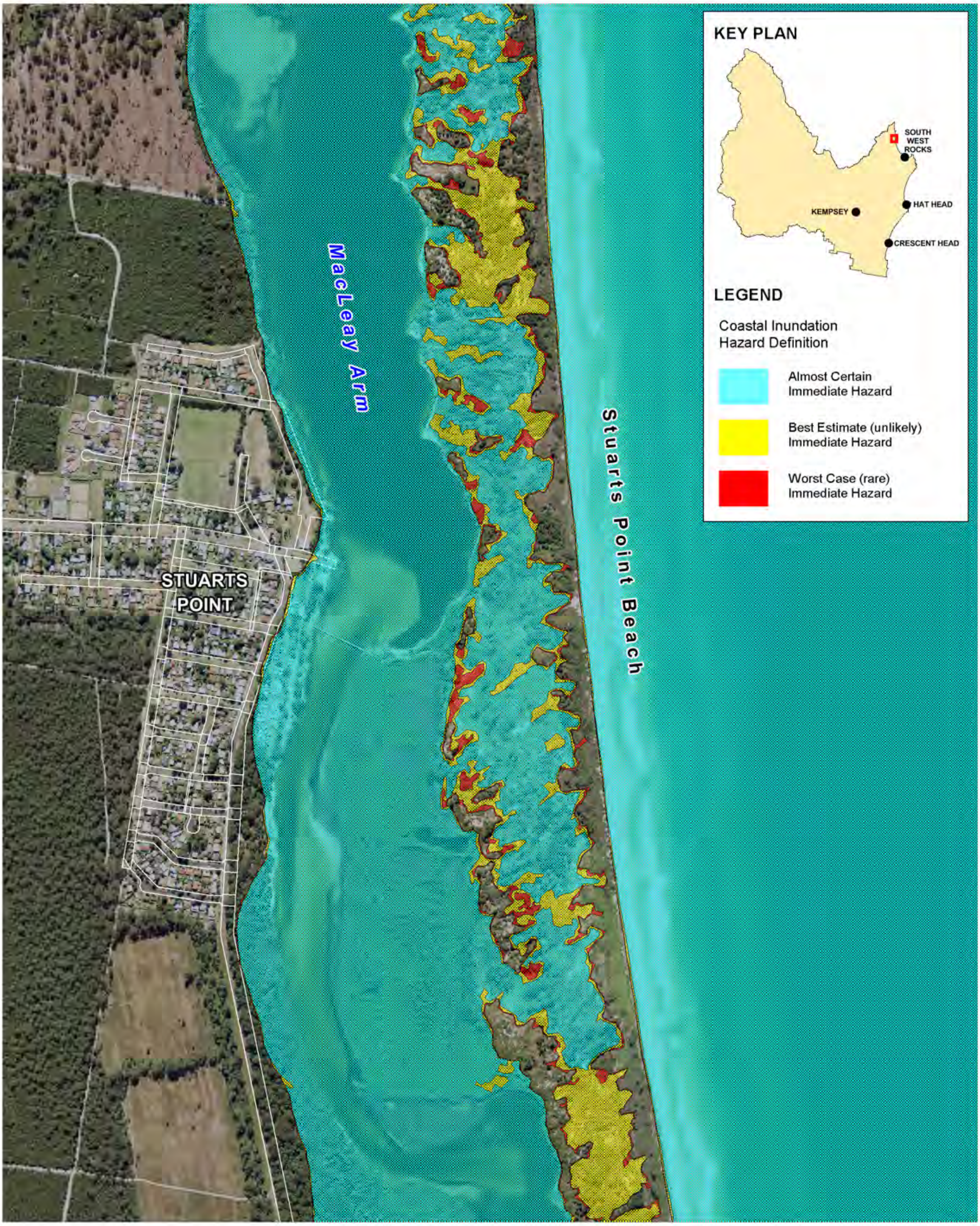
Filepath : K:\N2028_Kempsey_CoastalHazStudy\MapInfo\Workspaces\DRG_401_120912_Drawing_E-1.WOR



Title:

Coastal Inundation Hazard Definition 2050 Planning Horizon - Stuarts Point Beach

Figure: **E-2**

Rev: **A**

N

0 250 500m

Approx. Scale

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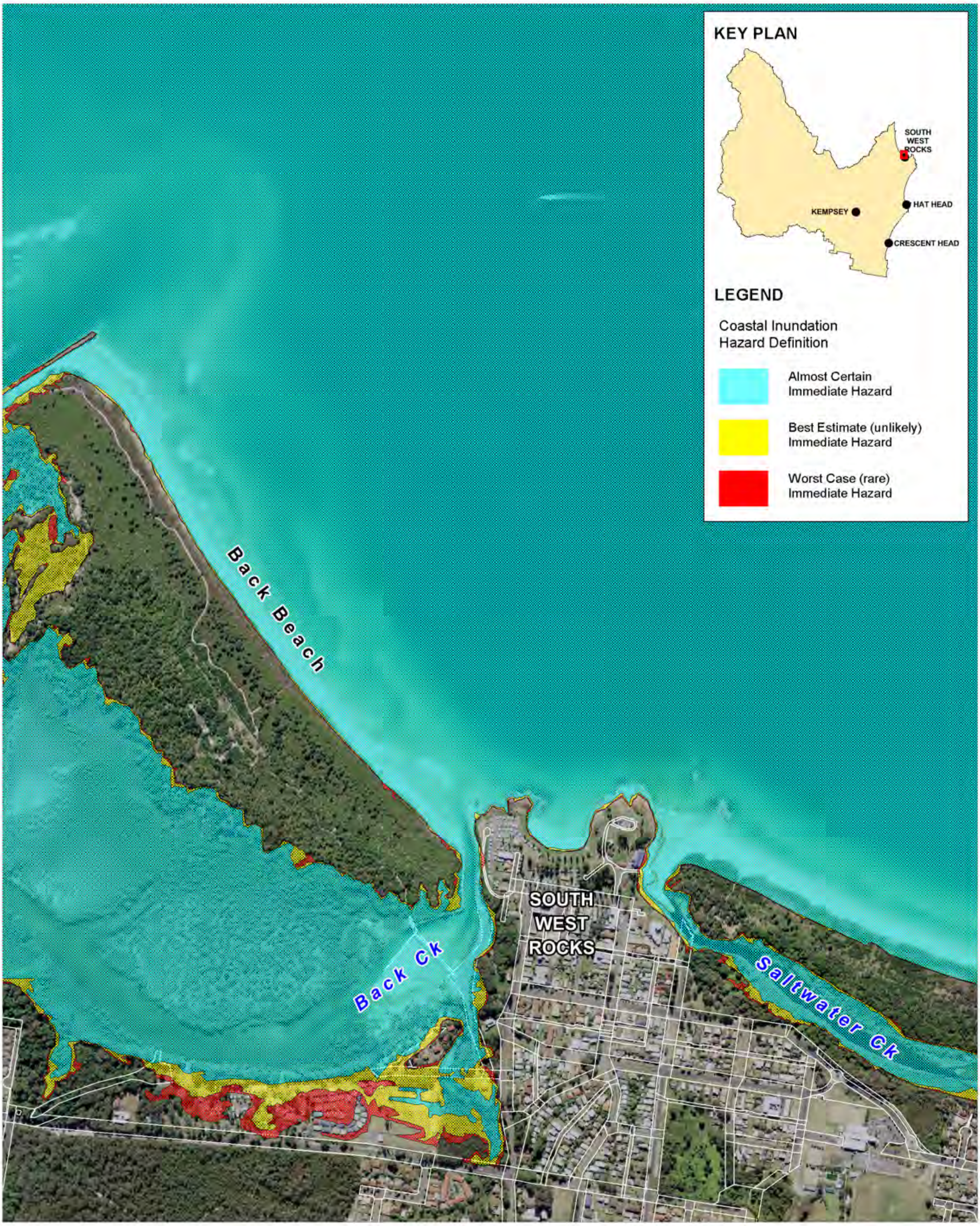
Filepath : K:\N2028_Kempsey_CoastalHazStudy\MapInfo\Workspaces\DRG_402_120912_Drawing_E-2.WOR



Title:

Coastal Inundation Hazard Definition 2050 Planning Horizon - South West Rocks

Figure: E-3

Rev: A

N

0 250 500m

Approx. Scale

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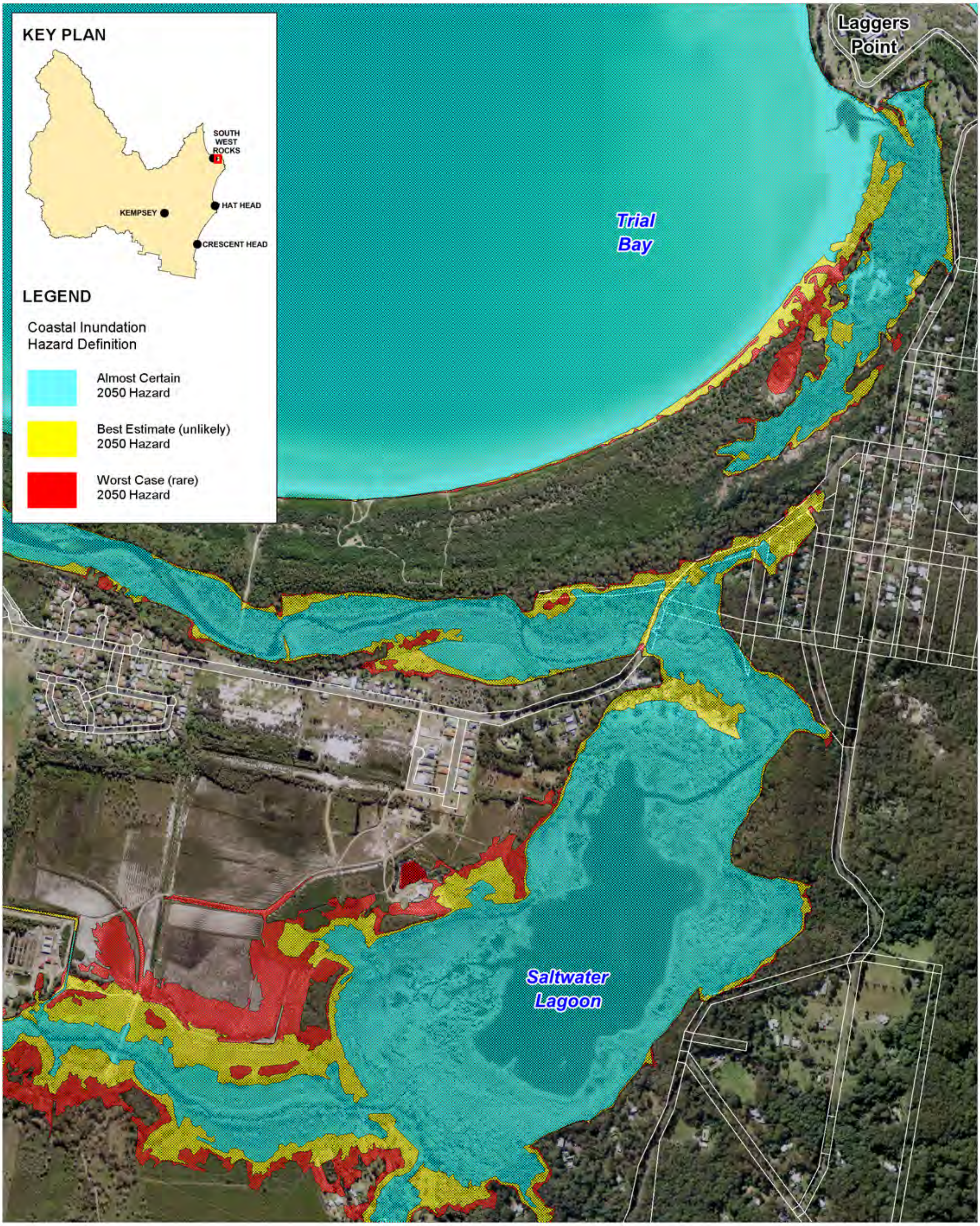

Title:

Coastal Inundation Hazard Definition 2050 Planning Horizon - Trial Bay

Figure: **E-4**

Rev: **A**

N

0 250 500m

Approx. Scale

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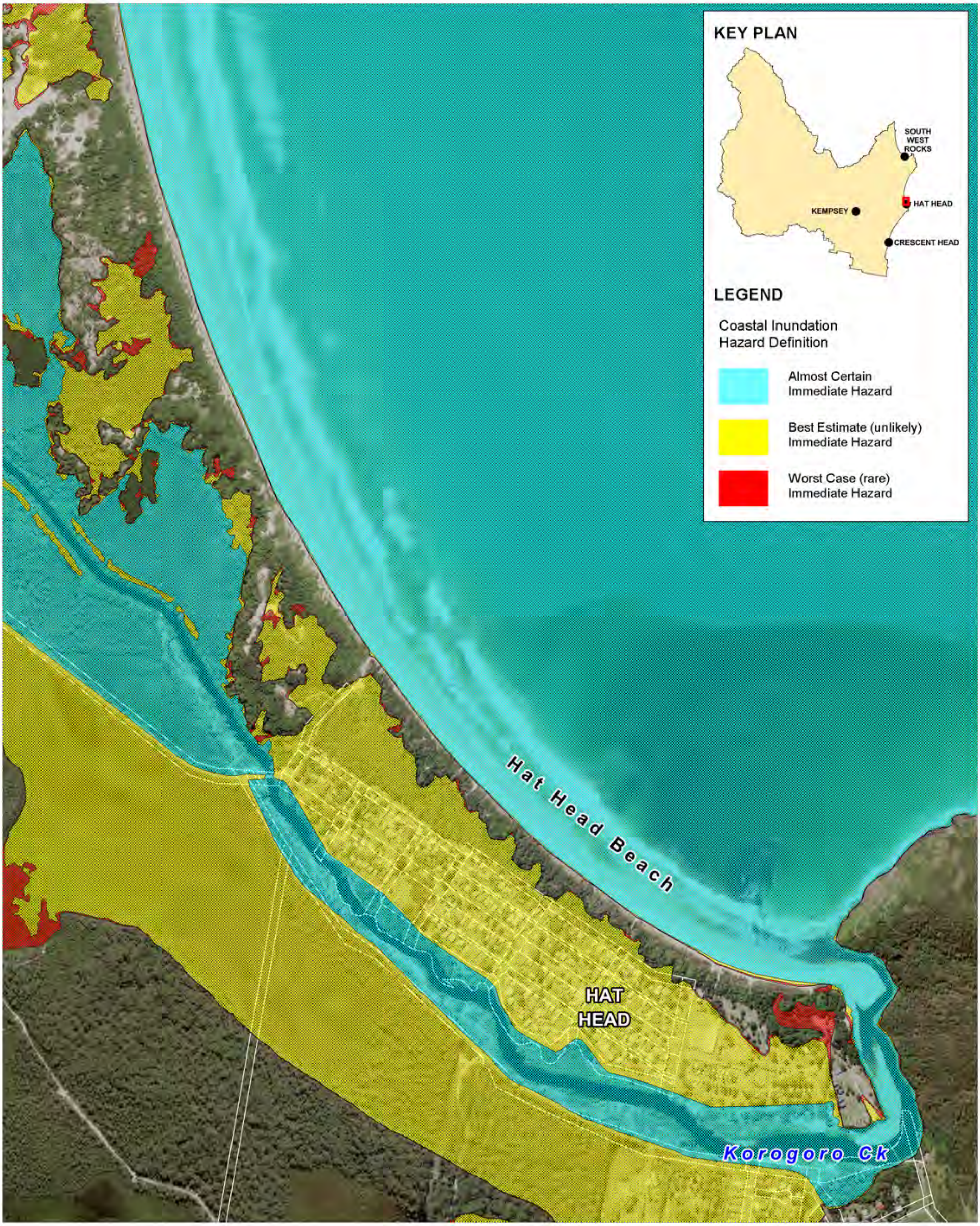
Filepath : K:\N2028_Kempsey_CoastalHazStudy\MapInfo\Workspaces\DRG_404_120912_Drawing_E-4.WOR



Title:

Coastal Inundation Hazard Definition 2050 Planning Horizon - Hat Head

Figure: E-5

Rev: A

N 0 250 500m Approx. Scale

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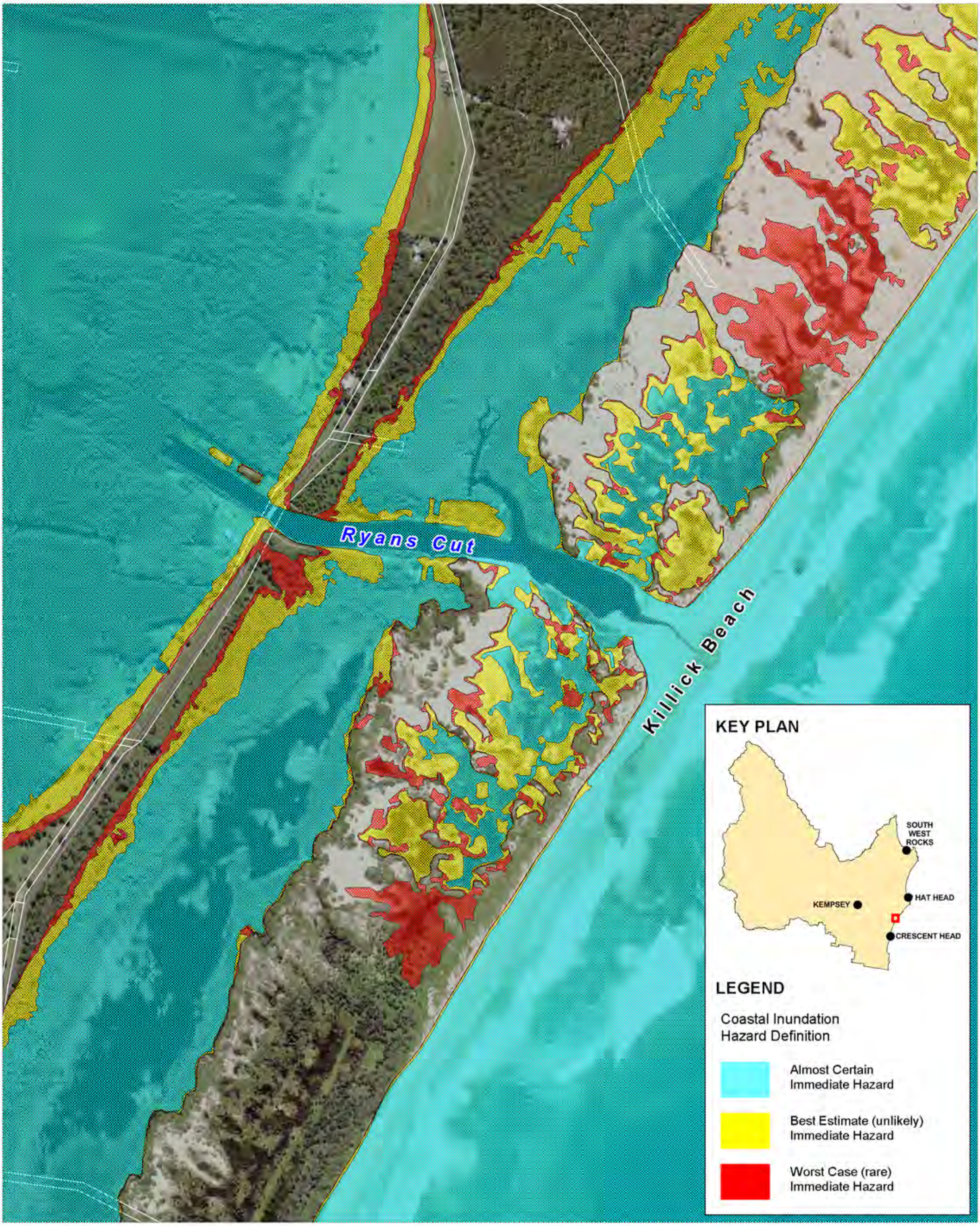
Filepath : K:\N2028_Kempsey_CoastalHazStudy\MapInfo\Workspaces\DRG_405_120912_Drawing_E-5.WOR



Title:

Coastal Inundation Hazard Definition
2050 Planning Horizon - Ryans Cut

Figure: E-6

Rev: A

N

0 250 500m

Approx. Scale

BMT WBM

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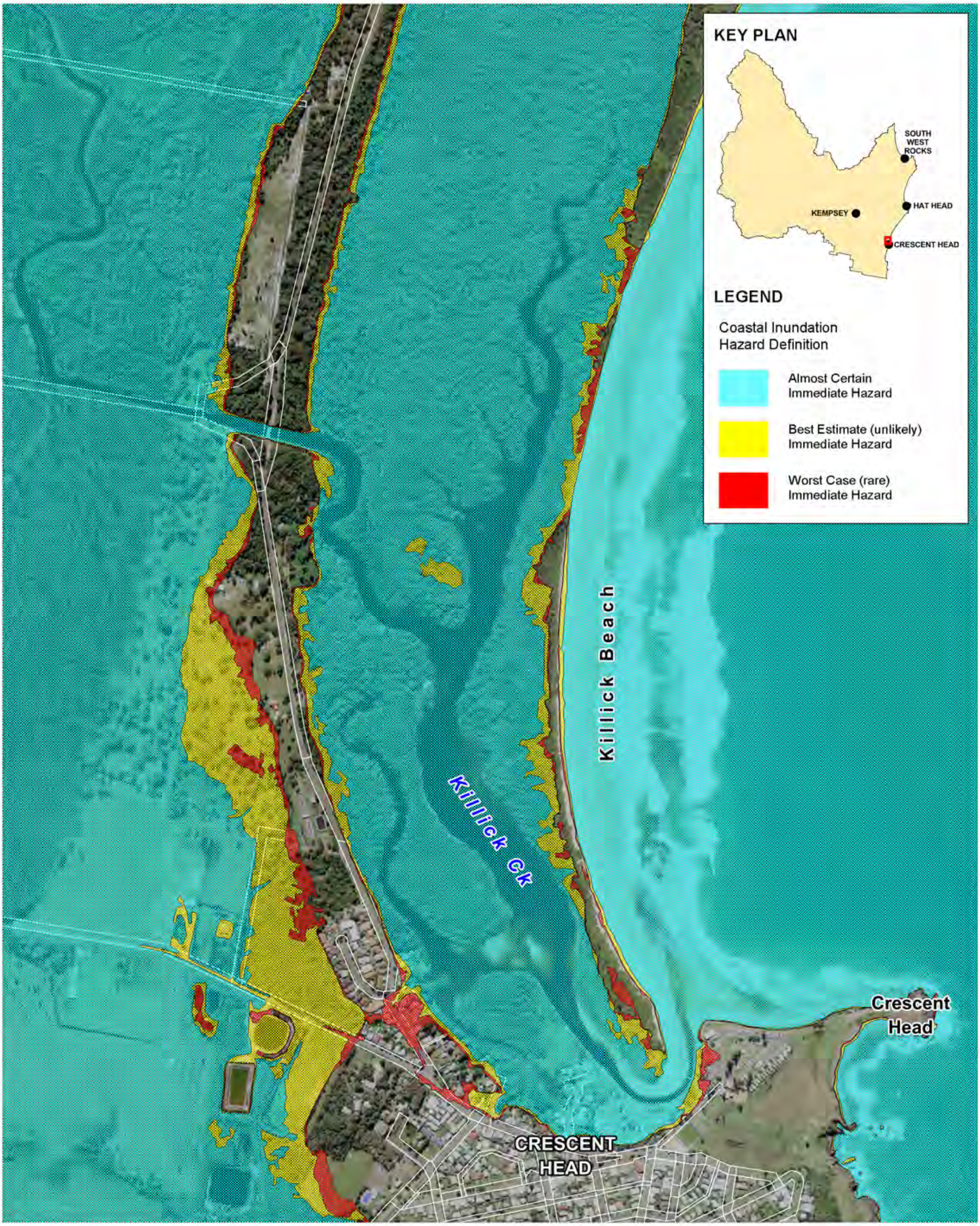
Filepath : K:\N2028_Kempsey_CoastalHazStudy\MapInfo\Workspaces\DRG_406_120912_Drawing_E-6.WOR



Title:

Coastal Inundation Hazard Definition
2050 Planning Horizon - Crescent Head

Figure: **E-7**

Rev: **A**

N

0 250 500m

Approx. Scale

BMT WBM

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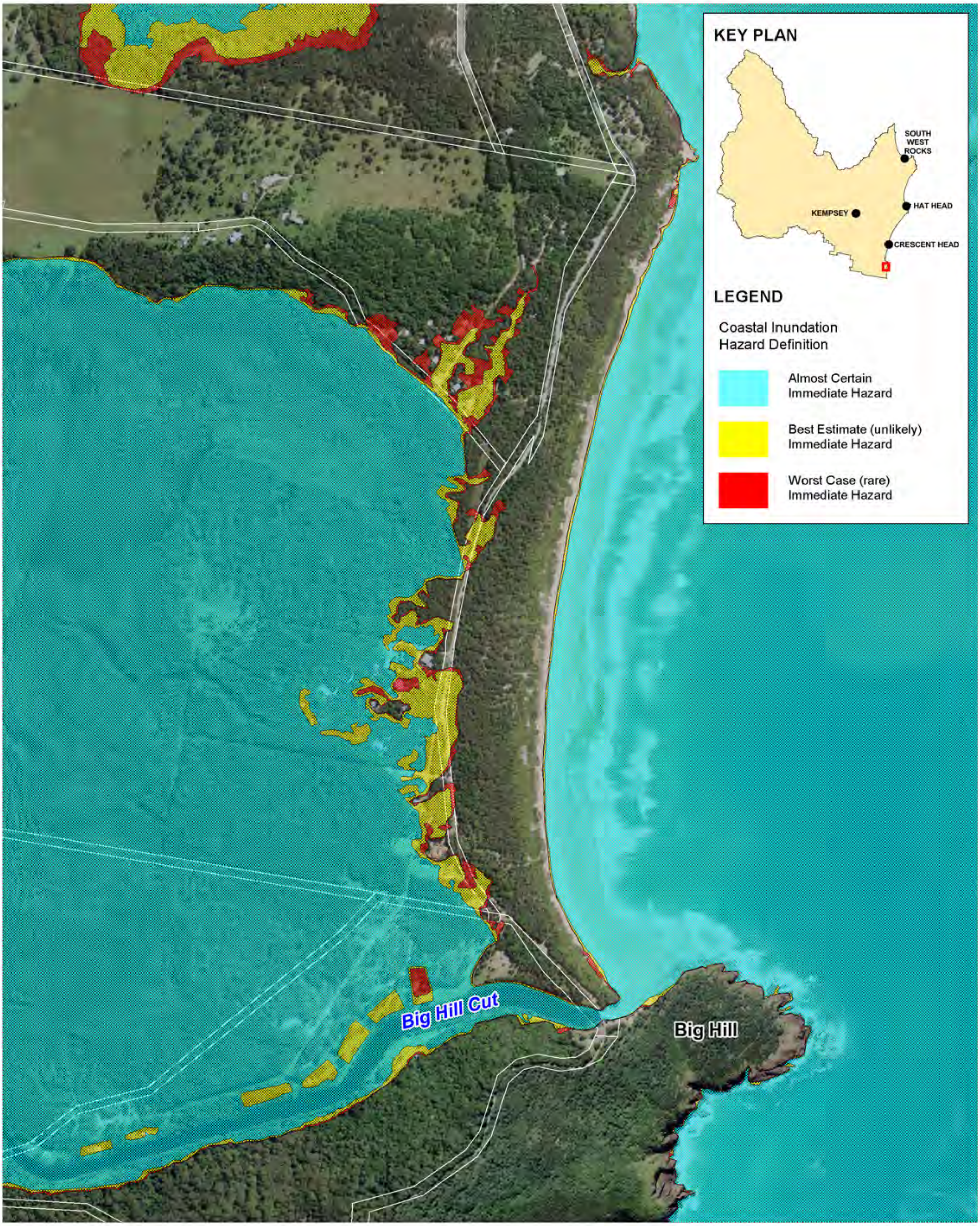
Filepath : K:\N2028_Kempsey_CoastalHazStudy\MapInfo\Workspaces\DRG_407_120912_Drawing_E-7.WOR



Title:

Coastal Inundation Hazard Definition
2050 Planning Horizon - Big Hill Cut

Figure: **E-8**

Rev: **A**

N

0 250 500m
Approx. Scale

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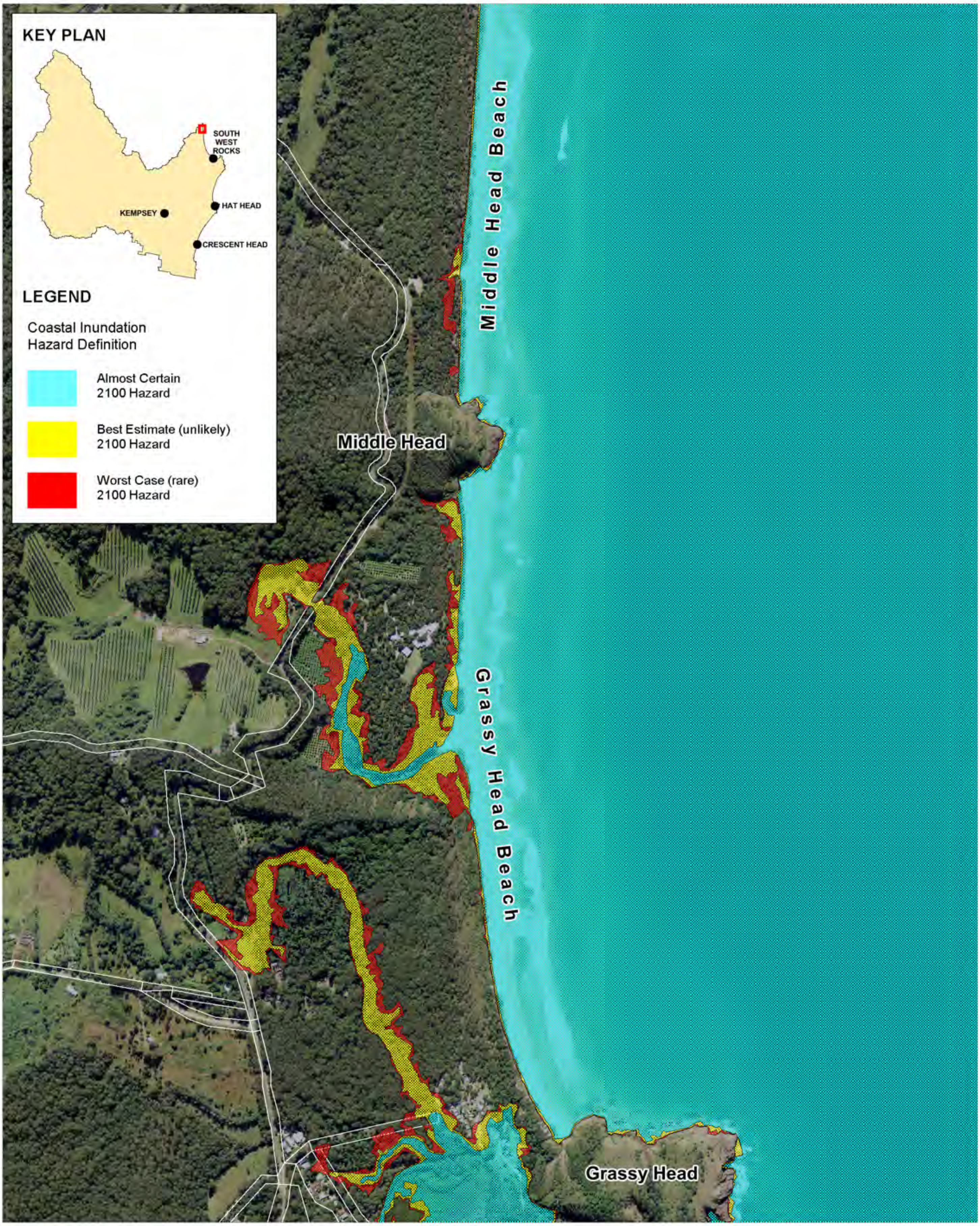
Filepath : K:\N2028_Kempsey_CoastalHazStudy\MapInfo\Workspaces\DRG_408_120912_Drawing_E-8.WOR



Title:

Coastal Inundation Hazard Definition 2100 Planning Horizon - Grassy Head Beach

Figure: **F-1**

Rev: **A**

N

0 250 500m

Approx. Scale

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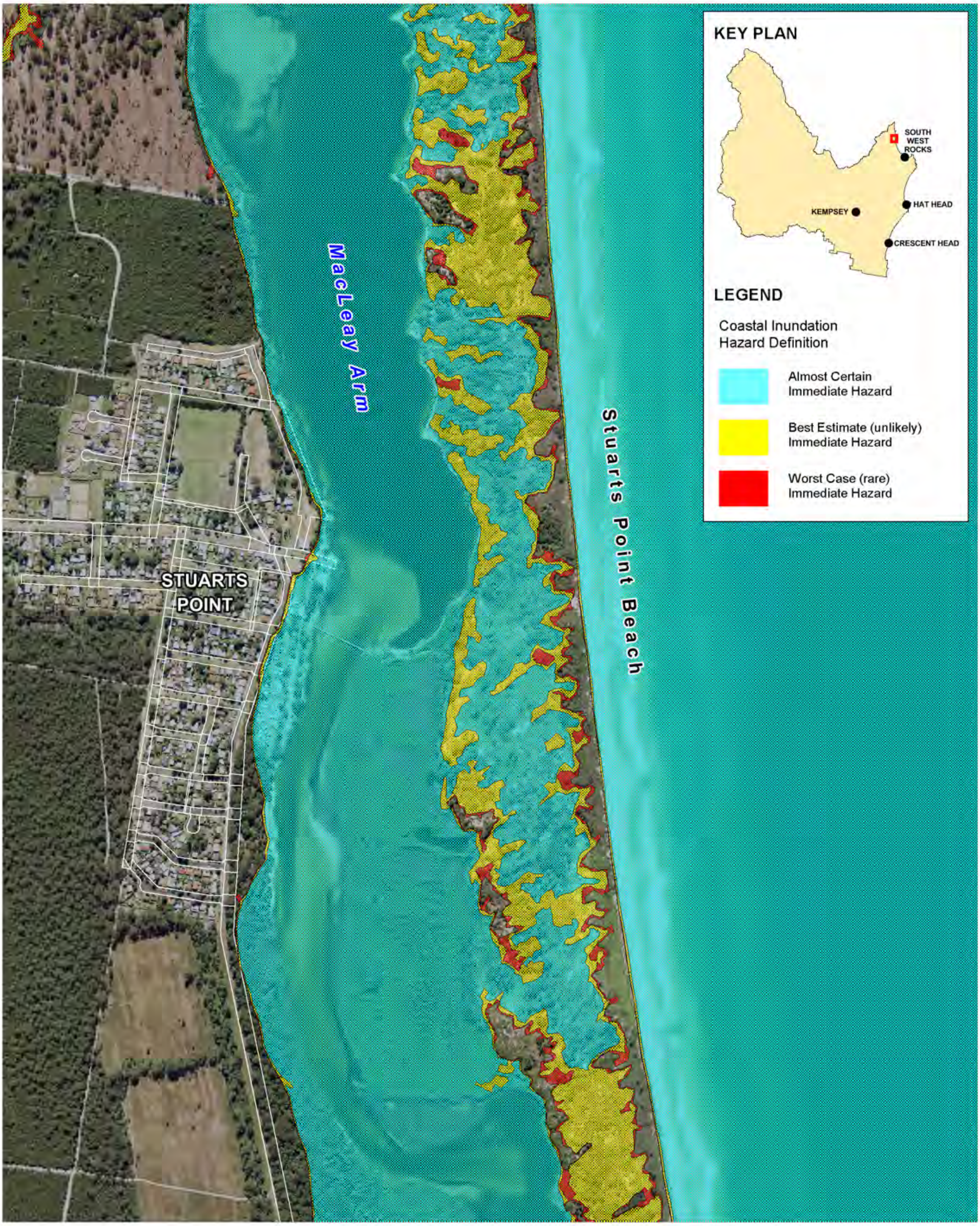
Filepath : K:\N2028_Kempsey_CoastalHazStudy\MapInfo\Workspaces\DRG_501_120912_Drawing_F-1.WOR



Title:

Coastal Inundation Hazard Definition
2100 Planning Horizon - Stuarts Point Beach

Figure: **F-2**

Rev: **A**

N

0 250 500m

Approx. Scale

BMT WBM

www.bmtwbm.com.au

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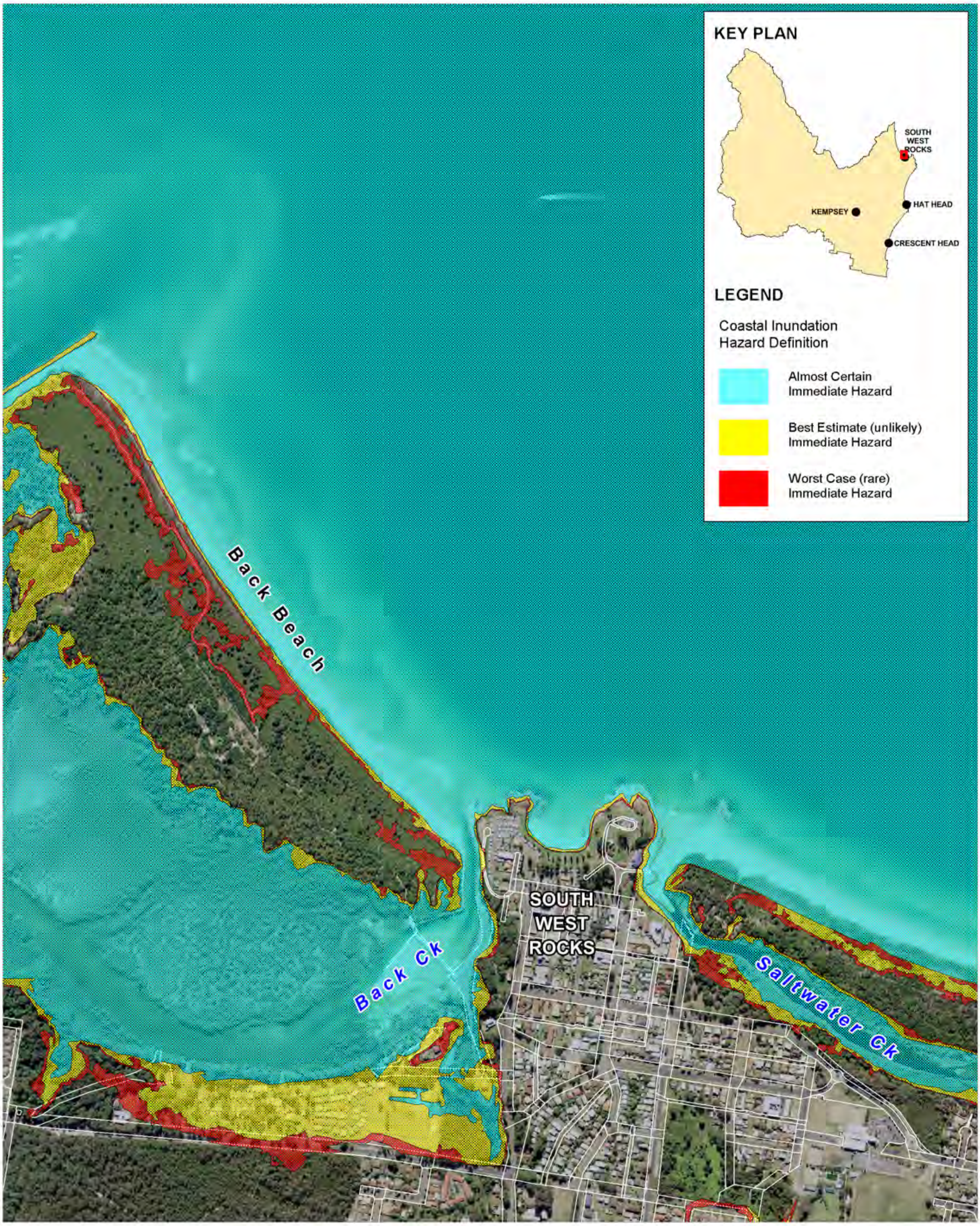

Title:

Coastal Inundation Hazard Definition
2100 Planning Horizon - South West Rocks

Figure: **F-3**

Rev: **A**

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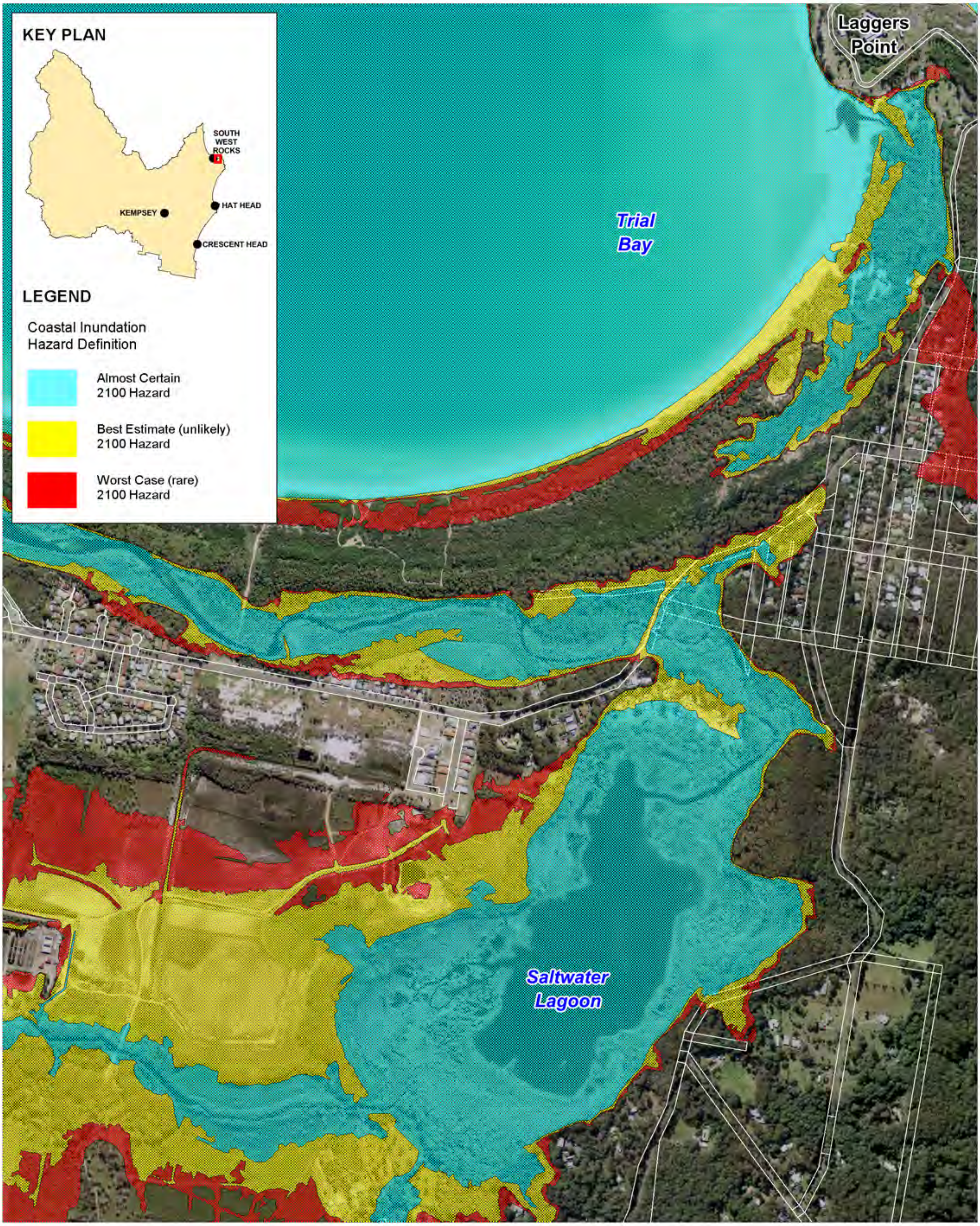


Title:

Coastal Inundation Hazard Definition
2100 Planning Horizon - Trial Bay

Figure: **F-4**

Rev: **A**

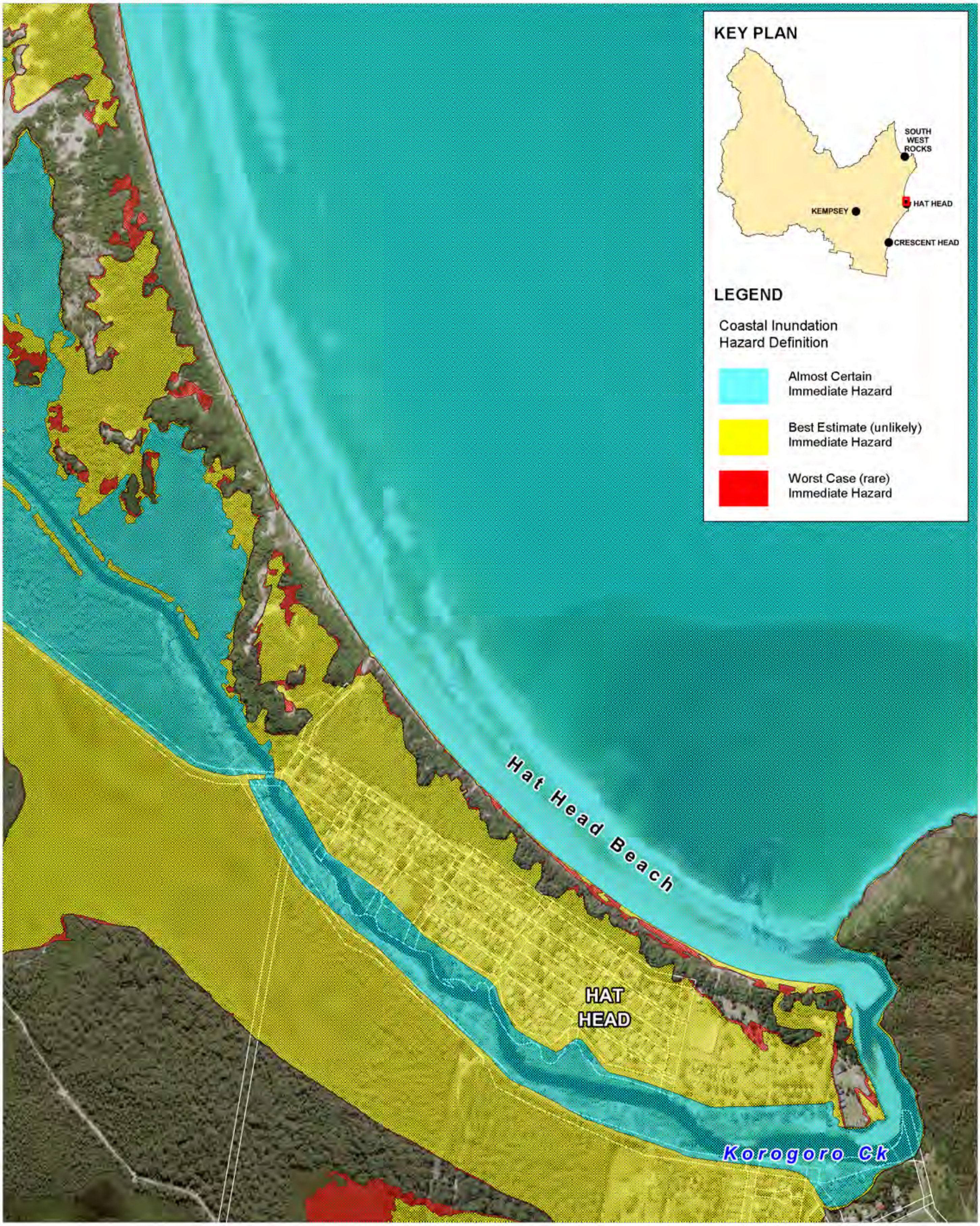
N

0 250 500m

Approx. Scale

BMT WBM
www.bmtwbm.com.au

Filepath : K:\N2028_Kempsey_CoastalHazStudy\MapInfo\Workspaces\DRG_504_120912_Drawing_F-4.WOR



Title:

Coastal Inundation Hazard Definition
2100 Planning Horizon - Hat Head

Figure: **F-5**

Rev: **A**

N

0 250 500m

Approx. Scale

BMT WBM

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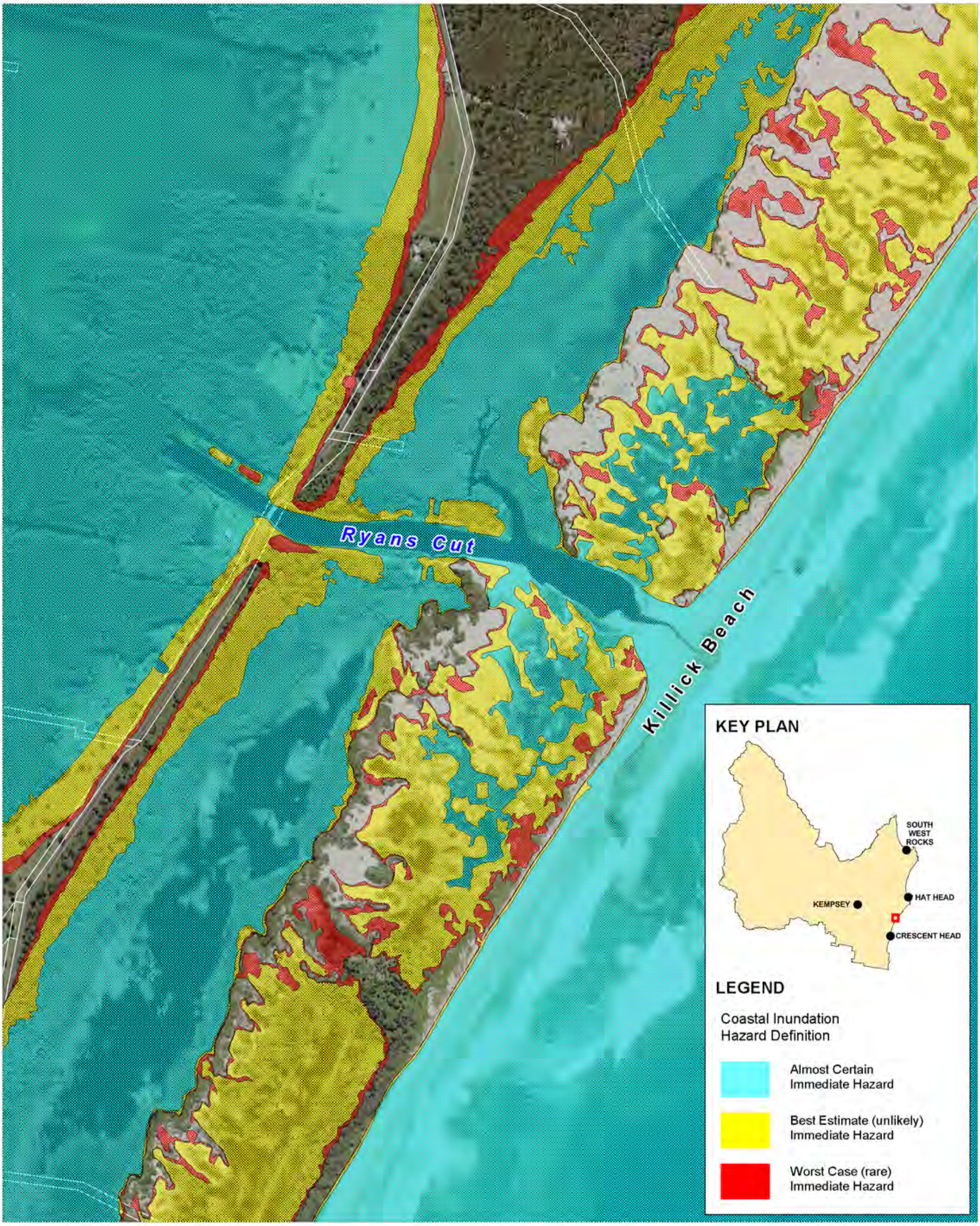
Filepath : K:\N2028_Kempsey_CoastalHazStudy\MapInfo\Workspaces\DRG_505_120912_Drawing_F-5.WOR



Title:
Coastal Inundation Hazard Definition
2100 Planning Horizon - Ryans Cut

Figure: **F-6**

Rev: **A**

N

0 250 500m
Approx. Scale

BMT WBM
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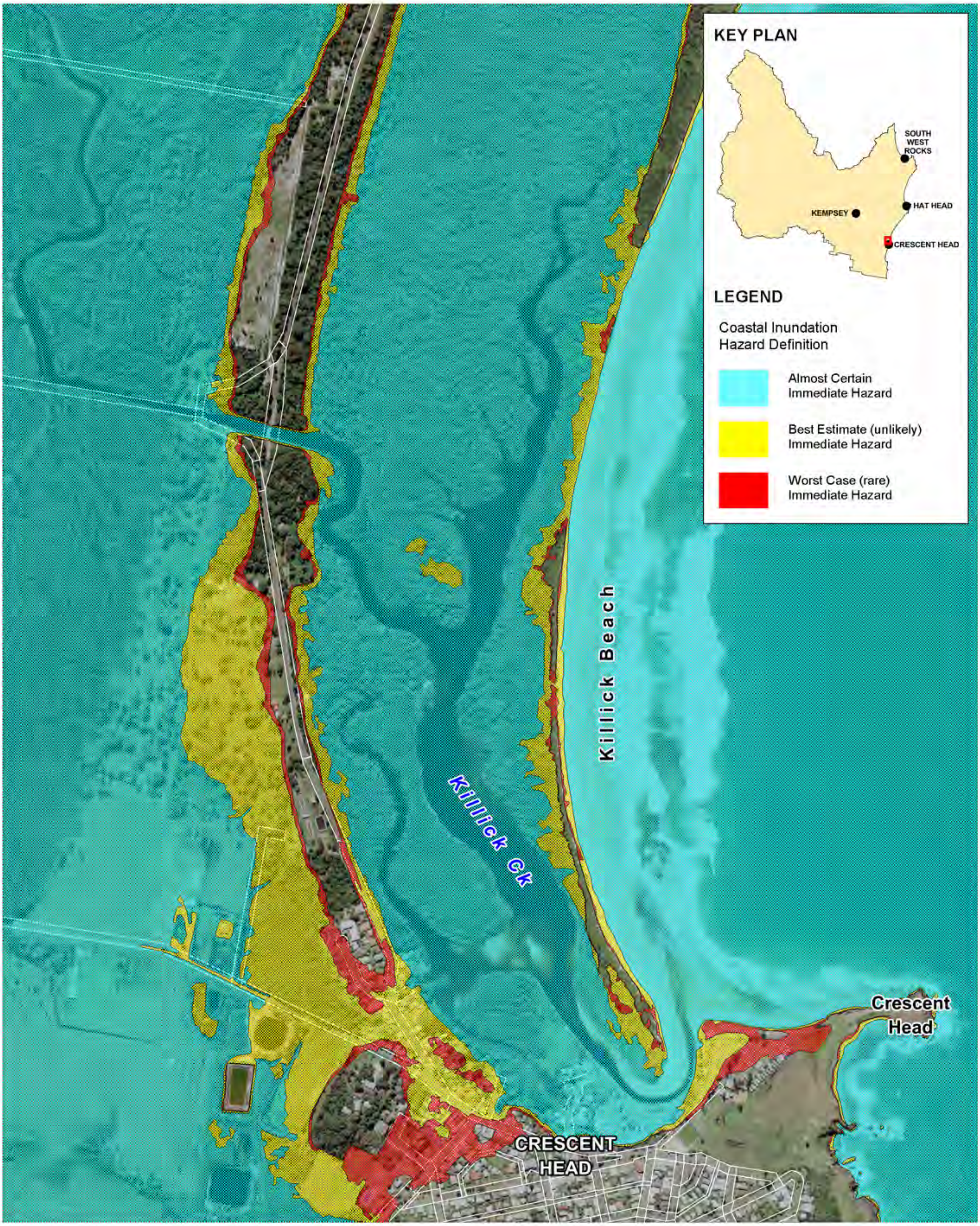
Filepath : K:\N2028_Kempsey_CoastalHazStudy\MapInfo\Workspaces\DRG_506_120912_Drawing_F-6.WOR



Title:

Coastal Inundation Hazard Definition
2100 Planning Horizon - Crescent Head

Figure: F-7

Rev: A

N

0 250 500m

Approx. Scale

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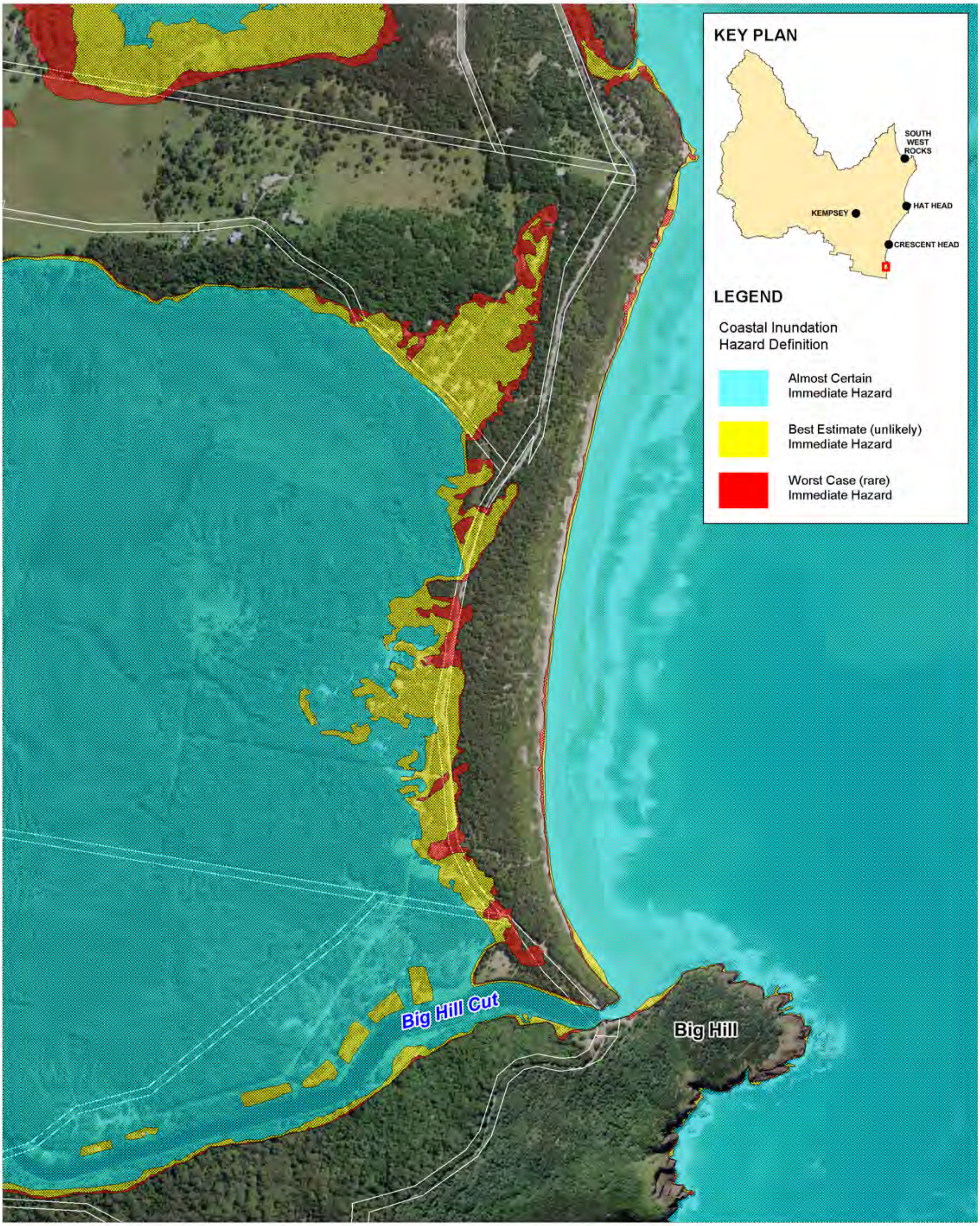
Filepath : K:\N2028_Kempsey_CoastalHazStudy\MapInfo\Workspaces\DRG_507_120912_Drawing_F-7.WOR



Title:

Coastal Inundation Hazard Definition
2100 Planning Horizon - Big Hill Cut

Figure: **F-8**

Rev: **A**

N

0 250 500m

Approx. Scale

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