Old Bar to Manning Point Coastal Erosion Hazard Mapping Update

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BMT Commercial Australia Pty Ltd
126 Belford Street
Broadmeadow NSW 2292
Australia
PO Box 266
Broadmeadow NSW 2292

Tel: +61 2 4940 8882
Fax: +61 2 4940 8887

ABN 54 010 830 421

www.bmt.org

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Project Manager:	Toby Devlin
Author:	Toby Devlin
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Executive Summary

The Old Bar Beach area, as well as much of the coastline north of Old Bar, has a history of erosion impacts. This report has been commissioned by Mid Coast Council for the purpose of updating the coastal erosion and recession hazard mapping, based on the updated information from a geotechnical field investigation recently conducted by BMT and implementing a contemporary, best-practice probabilistic modelling approach.

The study area spans the coastline from Wallabi Point in the south to Crowdy Head in the north, siting within a secondary sediment compartment extending between rocky headlands of Black Head in the south to Crowdy Head in the north. The study area encompasses two tidal entrances to the Manning River system (Farquhar Inlet and Harrington Inlet) and several important beaches, which are all largely sediment starved due to minimal volumes of sediment entering the sediment compartment annually. Key townships within the study area are the town of Old Bar, the town of Manning Point on Mitchell Island (between the two river entrances) and the town of Harrington behind the Harrington Inlet entrance.

The above mentioned geotechnical field investigation revealed several substrate materials throughout the study area, which are of relevance to the erosion hazards and can be categorised as:

- Erosion limiting substrate – bedrock landforms that resist all erosion;
- Erosion influencing substrate – bedrock landforms that influence adjacent erosion patterns, such as offshore rocks that shelter sections of the beach from wave impacts;
- Erosion resisting substrate – indurated sediments (e.g. coffee rock) that may provide partial resistance to short-term erosion, but will generally yield under long-term weathering, erosion and shoreline recession; and
- Erodible substrate – unconsolidated (generally sandy) sediments that are readily mobile and are easily eroded and transported.

It is considered critical that a review of the existing erosion and recession hazard mapping incorporates the effect of these categories to ensure the most useful outcomes in making future planning decisions. Therefore, Council commissioned BMT to revise the existing coastal erosion and shoreline recession hazard mapping to incorporate this new information. Further, since the NSW Coastal Management Manual (2018) encourages the use of probabilistic modelling approaches to incorporate a range of factors and parameter input values into recession calculations, an updated modelling tool was required. In view of this, the present study developed a simple probabilistic (*Monte-Carlo*) model based on the previous work by Kinsela *et al* (2017) and considering inputs from the existing literature and best-practice. In order to confirm the most applicable sources of these inputs, an expert modelling workshop was convened with members of BMT, Mid Coast Council and the Department of Planning, Industry and Environment (DPIE). In this workshop, a gap was identified in the understanding of the net sediment budget of the study area; subsequently, an analysis of the existing photogrammetry and LiDAR along the coastal foredunes was conducted by Council, with the outputs incorporated in the probabilistic model developed.

The probabilistic model developed was then used to run 1 million different simulations for a series of cross-beach profiles at 5 m spacings along the study shoreline. Each of these simulations randomly selected a set of input parameters from the probability distributions to predict setback distance, due to erosion and shoreline recession hazards. This approach (running 1 million simulations) was applied to predict setback for three timeframes:

(1) Present Day, incorporating only the effect from storm erosion.

(2) 2060, incorporating 40-years of ongoing sea level rise and sediment budget changes, as well as storm erosion effect in the final year; and

(3) 2100, incorporating 80-years of ongoing sea level rise and sediment budget changes, as well as storm erosion effect in the final year.

After discussions with Council three exceedance levels, i.e. degrees of risk (50%, 10% and 1%) were selected and used to interrogate the probabilistic modelling results of setback distance. This allowed mapping the hazard line associated with those defined degrees of risk predicted for the slumped Zone of Slope Adjustment (ZSA) and Zone of Reduced Foundation Capacity (ZRFC) metrics, for each timeframe. A mapping compendium of these hazard lines was then produced and accompanies this report.

During the modelling study several areas were identified close to the entrances of the Manning River estuary where erosion and coastal processes are highly complex and interact strongly with the changing river, or with construction features. As such, wherever these limitations occurred, the hazard mapping has been overlayed in the mapping as ‘Area of Hazard Uncertainty’. These uncertainty areas represent sections of shoreline prone to significant coastal erosion and recession hazards, but where these hazards cannot be meaningfully quantified.

The collaborative development of the probabilistic model for prediction of coastal erosion and recession hazards and the output mapping are of great value to making strategic planning decisions for the study area. The model quantified and allowed mapping the uncertainty of these hazards, providing a more detailed insight into the risk of a given level of hazard, which can inform a risk-based approach to coastal management. Finally, the incorporation of geotechnical observations into the methodology has added a new dimension to assessing erosion and recession hazards, which provides a more realistic and useful set of hazard predictions, particularly in areas with significant bedrock and therefore limited recession risk.

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Glossary

Accretion – the build-up of sedmients, either to form shoals or increase in bed level, or to extend a beach or dune seaward.

Aleatory (uncertainty) – refers to uncertainty that is inherent to the process and can be defined by probabilistic distributions or quantities. For example, rolling a die has an aleatory uncertainty in that no single result is guaranteed, however the expected likelihood of results can be well-quantified.

Alongshore (Longshore) – parallel to the shoreline.

Beach Profile – A cross-section taken across the beach from the dune into the ocean in the nearshore zone.

Bedrock – a general term for rock underlying soil or sand.

Berm – A protruding horizontal sandform on the beach caused by wave action depositing sand.

Breaker zone – the nearshore area in which waves begin breaking.

Bruun Rule – A methodology for estimating coastal recession due to changes in sea level.

Closure depth – a depth beyond which changes in the seabed are not thought to occur.

Coastal Hazard – potential threats to assets defined under the Coastal Management Act (NSW, 2016) that encompasses: (1) beach erosion, (2) shoreline recession, (3) watercourse entrance instability, (4) coastal inundation, (5) cliff instability, (6) tidal inundation and (7) hazards due to the interaction of coastal processes and catchment floodwaters.

Coastal Management Plan (CMP) – as detailed in the Coastal Management Act (NSW, 2016) a strategy for managing land and assets within the coastal zone.

Dune – shore-parallel sandforms that typically lie at the back of beaches. Formed by beach sand being blown landward and interact with the sand on the beach.

Epistemic (uncertainty) – refers to uncertainty due to a lack of understanding or potential error in the inputs to a process. For example, in a coastal management context, sea level rise in 2100 will be a fixed number, however as it relies on many assumptions about ongoing oceanic/atmospheric processes and potential emissions, it cannot be accurately predicted. Therefore, a range of potential scenarios and outcomes is used to attempt to quantify its *epistemic* uncertainty.

Foredune – Larger and more established dune systems that are often eroded under heavy storm activity (forming a dune scarp). Foredune sediments interact with the beach under erosion/recession processes.

Intermittently closed and open lakes and lagoons (ICOLL) – Coastal lakes and lagoons that are open to the sea from time to time, but also experience closure when sediments infill their entrances.

Littoral – pertaining to the shore. i.e. littoral sediment transport is sediment transport occurring in or adjacent to intertidal areas.

Overwash – the effect of waves overtopping a beach berm and flowing into areas behind it. Typically, overwash might occur over a coastal barrier into the estuary behind it.

Probabilistic model – a mathematical tool for assessing a range of variables and outcomes based on their predicted probability of occurring.

Progradation – a movement (of a dune for example) towards the sea.

Recession – a movement (of the shoreline for example) landward. Typically used to refer to ongoing landward movement of the shoreline under a rising sea level or due to a net sediment deficit in the sediment sub-compartment.

Sediment Compartment – a section of the coast defined by similar sediment transport features. Often broken down into primary, secondary and tertiary sediment compartments, that relate to increasingly specific and local sediment transport processes. Usually constrained at each end by significant landforms such as headlands, islands, etc.

1 Introduction and Background

1.1 Background to this Study

This report has been commissioned by Mid Coast Council (Council) for the purpose of modelling, assessing and updated mapping of coastal erosion and recession hazards along the Old Bar to Manning Point coastline.

The Old Bar Beach area has history of severe erosion impacts that have been assessed in many coastal studies. Previous reports have identified the potential for variable geological conditions to influence future erosion potential around the Old Bar township. A geotechnical field investigation and coastal geomorphology report recently completed by BMT (2019) has identified geological controls that will influence future shoreline behaviour. This mapping study incorporates this new information into an innovative probabilistic modelling approach for coastal erosion and recession hazard assessment.

The results of this assessment are presented as a series of coastline hazard maps detailing erosion hazard setback zones for various probabilities. Erosion hazards have been forecast for current and future timeframes.

This modelling and mapping assessment has been prepared as a technical study for a Stage 2 of a Coastal Management Program (CMP) for the Old Bar to Manning Point Coastline. The hazard maps produced through this study will inform and guide subsequent coastal risk planning and more broadly: coastal management initiatives that will take place as part of the CMP.

1.2 Study Area Shoreline

The Old Bar study area is located on the NSW Mid North Coast near to Taree, around 130 kilometres north of Newcastle. The study coastline spans 25 kilometres north of Wallabi Point to Crowdy Head, which includes sandy beach and dune systems, two tidal entrances to the Manning River system (Farquhar Inlet and Harrington Inlet) and areas of nearshore and offshore rocky reef (e.g. Urana Bombora). The residential townships of Old Bar and Manning Point are located behind the study coastline (localities are shown in Figure 2-1). Section 2.2 characterises the study coastline further.

Sources:
Cadastral Data: Spatial Services - Department of Finance, Services and Innovation, NSW
Aerial Imagery by nearmap - 21/07/2019

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Study Area and Localities

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1.3 Aims, Objectives and Scope

The primary objective of this study is to identify and assess areas that may be subject to coastal erosion and recession hazards under current and future timeframes to support the preparation of a CMP. The study has the following specific aims:

- Model erosion and recession hazards within a sediment compartment framework, accounting for local coastal processes, shoreline behaviour, sediment movements, geology and climate change (particularly sea level rise);
- Determine the potential coastal hazard areas for a range of timeframes and probabilities;
- Incorporate within the probabilistic modelling approach the varied geomorphology conditions identified in the preceding field based coastal geomorphology investigation (BMT, 2019); and
- Document the modelling approach, assessment and mapping outcomes in a technical report and set of coastal hazard maps.

To achieve the above-mentioned objective, BMT was engaged by Council to re-map coastal erosion and recession hazards for the study areas based on existing coastal processes and sediment budget information, and the new field geotechnical information compiled through the recently completed coastal geomorphology study (BMT, 2019).

The coastal hazard modelling and assessment undertaken for this study was therefore limited to using the below information only:

- Previous work on broad-scale probabilistic erosion hazard modelling by Kinsela *et al* (2017).
- Topographic LiDAR, Marine LiDAR and other bathymetric survey data provided by Council.
- Geotechnical field investigations conducted by BMT (2019); and
- Photogrammetric analysis conducted for this study at Council (by Dr Thomas Doyle, following Doyle *et al* (2019)).

1.4 About this Report

The document is set out in the following sections:

Chapter 2	Outlines the physical characteristics of the study areas and region more broadly.
Chapter 3	Provides an overview of the adopted modelling approach.
Chapter 4	Documents the model development and inputs.
Chapter 5	Summarises the coastal hazard modelling and assessment results.
Chapter 6	Provides conclusions, limitations and recommendations
References	Contains the list of references cited in this study.
Appendix A	Documents the photogrammetry assessment of beach change.
Appendix B	Presents the coastal erosion hazard mapping compendium.
Appendix C	Contains the expert panel modelling workshop minutes.

2 Coastal Geomorphology and Processes

2.1 Introduction

An understanding of the critical influences on erosion in the study area and broader region is fundamental to the development of this coastal hazard mapping study. This chapter details the understanding of the important delineations and processes within the study area, as well as the relevant outcomes of the preceding geotechnical field investigation conducted by BMT (2019).

2.2 Sediment Compartment Framework

The Coastal Management Manual (NSW, 2018) recommends the use of sediment compartments as a framework for considering coastal processes to analyse coastal hazards. Sediment compartments are defined as an area of coast that behaves in a broadly homogenous way with respect to sediment transport processes, sources and sinks (Thom *et al.*, 2018).

The study area, extending from Wallabi Point to Crowdy Head, sits within a primary sediment compartment that extends from Laggers Point in the north to Cape Hawke at Forster in the south (CoastAdapt, 2016). This area experiences primarily northward sediment transport in line with the predominant south-easterly wave direction. The compartment is exposed to storms, including east coast lows (extra-tropical cyclones) as well as climate variations due to the El Niño Southern Oscillation (ENSO).

The study area is also encompassed within a secondary sediment compartment extending from Crowdy Head in the north to Black Head in the south, which are the major rocky headlands either side of the study area. These points control the movement of sediments, with only minor net sediment transport into the compartment from around Black Head (CoastAdapt, 2016). The sediments are largely composed of sands (Terrigenous Quartz), with some rocky outcrops offshore and in minor headlands. A major feature within this secondary compartment is the Manning River, which has two entrances in its delta – Farquhar Inlet in the south (where the Old Bar township sits) and Harrington Inlet in the north. Between these entrances is Mitchell Island, a largely low-lying and receding Holocene Barrier that includes the town of Manning Point.

There are six key tertiary compartments within the study area. These are coastline sections on the scale of individual beach systems, each one affected by a set of coastal processes. The tertiary sub-compartments are:

(1) Old Bar Beach: which has historically experienced heavy erosion and progressive recession, with limited inflow of sediment from the south.

(2) Urana Bombora: which experiences erosion and recession in line with Old Bar Beach, but at a reduced rate.

(3) Farquhar Inlet: an area that often intercepts longshore sediment transport leading to accretion of the bar and infilling of the mouth (giving the town of Old Bar its name). However, it does experience some erosion events, as well as riverine floods causing breakthroughs and historically has had instances of mechanical opening of the mouth.

(4) Mitchell Island to Manning Point: a Holocene Barrier that is low-lying and experiences steady recession.

(5) Harrington Entrance: the northern mouth of the Manning River, with significant seawalls controlling the hydraulics inside the mouth and in turn the sediment movement. The entrance shoals at times, but there is limited information about the volume of sediment movement historically.

(6) Harrington Beach: a beach system that is constrained by Crowdy Head at the north and an extension of the Harrington seawall in the south. It has been suggested that the seawall appears to limit southward longshore transport and the beach system is accreting steadily.

2.3 Erosion Processes

The key processes that influence erosion and shoreline recession can be divided into two major categories:

(1) *Fluctuating erosion,* which includes the short to medium term erosion that is in a dynamic equilibrium between an eroded state, and a state of progressive recovery (intermittent accretion). This component is largely due to the so called ‘storm bite’, where large wind, wave and surge events move shoreline sediments further offshore into bar systems that are gradually redeposited on the beach during relatively milder periods.

(2) *Cumulative erosion*, which encompasses those factors that act over a longer-term (resulting in shoreline recession), made up of two main contributions:

    (a) Net imbalances in the natural sediment budget; and

    (b) The recession effects associated with the adjusted equilibrium beach profile under higher mean-sea-levels (sea level rise).

While the fluctuating erosion and the recession effects of sea level rise can be relatively easily isolated from other influences, the net sediment budget effects are caused by long-term changes in the natural conditions. In the context of the study coastline, many of the following influences are suspected:

- The natural longshore sediment transport may fluctuate over a multi-decadal period, with insufficient data and understanding of these processes to date to accurately quantify.
- The estuarine delta entrances may intercept sediments, but equally catchment flood events may be a source of sediments over short time scales.
- Dredging at Harrington may have created a sediment sink that intercepts sediment transport.
- Human-made structures (such as seawalls, breakwaters and groynes) provide a barrier or limit to natural fluctuations that may interfere with dynamically balanced sediment transport. Specifically, the breakwater at Harrington limits southward transport of sediment at this location.
- Long-term changes in wind-wave patterns and directions (due to climate change) may alter longshore transport in and out of the sediment compartment and may result in realignments at the beach-scale; both of which could result in either erosion or accretion.

Due to much of the uncertainty and difficulty in studying any of these components individually, the net changes in historic sediment budget have been assessed at Mid-Coast Council (by Dr Thomas Doyle) via a photogrammetry analysis. This approach relies on past data, which are not guaranteed to be representative of future effects. However, as the future influences of the cumulative processes are unknown, it has been considered the best assumption that can be made for this study. Details of the photogrammetry analysis are provided in Appendix A.

2.4 Geological Factors Influencing Erosion Potential

Geological features form natural controls on the erosion potential of coastal systems. Chiefly, changes in the sediment characteristics spatially and with depth can alter the ability of these areas to erode and can provide sheltering of adjacent regions.

The Old Bar to Manning Point Coastal Geomorphological Field Study conducted by BMT (2019) investigated each tertiary sub-compartment based on its geological influences on erosion potential. It analysed the sub-compartments in terms of the following:

- Erosion limiting bedrock – bedrock landforms that limit the extent of recession.
- Erosion influencing bedrock – bedrock landforms that affect erosion in adjacent beach areas.
- Erosion resistant sediments – indurated sediments that may be partially resistant to erosion.
- Erodible substrates – sediments that are generally unconsolidated and erodible.

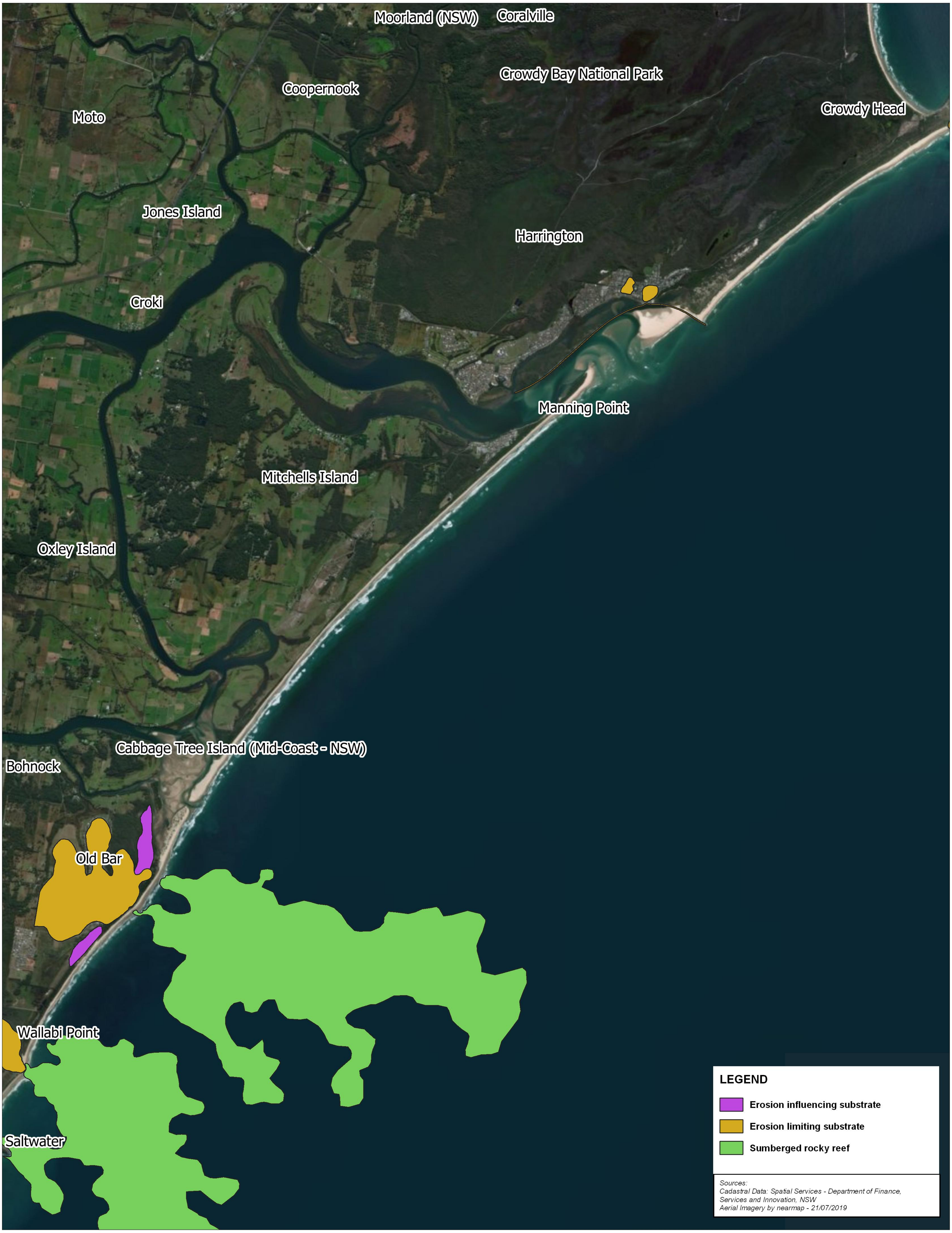
A map of the identified geological influences is shown in Figure **2**-**1**.

Along the study shoreline, there are several areas of rocky reef systems, such as the well-known underwater feature Urana Bombora. Bomboras that comprise of bedrock are often hazardous features to navigation but are also capable of sheltering adjacent beach areas by reducing the incoming wave energy, and thus, reducing erosion potential. The Urana Bombora may shelter parts of the beach in its immediate lee, however this erosion protection effect is relatively localised and dependent on the incident wave direction.

Rocky headlands provide a natural control to erosion and longshore sediment transport movements by resisting erosion. Because of this, significant rocky headlands often form the boundaries of sediment compartments. Within the study coastline, Black Head in the south and Crowdy Head in the north are they key headlands and are the extremes of the (secondary) sediment compartment of relevance.

Indurated sands are known to occur within the study locality (BMT, 2019). These compacted sandstone rocky materials are thought to be resistant to many short-term (fluctuating) erosive effects, such as those caused by storm events. However, in the longer-term (cumulative erosion) it is likely that such features will eventually weather and recede. A geotechnical assessment by Regional Geotechnical Solutions at Lake Cathie (2019) showed that the strength of the indurated sediments reduced rapidly upon simulated weathering of the materials. This process may take longer than for typical beach sands, but the exact delay in effect is unknown and in the context of cumulative erosive effects (long-term recession) it can be considered similar to sandy substrate.

While not natural geological features, there are several seawalls within the study area that will also form key controls on the erosive behaviour. In this study, it has been assumed that Harrington Seawall provides a boundary to erosive effects. While significant long-term erosion may undermine the structural integrity, the processes of this and potential responses are considered too fine-scaled for the purpose of this coastal hazard mapping study.



Sources:
Cadastral Data: Spatial Services - Department of Finance, Services and Innovation, NSW
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Identified Geological Constraints and Localities

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3 Erosion Hazard Assessment

3.1 Erosion Hazard Modelling Assessment Approach

Broadly speaking, there are two different modelling approaches that can be applied to estimating erosion hazards. These include *deterministic* and *probabilistic* modelling approaches. Put simply:

- *Deterministic* methods apply single value variables to calculate a single erosion setback distance or storm bite volume that represents, for example, a 1 in 100-year storm event. The determination of suitable 'single value' inputs to these models requires either a high degree of certainty about those processes, or a high degree of conservativism to not under-estimate the potential erosion hazard impacts. It also does not provide any context or acknowledgement of the considerable levels of uncertainty that can be associated with one or many of the input variables, which is generally considered a limitation, particularly when assessing long-term impacts.
- *Probabilistic* methods provide a more inclusive approach to estimating erosion hazards that can overcome and incorporate the inherent uncertainty in understanding the influence of coastal processes, sediment movements and varied geotechnical conditions on erosion potential. Probabilistic methods use a range (or distribution) of values for each input parameter to be assigned. Consequently, a range (probability distribution) of outputs are derived, allowing development of an understanding of the uncertainty in different areas, to select a single appropriate measure of conservativism as desired or conversely, to determine the probability of a given hazard. This has the benefit of managing the uncertainty that is inherent to forecasting beach and shoreline behaviour and the influence of potential climate change and sea level rise scenarios on future shoreline changes.

In the NSW coastal management context, coastal erosion and recession hazards (coastline hazards) have been traditionally estimated using deterministic, 'standard', approaches (e.g. Bruun rule of coastline retreat due to sea level rise (Bruun, 1962)). However, such approaches have inherent limitations on the consideration of the natural complexity of many beach systems and the uncertainty associated with coastal processes and beach behaviour. The limitations of 'standard' coastal erosion hazard estimation methods have become increasingly recognised within the industry (e.g. Kinsela and Hanslow, 2013). As such, more sophisticated modelling approaches that can reflect the geomorphic variability of a sediment compartment is now the preferred approach of the NSW Government in locations where erosion risks are significant:

> *In situations where essential infrastructure, or very strategic or high-value assets may be exposed to coastal hazards, it is important to consider the probability of extremely rare scenarios, as well as uncertainty in coastal forcing, processes and response (NSW Coastal Management Manual; OEH, 2018).*

The coastal townships at Old Bar and Manning Point fit the above situation. As such, a probabilistic approach to modelling erosion hazards has been adopted as the preferred methodology to forecast coastline hazards across the study area. The range (distribution) of results predicted by the model is a useful predictor of the sensitivity of a particular section of coastline to recession effects, and the appropriate level of conservativism can be selected from this final distribution.

3.2 Calculating Shoreline Change (Hazard Setback Lines)

The shoreline change (setback) due to a derived future erosion volume needs to be calculated based on the profile of the dune topography. The typical approach is to calculate the base setback as the ‘Zone of Wave Impact’ (ZWI), which corresponds to the minimum setback distance that contains the erosion volume above mean-sea-level. This results in a vertical dune slope that is simplified and unstable for sand materials. When considering the slumped behaviour of sand, two further setback distances are provided as defined in Nielsen *et al* (1992) and illustrated in Figure 3-1:

Zone of Slope Adjustment

The ‘Zone of Slope Adjustment’ (ZSA) allows for the natural slumping that occurs in loosely consolidated sands in the subaerial eroded beach profile. The dune is assumed to slump at the angle of repose for the dune height above the swash zone. This study has adopted the common values of 34° as the angle of repose and RL 2m as the top of the swash zone.

Zone of Reduced Foundation Capacity

The ‘Zone of Reduced Foundation Capacity’ (ZRFC) is an area behind the slumped dune profile where the bearing capacity (capacity to support building foundations) is reduced. It is calculated based on a ‘safe angle of repose’ for the sand materials, which is given to be that with a safety factor of 1.5 on the slope of the slumped profile, down to a scour level of RL -1.0m:

$$\emptyset_{cv} = \tan^{-1}(\frac{\tan \emptyset}{1.5}) \approx 24°$$

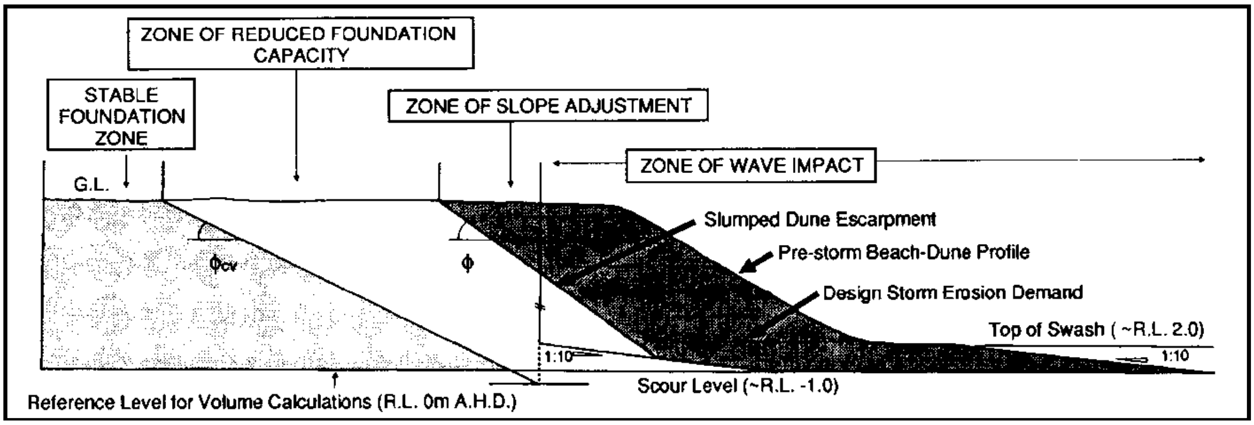


Figure 3-1 Zones of Instability after Erosion (from Nielsen *et al* (1992))

Bedrock Slumping Allowance

Where bedrock has been found to be present and is at least above the mean water level, the Zone of Wave Impact (basic 'box cut' setback) is limited to the bedrock. Allowances have been made for a Zone of Slope Adjustment and a Zone of Reduced Foundation capacity, by applying their respective angles of repose above the bedrock level. An example of this is shown in Figure 3-2.

It is assumed that the loose materials above the bedrock might slump above bedrock at these angles. Assumptions of the depth of bedrock have been applied conservatively, with the initial depths based on findings from the ground penetrating radar and borehole logs in the Geotechnical Study presented in Appendix I. These depths have then been limited to be at least 4m below the ground level at that location for conservativism. With an angle of repose of 24° (as in the case for ZRFC) a 1m change in the bedrock depth will result in an additional setback of 2.25m (for 1m deeper bedrock depth) or 2.25m less setback (for a 1m shallower bedrock depth).

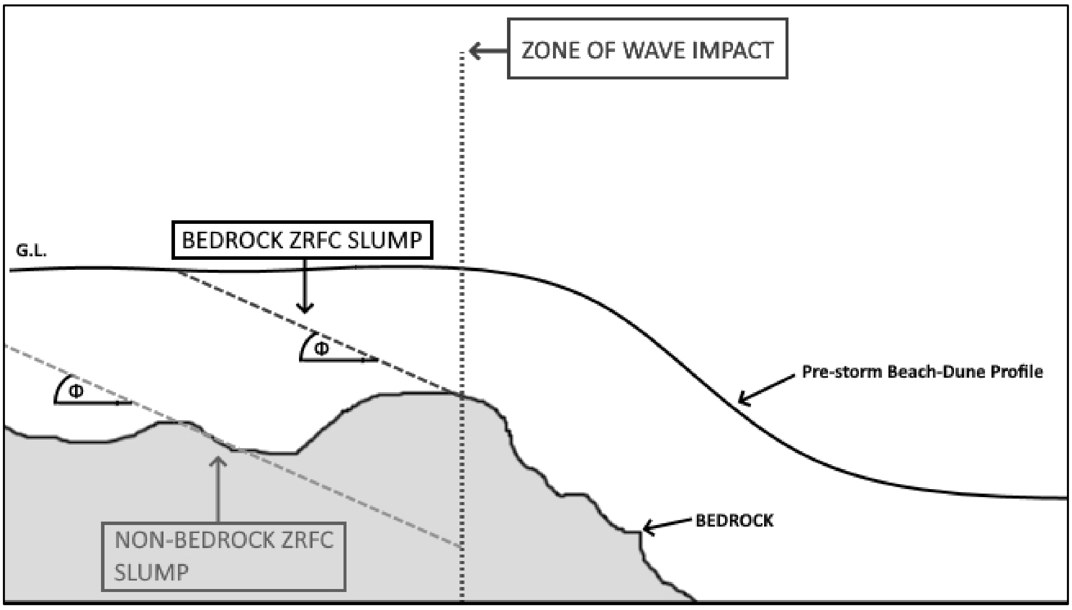


Figure 3-2 Zone of Reduced Foundation Capacity Above Bedrock

4 Probabilistic Model Development

4.1 Monte Carlo Probabilistic Model

A traditional erosion/recession assessment approach involves selecting a single value for each input parameter (such as sea-level rise, net-sediment budget, or storm demand) and applying these to simple formulations to calculate the setback distance. This approach is inflexible in that it relies solely on the selection of these input parameters and does not provide any understanding of the uncertainty associated with them.

To alleviate this limitation, a probabilistic (stochastic) model of the coastal erosion and recession hazard potential of the Old Bar to Manning shoreline has been developed following what is commonly referred to as a *Monte Carlo* approach. A Monte Carlo model uses a distribution (range of values) for each parameter, based on the natural variability of the parameter (known as aleatory variability), or a range of uncertainty based on the understanding of that parameter (known as epistemic uncertainty). Instead of a single set of values being selected, many simulations are modelled, each with its own set of inputs randomly sampled from the distributions. When these are applied to the setback formulations, a series of setback outputs is generated. These outputs form a probability distribution of erosion/recession hazard that can be interrogated to inform decision making.

The formulations used to derive the erosion volume and then to relate that to an associated setback follow Kinsela, *et al* (2017). This uses a modified Bruun rule to calculate shoreface accommodation to sea level rise, but also incorporates net sediment transport, estuarine delta accommodation and storm demand as separate volumetric sink/source terms. The volume is applied to a simple encroachment model using the geometry of the existing dune. Such formulations are simple, but are considered appropriate given the number of scenarios required to capture the ranges and uncertainty in the input parameter sets. It is also not clear that more ‘advanced’ numerical sediment transport models would provide any improvement over this approach as they carry the same inherent uncertainties in the inputs. Further details of the adopted modelling approach are provided in this chapter.

For this study, the set of input distributions was developed based on an expert model development workshop, the minutes for which are presented in Appendix H. Each distribution has been sampled one-million times (1,000,000) to prepare the range of outputs that have been interpreted based on the percentage of simulations that exceed their magnitude (as exceedance probabilities). The model has been developed in the MATLAB programming platform (MATLAB, ver. R2019b), which provides a random number generator (RNG) to rapidly select parameters and calculate the associated setback.

The number of simulations was validated by rerunning the model several times (iterations) to ensure that the results had converged (i.e. insignificant variation occurred in the target exceedances between these iterations).

4.1.1 Input Distributions

The modelling approach requires that every input parameter be described as a probability distribution that captures the variability and uncertainty of the parameter. The distribution types (Figure 4-1) represent the collective understanding about a parameter's likely range of values, with an appropriate degree of complexity. Naturally variable but well understood inputs are represented by 'complex' statistical distributions (such as normal distributions or gaussian curves) based on a detailed research. Less well understood parameters use simplistic distributions (such as the triangular distribution) that are suitable for representing an approximate range of probable values (upper and lower bounds), centred around a 'best guess' modal value. The bounds of these simplistic distributions are designed to capture a range of observed or potential values with an appropriate level of conservativism.

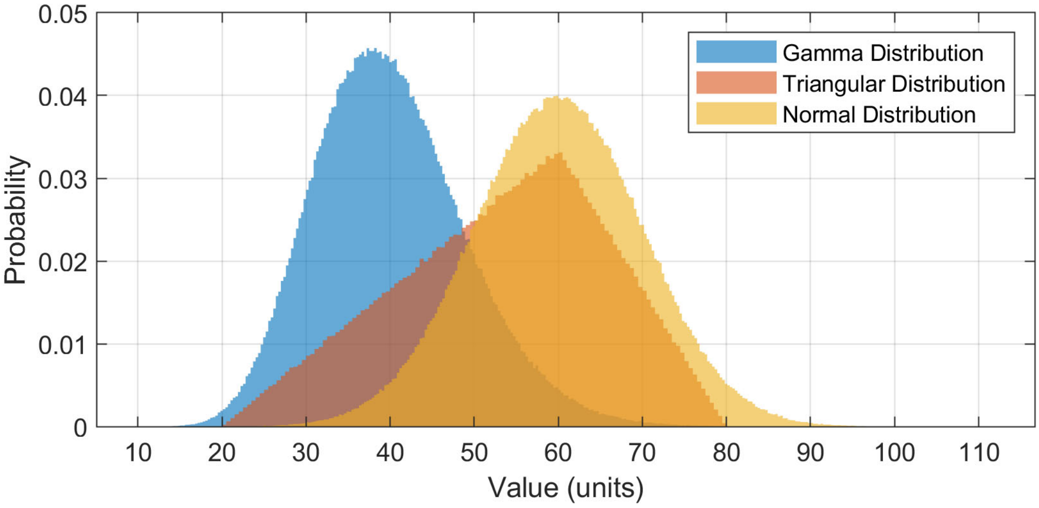


Figure 4-1 Example distribution types

4.2 Model Domain

The model domain was developed based on a series of 'cross-beach profiles' extending from the shoreline up to 2 km both landward and seaward. These profiles are spaced at approximately every 100 m (except where they intercept river entrances) and are roughly shore-normal to the alignment of each sub-compartment (Figure 4-3).

The existing terrain (topography/bathymetry) has been inspected onto the profiles as a basis for calculating the accommodation (erosion/accretion) volume of the shoreface due to sea level rise, as well as for calculating the resulting setback distance in response to a given volume.

The elevation data has been sourced from several key datasets and has been inspected according to the following order of priority:

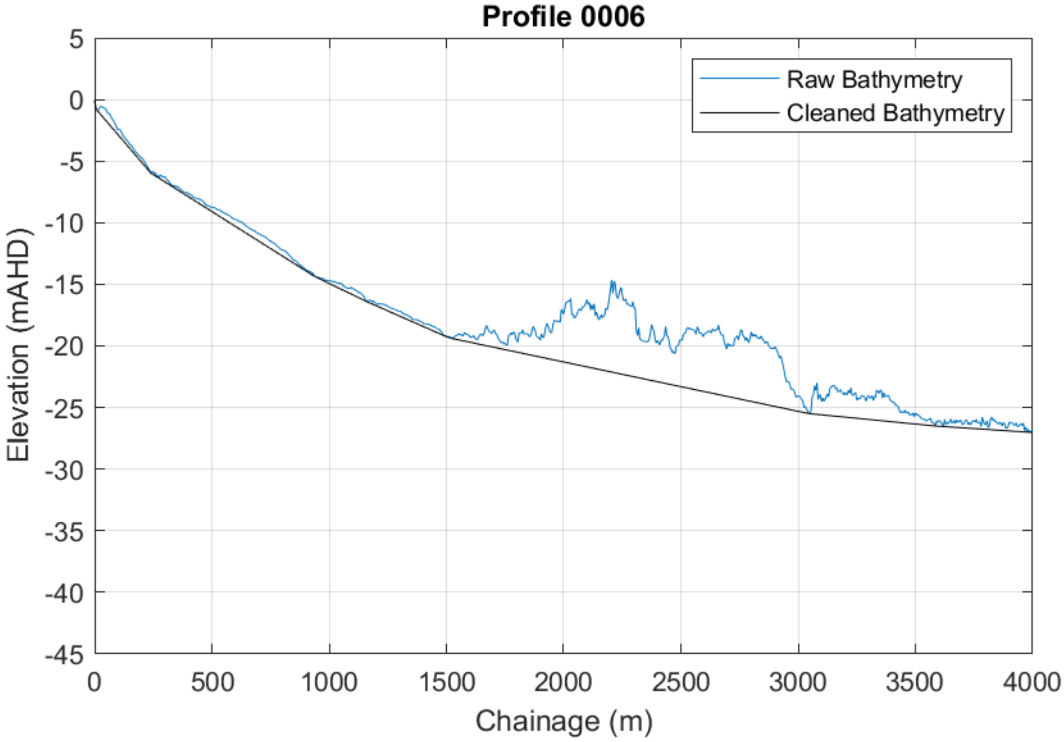
(1) NSW Marine LiDAR Mapping project (made available for this project in its point-scatter form) (NSW, 2018);

(2) Electronic Navigational Charts (ENC) data (Australian Hydrographic Service, ENC Data);

(3) DEM of Terrestrial LiDAR at 2m resolution (LPI LiDAR from 2012).

The sub-aqueous elevation of each profile has been processed to remove any submerged reef features to accurately capture the distance to the depth of closure (as based on a likely 'equilibrium' profile, Figure 4-2). This has been simply applied by calculating the piecewise convex curve that fits under the inspected bathymetry. The raw profile above this 'cleaned' profile has been used as the area of submerged rock and is later used to define reductions to the sea level rise sink terms in Section 4.4.1.

Any uncertainty in the bathymetric and topographic data is assumed to have a mean of zero. If there is an inherent bias in the bathymetry then it will affect the recession due to sea level rise in proportion to the beach slope (likely to be a <5% error). However, bias in the topography can have a large influence on the setback distance associated with a given erosion volume. This is proportional to the bias as a percentage of the average height of the dune being eroded, i.e. for low-lying areas and error of ± is more significant.



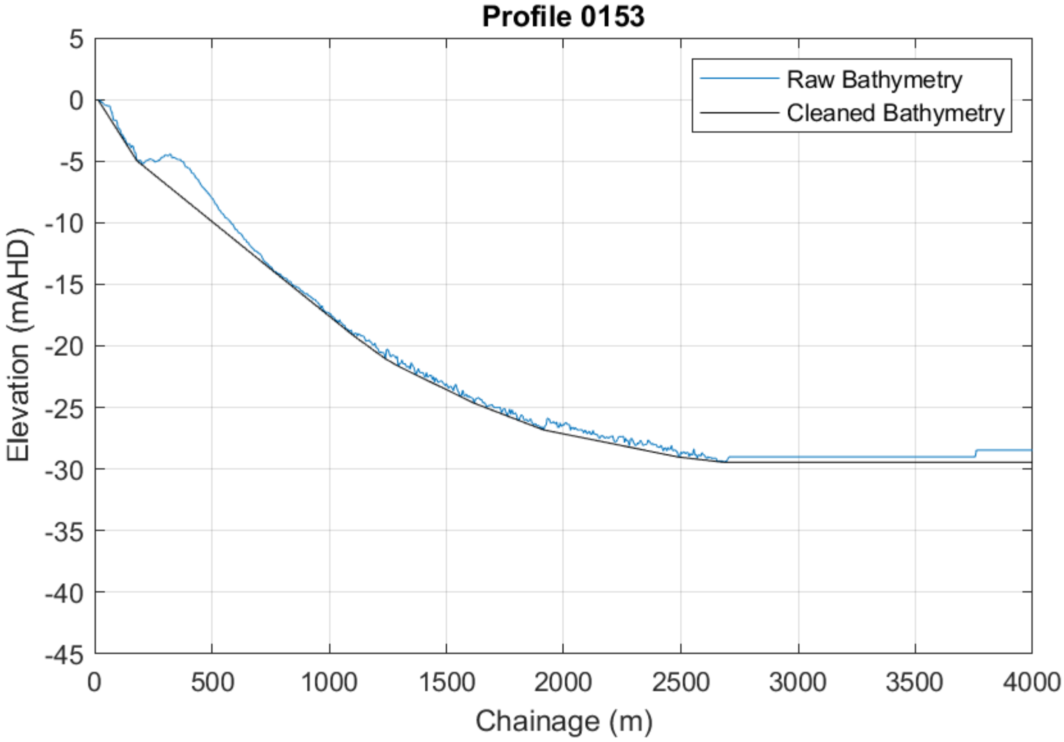
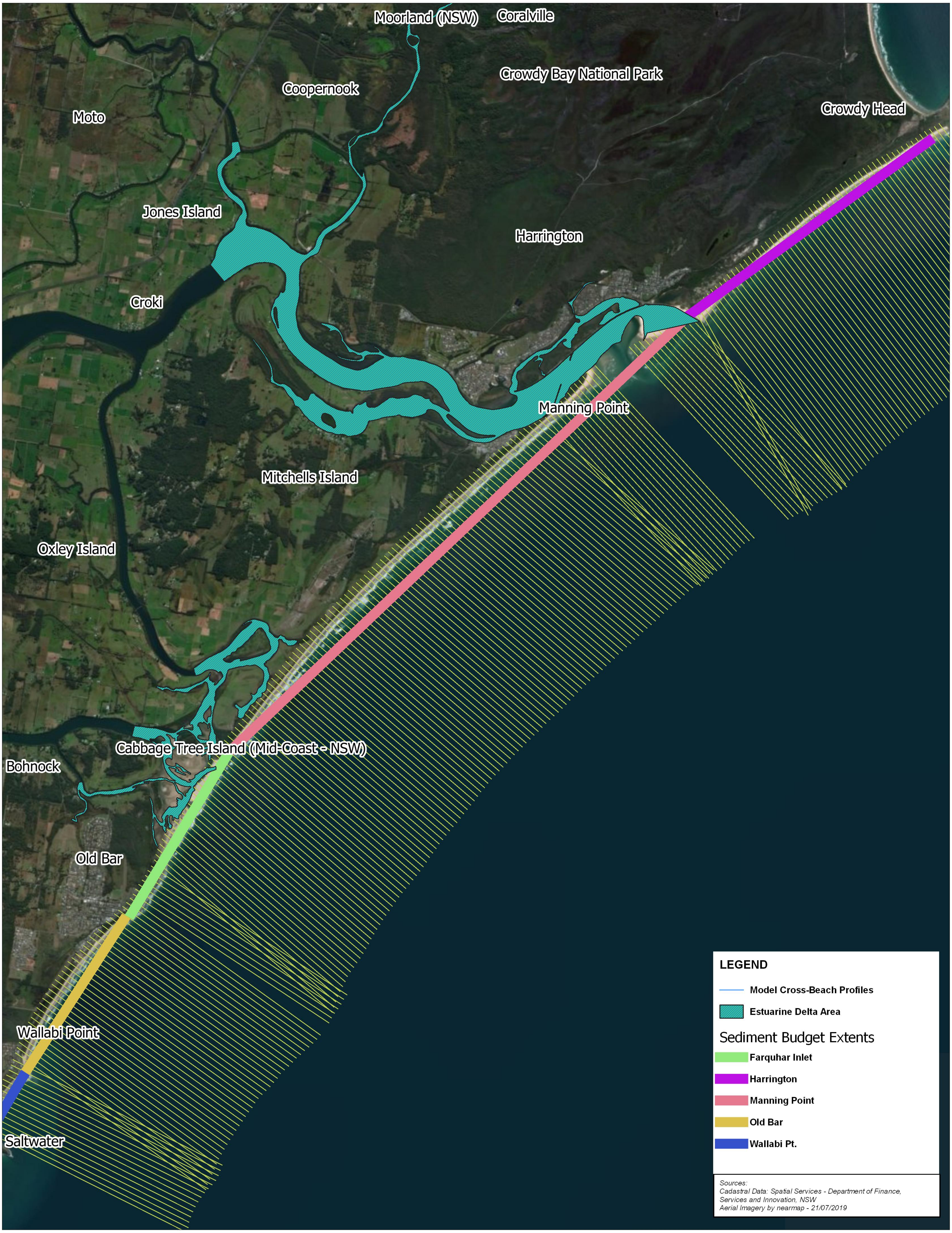


Figure 4-2 Example of processed cross-shore profile bathymetry



Sources:
Cadastral Data: Spatial Services - Department of Finance, Services and Innovation, NSW
Aerial Imagery by nearmap - 21/07/2019

Title:

Model Cross Beach Profiles and Sediment Budget Extents

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4-3

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4.3 Model Timeframe Scenarios

As per the requirements of Council, the probabilistic modelling and Hazard Line mapping update has been conducted for the following timeframes:

- Present day (incorporating no cumulative erosion effects);
- 2060 (incorporating cumulative erosion effects for 40 years as well as fluctuating erosion effects in the ‘final’ year);
- 2100 (incorporating cumulative erosion effects for 80 years as well as fluctuating erosion effects in the ‘final’ year).

4.4 Cumulative Erosion (Shoreline recession response to Long-term processes)

4.4.1 Sea Level Rise

The model incorporates quantification of shoreline recession due to sea level rise due to both the adjustment in the beach profile with an increased water level and the adjustment in the stable volume of the estuarine delta.

Sea level rise values for the future periods were considered as distributions based on the data made available as part of the IPCC 5th Assessment Report (AR5, IPCC, 2014) models assessing the Relative Concentration Pathway 8.5 (RCP8.5). This is the most extreme concentration pathway and represents low efforts to limit emissions. This has been selected for its conservativism, and because the mean sea level rise predictions are similar to Council's current adopted sea level rise policy. RCP8.5 data was only available to 2098, but the mean water level increase has been extrapolated for this study. The modelled distributions are presented as normal distributions with as shown in Figure 4-4, and with the mean and standard deviation shown in Table 4-1.

Table 4-1 Sea Level Rise

Future Year	Council Sea Level Rise Policy	RCP8.5 Mean	RCP8.5 Standard Deviation
2060	0.4 m	0.39	0.08
2100	0.9 m	0.86 (extrapolated from 2098)	0.18 (equal to 2098)

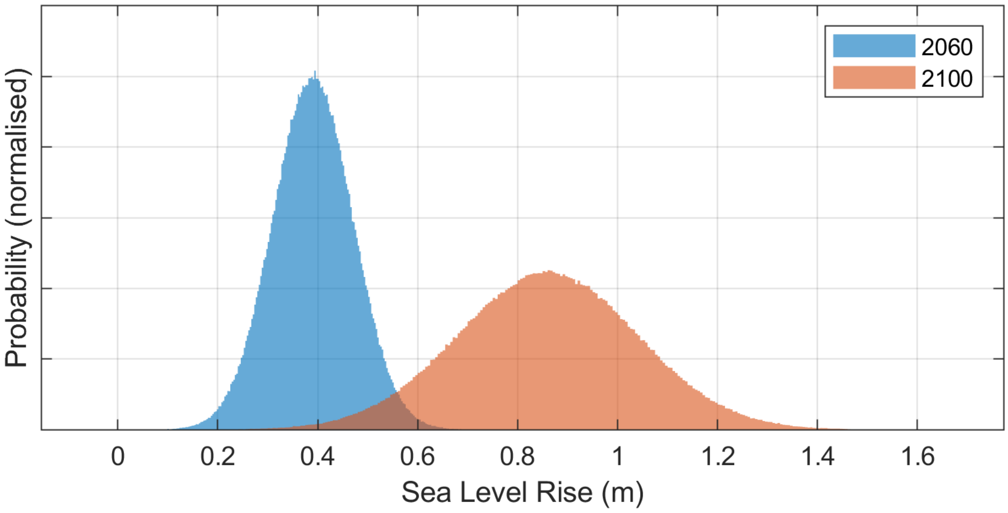


Figure 4-4 Adopted Sea Level Rise Distributions

Shoreface Sediment Sink

Typically, beach recession from sea level rise has been calculated using the Bruun Rule (Bruun, 1962). This assumes that over the long-term, the beach profile will remain constant, resulting in an increased bed elevation in the shoreface in response to the increase in overall water level. With all other exchanges in sediment volumes accounted for, this increase will come from an associated setback from the shoreline due to natural erosion events that are no longer able to recover with the new equilibrium profile.

A volumetric Bruun-based approach has been adopted in the probabilistic model (following Kinsela *et al,* 2017) that integrates an increase in the overall bed elevation to determine the 'accommodation volume' (shoreface sediment sink).

A key sensitive input into any Bruun formulation is the 'depth of closure', relating to the depth (below mean sea level) to which active sediment transport is possible/likely. Formulations for closure depths are typically related to the wave energy and to some extent tidal transport also. The closure depths have been represented in the model as different triangular distributions for each future scenario. The bounds of these have been selected based on professional judgement in consideration of the following inputs:

- Worley Parsons (2010), assessed a range 12m ± 4m for the Black Head to Crowdy Head Coastline Hazard Definition Study, and adopted a final value of 10m;
- The Hallermeier littoral zone limit and outer shoal depths (Hallermeier, 1981) based on the wave record at Crowdy Head (to 2017) suggests depths up to ~5m and ~35m respectively (for beach sand);
- Worley Parsons (2010), presented the simplified formulae following Rijkswaterstaat (1987) and Bruun (1988) suggesting depths of closure of 8.2m and 9.4m respectively;
- Worley Parsons (2010), also assessed sedimentological data showing changes between Inner and Outer Nearshore Sand at 11-15m and to Shelf Plain Relict Sand at 18-26m.

The selected closure depths are greater in 2100 than in 2060 due to the greater likelihood of large storms (over the longer timeframe) that can mobilise sediments to deeper depths, and also to incorporate the longer period over which to assess the uncertainty. Ultimately, the two distributions have been chosen as shown in Table 4-2 and Figure 4-5. The depths for the 2060 period have a model value of 10m as per the existing Hazard Definition Study (Worley Parsons, 2010), extending to a minimum value of 5m (unlikely but possible) and 15m (extreme but possible), which extend from the littoral zone limit to the boundary of Inner and Outer nearshore sand. For 2100 the minimum value was kept consistent, but the modal value was increased in line with the boundary of Inner and Outer nearshore sand, and the maximum value extending out to the boundary of Shelf Plain Relict Sand.

Table 4-2 Depth of Closure Distributions

Future Scenario	Minimum (m)	Mode (m)	Maximum (m)
2060	5	10	15
2100	5	15	25

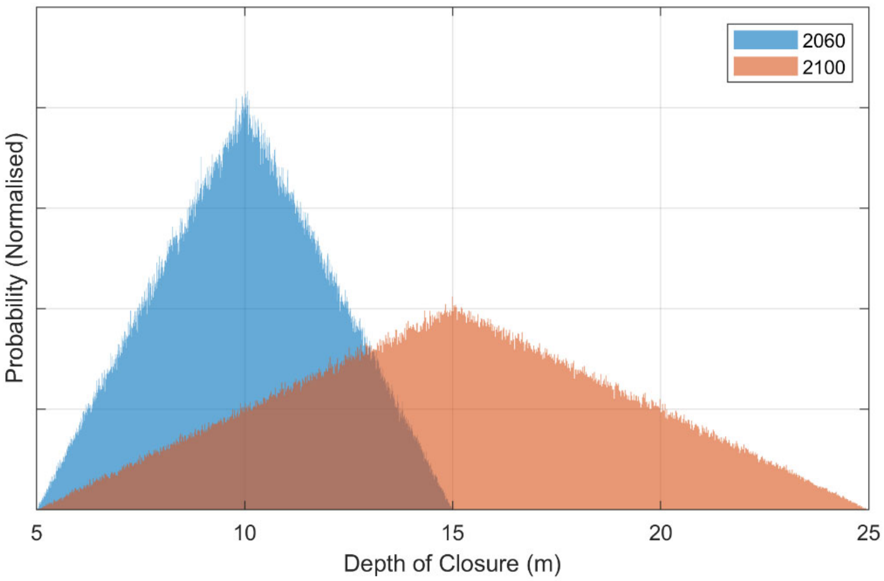


Figure 4-5 Sampled Depth of Closure Distributions for 2060 and 2100

As has been used in Kinsela *et al* (2017), the accommodation volume is calculated as half of the lifted volume of the whole beach profile to the depth of closure. This sink term is reduced where existing offshore reef structures are already above the future beach profile level (based on the difference between the 'smoothed' profile and the 'inspected' profile as described in Section 4.2).

Lastly, the volume of shoreface accommodation calculated for each individual cross-beach profile has been smoothed in the longshore direction. This has been done to minimise the 'noise' of individual profiles in having an unrealistically high or low shoreface sink relative to adjacent profiles. The smoothing has been done by applying a 2.5 km wide (along the shoreline) moving average on the shoreface sink. This scale has been selected to partially homogenise the accommodation effects within each sub-compartment and to maintain distinctions between separate sub-compartments, but to avoid discontinuities between adjacent sub-compartments. This smoothing is considered physically realistic as the natural processes of sediment transport will tend to restrict any cross-shore profile that is slightly steeper or flatter from receding significantly more than others by distributing sediment alongshore near the shoreface.

Estuarine Delta Sediment Sink

A similar methodology to the shoreface sink has been adopted to account for the estuarine sediment sink terms. It is possible that just as the shoreface level increases in-line with the sea level increases, so to might the estuarine delta bed level increase. This effect would be based on these areas intercepting longshore sediment movements, and also intercepting any fluvial sediment discharge that may otherwise become available to the coast.

Quaternary geological mapping was used as local information source to guide estimates of a potential sediment flood tide delta sediment sink due to ongoing sea level rise. The area of sediment types classified as estuarine channel (subaqueous) deposits (marine sand dominant texture) has been adopted as an appropriate estuarine accommodation area. Kinsela *et al* (2017) adopted a similar approach, though also incorporating aerial imagery to determine appropriate mapped delta areas.

The sink term is based on the volume of sediment required (‘demand’) by lifting the marine delta area by the same height as the mean-sea-level rise. This volume demand was distributed across the entire (secondary) sediment compartment to calculate a per-metre sediment demand. The areas are shown in Table 4-3 below.

Table 4-3 Marine Delta Area

Mapped Coastal Depositional Unit	Depositional Environment (Dominant Lithology)	Farquhar Inlet – Mapped Area (km2)	Harrington Inlet (Manning River) – Mapped Area (km2)
Estuarine channel (subaqueous) [Qec]	Estuarine Plain (Marine Sand)	1.658	7.131
ADOPTED MARINE DELTA SINK AREA (km2)		**1.6**	**7.1**
TOTAL AREA (km2)		**8.7**	
Volume Demand (m^2/m per meter of SLR)		**~248 m^3/m/m**	

4.4.2 Net Sediment Budget

Long term change in dune volume from beach profile records has been adopted as the indicator for historical sediment budget trends for the study area (see Appendix A). The long-term foredune volume change has been determined from the historical beach profile records and available LiDAR DEM information – broken down into the respective sub-compartments of the study area. This analysis was completed by Dr Thomas Doyle from Mid Coast Council and provided to BMT for the current study.

The timeseries of annualised sediment budget was analysed to derive an appropriate range of values for a triangular distribution of each tertiary sub-compartment. The model value of the triangular distributions was taken from the long-term trend (between the first available foredune volume and the last available foredune volume). The upper- and lower-bounds were taken from the maximum and minimum values respectively of a 10-year moving average net-sediment volume change.

It has been assumed that a 10-year moving average is appropriate to not include any trends that may be skewed by recent storm activity (which is otherwise accounted for in the model), or uncertainty in a single observation.

The resulting model input distributions are shown in Figure 4-6 and show that most of the sub-compartments have a sediment budget deficit on average. Harrington is the only beach system that tends to accrete sediment over a long-term average, but still has the possibility of significant erosion events. Note, the extents of the sub-compartments are shown in Figure 4-3.

Figure 4-7 to Figure 4-9 present the volumetric changes over time for the relevant sub-compartments, as well as the selected bounds for the triangular distributions (as the red lines). These show that the distribution ranges do not include extreme erosion or accretion observations that are unlikely to be maintained over the long-term (i.e. until 2060 or 2100). It also shows that the short-term extreme variations typically ‘recover’ quickly (typically by the next survey).

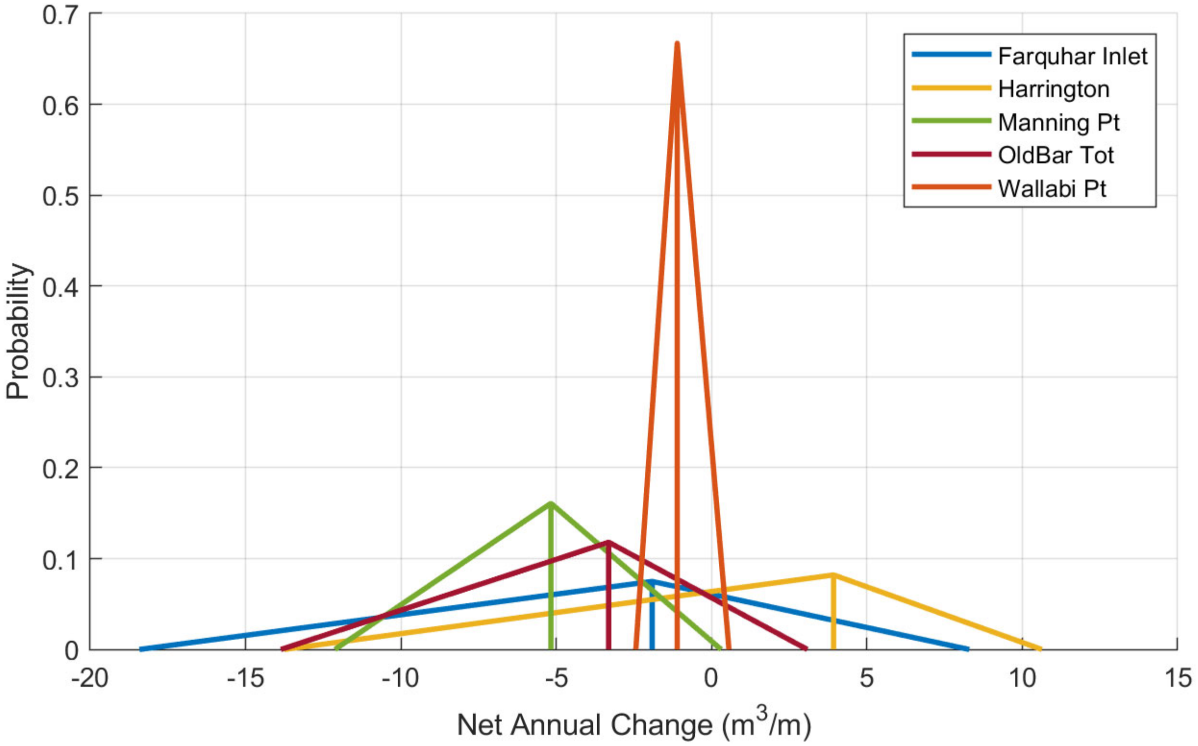


Figure 4-6 Modelled triangular distributions of net sediment budget

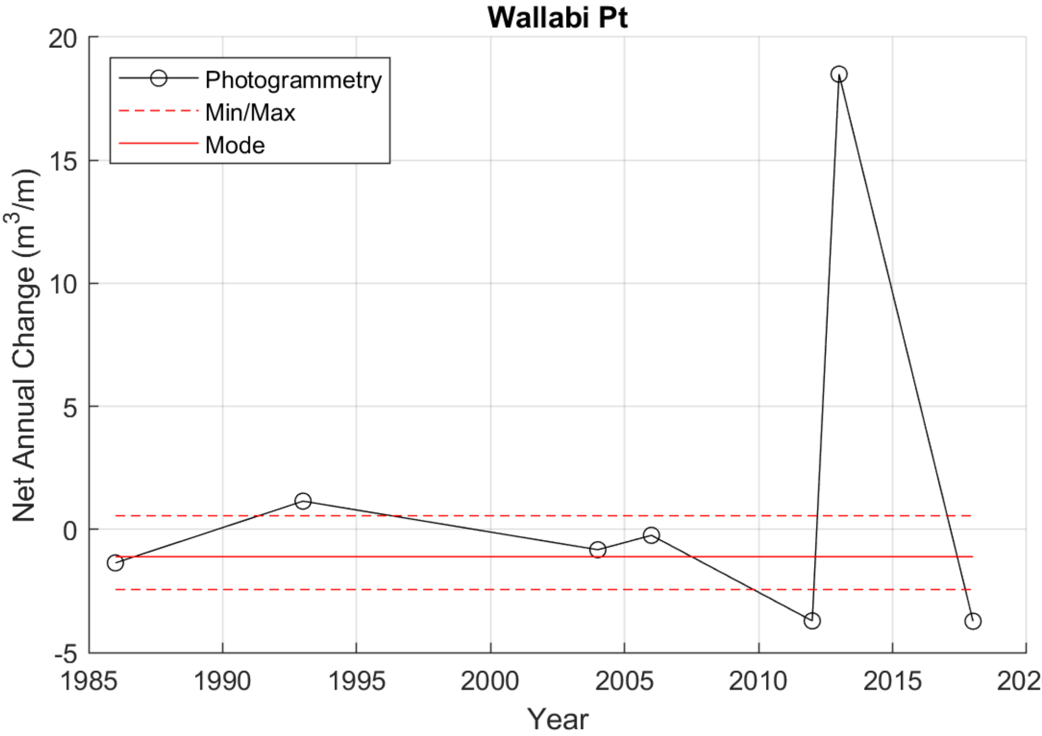
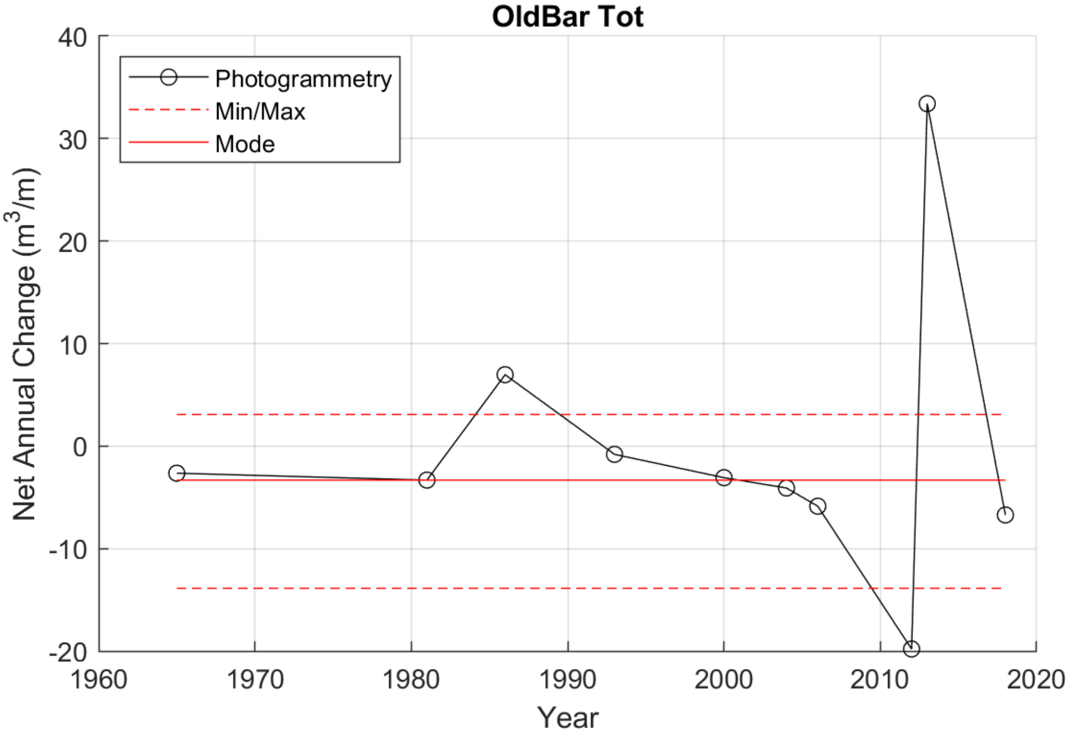


Figure 4-7 Inferred Sediment Budget and Selected Distribution Bounds – Wallabi Point



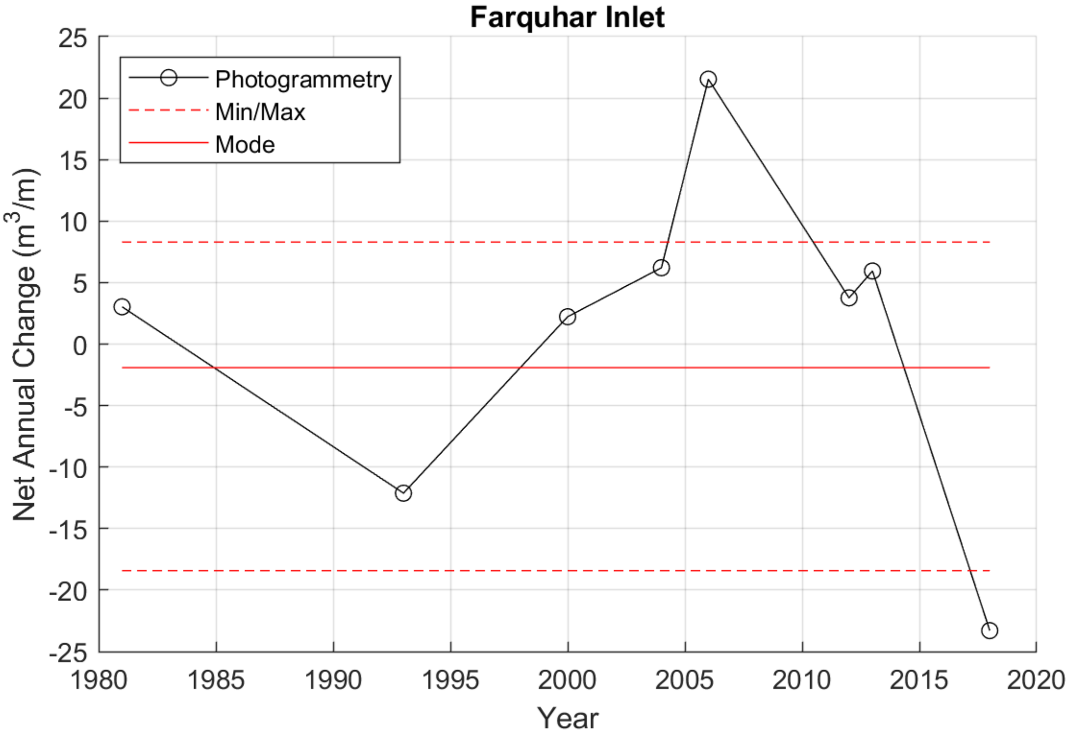
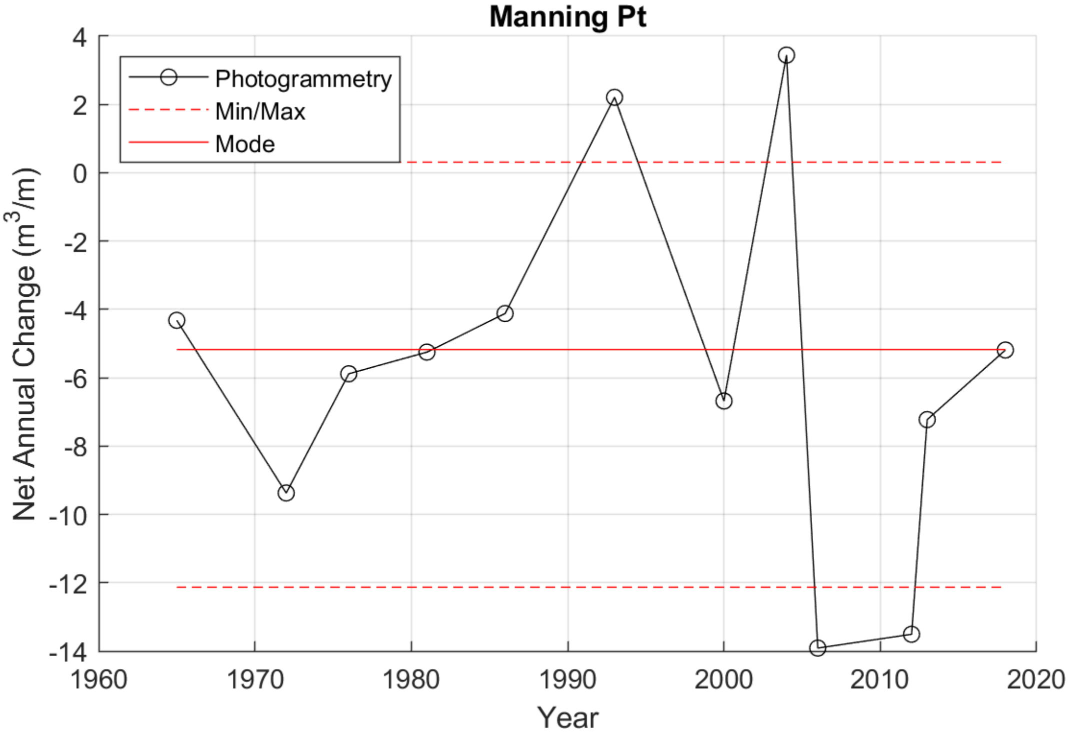


Figure 4-8 Inferred Sediment Budget and Selected Distribution Bounds – Old Bar (Top); and Farquhar Inlet (Bottom)



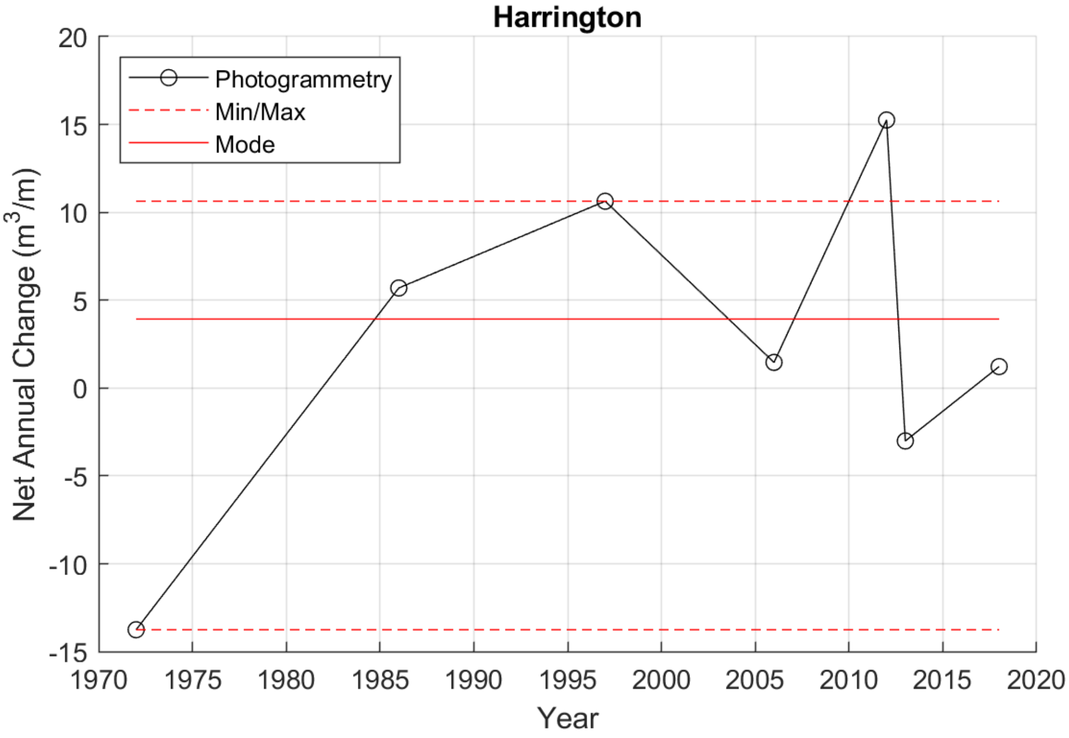


Figure 4-9 Inferred Sediment Budget and Selected Distribution Bounds – Manning Point (Top); and Harrington (Bottom)

4.5 Fluctuating Erosion (Coastal Response to Short Term Processes)

4.5.1 Fluctuating Beach Erosion

The 'fluctuating' component of erosion corresponds to the natural short-term changes that largely occur in response to storm events. While such events may be a trigger or instigator of recession corresponding to sea level rise (by successive events taking more beach sediment into the shoreface accommodation zone), the fluctuating component only represents the volume that is likely to return to the beach after a period of stable conditions. This will usually be due to individual storms but may also include successive storm events that compound one another.

As it is assumed that this component is stable over the long-term, for the purpose of modelling coastal erosion hazard, the only factor of interest is an event that may occurs in the final year of the simulated period.

The fluctuating component used in the current modelling follows Kinsela *et. al* (2017), which used a gamma function derived based on earlier work by Gordon (2015) to define the storm demand for exposed open-coast beaches in NSW. This parameterisation was validated as fit-for-purpose by Kinsela *et. al* by comparing the predictions to observations of historical maximum erosion escarpments at exposed beaches.

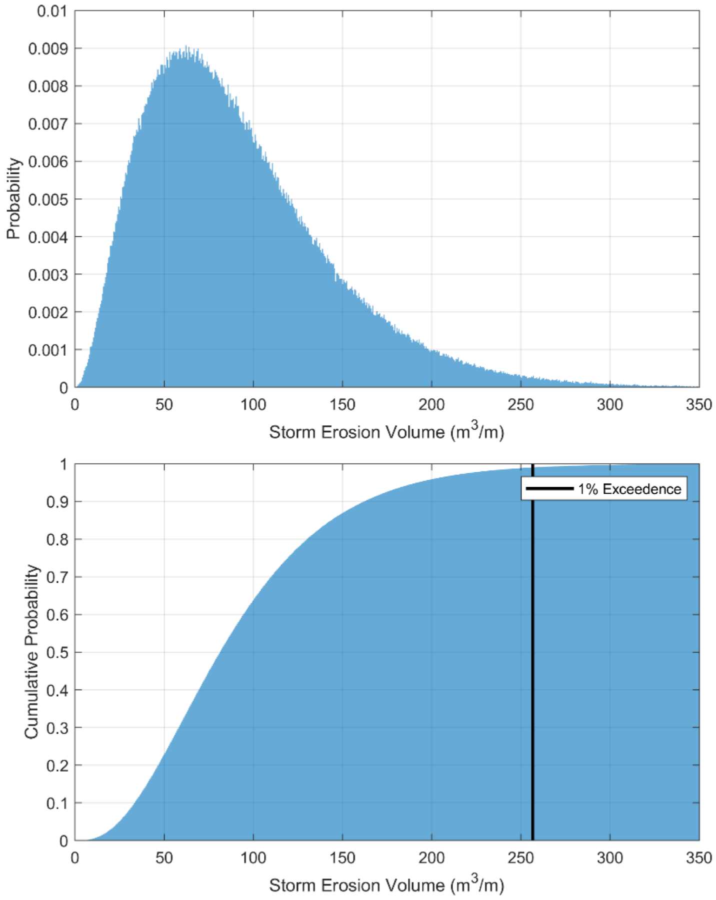


Figure 4-10 Storm Demand Probability Density Function

4.5.2 Erosion Scaling

Wave Exposure

As the angles of beaches in the study area are similar to the overall alignment of the sediment compartment and the coastline is not sheltered by significant headlands or islands, not adjustments are required to the gamma function for the storm demand.

However, known submerged geological features (such as Urana Bombora) are present offshore and may reduce the energy of incoming waves at a local scale. Shoreline sub-sections in the lee of such features have an additional factor applied to any fluctuating erosion effects. As the exact nature of this potential is unknown, a conservative triangular distribution has been adopted that allows for some reduction but errs heavily towards a fully-exposed effect. The sampled distribution (between 0.9 and 1.0) is shown in Figure 4-11.

This effect has been only applied in the immediate lee of such features and typically only affects one of the cross-shore profiles within the modelled domain.

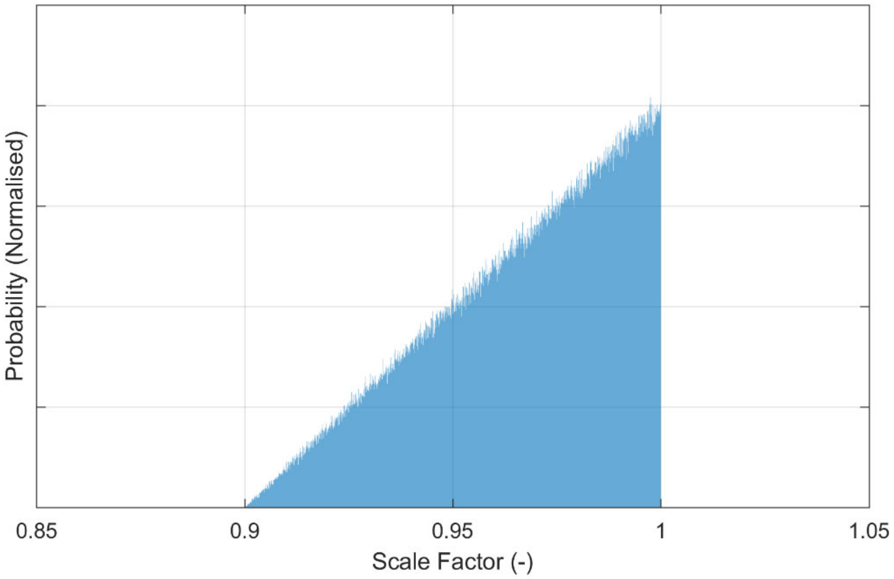


Figure 4-11 Wave Exposure Scale Factor behind Submerged Rock Features

4.6 Calculating Modelled Setback

The calculations within the model as described in the preceding sections detail the methodology used to determine a total erosion volume (per meter of shoreline), but not a setback distance. As such, an additional step in the computations was to apply these volumes to the sub-aerial beach and foredune system to directly calculate what an appropriate setback distance was (following Kinsella *et. al,* 2017). This was done at a finer scale (at 5 m increments) than the cross-shore profiles that were used in the initial stages of the model in order to ensure that a smooth setback line followed appropriate variations in the topography.

This methodology differs from the Bruun rule by discounting the potential aggradation of the dune system in response to sea-level rise. This is considered to be a conservative assumption, but suitable given that there is no certainty that a rapid rate of climate-change associated increases in mean-sea level will occur slowly enough to allow for these processes to keep up.

This methodology generated the Zone of Wave Impact (ZWI), which can then be used to calculate the Zone of Slope Adjustment and Zone of Reduced Foundation Capacity as described in Section 3.2, using a conservative angle of repose of 34°. These conditions have been further modified by the geology as follows:

Indurated Sediments

Indurated sands (also known as *coffee rock*) are sands that have been heavily compacted into rock forms, potentially other interstitial materials.

The model has therefore incorporated the knowledge of the indurated sands by reducing scaling the effects of the fluctuating erosion component only. As with the wave exposure, the understanding of this process is limited, so a similarly conservatively skewed scale factor has been adopted. The sampled distribution is shown in Figure 4-12. This potential scale factor was only applied to cross-beach profiles that intersected areas of identified indurated sands as shown in Figure **2-1**, and only when the recession encroached into these areas.

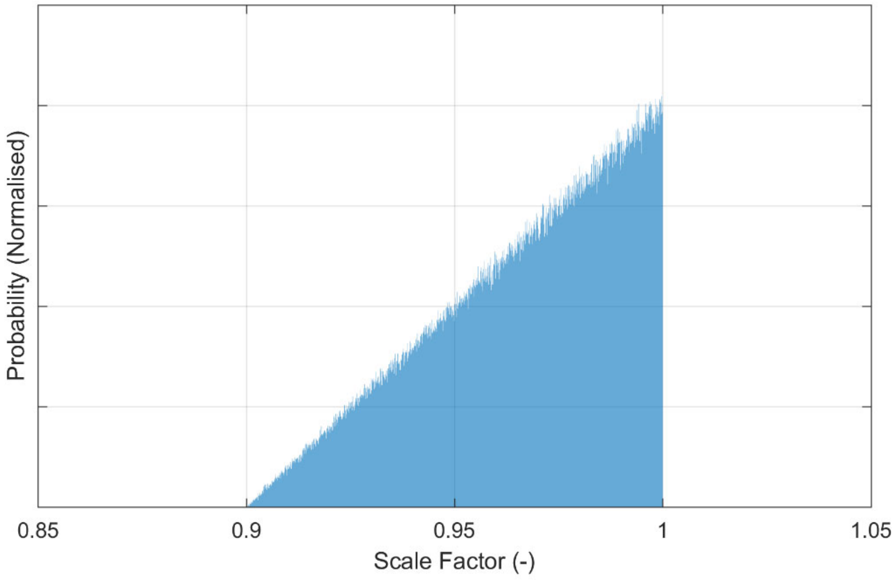


Figure 4-12 Scaling factor for Erosion in Areas comprised of Indurated Sands

Erosion Influencing Bedrock

Where bedrock has been identified as part of the geological survey, erosion is thought to be constrained. As such, the model implements a limit to not allow any Zone of Wave Influence to encroach behind the beginning of any bedrock that is above mean-sea-level. Furthermore, sediment slumping as per the ZSA and ZRFC (as discussed in Section 3.2), has only been applied above the bed rock level. The identified areas of bedrock are shown in Figure **2-1**.

There is uncertainty in the depth of bedrock as interpreted from ground-penetrating radar and boreholes. A conservative approach has been adopted where bedrock depth has been limited to at least 4m below the ground level and by using the conservative angle of repose. It is noted that the uncertainty introduced in the setback distance is up to 2.5m of additional setback for an additional meter of bedrock depth. Similarly, it makes no account of potential undermining or weathering/failure of the exposed bedrock after the erosion/recession. Further limitations are detailed in Section 6.2.

5 Coastal Erosion Hazard Assessment Results

5.1 Summary of Results

The probabilistic erosion hazard model produced a distribution of potential volume demands for each period (present-day, 2060 and 2100) that incorporates the variations in both fluctuating erosion and cumulative erosion (long-term recession) processes. Examples of these distributions are shown for central locations in each sub-compartment in Figure 5-1 to Figure 5-5. The local topography was then used to infer setback distances from these volume demands.

The lines representing the Zone of Slope Adjustment (ZSA) have been provided, as has the Zone of Reduced Foundation Capacity (ZRFC). In regions where the recession has reached the mapped bedrock areas, the formulae for calculating the ZSA and ZRFC has incorporated the local geomorphology information by applying the slumping formulae above the inferred bedrock depths.

As per agreement with Council, and considering the requirement of a set of outputs that convey the variability and magnitude of potential erosion recession hazards, several hazard exceedances are presented:

(1) The 50% exceedance, corresponding to the median setback distance **exceeded** by half of all simulations (50% of 1 million simulations predicted shoreline setback **smaller or equal** to this distance).

(2) The 10% exceedance, corresponding to a setback distance **exceeded** by only 10% of all simulations (90% of 1 million simulations predicted shoreline setback **smaller or equal** to this distance).

(3) The 1% exceedance, corresponding to a setback distance exceeded by only 1% of all simulations (99% of 1 million simulations predicted shoreline setback **smaller or equal** to this distance).

No single exact setback distance is described as definite, but each can be described in terms of the percentage of modelling predictions that were greater (i.e. ‘worse’) or less (i.e. ‘better’) than the presented line. Such conditions provide Council with an improved decision-making tool where different ‘risk appetites’ can be adopted for different applications as required.

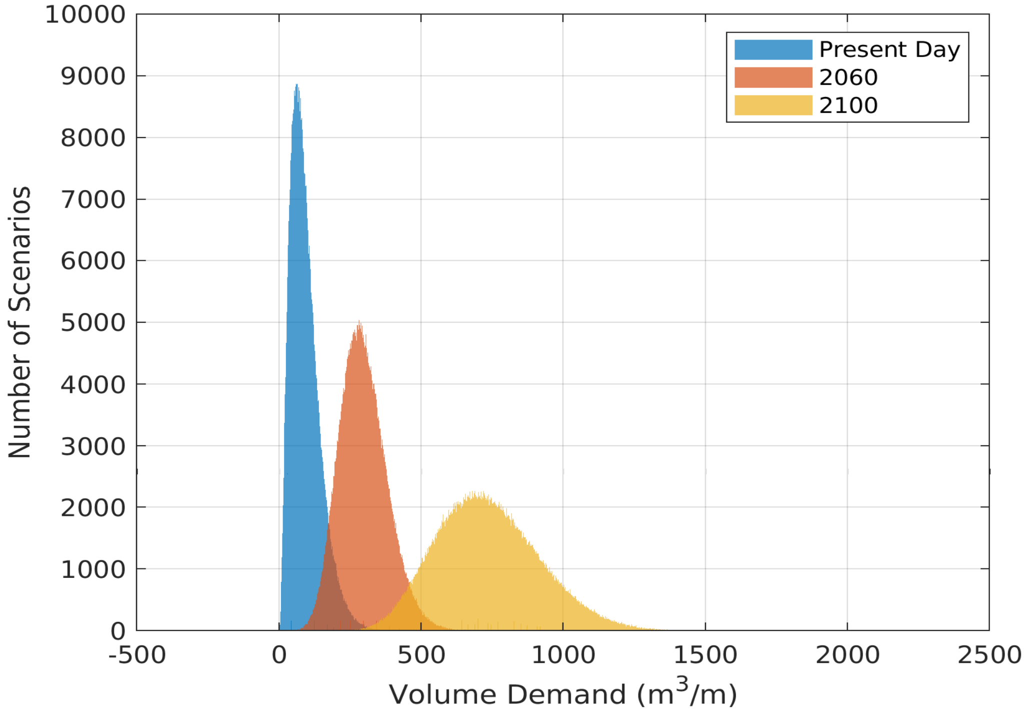


Figure 5-1 Wallabi Point Volume Demand Results

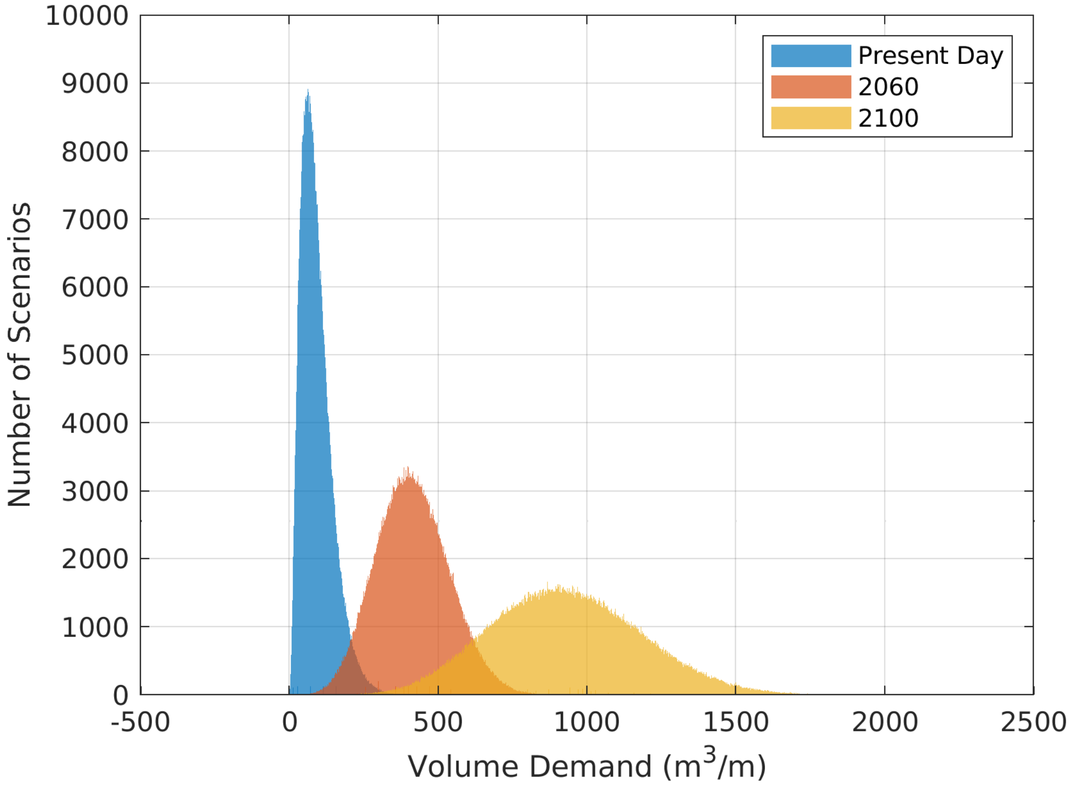


Figure 5-2 Old Bar Volume Demand Results

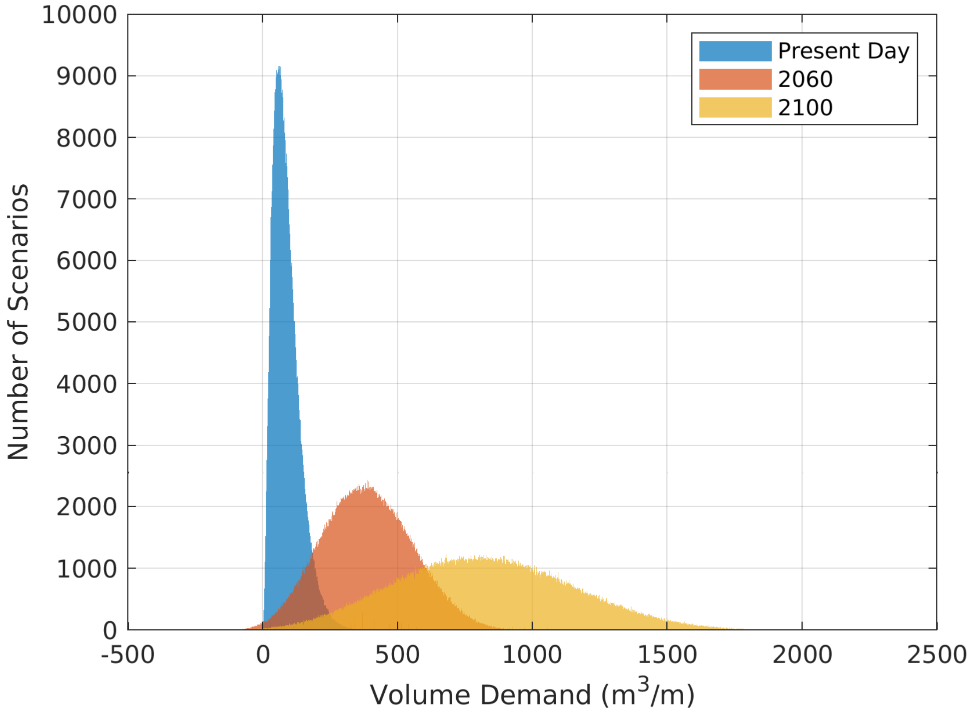


Figure 5-3 Farquhar Inlet Volume Demand Results

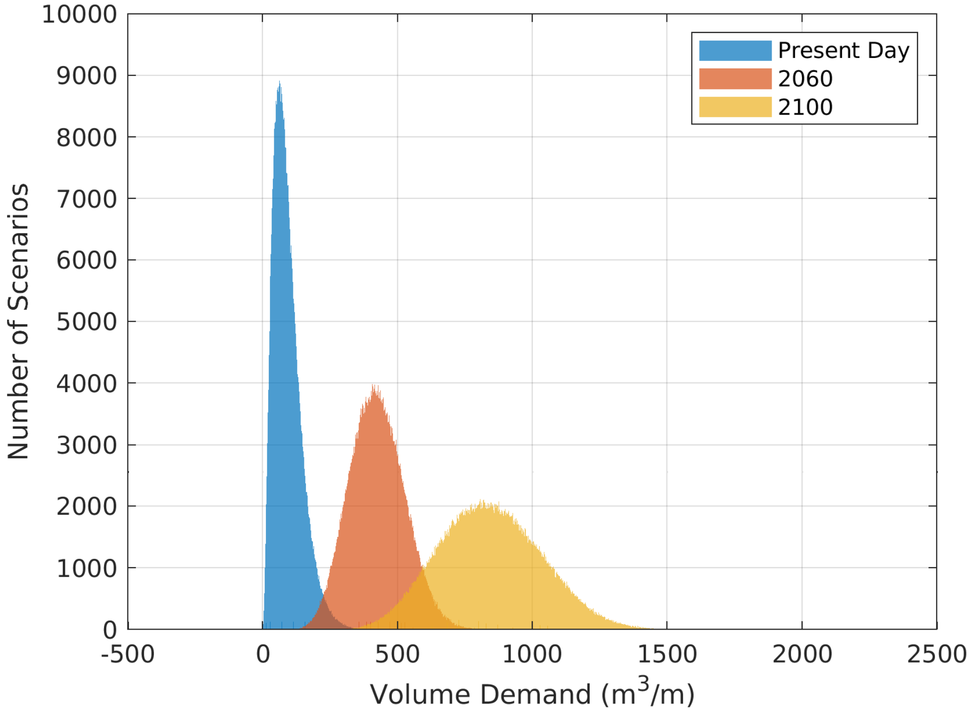


Figure 5-4 Manning Point Volume Demand Results

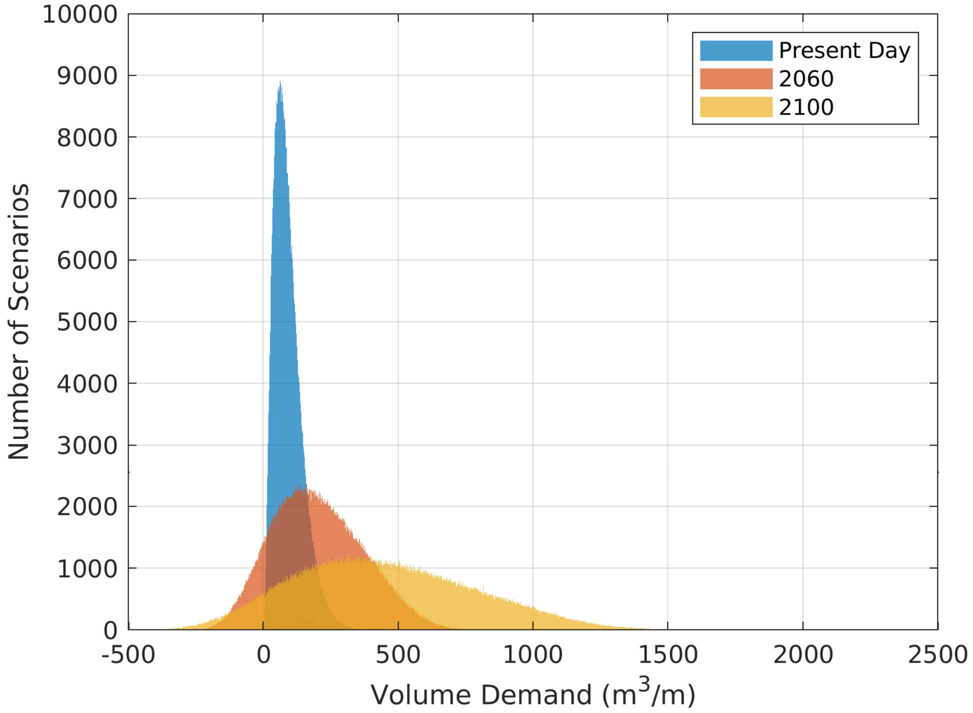


Figure 5-5 Harrington Beach Volume Demand Results

5.2 Areas of Uncertainty

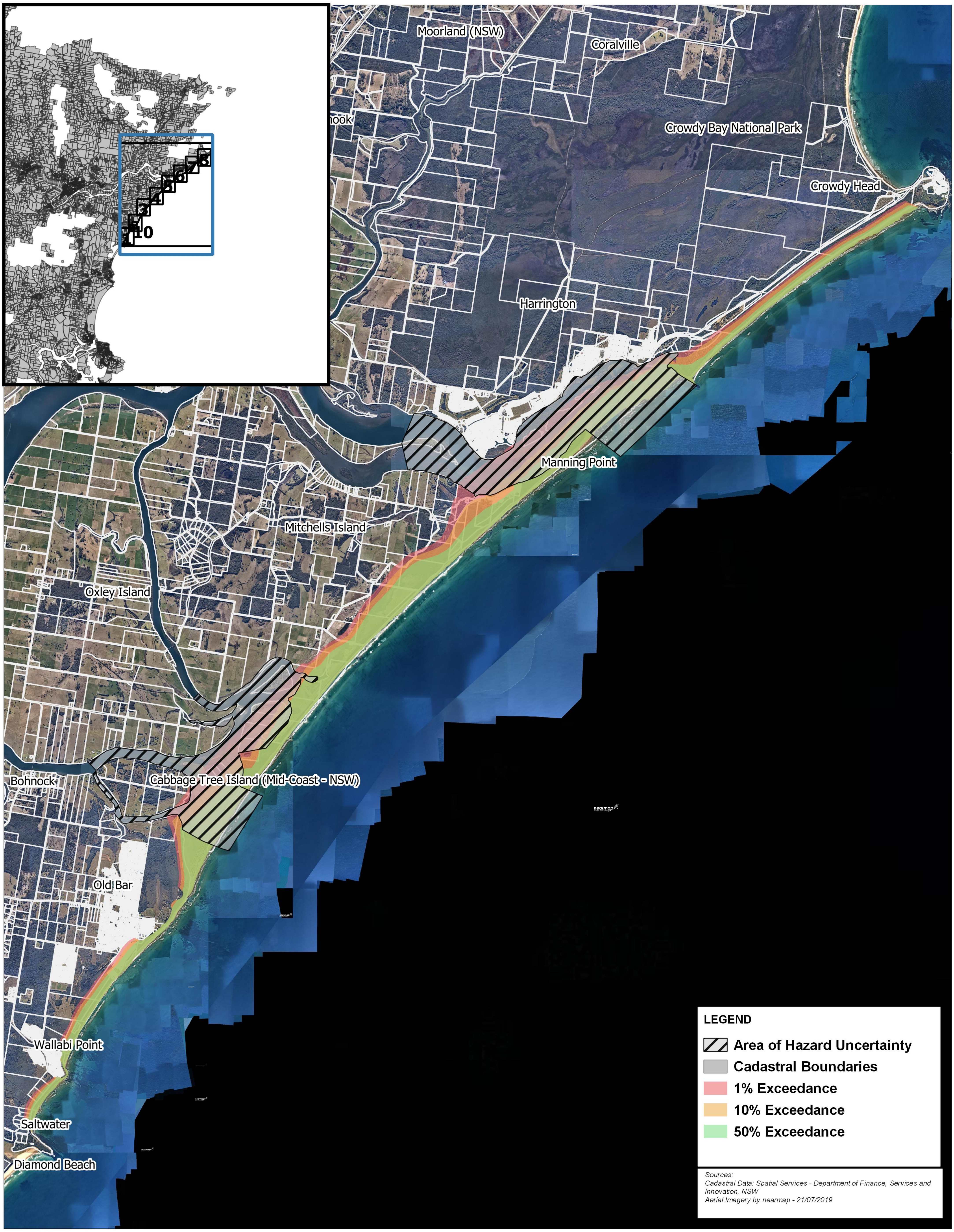
There are several cross-shore profiles in the modelled study area that calculate a higher erosion volume than is available in the associated foredune system. These are typically in the areas adjacent to the estuarine entrances, where erosion can extend back into the estuary itself. Such physical effects can occur and will be associated with wave and tidal over-wash of the dune barrier, as well as potential break-through and migration of river entrances through these systems. As the future response of these highly variable areas is uncertain and beyond the predictive ability of the 1-dimensional probabilistic model, these areas cannot be determined for their exact erosion/recession hazard. Paradoxically they are likely to be some of the areas with the highest potential hazards as the non-linear interactions between the estuary and the coastal hazards can cause rapid changes in the geomorphology. As such, these areas have been highlighted in the mapping as ‘areas of uncertain hazard’ wherever the setback extends greater than the available dune.

Notably, the ultimate extent of these areas of uncertainty has been mapped back to the opposite side of the adjacent estuary sections, however even these areas may be exposed to coastal hazards should significant changes to the configuration of the estuarine entrances occur. Such changes will trigger the need for an updated assessment of coastal hazards in these areas under the new configuration.

5.3 Coastal Mapping

Maps of the ZSA and ZRFC for the whole study area for the 2100 timeframe (excluding areas of uncertainty adjacent to the estuarine entrances) are shown in Figure 5-6 and Figure 5-7, respectively. Areas with a large separation between successive percentiles (such as along Mitchells Island) suggest a high degree of sensitivity to the assumed inputs. Conversely, where there are limited differences (such as when setback reaches bedrock controls behind Urana Bombora), the uncertainty in the processes are less important.

Detailed maps of each sub-section are presented in the mapping compendium in Appendix B to Appendix G for all modelled timeframes.



Sources:
Cadastral Data: Spatial Services - Department of Finance, Services and Innovation, NSW
Aerial Imagery by nearmap - 21/07/2019

Title:

Study Area - 2100 Zone of Slope Adjustment

Figure: **5-6**

Rev: **A**

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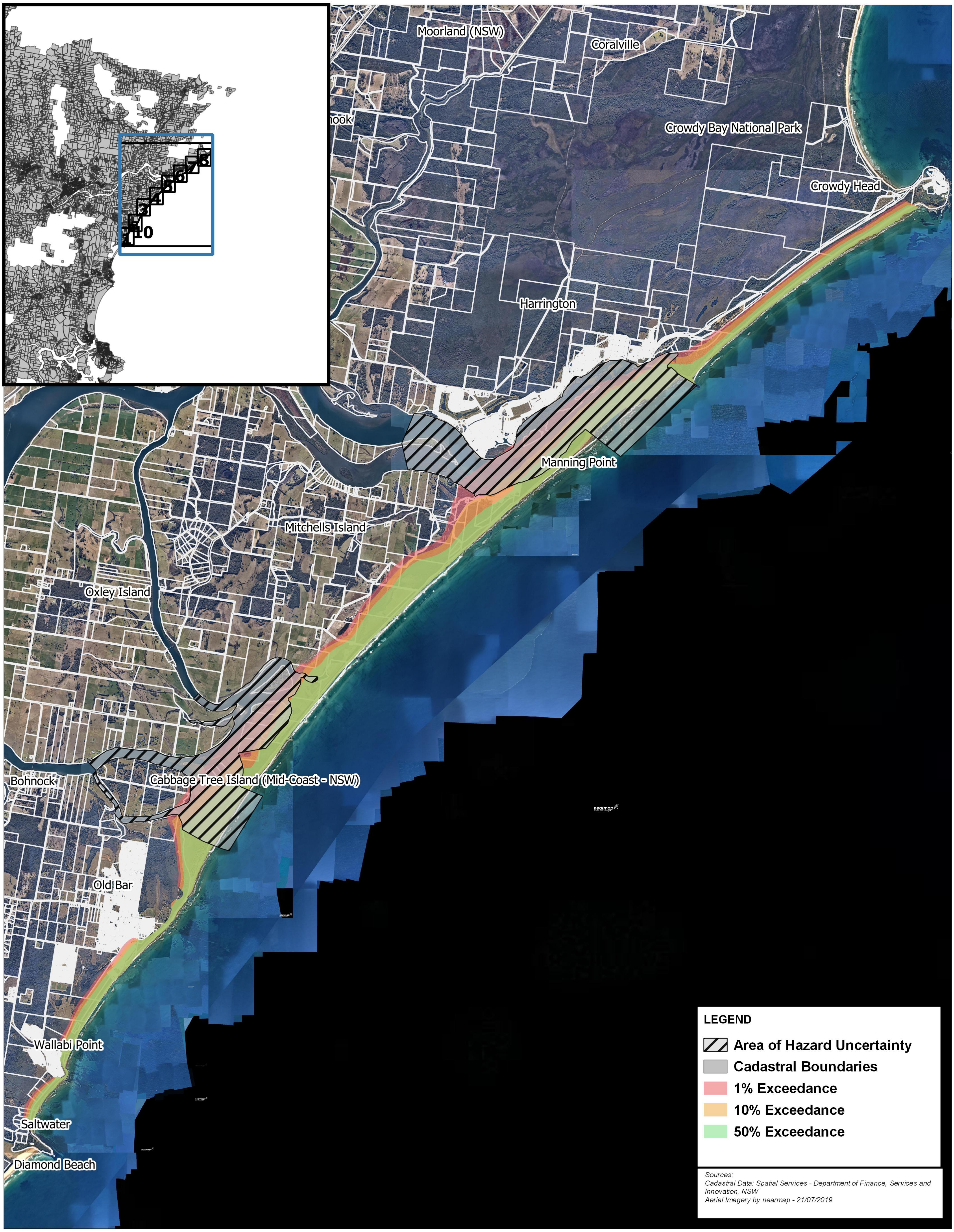
0 1000 2000 3000 4000 m

BMT
www.bmt.org

Filepath: I:\N21005.i.ajs.Old Bar Manning Point CMP\QGZ\COA_017_200207_2100_ZSA_Atlas.qgz



Sources:
Cadastral Data: Spatial Services - Department of Finance, Services and Innovation, NSW
Aerial Imagery by nearmap - 21/07/2019

Title:

Study Area - 2100 Zone of Reduced Foundation Capacity

Figure: 5-7

Rev: A

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6 Conclusions and Recommendations

6.1 Conclusions

A probabilistic model combining the current literature understanding of sediment transport processes and the recent geotechnical investigations within the Old Bar to Manning Point region has been developed in this study. This model provides a way to reassess coastal erosion hazards and update existing hazard lines in the context of the new understanding of geological features that may influence different sediment transport components and limit (long-term) recession.

The results show that under all time periods assessed there are sections of the coastline where recession is limited by the known bedrock and the hazard lines converge. Conversely, there are areas along Mitchell Island where the distributions of setback distances are wide, showing areas that are highly sensitive to the input parameters of the model.

Furthermore, there is significant uncertainty for areas that are shown to recede past the coastal barriers and into the estuarine deltas. Due to these uncertainties, these hazard lines have not been shown. For the most part, it is unlikely to be of concern for planning purposes as these areas are highly variable parts of the estuary in the present day due to fluvial changes. However, the town of Manning Point is shown to be in an area of high-risk under future timelines (2060 and 2100) and falls within an area of high uncertainty due to the risk of breakthrough of the Manning Point spit.

However, the results are more certain for most of the shoreline and the output from the model can be used to assign a likelihood of a certain setback distance occurring in a future scenario, allowing for advanced assessments based on risk.

6.2 Study Limitations

The scope of this study has been to develop a probabilistic erosion hazard model based on the existing literature on sediment transport processes in the area, and to incorporate these with the recent geotechnical assessment learnings.

As such, the model is limited by the limited knowledge of each process. Where possible, any likely error in the historical observations of different processes (for example, storm demand, or net sediment budget) has been accounted for with conservativism in the input distributions. However, there is a high degree of uncertainty as to whether these processes and distributions are valid for future climate scenarios. Chiefly, it is possible that climate change could alter the natural regional scale processes and/or the intensity and frequency of storms, both of which the model is highly sensitive to.

Similarly, any uncertainties in the topography or offshore bathymetry can influence the final setback distances. The underlying data carries with it an uncertainty, both horizontal and vertical that may have a small influence on the conclusions (this has been roughly quantified in Section XX). Additionally, these data may change based on natural events, or based on future construction. As such, the model has assumed no changes to these elevations from the survey data that has been used.

There are also inherent uncertainties and limitations in the applied ‘multi-line’ 1-dimensional modelling approach to the recession due to accommodation due to sea level rise. It is not guaranteed that the shoreface will accrete at the same rate as the mean sea level, and overall changes to the sediment transport regimes and the natural beach slope may therefore occur. It is also unclear that there is a critical depth beyond which no sediment exchange (negative and positive) can occur (the so called ‘depth of closure’). However, it is likely that excepting for the other limitations detailed in this section, these assumptions are likely to be the best available tools and the assumption of an equal increase in the shoreface relative to sea level will result in a conservative estimation of the associated setback of the beach.

The study is also limited within the areas adjacent to estuary entrances. The location of river entrances is known to be variable, as is the ‘openness’ of the mouth itself (such as at Farquhar Inlet, an ICOLL). Any fluvial sediment exchange has been accounted for within the net sediment budget values, which may overlook highly local scale effects immediately adjacent to the deltas. Moreover, the volumetric coastline response framework does not account for recession in areas that may respond non-linearly to erosion with breakthroughs and over-wash, adding to the uncertainty. These limitations have been addressed by not reporting on hazard lines in areas adjacent to the delta areas. However, this limitation may impact upon the ability to assess the hazards in detail for the parts of the town of Manning Point.

The modelling has been greatly informed by the geotechnical study that preceded it, however any geotechnical study relies on interpolating between observed features and on drawing inferences from the data. This hazard assessment has sought to use the most conservative end of the inputs drawn from the geotechnical study, and to attempt to qualify the expected range of uncertainty that these unknowns may introduce.

Furthermore, the erosion/recession modelling does not account for fundamental changes to these geotechnical observations under future conditions. For example, while bedrock has been assumed to limit the potential for erosion, any significant weathering and failure of the bedrock has not been accounted for, though may significantly further influence erosion potential. Similarly, changes to the geological constraints around the estuarine entrances can cause similar changes to the conclusions of this study.

Finally, the study assumes that there will be no intervention of erosion processes for the modelled periods. It is possible however, that significant erosion events may result in emergency measures to protect property and amenities, such as by creating seawalls or conducting beach nourishment. Such measures can disrupt the natural sediment transport processes and result in altered likelihoods of setback in different areas than has been identified.

6.3 Recommendations

This study has provided an updated set of erosion hazard lines based on the best understanding of regional sediment transport processes available in the literature. As discussed in the Study Limitations (Section 6.2), there is uncertainty around the future trajectory of these processes. It is recommended that when new data become available, this study is reviewed to ensure that the best possible information is being incorporated. This is particularly important for the long-term scenarios (i.e. 2100).

Furthermore, any fundamental changes to the geological constraints of the study area (such as significant changes to the estuarine entrances, the offshore reefs, or of headland cliff failures) may change the conclusions of this study. It is therefore recommended that such events trigger a review of the assumptions of this study to ensure that the conclusions are still valid.

Finally, it is recommended that any decision maker should consider the outputs of this study (erosion/recession hazard area maps) in combination with this document to ensure that the conclusions are used within their intent. Notably, for very fine-scale planning (where critical decision making depends on the resolution of the inputs to this study) or structural decision-making purposes, it is recommended that a site-specific assessment be conducted (potentially using the conclusions and methodology of this study as a starting point). Such a study would require detailed site-specific survey (geotechnical and topographical) to inform the inputs so as to better understand those specific cases.

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Appendix A Photogrammetric Assessment by Mid Coast Council

A.1 Introduction

An assessment of the historical beach and foredune profile information was completed by Dr Thomas Doyle from the Mid Coast Council, to provide an up-to-date assessment of long-term change on shoreline position and sediment budget trends.

This appendix documents the methodology and results of that assessment.

Note: the scope of the BMT engagement did not extend to a re-assessment of historical beach behaviour and beach / dune sediment volumes. The long-term sediment budget trends applied to the modelling work were based on the technical work outlined herein.

A.1.1 Beach & Dune Profile Data

The assessment of shoreline change and trends in sediment volume over time used the following data sources:

- Photogrammetry data, accessed from the NSW Beach Profile Database
- Available high resolution (LiDAR) digital elevation model datasets

Details of the above two datasets are provided in the below table.

Table A-1 Summary of beach and dune profile information used in the MCC assessment

Profile Years	Location [1]	Data Sources	Comments
1940	OB, MP,	Photogrammetry	
1965	OB, FI, MP, HB	Photogrammetry	
1970	OB (MS)	Photogrammetry	
1972	MP, HB	Photogrammetry	
1976	MP	Photogrammetry	
1981	OB, FI, MP	Photogrammetry	
1986	OB, MP, HB	Photogrammetry	
1989	OB (MS)	Photogrammetry	
1991	OB (MS)	Photogrammetry	
1993	OB, FI, MP	Photogrammetry	
1996 / 1997	OB (MS), HB	Photogrammetry	
2000	OB, FI, MP	Photogrammetry	
2004	OB, FI, MP	Photogrammetry	
2006	OB, FI, MP, HB	Photogrammetry	
2009	OB (MS)	Photogrammetry	
2012	OB, FI, MP, HB	Photogrammetry	
2012	OB, FI, MP, HB	LPI LiDAR	~1 m resolution
2013	OB, FI, MP	Photogrammetry	
2016	OB (MS)	Photogrammetry	
2018	OB, FI, MP, HB	Marine LiDAR	• 5 m resolution dataset

[1] OB - Old Bar Beach tertiary level compartment [OB (MS) – mid section only]; FI - Farquhar Inlet tertiary level compartment; MP - Mitchells Island/Manning Point Beach tertiary level compartment; HB - Harrington Beach tertiary level compartment.

A.2 Methodology

A.2.1 Approach

Coastal foredunes are considered to provide a good representation of coastal change over the medium to long term. Mid Coast Council applied the methodology outlined in the 'Interdecadal Foredune Changes along the Southeast Australian Coastline: 1942 – 2014' research paper by Doyle *et al.* (2019) to investigate coastal trends and aspects of the Old Bar sediment budget across the study areas. Details on the methodology applied for this assessment can be viewed here: https://doi.org/10.3390/jmse7060177.

A.2.2 Sediment Compartments

The Old Bar and Manning Point study area is located within the Manning River secondary sediment compartment, which spans north from Black Head to Crowdy Head. This is a secondary level compartment as defined in the framework outlined by Short and Thom (2018), which can be broken down into a suite of tertiary level (beach scale) compartments.

The following tertiary sediment compartment are identified within the study Wallabi Point to Crowdy Head study area:

- Old Bar Beach, extending from Wallabi Point to Urana Bombora
- Farquhar Inlet
- Mitchells Island to Manning Point
- Harrington Inlet
- Harrington Beach

This assessment of dune change, and historical coastal trends has been completed for the above listed tertiary sediment compartment. In some situations, dune change has been analysed at a sub-compartment scale where a distinct change in the local geomorphology and coastal sediment dynamics is known to occur (i.e. vicinity of Racecourse Creek, and in the lee of the Urana Bombora).

A.2.3 Considerations / Limitations

This analysis incorporates the available photogrammetric information for each of the sediment sub-compartments assessed. This carries several limitations and considerations as follows:

- The number of data points available for each area differ, and therefore some sub-compartments have less certainty about the long-term variability;
- Data points recorded after significant storm events may incorporate fluctuating erosion components that skew the analysis;
- Other ‘one-off’ changes, such as beach nourishment or dredging, may influence the observations;
- Historical data is not necessarily representative of sediment budget changes under long-term conditions due to long-period (multi-decadal) variations in sediment transport behaviour and due to climate change related effects.

A.3 Results

The below results are presented from the photogrammetry assessment in the following subsections:

- Table of results documenting a range of dune volume indicators; and
- Scatter plot showing long term trends in dune volume

The coastal trend proxies outlined below were investigated in an attempt to integrate the main physical processes of sand availability and dune evolution at a decadal timescale.

Abbreviation	**Coastal trend proxies**
Fd. Vol	Foredune volume (m3/m)
FVCR	Foredune volume change rate (m3/m/yr)
Fd Width	Foredune width
HCR	Horizontal change rate (m/yr)
Fd Hgt (max)	Maximum foredune height (m AHD)
VCR (max)	Vertical change rate, maximum foredune height (m/yr)
Fd Hgt (ave):	Average foredune height (m AHD)
VCR (ave)	Vertical change rate, average foredune height (m/yr)
Fd Vol:	Foredune volume (m3)
VCR	Foredune volume change rate (m3/yr)

A.3.1 Old Bar Beach

Table A-2 Old Bar Beach (Total Beach) Coastal Change Assessment Results

Year	Fd. Vol (m3/ m)	FVCR (m3/ m/yr)	Fd Width (m)	HCR (m/yr)	Fd Hgt (max) (m)	VCR (max) (m/yr)	Fd Hgt (ave) (m)	VCR (ave) (m/yr)	Fd Vol (m3):	FVCR (m3/ yr)
1940	575.3		83.3		11.0		7.1		1737601.3	
1965	509.3	-2.6	76.6	-0.3	11.7	0.0	7.0	0.0	1942350.7	8190.0
1981	456.2	-3.3	72.3	-0.3	11.7	0.0	6.4	0.0	1145509.6	-49802.6
1986	491.0	7.0	75.9	0.7	11.9	0.0	6.8	0.1	1884112.2	147720.5
1993	485.4	-0.8	76.1	0.0	12.4	0.1	6.9	0.0	1819545.3	-9223.9
2000	463.8	-3.1	73.1	-0.4	11.8	-0.1	6.7	0.0	1747256.3	-10327.0
2004	447.5	-4.1	69.7	-0.9	11.9	0.0	6.9	0.0	1681878.3	-16344.5
2006	435.8	-5.9	67.2	-1.3	11.6	-0.1	6.8	-0.1	1623380.5	-29248.9
2012	317.0	-19.8	56.0	-1.9	12.7	0.2	6.0	-0.1	1167085.1	-76049.2
2013	350.4	33.4	59.2	3.2	11.1	-1.6	6.2	0.2	1277803.0	110717.9
2018	316.8	-6.7	53.5	-1.2	12.6	0.3	6.2	0.0	1152094.5	-25141.7

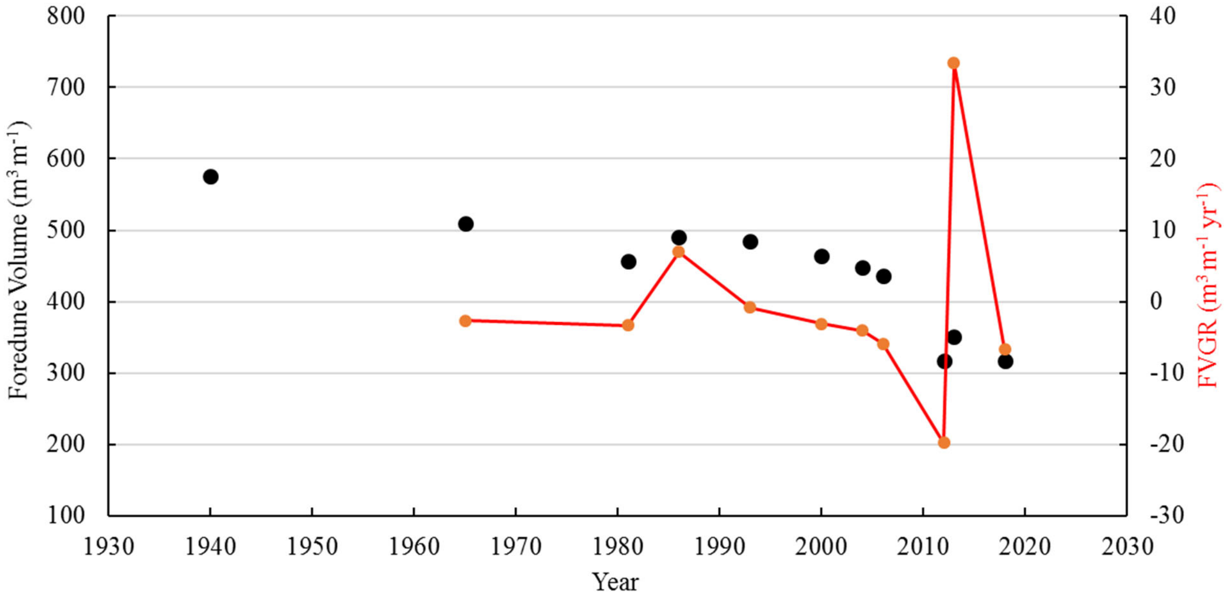


Figure A-1 Old Bar Beach (Total Beach) Coastal Change Trends

Black points - foredune volume (m3/m); red line - foredune volume rate of change (m3/m/yr)

Table A-3 Old Bar Beach (Mid-Section) Coastal Change Assessment Results

Year	Fd. Vol (m3/m)	FVCR (m3/m/yr)	Fd Width (m)	HCR (m/yr)	Fd Hgt (max) (m)	VCR (max) (m/yr)	Fd Hgt (ave) (m)	VCR (ave) (m/yr)	Fd Vol (m3):	FVCR (m3/yr)
1940	481.7		75.5		11.0		6.8		739304.0	
1965	468.9	-0.5	76.3	0.0	9.8	-0.1	6.4	0.0	762291.0	919.5
1970	510.9	8.4	82.4	1.2	11.0	0.2	6.7	0.1	830371.4	13616.1
1981	474.1	-3.3	78.7	-0.3	10.5	0.0	5.8	-0.1	833107.2	248.7
1986	473.7	-0.1	75.1	-0.7	11.1	0.1	6.5	0.1	774003.9	-11820.7
1989	462.8	-3.6	74.4	-0.2	11.0	0.0	6.4	0.0	765712.8	-2763.7
1991	458.3	-2.2	77.2	1.4	10.3	-0.4	6.3	-0.1	720528.1	-22592.4
1993	468.6	5.1	76.4	-0.4	11.4	0.5	6.7	0.2	746425.5	12948.7
1996	478.5	3.3	76.9	0.2	11.0	-0.1	6.8	0.0	749952.5	1175.7
2000	480.2	0.4	76.4	-0.1	10.6	-0.1	6.7	0.0	771485.4	5383.2
2004	479.0	-0.3	74.5	-0.5	10.7	0.0	6.8	0.0	749427.0	-5514.6
2006	450.4	-14.3	72.1	-1.2	10.6	-0.1	6.6	-0.1	706460.5	-21483.3
2009	385.5	-21.6	63.8	-2.8	10.5	0.0	6.4	0.0	613906.1	-30851.5
2012	305.5	-26.7	56.1	-2.6	9.4	-0.3	5.3	-0.4	447600.3	-55435.3
2013	337.5	32.0	59.5	3.4	9.3	-0.1	6.0	0.7	492435.3	44835.0
2016	312.6	-8.3	70.6	3.7	7.9	-0.5	4.5	-0.5	156693.9	-111913.8
2018	330.5	9.0	58.0	-6.3	9.8	0.9	5.6	0.5	471121.5	157213.8

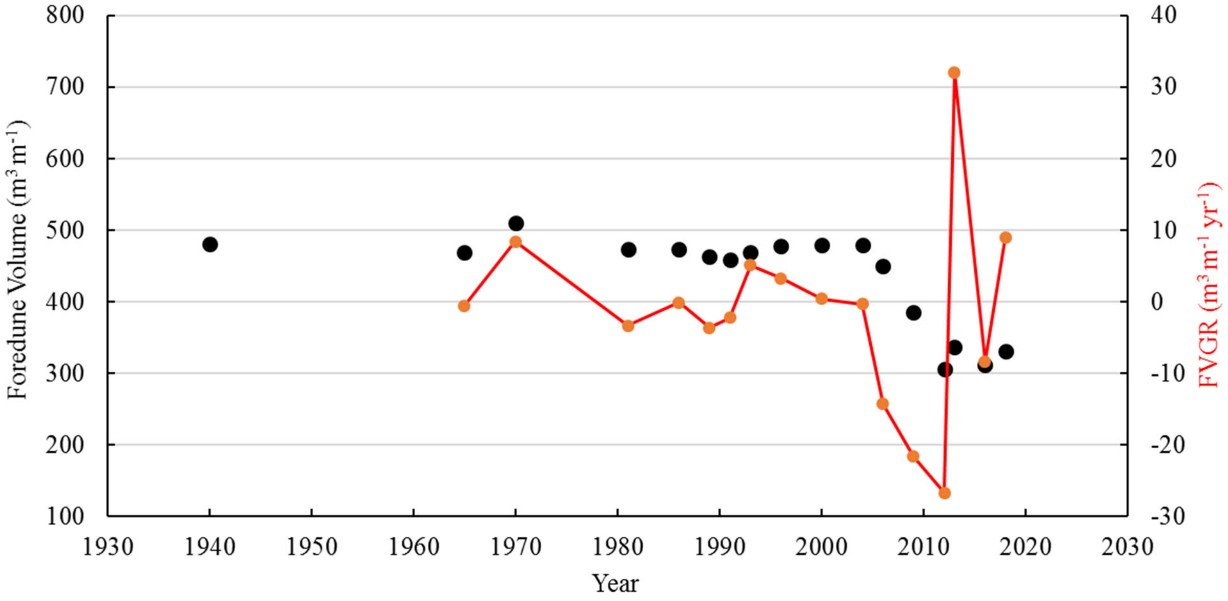


Figure A-2 Old Bar Beach (Mid-Section) Coastal Change Trends

Black points - foredune volume (m3/m); red line - foredune volume rate of change (m3/m/yr)

A.3.2 Farquhar Inlet

Table A-4 Urana Bombora to Farquhar Inlet Coastal Change Assessment Results

Year	Fd. Vol (m3/ m)	FVCR (m3/ m/yr)	Fd Width (m)	HCR (m/yr)	Fd Hgt (max) (m)	VCR (max) (m/yr)	Fd Hgt (ave) (m)	VCR (ave) (m/yr)	Fd Vol (m3):	FVCR (m3/ yr)
1965	*383.6*		58.5		12.8		6.9		243384.4	
1981	*397.3*	*0.9*	69.3	0.7	12.9	0.0	6.0	-0.1	249671.8	393.0
1993	*408.3*	*0.9*	61.2	-0.7	13.3	0.0	7.0	0.1	257239.8	630.7
2000	*373.2*	*-5.0*	56.6	-0.7	13.0	0.0	6.8	0.0	235010.2	-3175.6
2004	*372.4*	*-0.2*	61.0	1.1	13.3	0.1	6.5	-0.1	235299.1	72.2
2006	*371.6*	*-0.4*	61.5	0.3	13.1	-0.1	6.3	-0.1	235544.7	122.8
2012	*313.8*	*-9.6*	47.7	-2.3	14.0	0.1	7.1	0.1	228951.0	-1098.9
2013	*334.8*	*20.9*	57.8	10.2	13.5	-0.5	6.2	-0.9	211189.7	-17761.3
2018	*287.6*	*-9.4*	47.8	-2.0	13.9	0.1	6.5	0.1	207713.6	-695.2

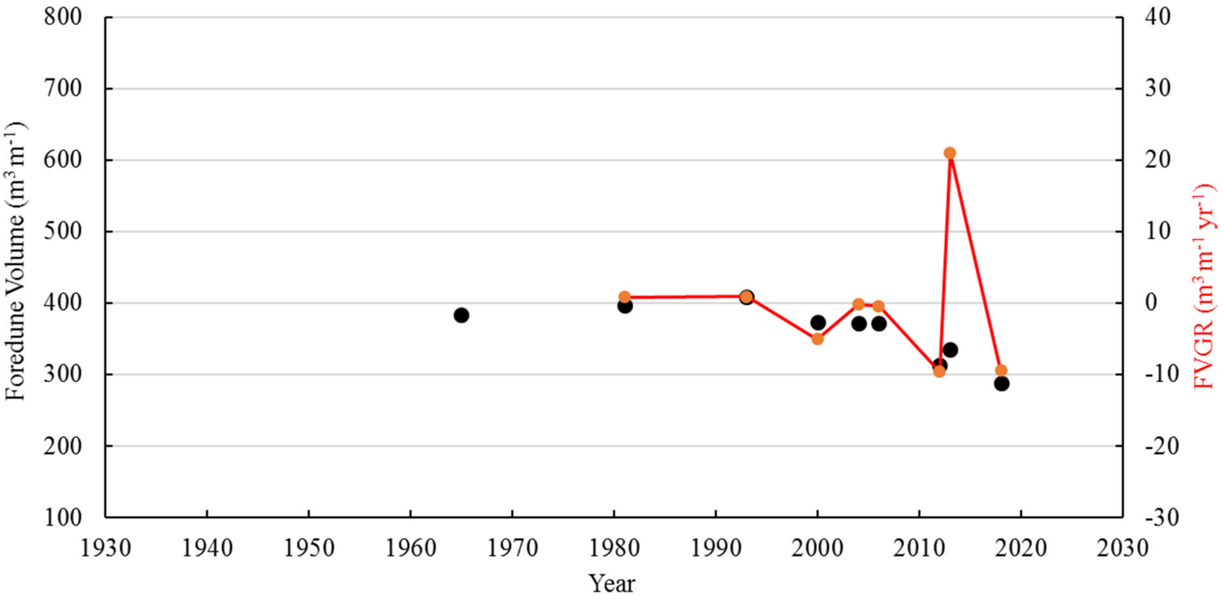


Figure A-3 Urana Bombora to Farquhar Inlet Coastal Change Trends

Black points - foredune volume (m3/m); red line - foredune volume rate of change (m3/m/yr)

Table A-5 Farquhar Inlet Coastal Change Assessment Results

Year	Fd. Vol (m3/ m)	FVCR (m3/ m/yr)	Fd Width (m)	HCR (m/yr)	Fd Hgt (max) (m)	VCR (max) (m/yr)	Fd Hgt (ave) (m)	VCR (ave) (m/yr)	Fd Vol (m3):	FVCR (m3/ yr)
1965	*292.1*		113.8		4.4		2.6		478884.0	
1981	*340.6*	*3.0*	125.0	0.7	5.3	0.1	2.7	0.0	602050.9	7697.9
1993	*195.2*	*-12.1*	83.5	-3.5	3.9	-0.1	2.4	0.0	342825.5	-21602.1
2000	*210.8*	*2.2*	79.3	-0.6	4.9	0.1	2.7	0.0	387281.2	6350.8
2004	*235.6*	*6.2*	98.5	4.8	4.2	-0.2	2.4	-0.1	488087.8	25201.7
2006	*278.7*	*21.5*	118.8	10.1	5.0	0.4	2.4	0.0	579690.3	45801.2
2012	*301.2*	*3.8*	106.9	-2.0	5.3	0.1	2.8	0.1	530471.3	-8203.2
2013	*307.1*	*5.9*	126.0	19.1	5.2	-0.2	2.4	-0.5	590163.0	59691.7
2018	*190.7*	*-23.3*	66.6	-11.9	6.6	0.3	2.9	0.1	395862.1	-38860.2

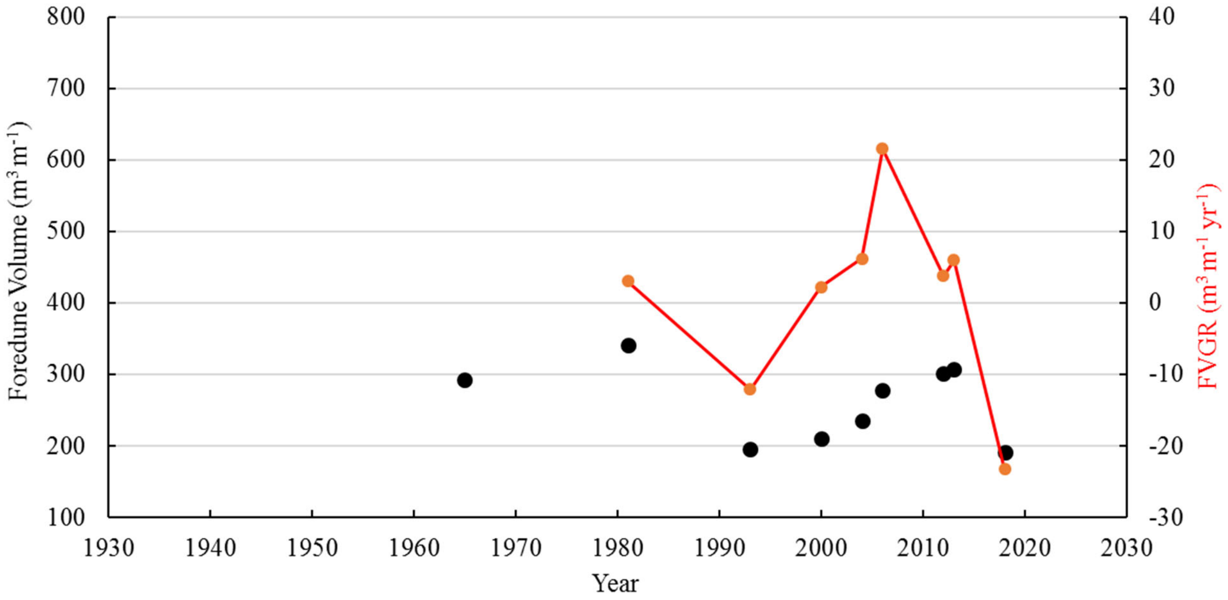


Figure A-4 Farquhar Inlet Coastal Change Trends

Black points - foredune volume (m3/m); red line - foredune volume rate of change (m3/m/yr)

A.3.3 Mitchells Island to Manning Point

Table A-6 Manning Point to Farquhar Inlet Coastal Change Assessment Results

Year	Fd. Vol (m3/ m)	FVCR (m3/ m/yr)	Fd Width (m)	HCR (m/yr)	Fd Hgt (max) (m)	VCR (max) (m/yr)	Fd Hgt (ave) (m)	VCR (ave) (m/yr)	Fd Vol (m3)	FVCR (m3/ yr)
1940	*707.2*		110.2		10.8		6.5		6799543.8	
1965	*599.3*	*-4.3*	95.5	-0.6	12.6	0.1	6.4	0.0	5784152.6	-40615.7
1972	*533.6*	*-9.4*	91.9	-0.5	11.5	-0.2	5.8	-0.1	5128772.2	-93625.8
1976	*510.1*	*-5.9*	90.5	-0.4	11.5	0.0	5.7	0.0	4895078.5	-58423.4
1981	*483.9*	*-5.2*	88.9	-0.3	12.4	0.2	5.5	0.0	4740827.3	-30850.2
1986	*463.3*	*-4.1*	85.8	-0.6	12.4	0.0	5.5	0.0	4453261.5	-57513.1
1993	*478.7*	*2.2*	87.3	0.2	12.1	0.0	5.6	0.0	4597406.9	20592.2
2000	*431.9*	*-6.7*	75.5	-1.7	12.3	0.0	5.8	0.0	4227646.3	-52822.9
2004	*445.7*	*3.4*	76.3	0.2	12.2	0.0	5.9	0.0	4349213.8	30391.9
2006	*417.9*	*-13.9*	78.6	1.1	12.2	0.0	5.8	-0.1	4401188.4	25987.3
2012	*336.9*	*-13.5*	64.5	-2.3	13.9	0.3	5.4	-0.1	3283140.7	-186341.3
2013	*329.6*	*-7.2*	64.1	-0.4	12.0	-2.0	5.3	-0.1	3197649.2	-85491.6
2018	*303.7*	*-5.2*	62.9	-0.3	14.1	0.4	4.9	-0.1	2974353.0	-44659.2

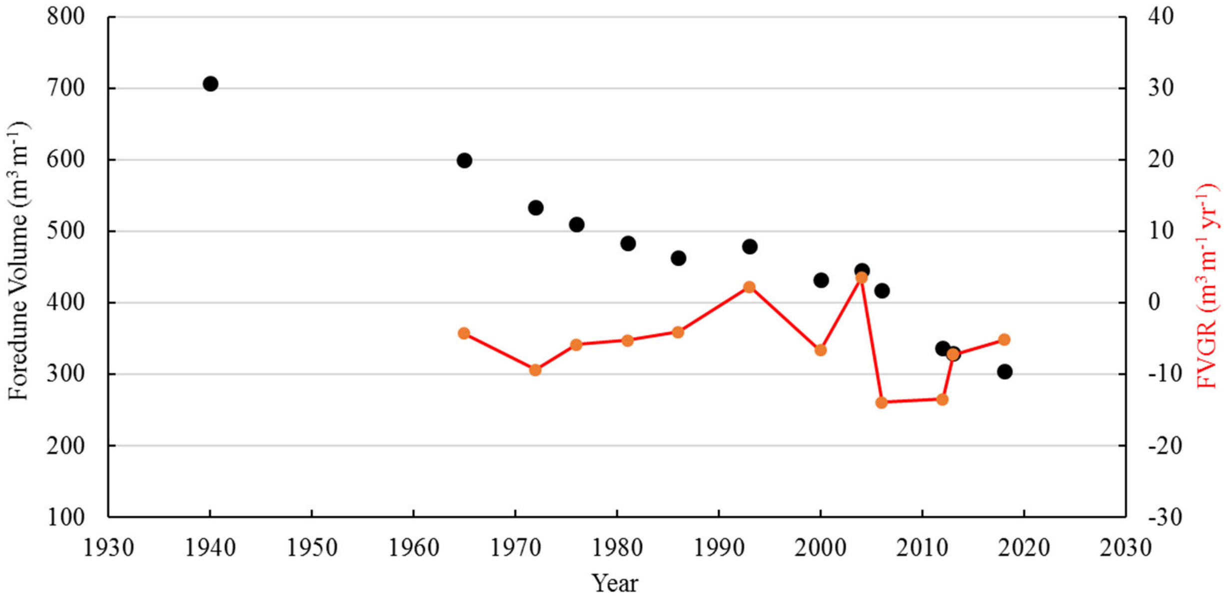


Figure A-5 Manning Point to Farquhar Inlet Coastal Change Trends

Black points - foredune volume (m3/m); red line - foredune volume rate of change (m3/m/yr)

A.3.4 Harrington Inlet

No dune areas occur within the Harington Inlet tertiary sediment compartment, and therefore no assessment of coastal change has been completed for Harrington Inlet in this assessment (which was limited to analysing dune change through time).

A.3.5 Harrington Beach

Table A-7 Harrington Beach Coastal Change Assessment Results

Year	Fd. Vol (m3/ m)	FVCR (m3/ m/yr)	Fd Width (m)	HCR (m/yr)	Fd Hgt (max) (m)	VCR (max) (m/yr)	Fd Hgt (ave) (m)	VCR (ave) (m/yr)	Fd Vol (m3)	FVCR (m3/ yr)
1965	*534.4*		64.8		15.0		8.3		2907162.1	
1972	*438.1*	*-13.8*	66.2	0.2	13.0	-0.3	6.7	-0.2	2377012.0	-75735.7
1986	*517.8*	*5.7*	79.9	1.0	12.0	-0.1	6.5	0.0	2810679.2	30976.2
1997	*634.7*	*10.6*	104.1	2.2	12.8	0.1	6.1	0.0	3448941.5	58023.8
2006	*647.9*	*1.5*	106.4	0.2	13.1	0.0	6.1	0.0	3512793.6	7094.7
2012	*739.4*	*15.3*	122.6	2.7	14.2	0.2	6.1	0.0	4202844.4	115008.5
2013	*736.4*	*-3.0*	121.0	-1.6	13.5	-0.6	6.2	0.0	3995604.3	-207240.2
2018	*742.5*	*1.2*	124.3	0.7	14.6	0.2	6.0	0.0	4249346.3	50748.4

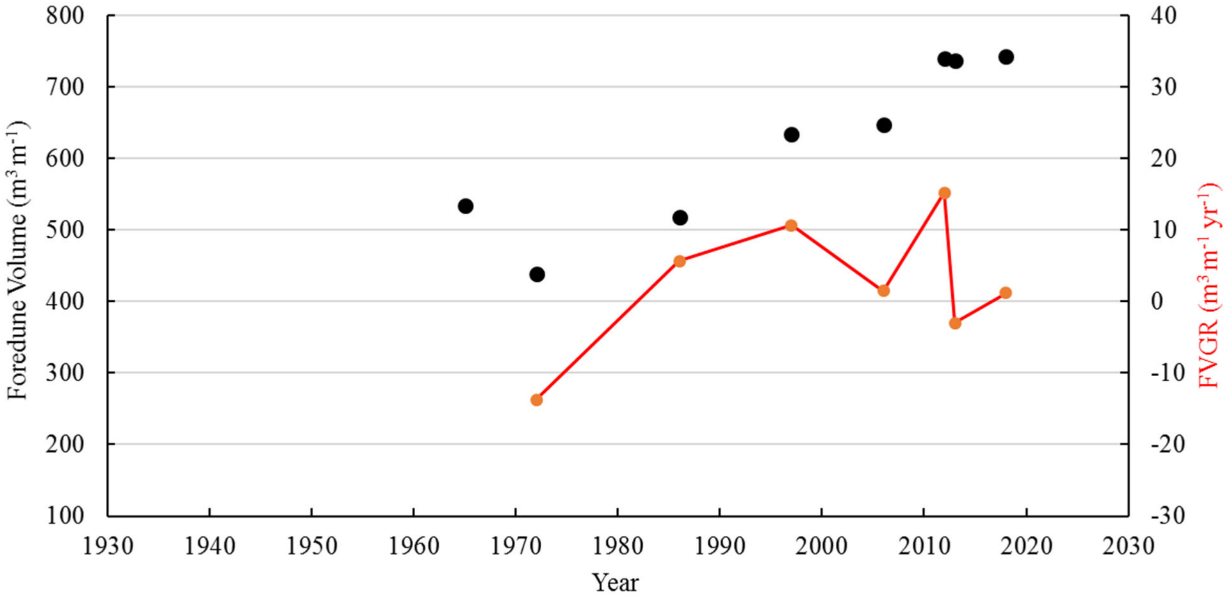


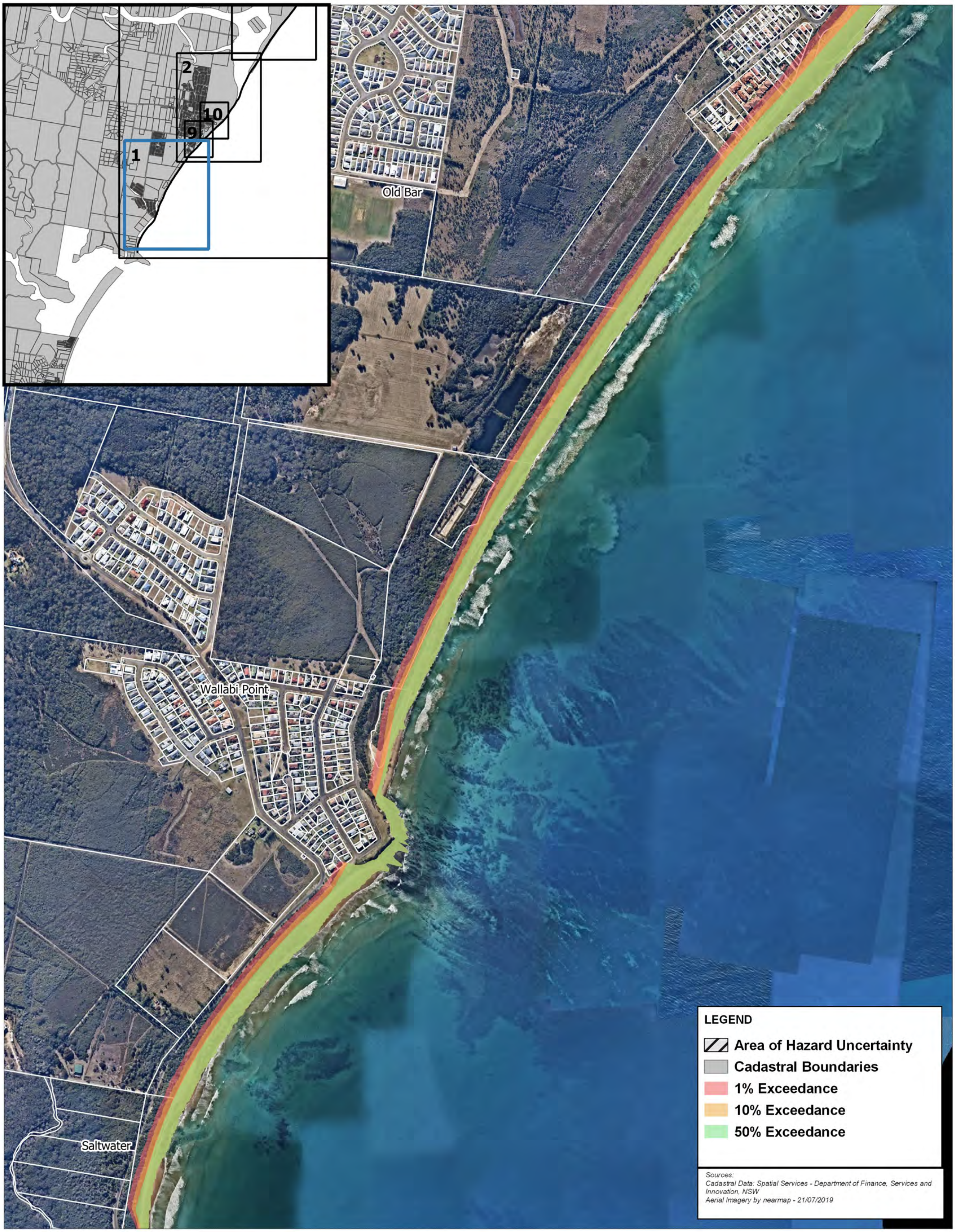
Figure A-6 Harrington Beach Coastal Change Trends

Black points - foredune volume (m3/m); red line - foredune volume rate of change (m3/m/yr)

A.4 Application

The up-to-date assessment of coastal change undertaken by Mid Coast Council forms the primary source of information for the cumulative net sediment budget effects of the probabilistic model developed to reassess the erosion and recession coastal hazard, as conducted by BMT.

Appendix B Present Day Zone of Slope Adjustment Capacity Mapping



Sources:
Cadastral Data: Spatial Services - Department of Finance, Services and Innovation, NSW
Aerial Imagery by nearmap - 21/07/2019

Title:

Wallabi Point - Present Day Zone of Slope Adjustment

Figure: **B-1**

Rev: **A**

N

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www.bmt.org

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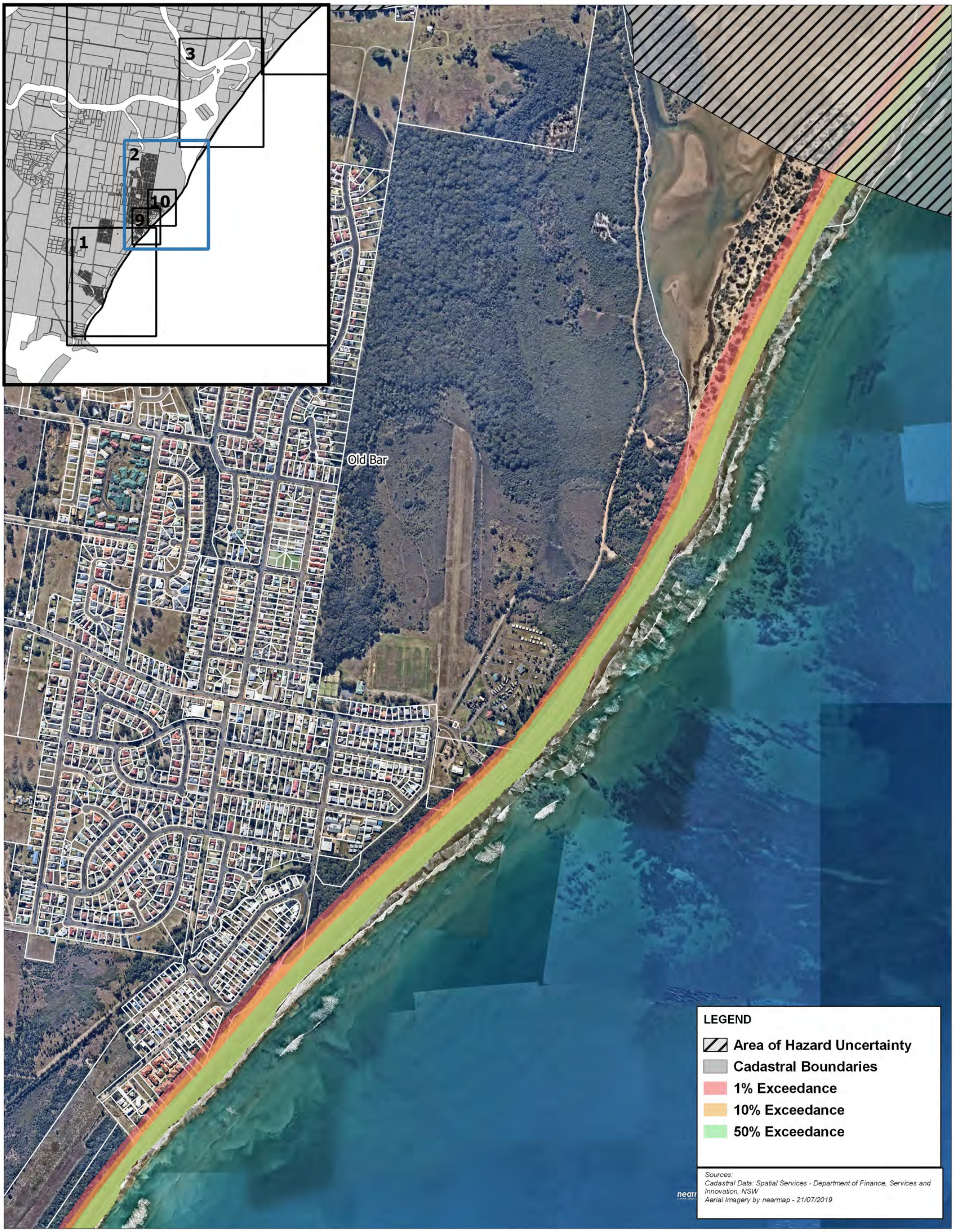

Sources:
Cadastral Data: Spatial Services - Department of Finance, Services and Innovation, NSW
Aerial Imagery by nearmap - 21/07/2019

Title:

Old Bar - Present Day Zone of Slope Adjustment

Figure: **B-2**

Rev: **A**

N

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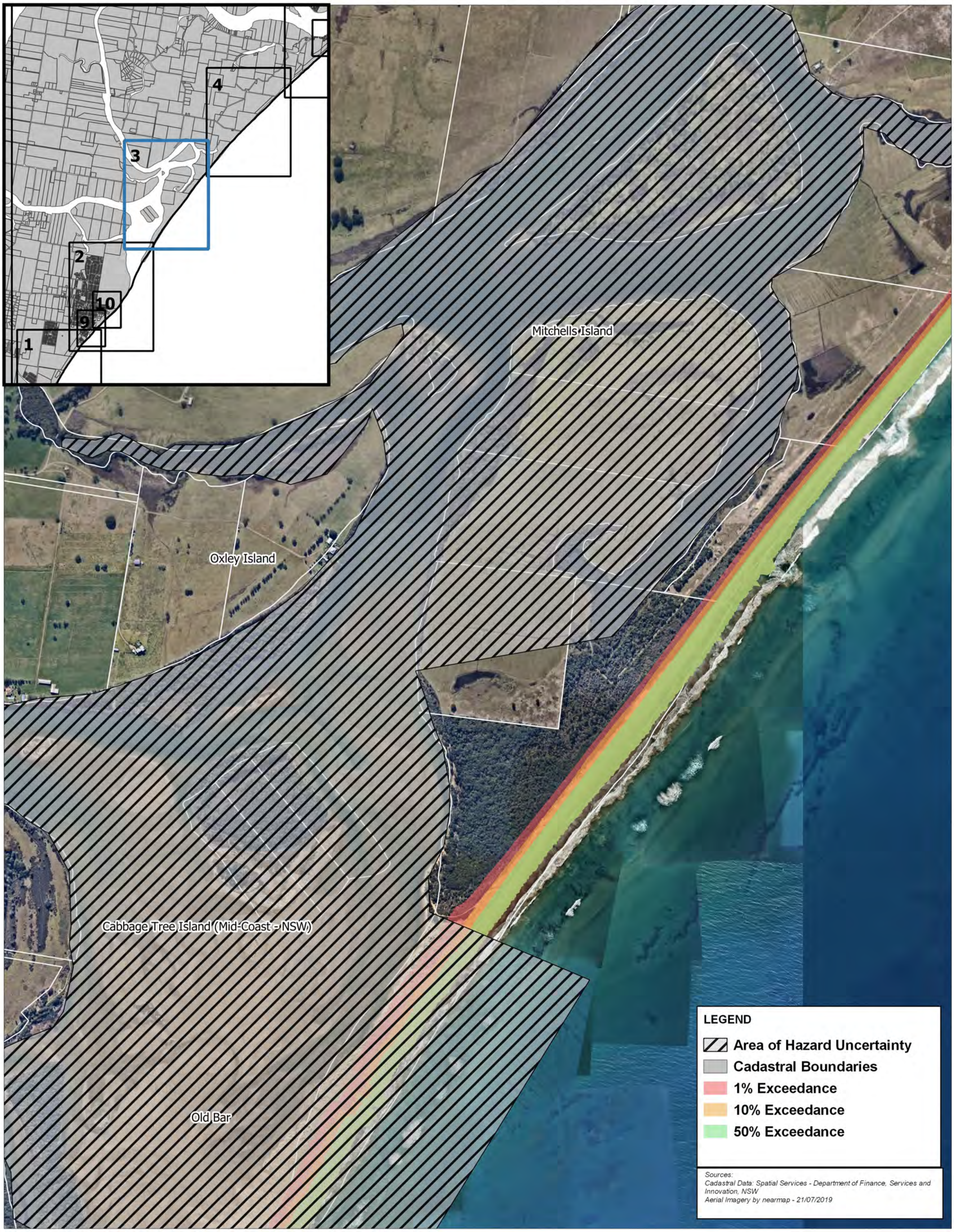
www.bmt.org

Filepath: I:\N21005.i.ajs.Old Bar Manning Point CMP\QGZ\COA_017_200207_2020_ZSA_Atlas.qgz



Sources:
Cadastral Data: Spatial Services - Department of Finance, Services and Innovation, NSW
Aerial Imagery by nearmap - 21/07/2019

Title:
Farquhar Inlet - Present Day Zone of Slope Adjustment

Figure: **B-3**

Rev: **A**

N

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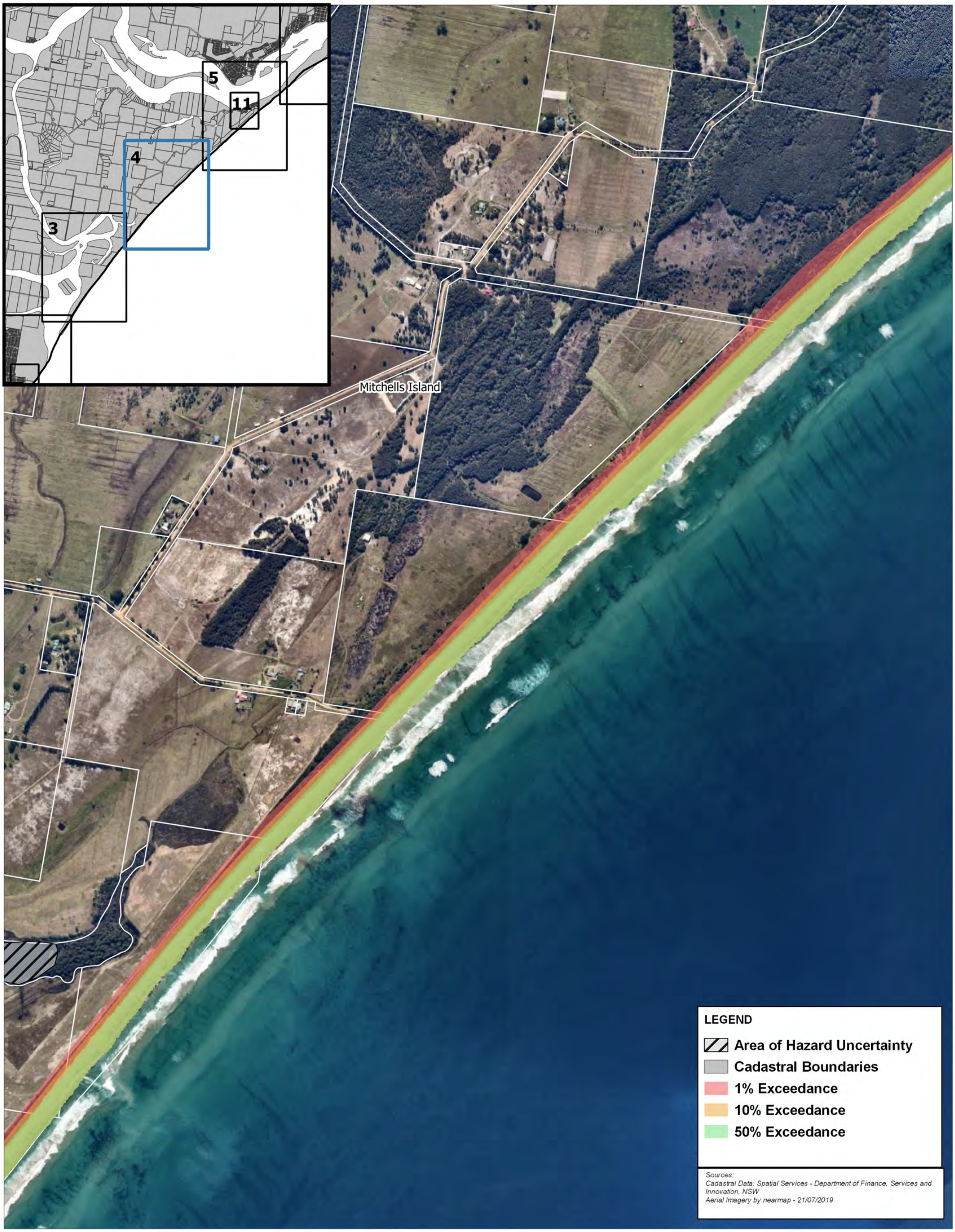
www.bmt.org

Filepath: I:\N21005.i.ajs.Old Bar Manning Point CMP\QGZ\COA_017_200207_2020_ZSA_Atlas.qgz



LEGEND

- ▨ Area of Hazard Uncertainty
- ⬜ Cadastral Boundaries
- 🟥 1% Exceedance
- 🟧 10% Exceedance
- 🟩 50% Exceedance

Sources:
Cadastral Data: Spatial Services - Department of Finance, Services and Innovation, NSW
Aerial Imagery by nearmap - 21/07/2019

Title:

Mitchells Island - Present Day Zone of Slope Adjustment

Figure: **B-4**

Rev: **A**

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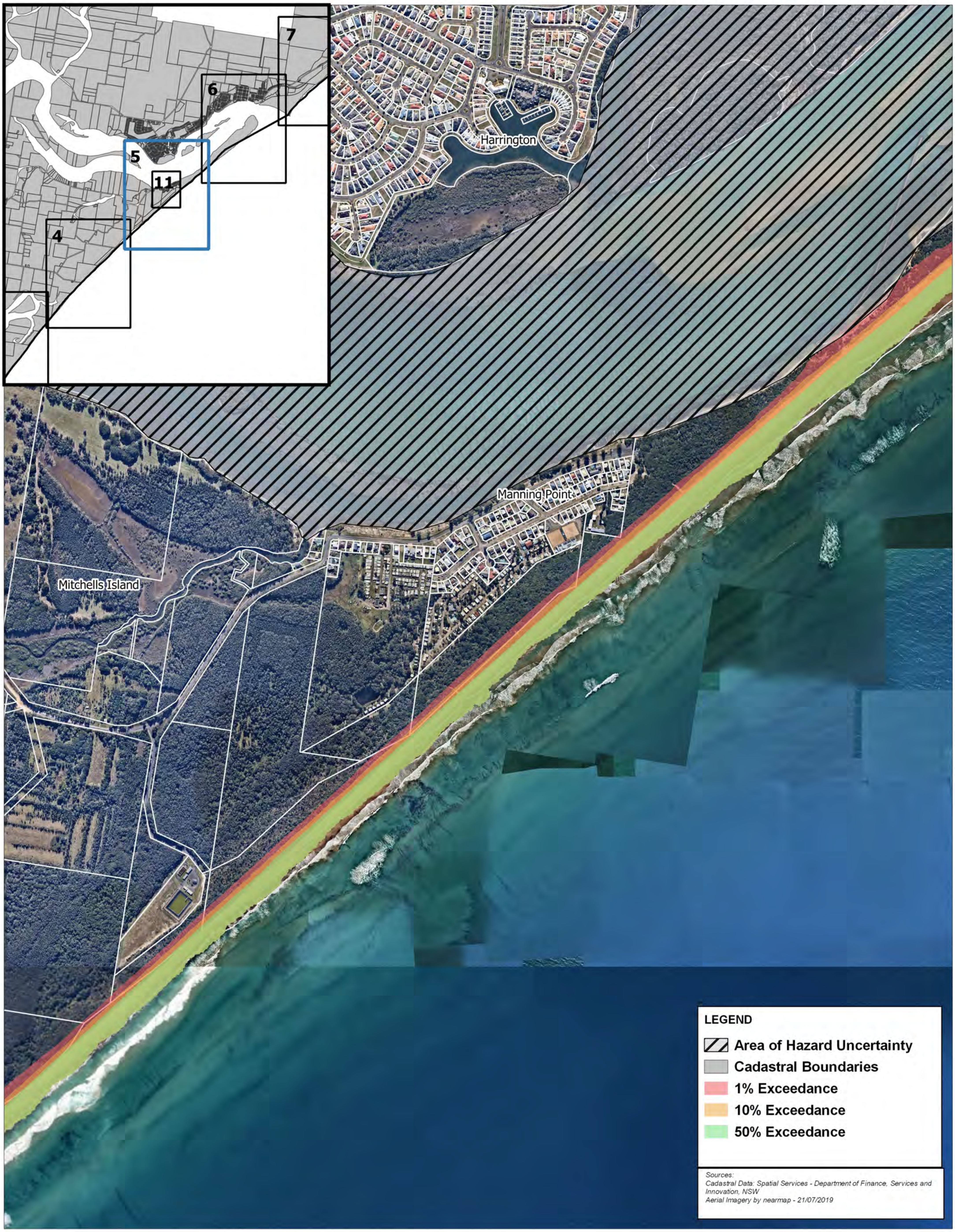


Sources:
Cadastral Data: Spatial Services - Department of Finance, Services and Innovation, NSW
Aerial Imagery by nearmap - 21/07/2019

Title:
Manning Point - Present Day Zone of Slope Adjustment

Figure:
B-5

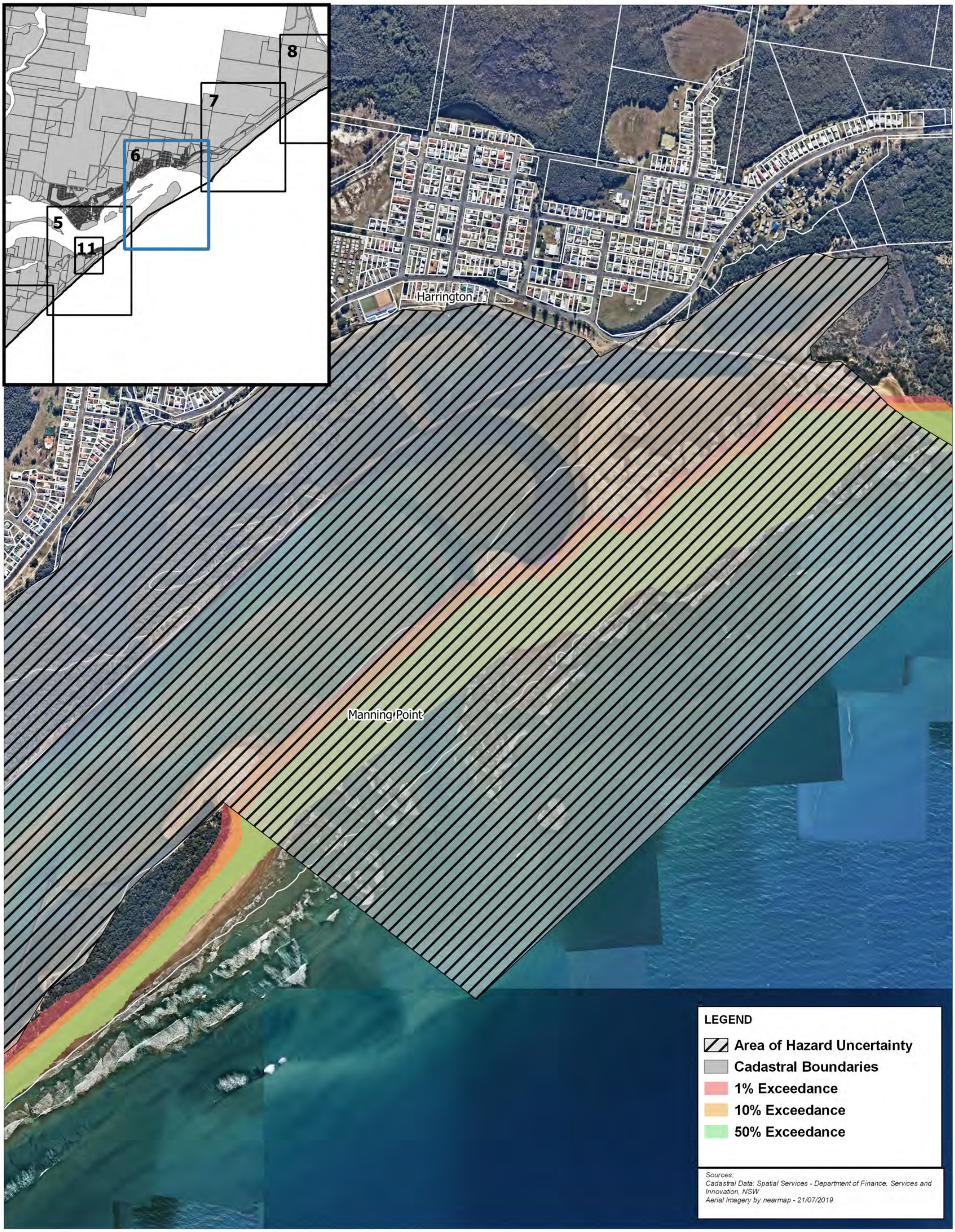
Rev:
A

N

0 200 400 600 800 m

BMT
www.bmt.org

Filepath: I:\N21005.i.ajs.Old Bar Manning Point CMP\QGZ\COA_017_200207_2020_ZSA_Atlas.qgz



Sources:
Cadastral Data: Spatial Services - Department of Finance, Services and Innovation, NSW
Aerial Imagery by nearmap - 21/07/2019

Title:

Harrington Entrance - Present Day Zone of Slope Adjustment

Figure:

B-6

Rev:

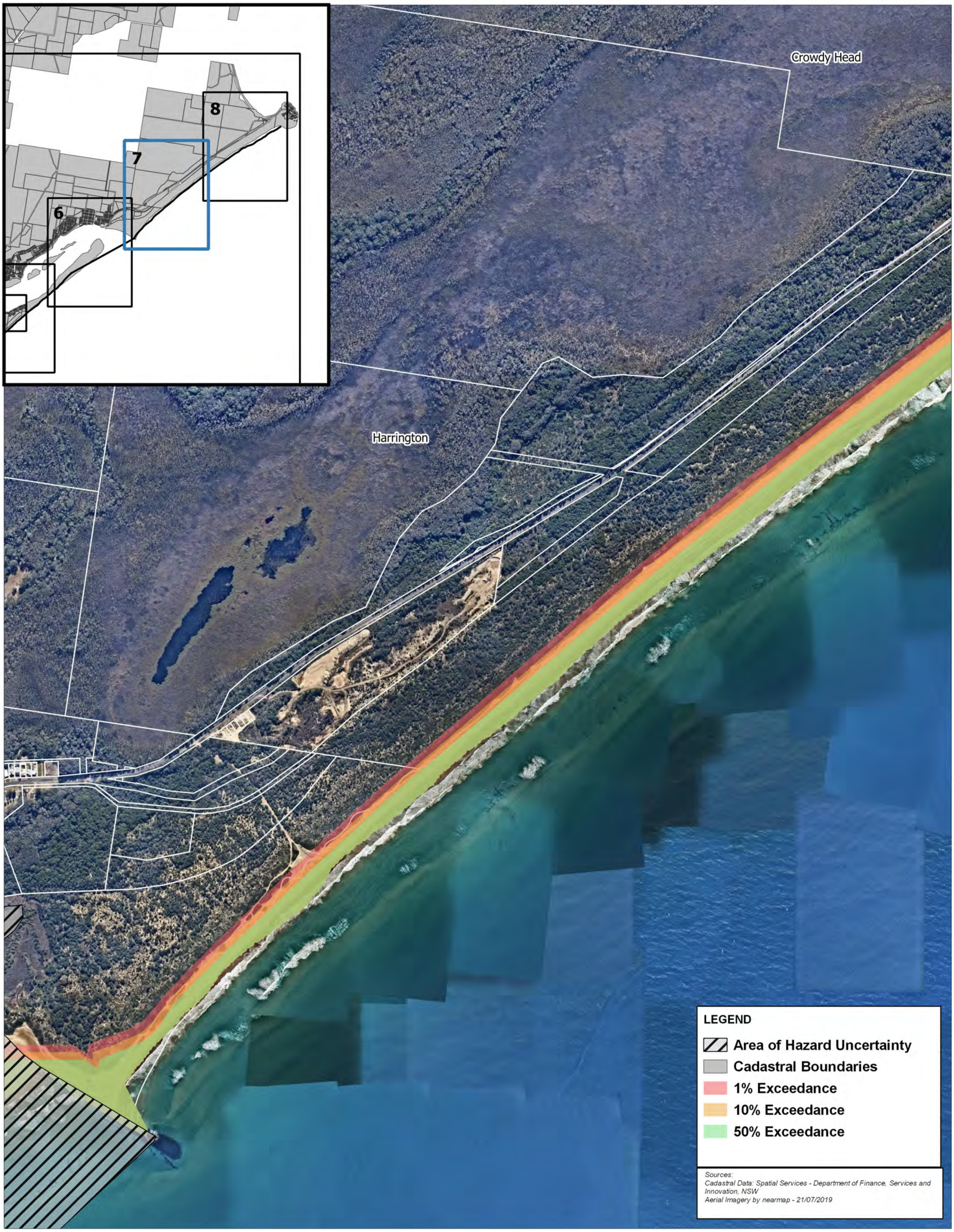
A

N

0 200 400 600 800 m

BMT
www.bmt.org

Filepath: I:\N21005.i.ajs.Old Bar Manning Point CMP\QGZ\COA_017_200207_2020_ZSA_Atlas.qgz



Sources:
Cadastral Data: Spatial Services - Department of Finance, Services and Innovation, NSW
Aerial Imagery by nearmap - 21/07/2019

Title:

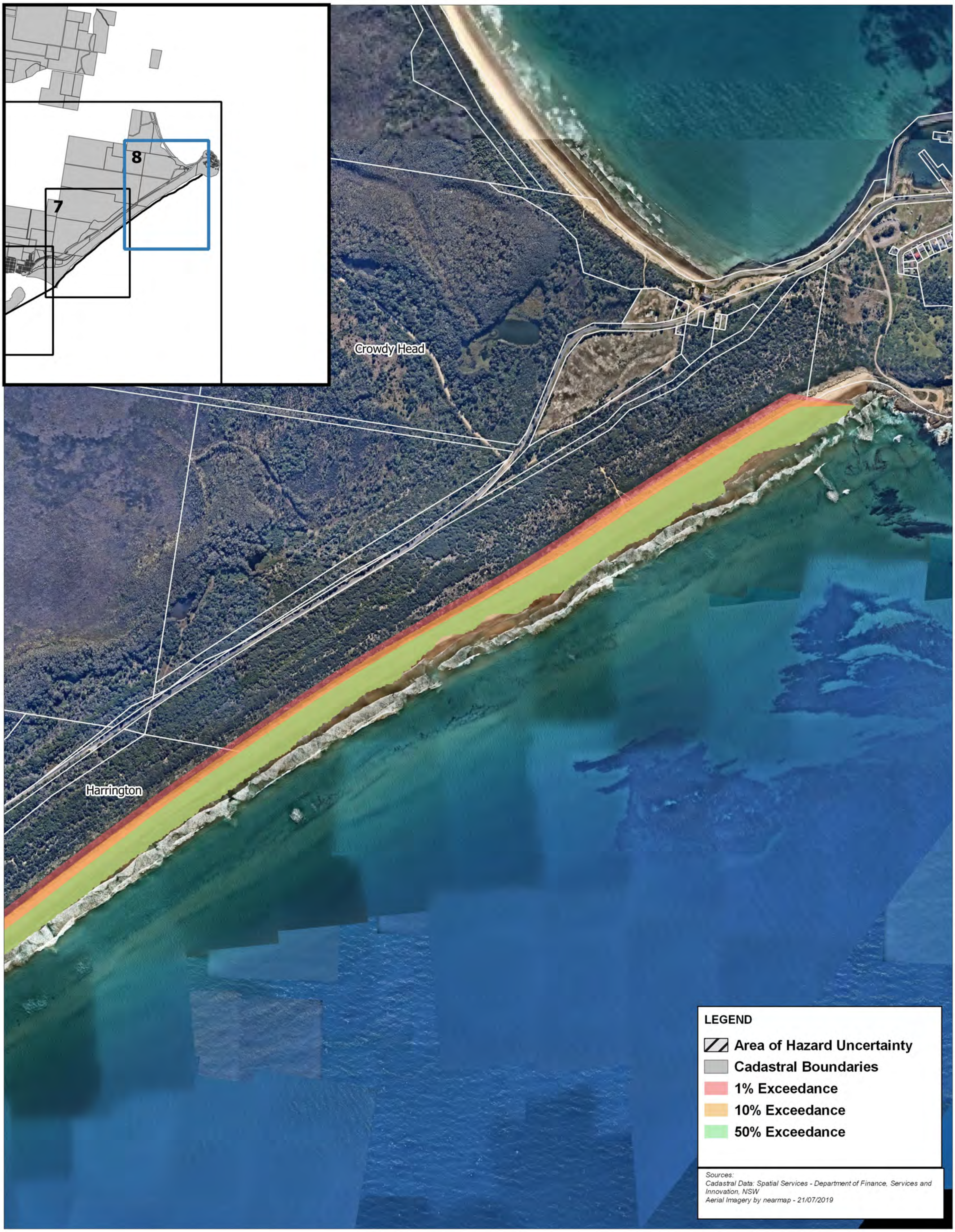
Harrington Beach (South) - Present Day Zone of Slope Adjustment

Figure: **B-7**

Rev: **A**

BMT
www.bmt.org

Filepath: I:\N21005.i.ajs.Old Bar Manning Point CMP\QGZ\COA_017_200207_2020_ZSA_Atlas.qgz



LEGEND

- ▨ Area of Hazard Uncertainty
- ⬜ Cadastral Boundaries
- 🟥 1% Exceedance
- 🟧 10% Exceedance
- 🟩 50% Exceedance

Sources:
Cadastral Data: Spatial Services - Department of Finance, Services and Innovation, NSW
Aerial Imagery by nearmap - 21/07/2019

Title:

Harrington Beach (North) - Present Day Zone of Slope Adjustment

Figure: **B-8**

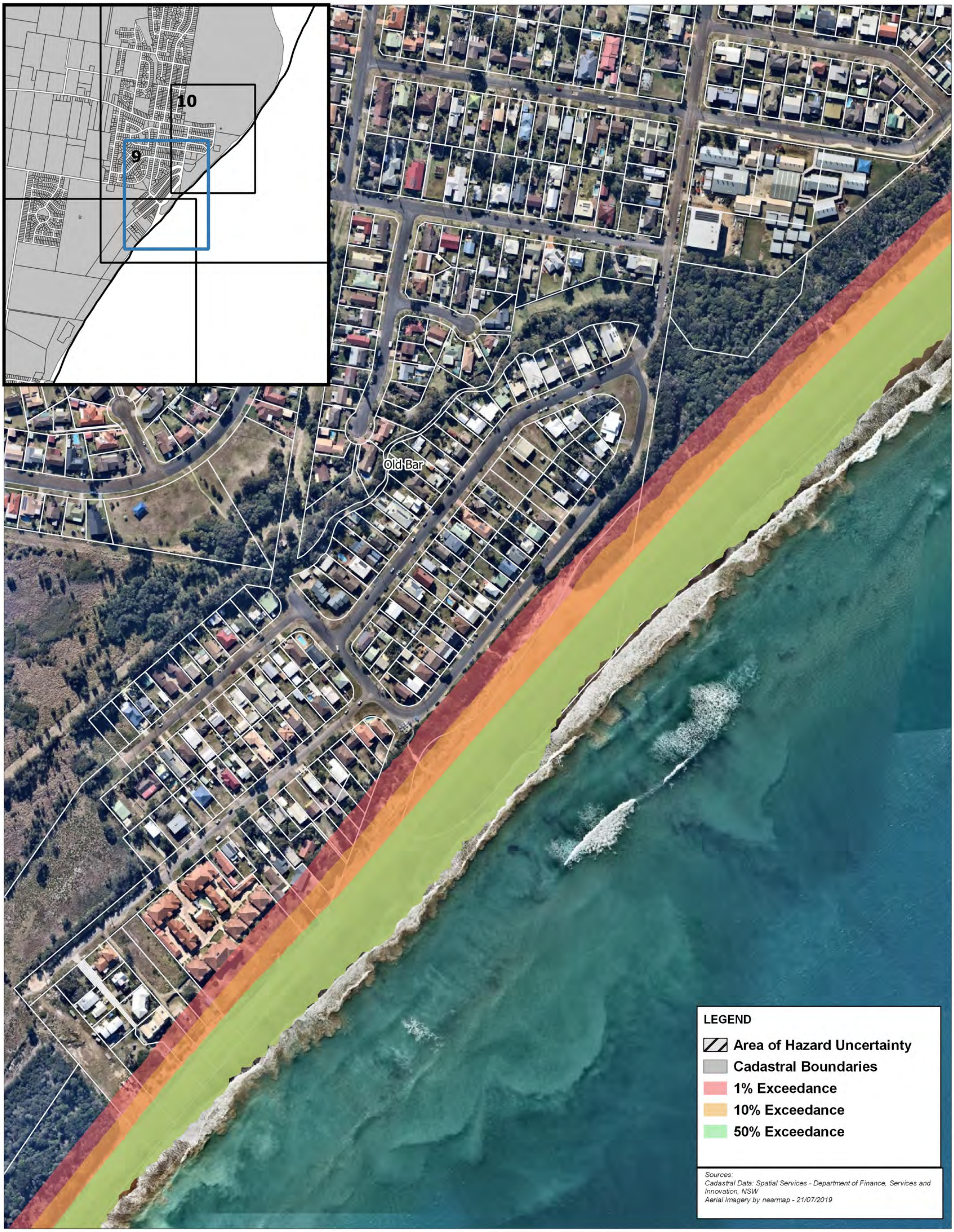
Rev: **A**

N

0 200 400 600 800 m

BMT
www.bmt.org

Filepath: I:\N21005.i.ajs.Old Bar Manning Point CMP\QGZ\COA_017_200207_2020_ZSA_Atlas.qgz



Sources:
Cadastral Data: Spatial Services - Department of Finance, Services and Innovation, NSW
Aerial Imagery by nearmap - 21/07/2019

Title:

Old Bar (South) - Present Day Zone of Slope Adjustment

Figure: **B-9**

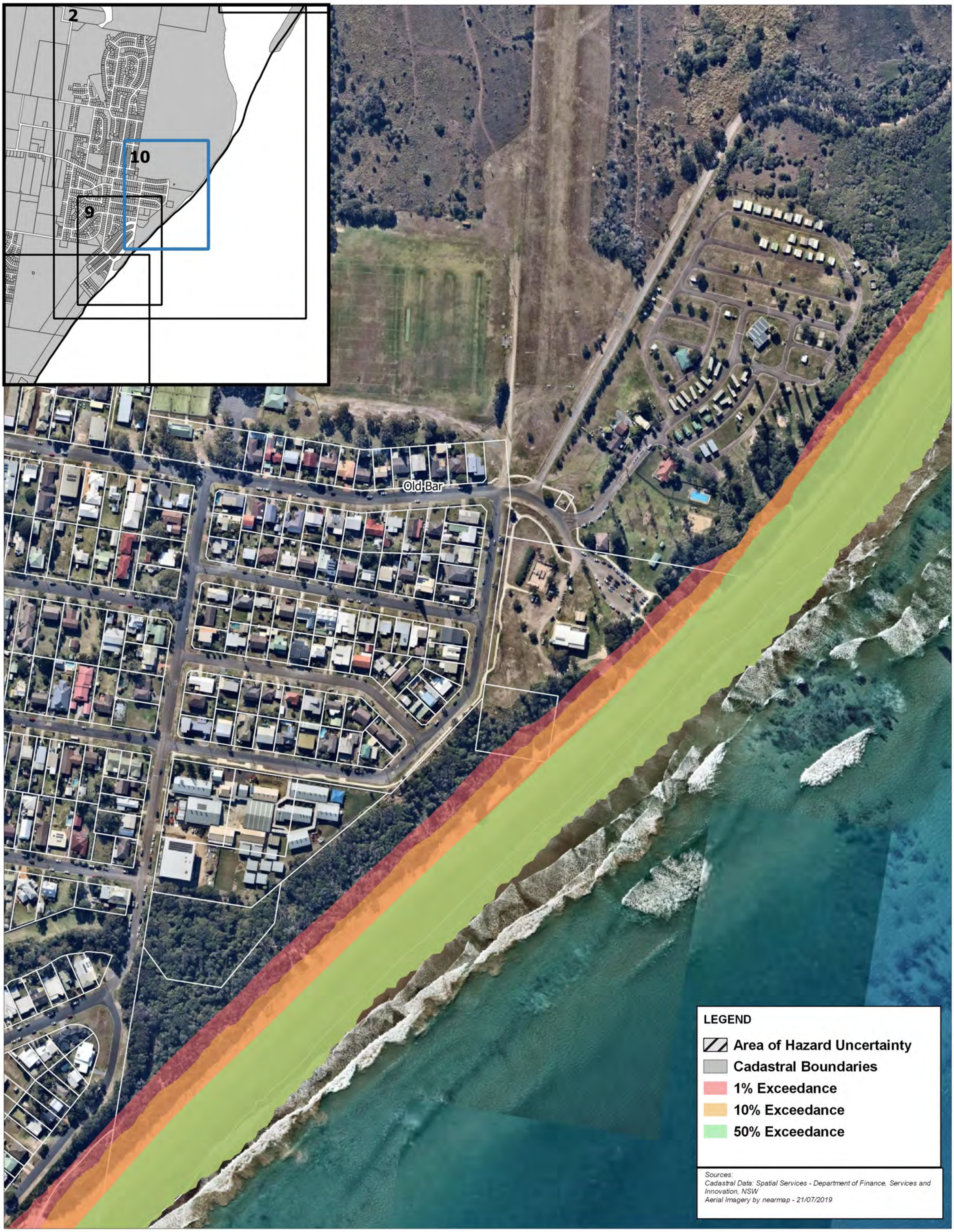
Rev: **A**

N

0 70 140 210 280 m

BMT
www.bmt.org

Filepath: I:\N21005.i.ajs.Old Bar Manning Point CMP\QGZ\COA_017_200207_2020_ZSA_Atlas.qgz



Sources:
Cadastral Data: Spatial Services - Department of Finance, Services and Innovation, NSW
Aerial Imagery by nearmap - 21/07/2019

Title:

Old Bar (North) - Present Day Zone of Slope Adjustment

Figure: **B-10**

Rev: **A**

BMT
www.bmt.org

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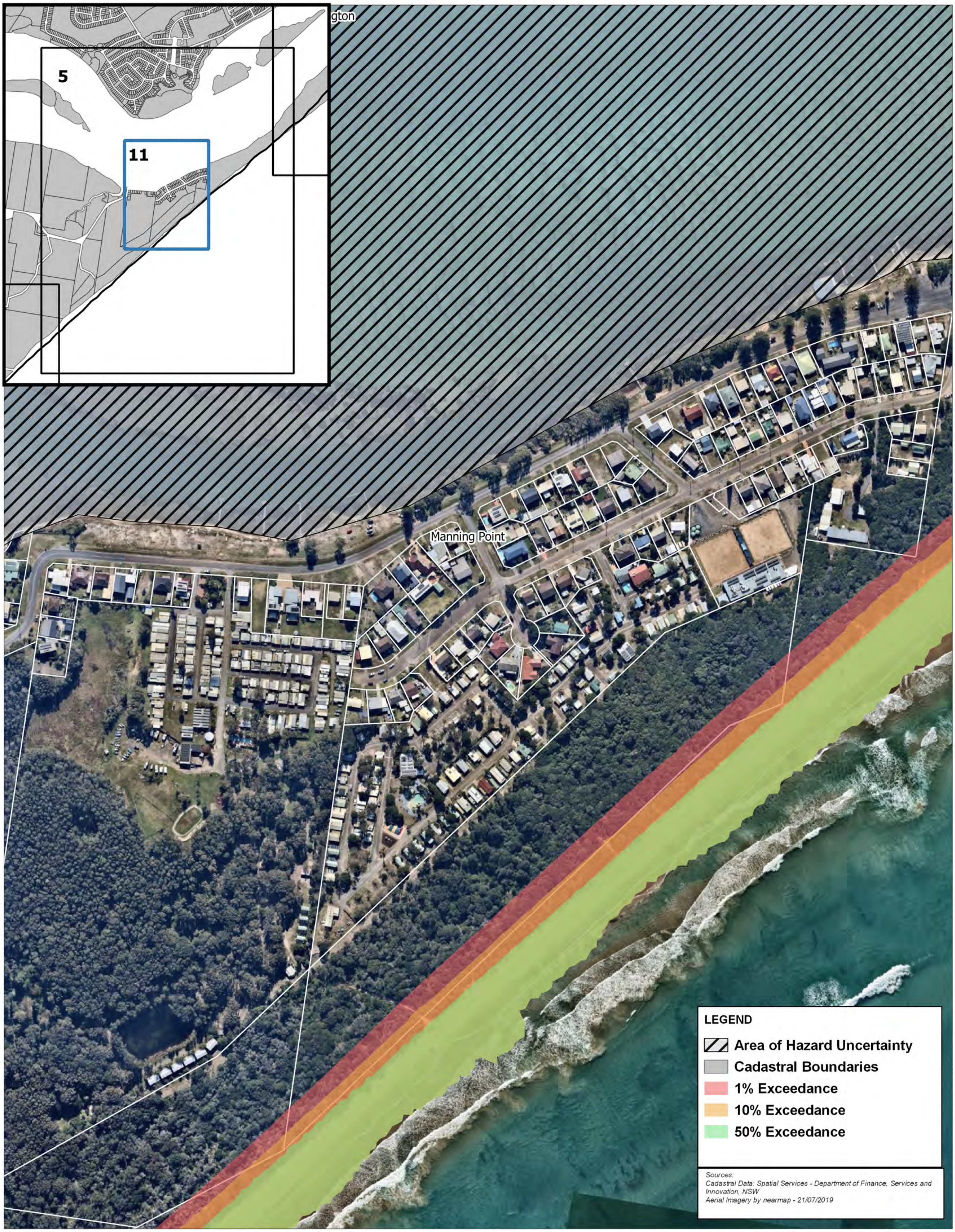


Sources:
Cadastral Data: Spatial Services - Department of Finance, Services and Innovation, NSW
Aerial Imagery by nearmap - 21/07/2019

Title:

Manning Point Township - Present Day Zone of Slope Adjustment

Figure: B-11

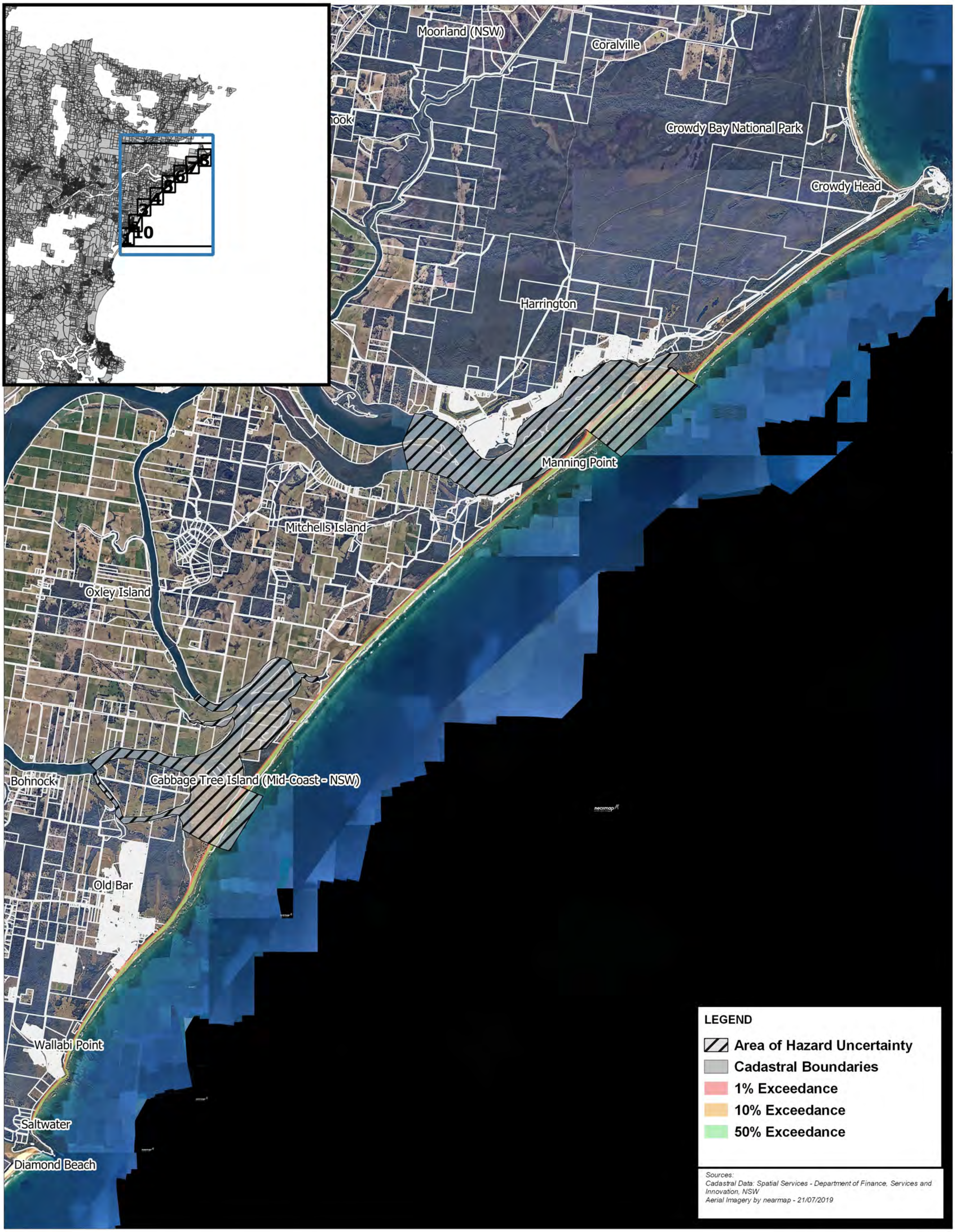
Rev: A

N

0 70 140 210 280 m

BMT
www.bmt.org

Filepath: I:\N21005.i.ajs.Old Bar Manning Point CMP\QGZ\COA_017_200207_2020_ZSA_Atlas.qgz



Sources:
Cadastral Data: Spatial Services - Department of Finance, Services and Innovation, NSW
Aerial Imagery by nearmap - 21/07/2019

Title:

Study Area - Present Day Zone of Slope Adjustment

Figure: **B-12**

Rev: **A**

N

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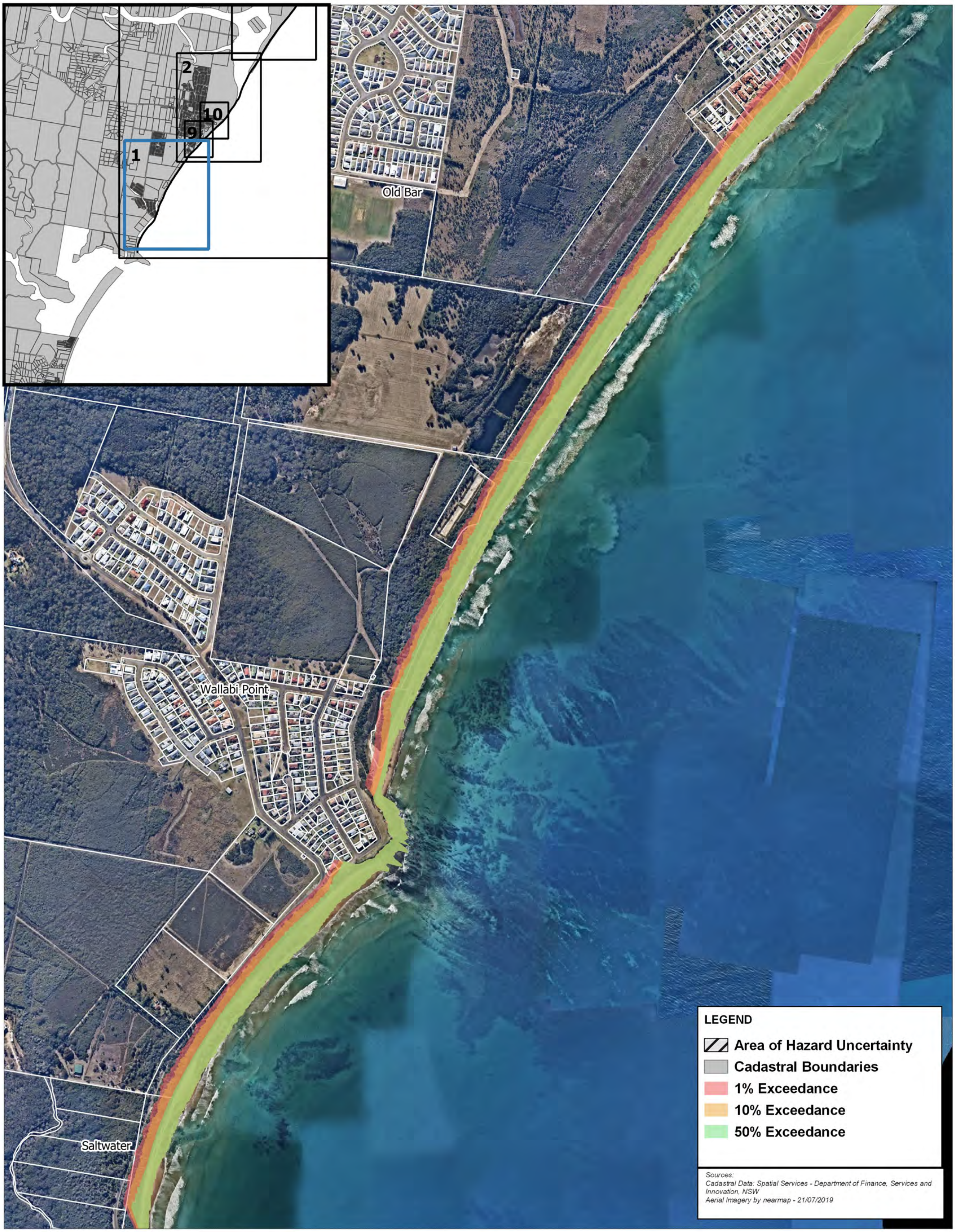
BMT
www.bmt.org

Filepath: I:\N21005.i.ajs.Old Bar Manning Point CMP\QGZ\COA_017_200207_2020_ZSA_Atlas.qgz

Appendix C Present Day Zone of Reduced Foundation Capacity Mapping



Sources:
Cadastral Data: Spatial Services - Department of Finance, Services and Innovation, NSW
Aerial Imagery by nearmap - 21/07/2019

Title:

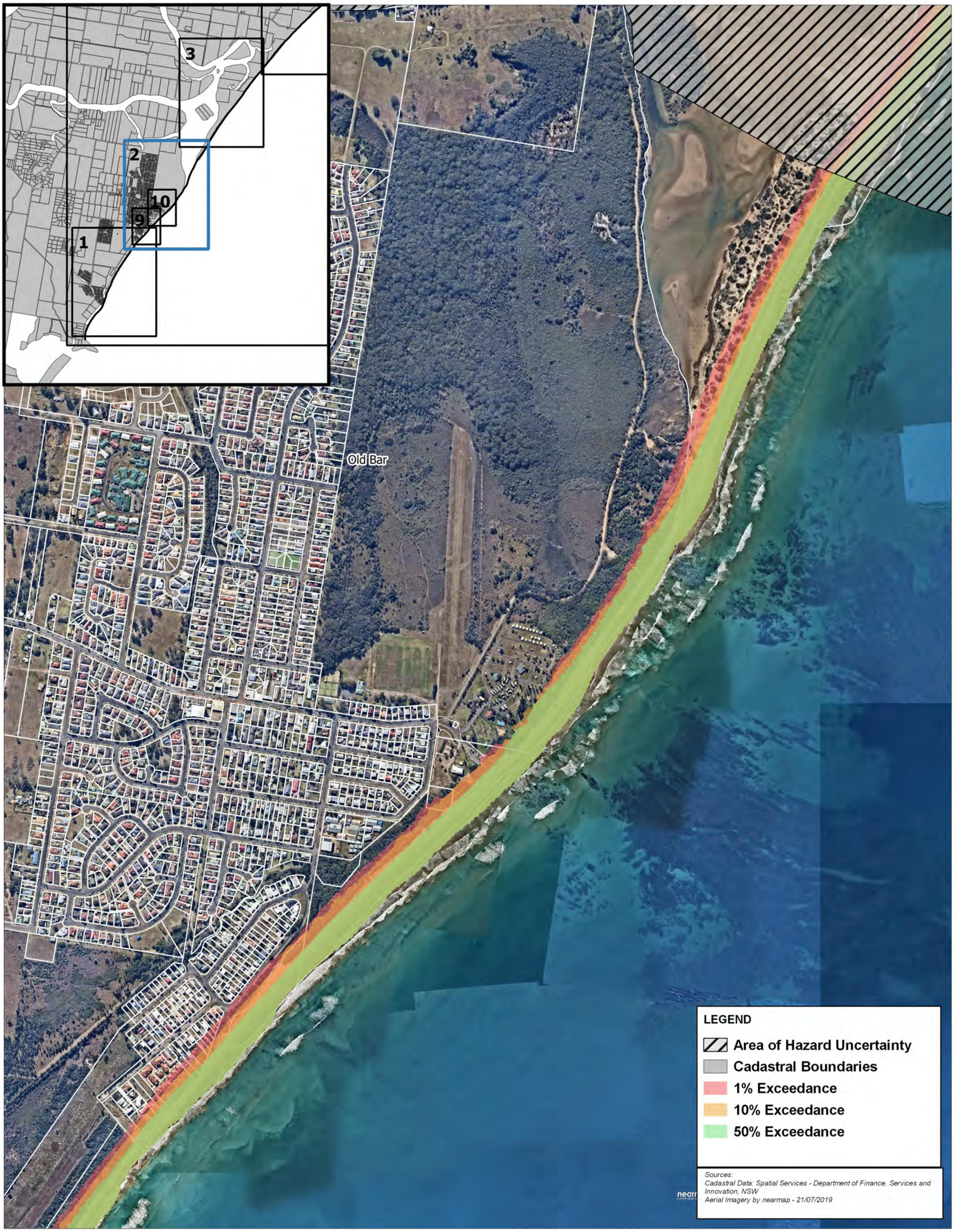
Wallabi Point - Present Day Zone of Reduced Foundation Capacity

Figure: C-1

Rev: A

BMT
www.bmt.org

Filepath: I:\N21005.i.ajs.Old Bar Manning Point CMP\QGZ\COA_017_200207_2020_ZRFC_Atlas.qgz



Sources:
Cadastral Data: Spatial Services - Department of Finance, Services and Innovation, NSW
Aerial Imagery by nearmap - 21/07/2019

Title:

Old Bar - Present Day Zone of Reduced Foundation Capacity

Figure: C-2

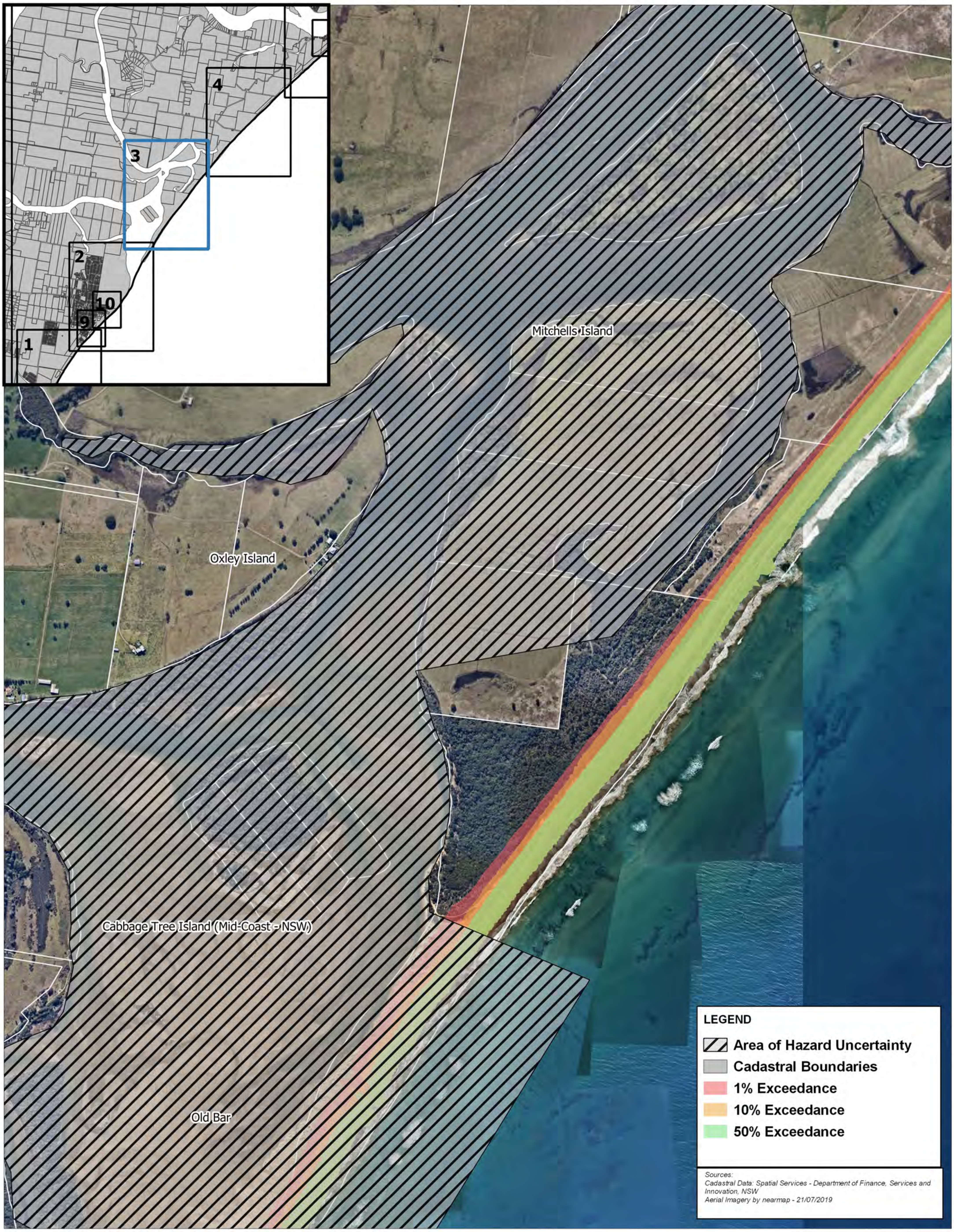
Rev: A

N

0 200 400 600 800 m

BMT
www.bmt.org

Filepath: I:\N21005.i.ajs.Old Bar Manning Point CMP\QGZ\COA_017_200207_2020_ZRFC_Atlas.qgz



Sources:
Cadastral Data: Spatial Services - Department of Finance, Services and Innovation, NSW
Aerial Imagery by nearmap - 21/07/2019

Title:

Farquhar Inlet - Present Day Zone of Reduced Foundation Capacity

Figure: C-3

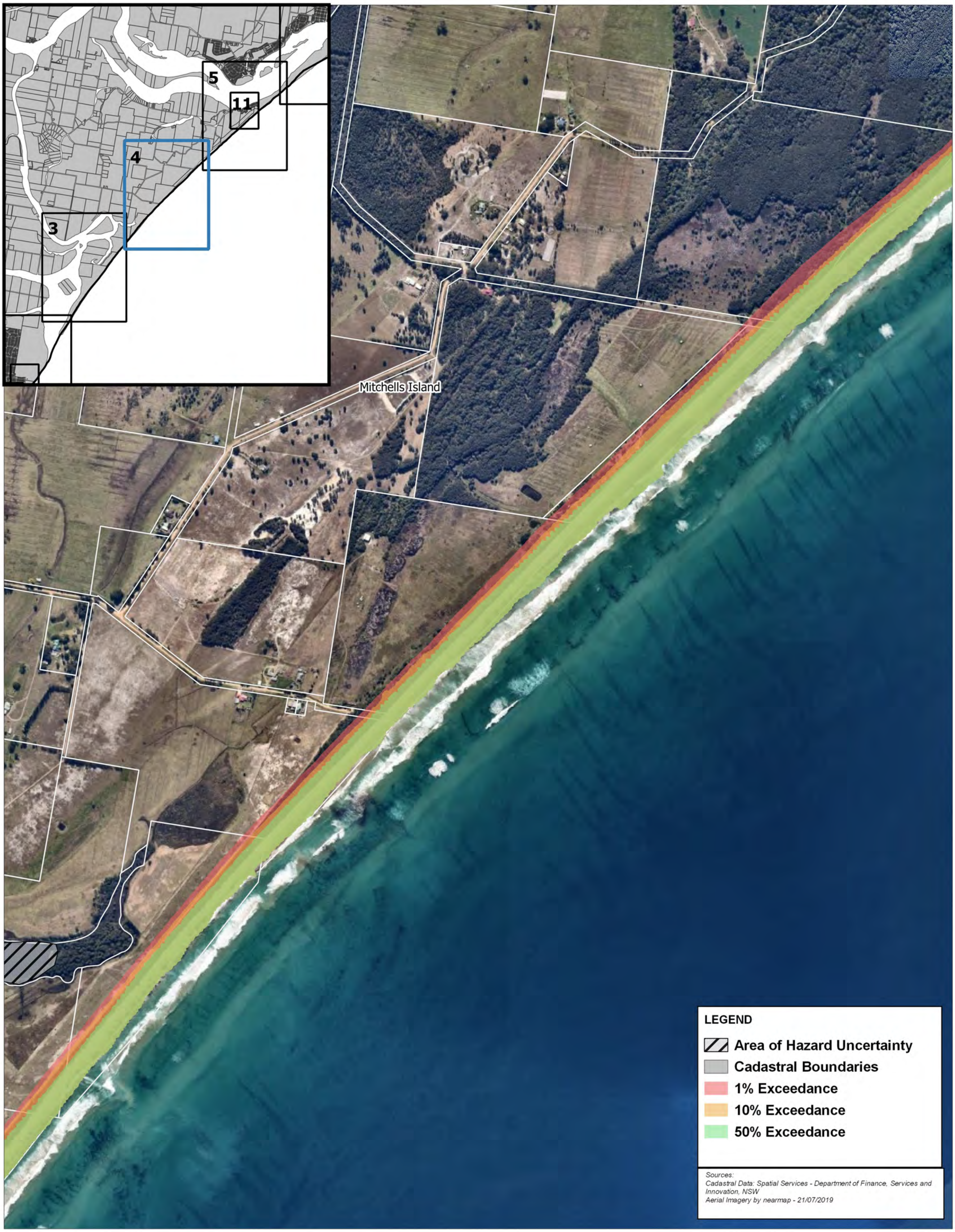
Rev: A

N

0 200 400 600 800 m

BMT
www.bmt.org

Filepath: I:\N21005.i.ajs.Old Bar Manning Point CMP\QGZ\COA_017_200207_2020_ZRFC_Atlas.qgz



Sources:
Cadastral Data: Spatial Services - Department of Finance, Services and Innovation, NSW
Aerial Imagery by nearmap - 21/07/2019

Title:

Mitchells Island - Present Day Zone of Reduced Foundation Capacity

Figure: **C-4**

Rev: **A**

N

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www.bmt.org

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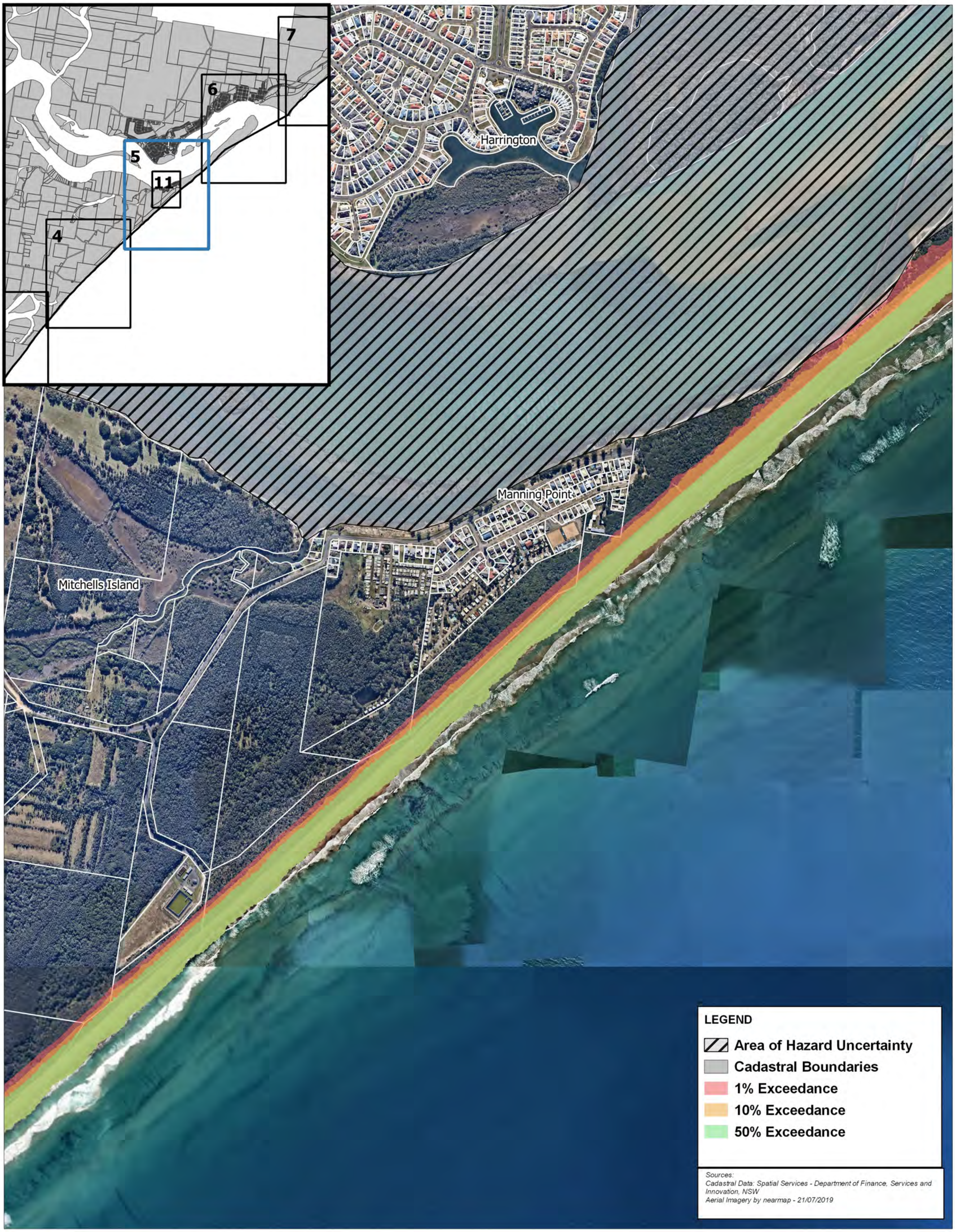


Sources:
Cadastral Data: Spatial Services - Department of Finance, Services and Innovation, NSW
Aerial Imagery by nearmap - 21/07/2019

Title:

Manning Point - Present Day Zone of Reduced Foundation Capacity

Figure: C-5

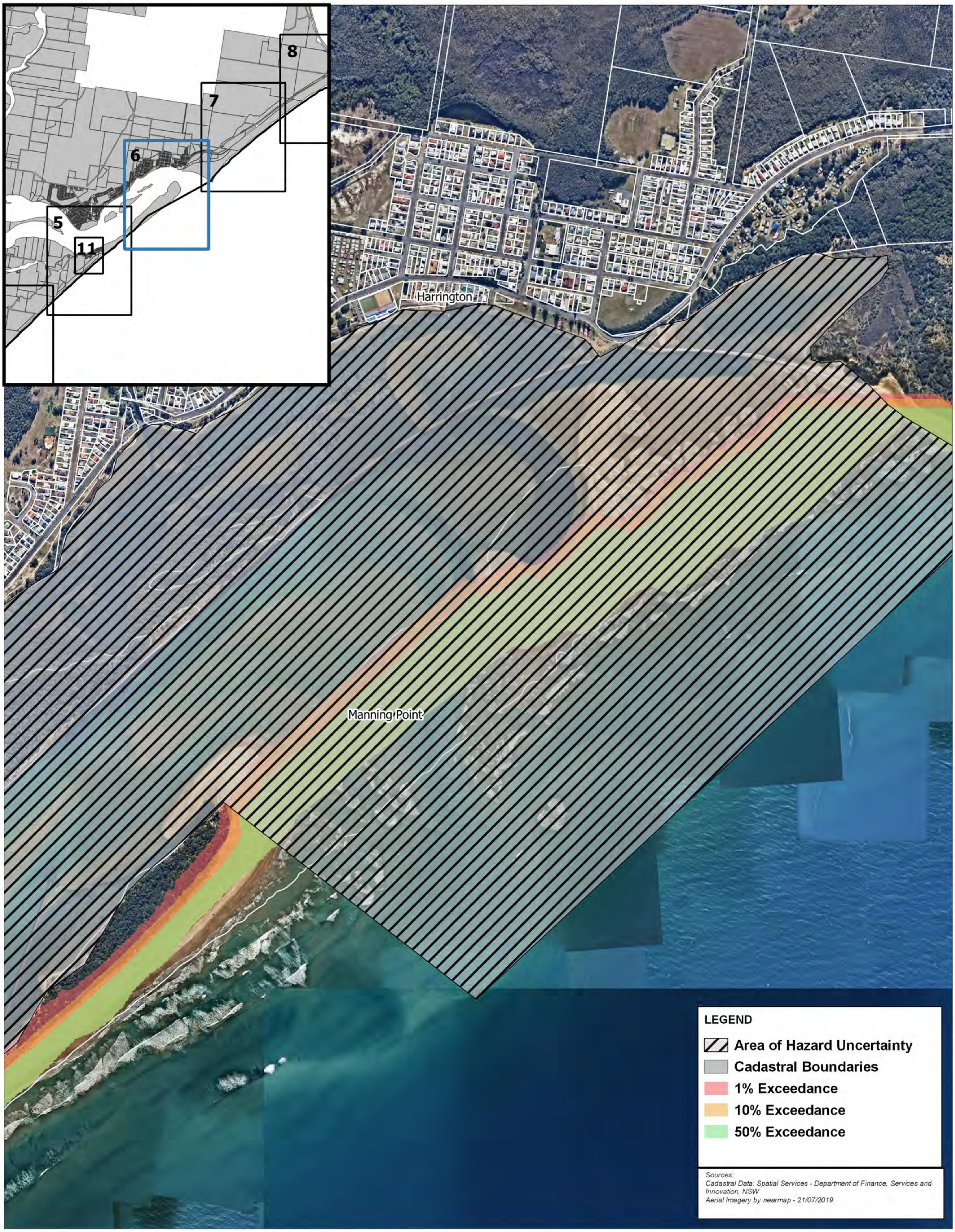
Rev: A

N

0 200 400 600 800 m

www.bmt.org

Filepath: I:\N21005.i.ajs.Old Bar Manning Point CMP\QGZ\COA_017_200207_2020_ZRFC_Atlas.qgz



Sources:
Cadastral Data: Spatial Services - Department of Finance, Services and Innovation, NSW
Aerial Imagery by nearmap - 21/07/2019

Title:

Harrington Entrance - Present Day Zone of Reduced Foundation Capacity

Figure: **C-6**

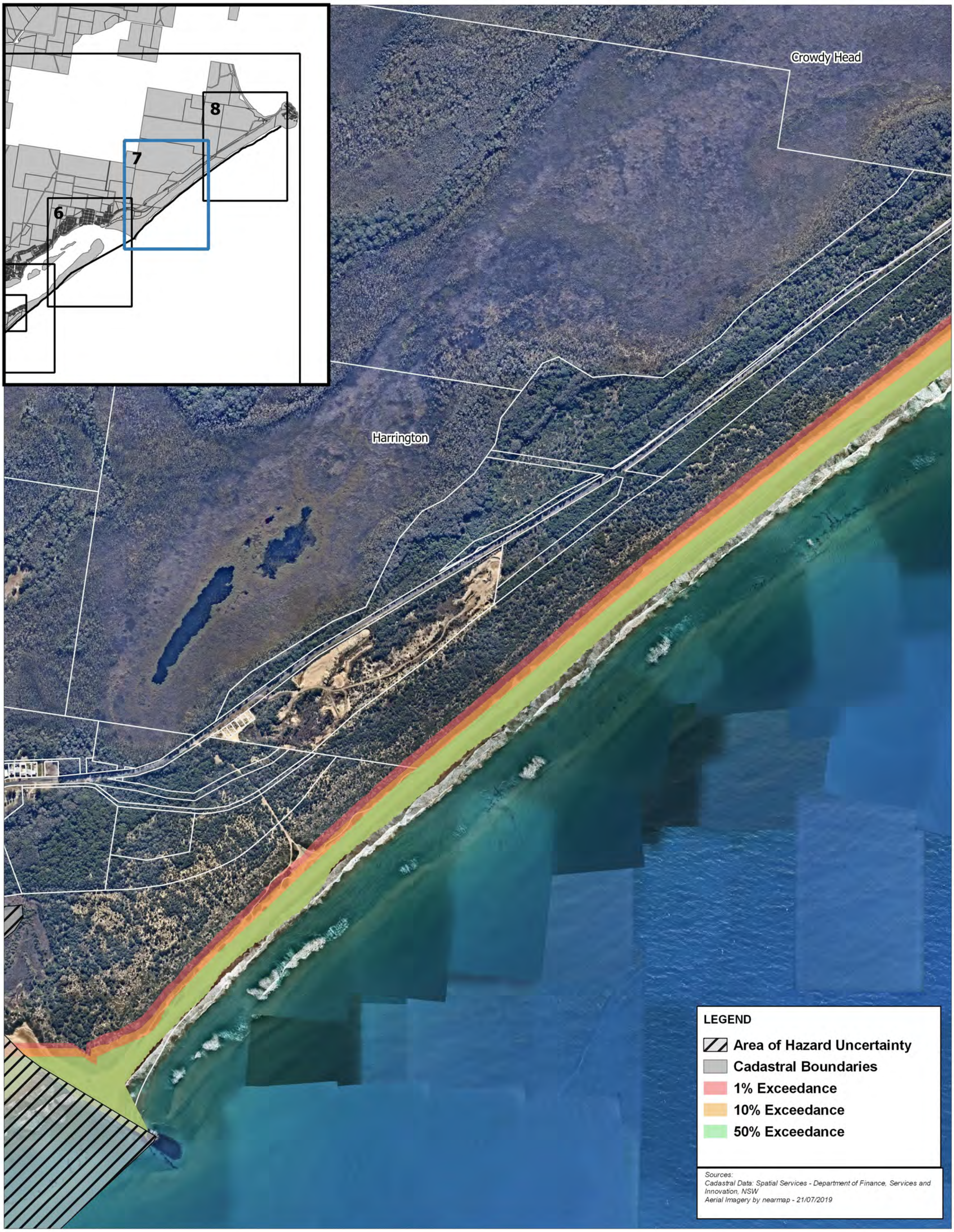
Rev: **A**

N

0 200 400 600 800 m

BMT
www.bmt.org

Filepath: I:\N21005.i.ajs.Old Bar Manning Point CMP\QGZ\COA_017_200207_2020_ZRFC_Atlas.qgz



Sources:
Cadastral Data: Spatial Services - Department of Finance, Services and Innovation, NSW
Aerial Imagery by nearmap - 21/07/2019

Title:

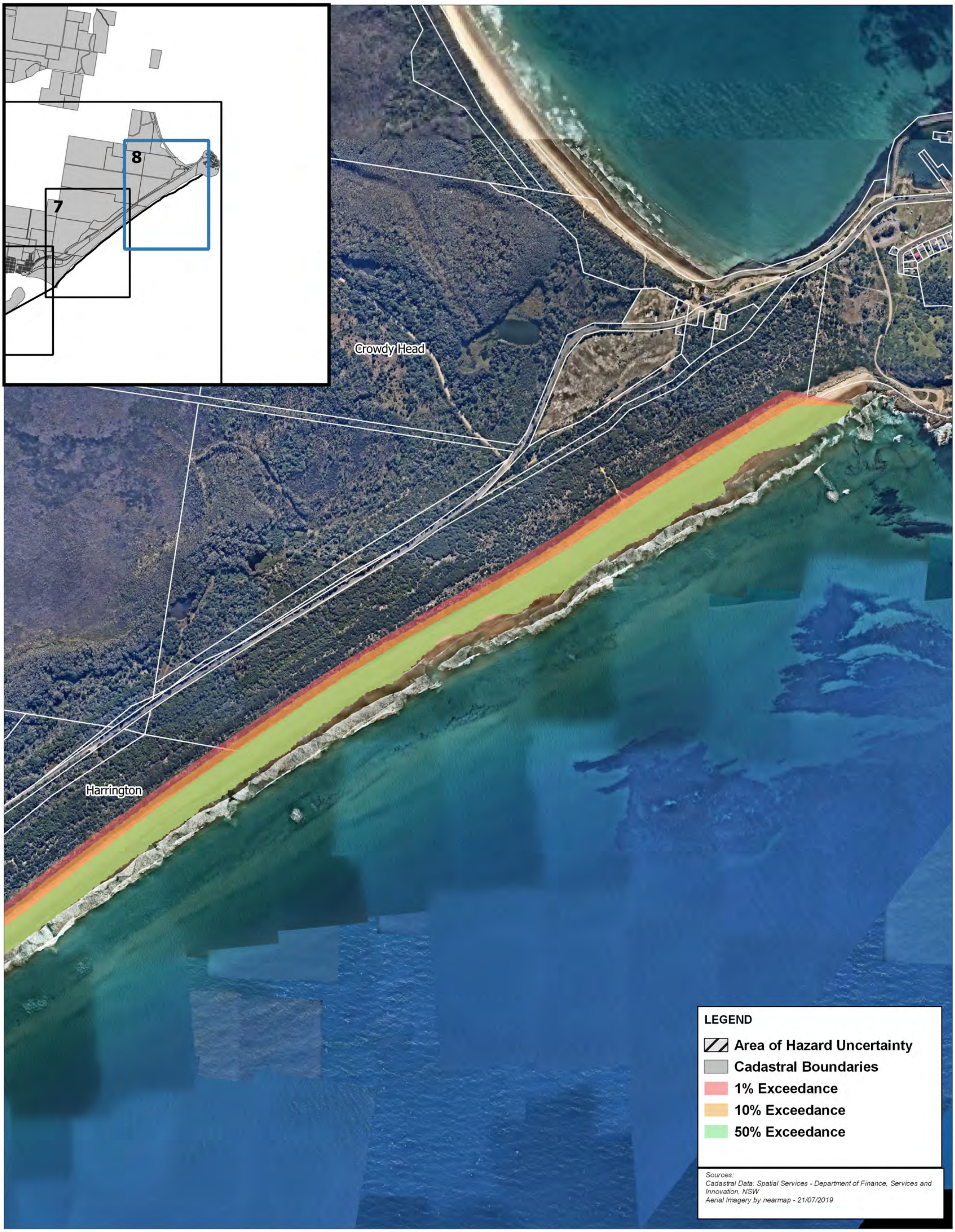
Harrington Beach (South) - Present Day Zone of Reduced Foundation Capacity

Figure: **C-7**

Rev: **A**

BMT
www.bmt.org

Filepath: I:\N21005.i.ajs.Old Bar Manning Point CMP\QGZ\COA_017_200207_2020_ZRFC_Atlas.qgz



Sources:
Cadastral Data: Spatial Services - Department of Finance, Services and Innovation, NSW
Aerial Imagery by nearmap - 21/07/2019

Title:

Harrington Beach (North) - Present Day Zone of Reduced Foundation Capacity

Figure:
C-8

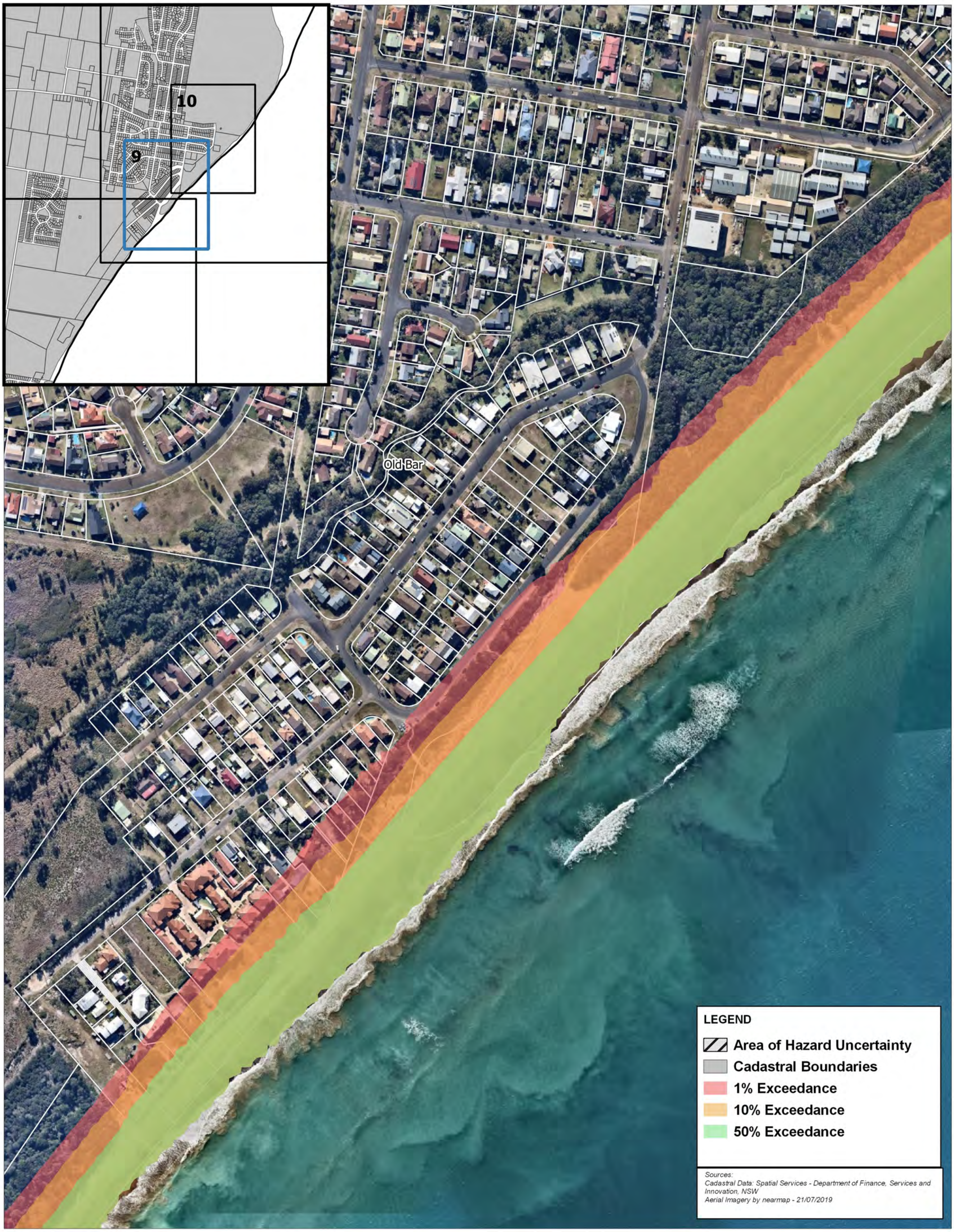
Rev:
A

N

0 200 400 600 800 m

BMT
www.bmt.org

Filepath: I:\N21005.i.ajs.Old Bar Manning Point CMP\QGZ\COA_017_200207_2020_ZRFC_Atlas.qgz



Sources:
Cadastral Data: Spatial Services - Department of Finance, Services and Innovation, NSW
Aerial Imagery by nearmap - 21/07/2019

Title:

Old Bar (South) - Present Day Zone of Reduced Foundation Capacity

Figure: **C-9**

Rev: **A**

N

0 70 140 210 280 m

BMT
www.bmt.org

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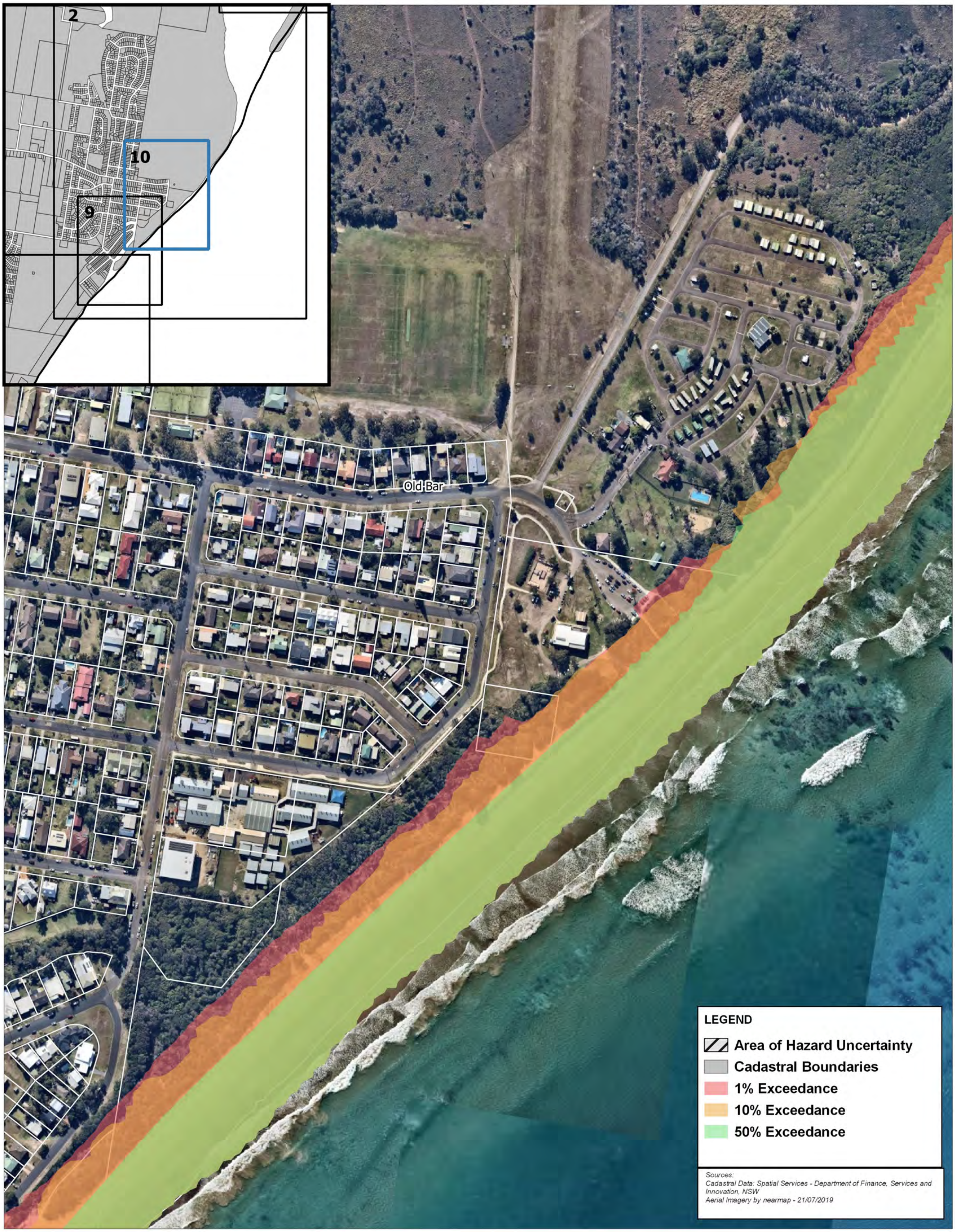


Sources:
Cadastral Data: Spatial Services - Department of Finance, Services and Innovation, NSW
Aerial Imagery by nearmap - 21/07/2019

Title:

Old Bar (North) - Present Day Zone of Reduced Foundation Capacity

Figure: **C-10**

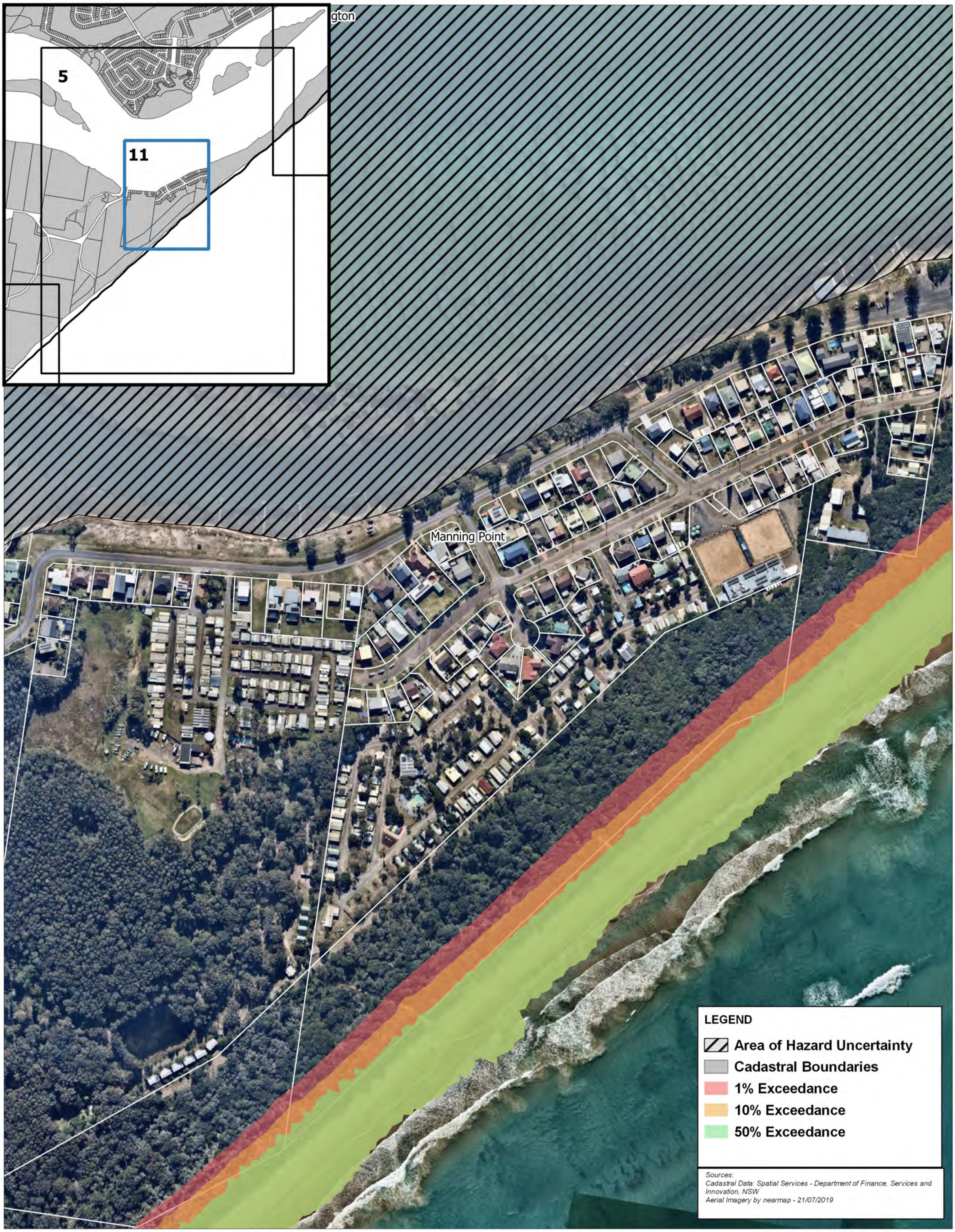
Rev: **A**

N

0 70 140 210 280 m

www.bmt.org

Filepath: I:\N21005.i.ajs.Old Bar Manning Point CMP\QGZ\COA_017_200207_2020_ZRFC_Atlas.qgz



Sources:
Cadastral Data: Spatial Services - Department of Finance, Services and Innovation, NSW
Aerial Imagery by nearmap - 21/07/2019

Title:

Manning Point Township - Present Day Zone of Reduced Foundation Capacity

Figure: **C-11**

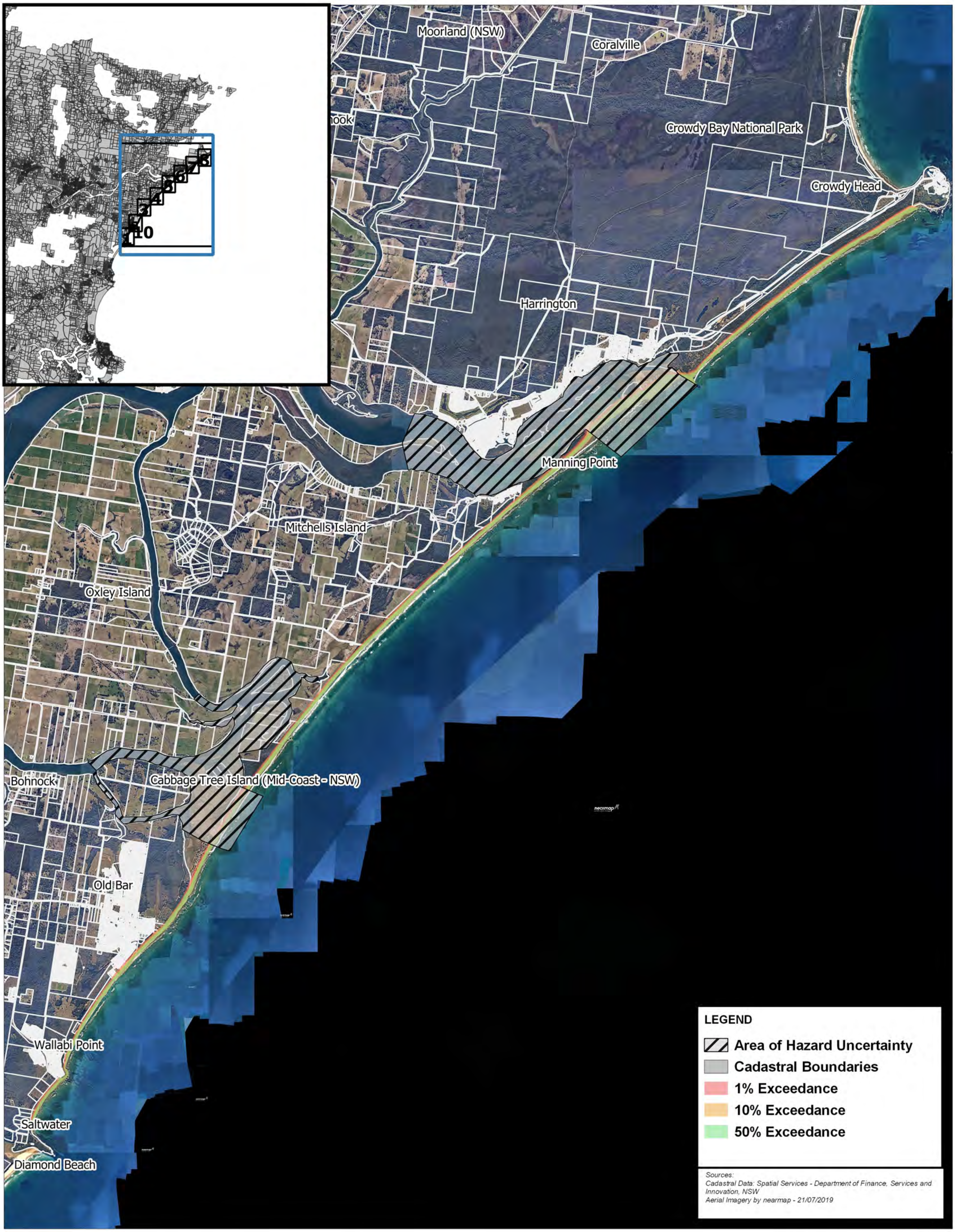
Rev: **A**

N

0 70 140 210 280 m

www.bmt.org

Filepath: I:\N21005.i.ajs.Old Bar Manning Point CMP\QGZ\COA_017_200207_2020_ZRFC_Atlas.qgz



Sources:
Cadastral Data: Spatial Services - Department of Finance, Services and Innovation, NSW
Aerial Imagery by nearmap - 21/07/2019

Title:

Study Area - Present Day Zone of Reduced Foundation Capacity

Figure: C-12

Rev: A

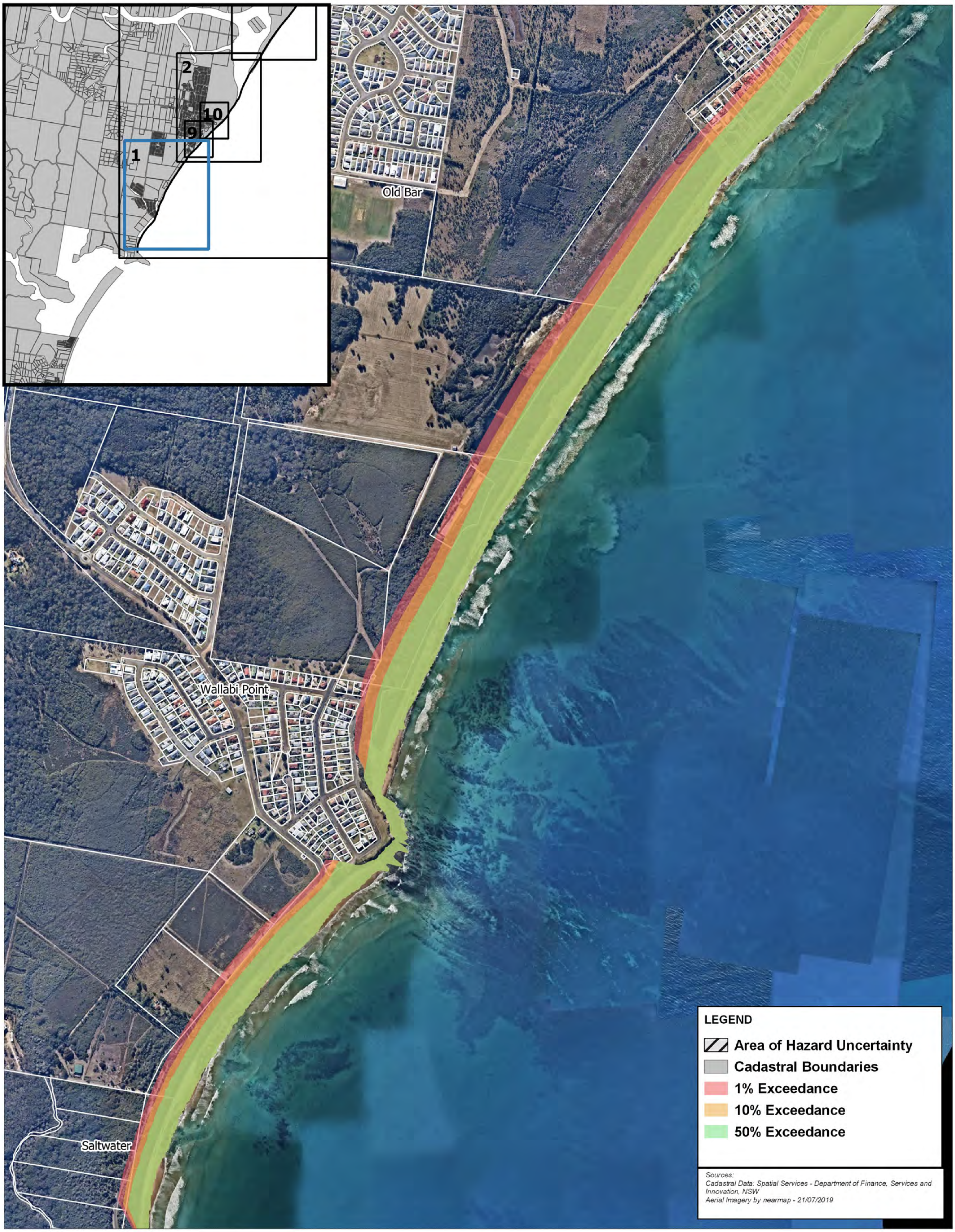
N

0 1000 2000 3000 4000 m

BMT
www.bmt.org

Filepath: I:\N21005.i.ajs.Old Bar Manning Point CMP\QGZ\COA_017_200207_2020_ZRFC_Atlas.qgz

Appendix D 2060 Zone of Slope Adjustments Mapping



Sources:
Cadastral Data: Spatial Services - Department of Finance, Services and Innovation, NSW
Aerial Imagery by nearmap - 21/07/2019

Title:

Wallabi Point - 2060 Zone of Slope Adjustment

Figure: **D-1**

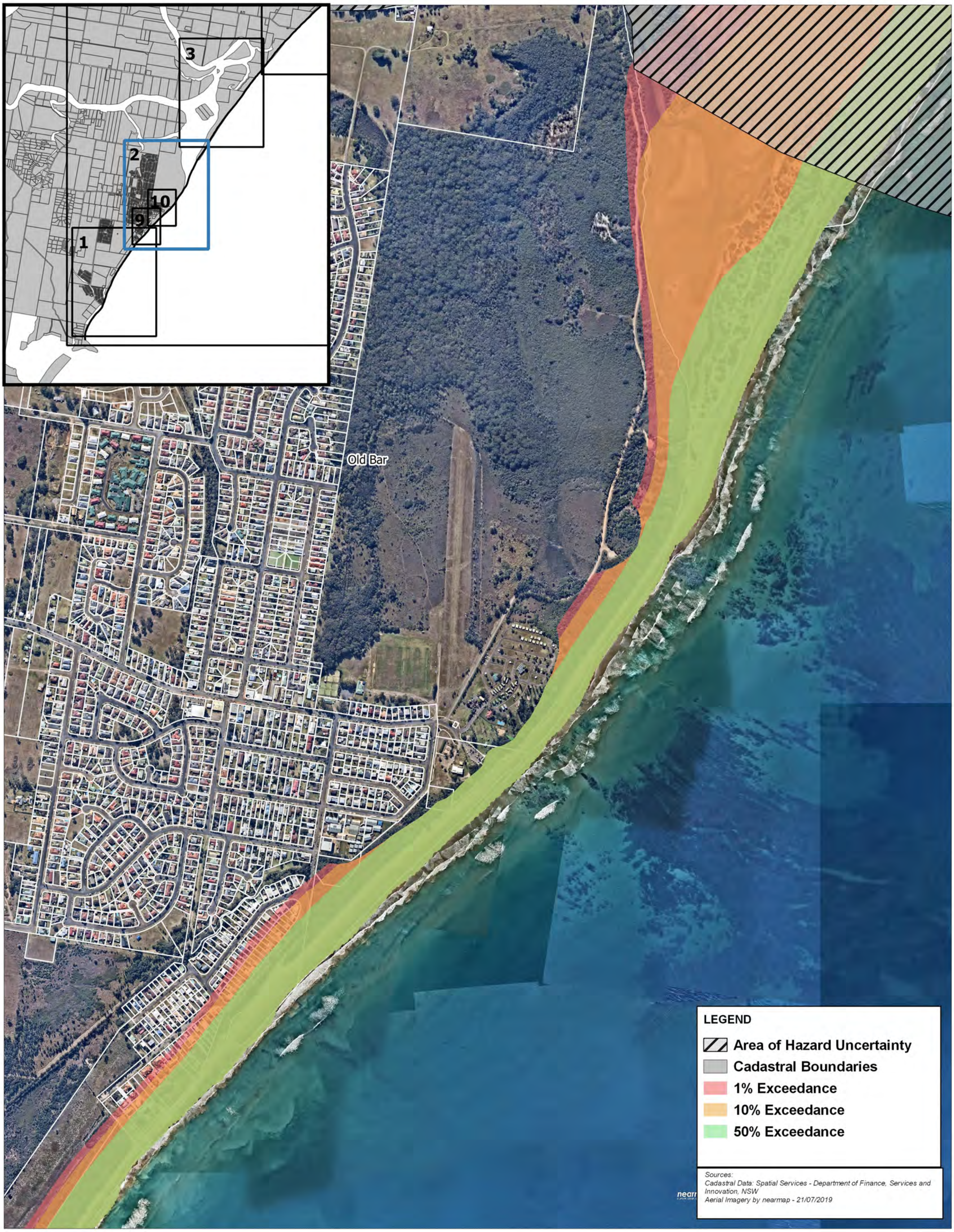
Rev: **A**

N

0 200 400 600 800 m

BMT
www.bmt.org

Filepath: I:\N21005.i.ajs.Old Bar Manning Point CMP\QGZ\COA_017_200207_2020_ZSA_Atlas.qgz



Sources:
Cadastral Data: Spatial Services - Department of Finance, Services and Innovation, NSW
Aerial Imagery by nearmap - 21/07/2019

Title:
Old Bar - 2060 Zone of Slope Adjustment

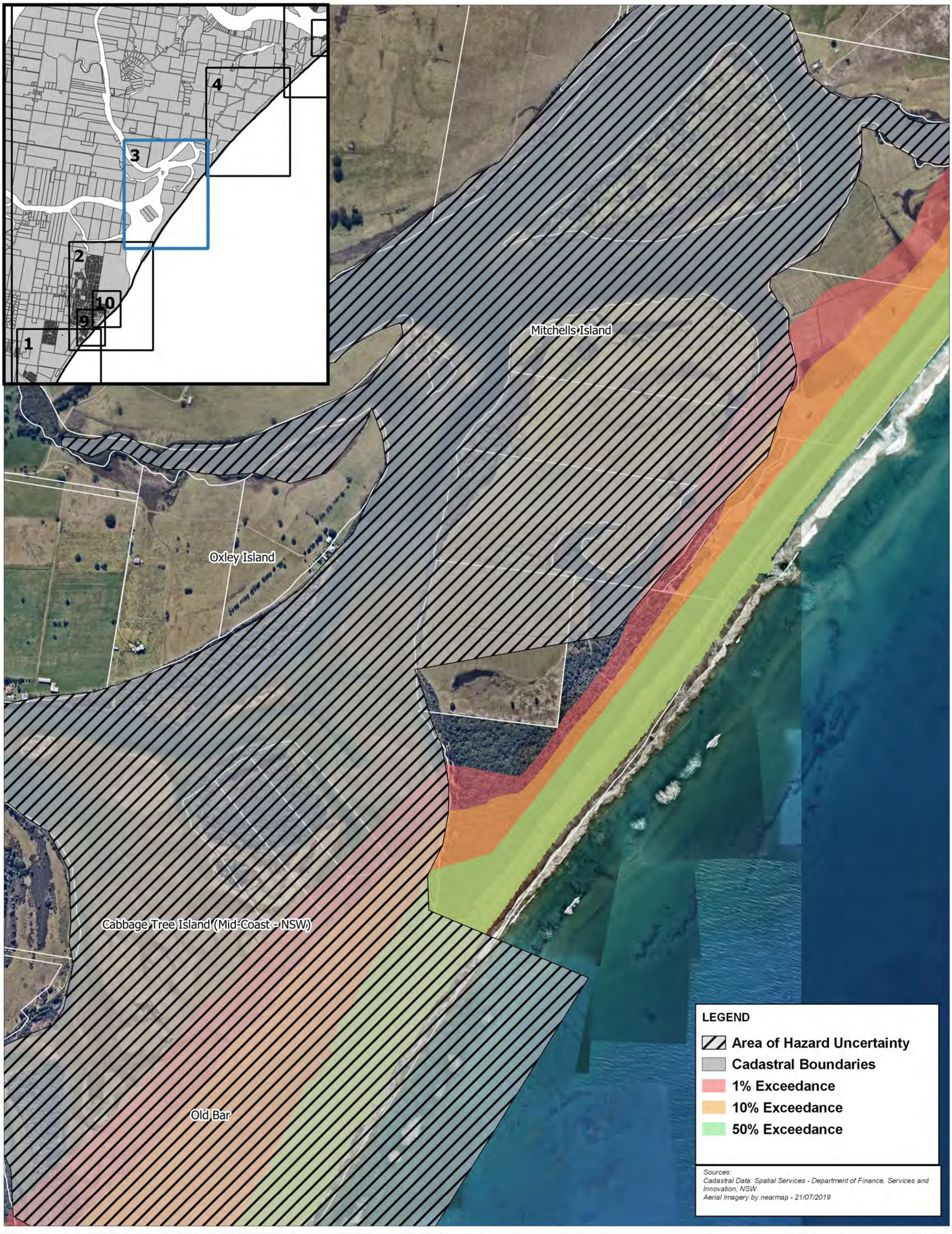
Figure:	Rev:
D-2	A

N

0 200 400 600 800 m

BMT
www.bmt.org

Filepath: I:\N21005.i.ajs.Old Bar Manning Point CMP\QGZ\COA_017_200207_2020_ZSA_Atlas.qgz



LEGEND

- ▨ Area of Hazard Uncertainty
- ⬜ Cadastral Boundaries
- 🟥 1% Exceedance
- 🟧 10% Exceedance
- 🟩 50% Exceedance

Sources:
Cadastral Data: Spatial Services - Department of Finance, Services and Innovation, NSW
Aerial Imagery by nearmap - 21/07/2019

Title:
Farquhar Inlet - 2060 Zone of Slope Adjustment

Figure:
D-3

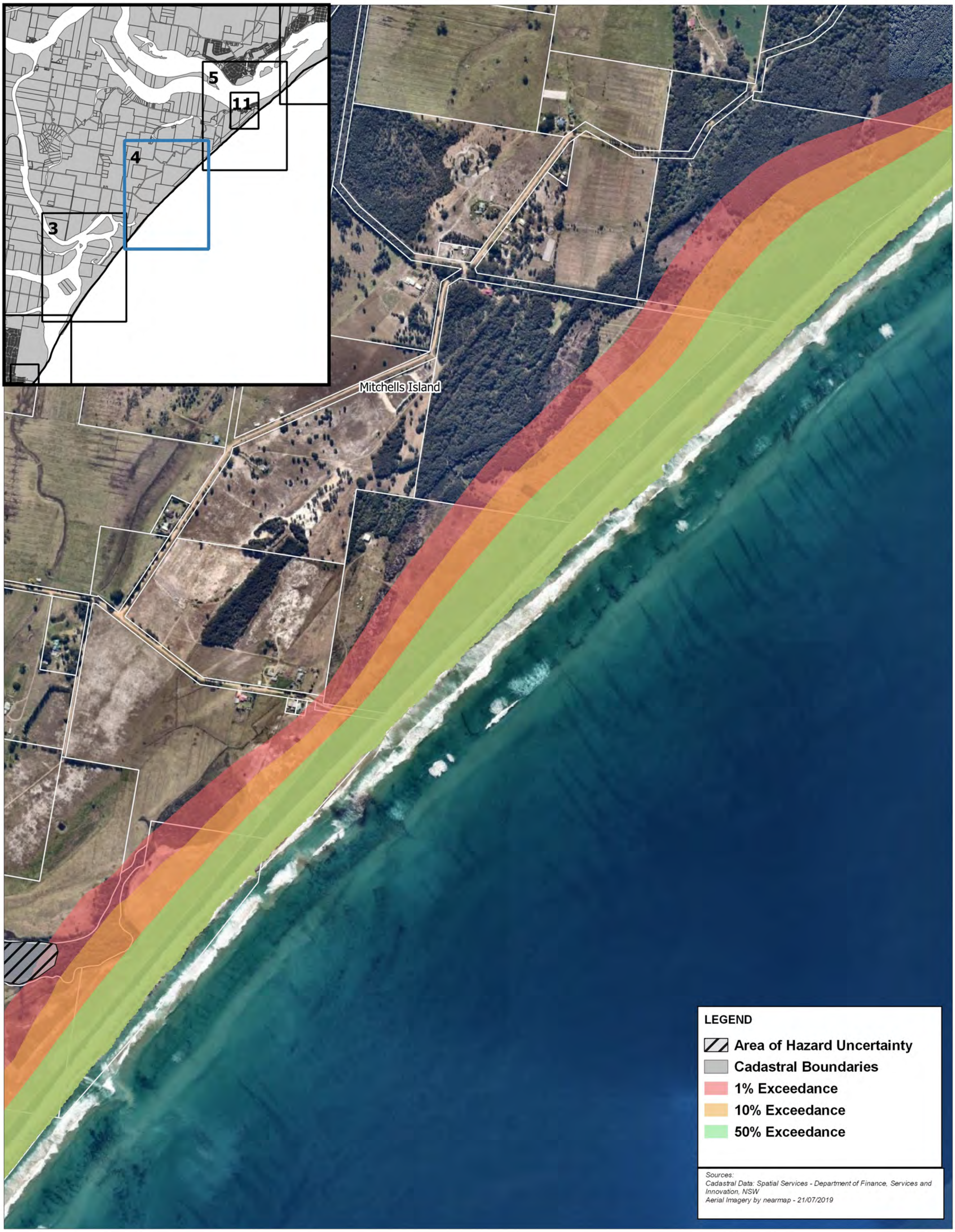
Rev:
A

N

0 200 400 600 800 m

BMT
www.bmt.org

Filepath: I:\N21005.i.ajs.Old Bar Manning Point CMP\QGZ\COA_017_200207_2020_ZSA_Atlas.qgz



Sources:
Cadastral Data: Spatial Services - Department of Finance, Services and Innovation, NSW
Aerial Imagery by nearmap - 21/07/2019

Title:

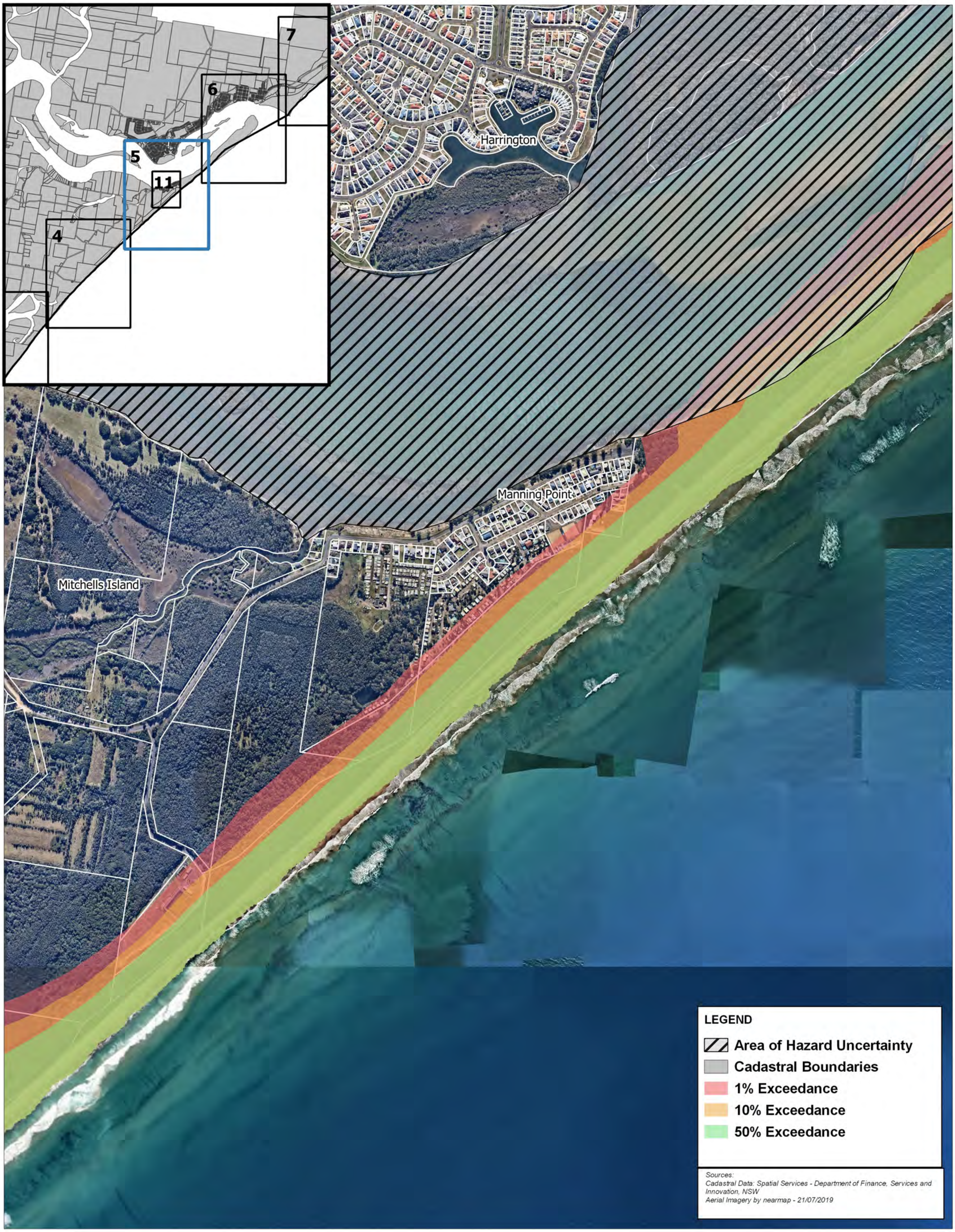
Mitchells Island - 2060 Zone of Slope Adjustment

Figure: **D-4**

Rev: **A**

BMT
www.bmt.org

Filepath: I:\N21005.i.ajs.Old Bar Manning Point CMP\QGZ\COA_017_200207_2020_ZSA_Atlas.qgz



LEGEND

- ▨ Area of Hazard Uncertainty
- ▢ Cadastral Boundaries
- 🟥 1% Exceedance
- 🟧 10% Exceedance
- 🟩 50% Exceedance

Sources:
Cadastral Data: Spatial Services - Department of Finance, Services and Innovation, NSW
Aerial Imagery by nearmap - 21/07/2019

Title:

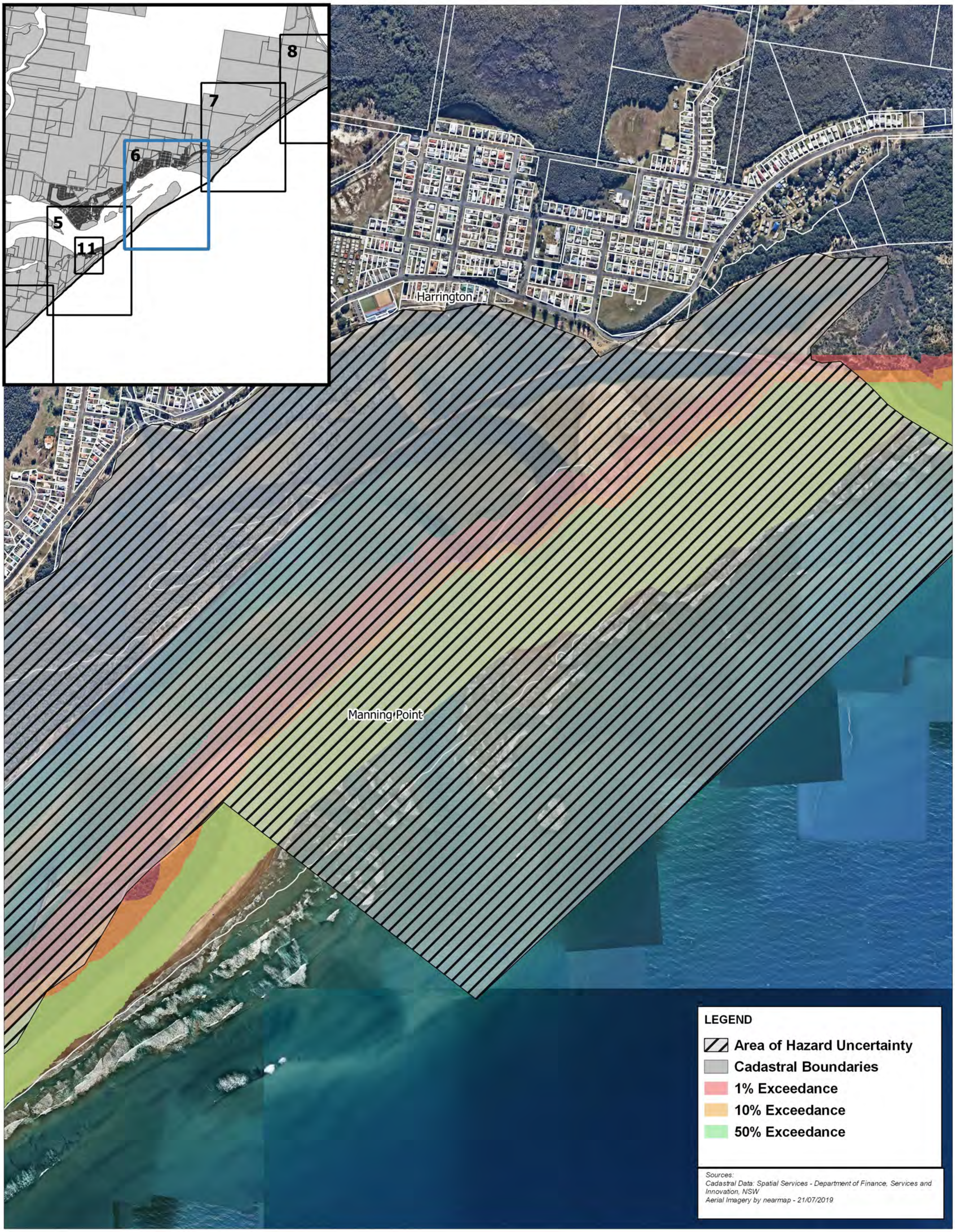
Manning Point - 2060 Zone of Slope Adjustment

Figure: D-5

Rev: A

BMT
www.bmt.org

Filepath: I:\N21005.i.ajs.Old Bar Manning Point CMP\QGZ\COA_017_200207_2020_ZSA_Atlas.qgz



Sources:
Cadastral Data: Spatial Services - Department of Finance, Services and Innovation, NSW
Aerial Imagery by nearmap - 21/07/2019

Title:
Harrington Entrance - 2060 Zone of Slope Adjustment

Figure: **D-6**

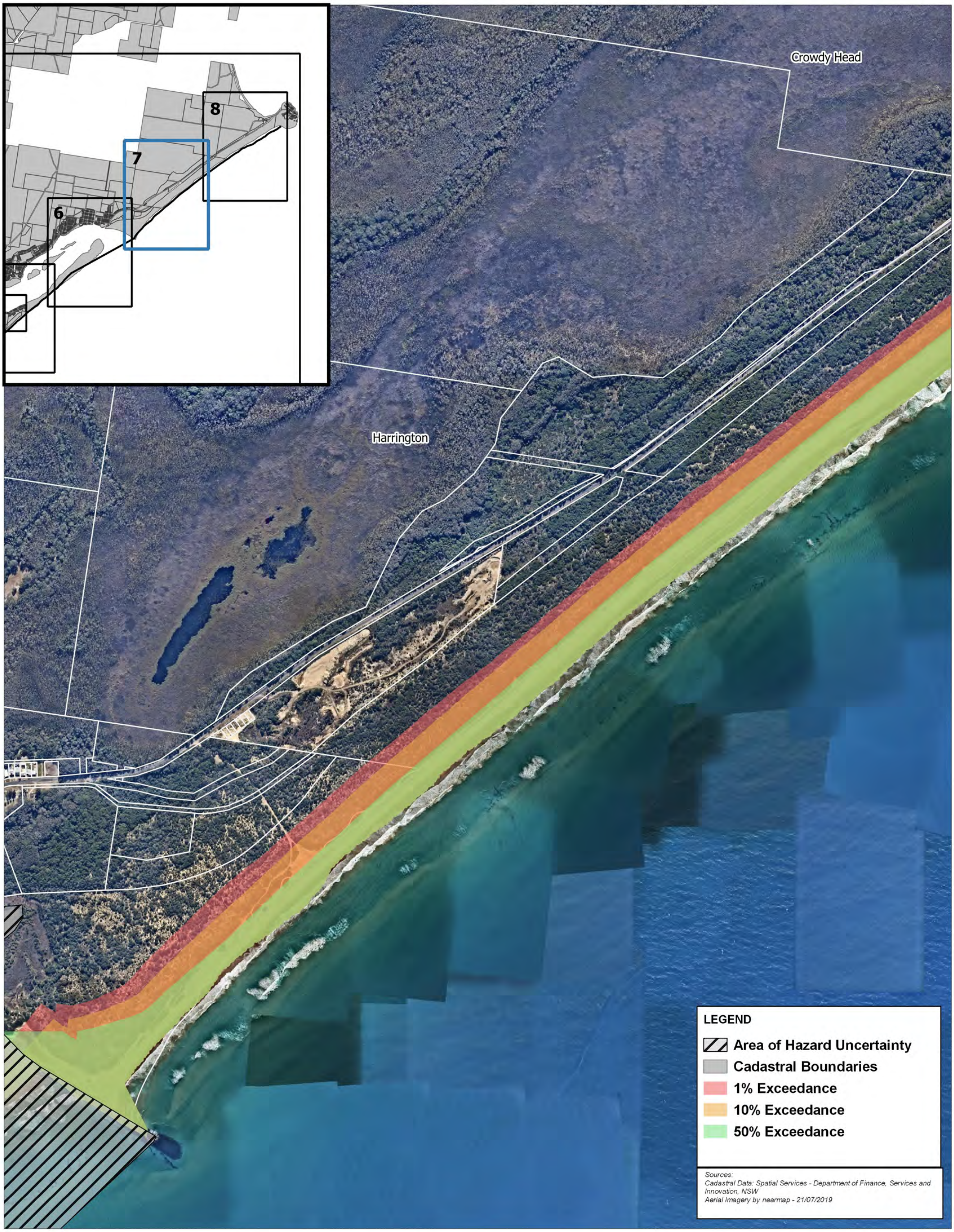
Rev: **A**

N

0 200 400 600 800 m

BMT
www.bmt.org

Filepath: I:\N21005.i.ajs.Old Bar Manning Point CMP\QGZ\COA_017_200207_2020_ZSA_Atlas.qgz



Sources:
Cadastral Data: Spatial Services - Department of Finance, Services and Innovation, NSW
Aerial Imagery by nearmap - 21/07/2019

Title:

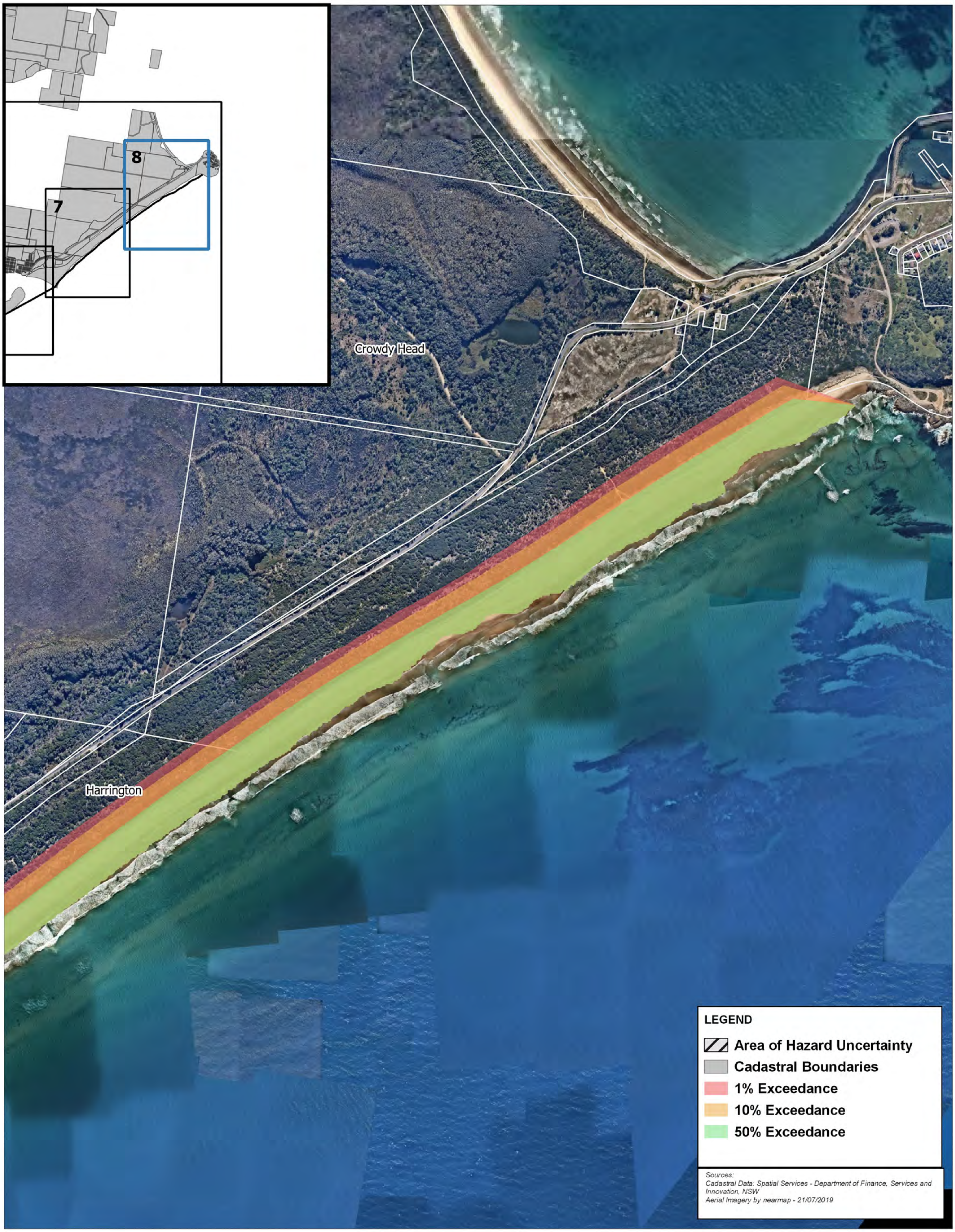
Harrington Beach (South) - 2060 Zone of Slope Adjustment

Figure: **D-7**

Rev: **A**

BMT
www.bmt.org

Filepath: I:\N21005.i.ajs.Old Bar Manning Point CMP\QGZ\COA_017_200207_2020_ZSA_Atlas.qgz



Sources:
Cadastral Data: Spatial Services - Department of Finance, Services and Innovation, NSW
Aerial Imagery by nearmap - 21/07/2019

Title:

Harrington Beach (North) - 2060 Zone of Slope Adjustment

Figure: **D-8**

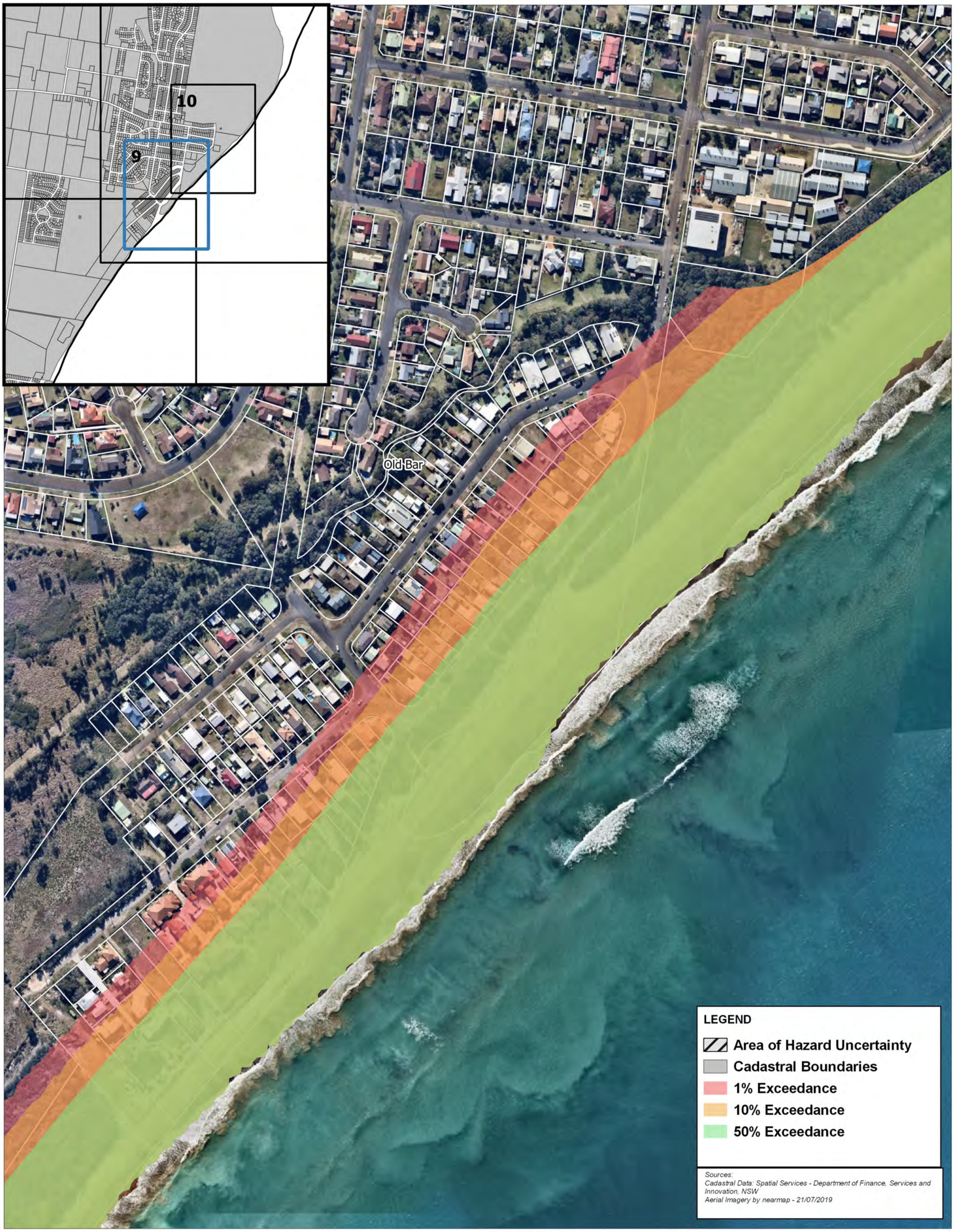
Rev: **A**

N

0 200 400 600 800 m

BMT
www.bmt.org

Filepath: I:\N21005.i.ajs.Old Bar Manning Point CMP\QGZ\COA_017_200207_2020_ZSA_Atlas.qgz



Sources:
Cadastral Data: Spatial Services - Department of Finance, Services and Innovation, NSW
Aerial Imagery by nearmap - 21/07/2019

Title:

Old Bar (South) - 2060 Zone of Slope Adjustment

Figure: **D-9**

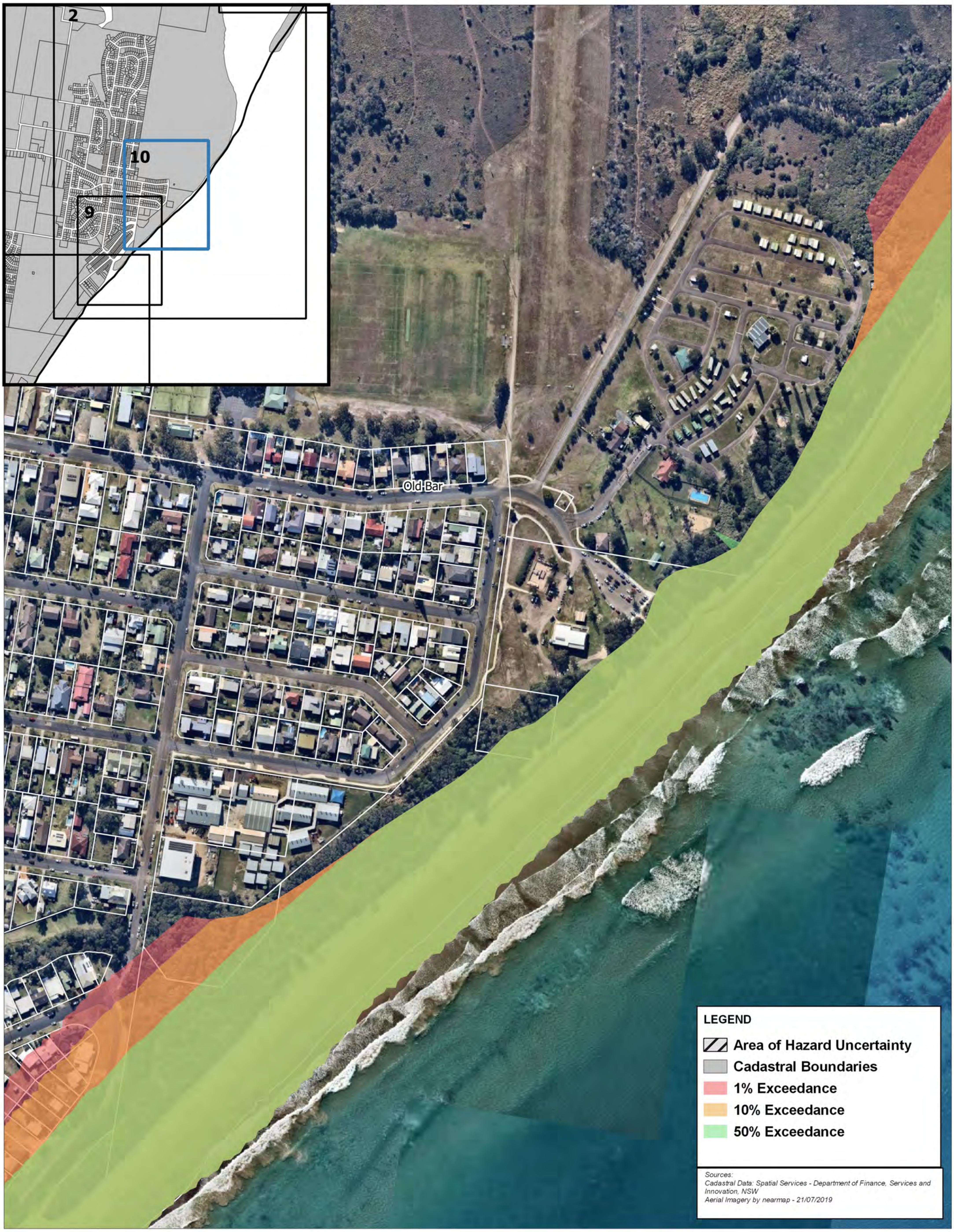
Rev: **A**

N

0 70 140 210 280 m

www.bmt.org

Filepath: I:\N21005.i.ajs.Old Bar Manning Point CMP\QGZ\COA_017_200207_2020_ZSA_Atlas.qgz



Sources:
Cadastral Data: Spatial Services - Department of Finance, Services and Innovation, NSW
Aerial Imagery by nearmap - 21/07/2019

Title:

Old Bar (North) - 2060 Zone of Slope Adjustment

Figure: **D-10**

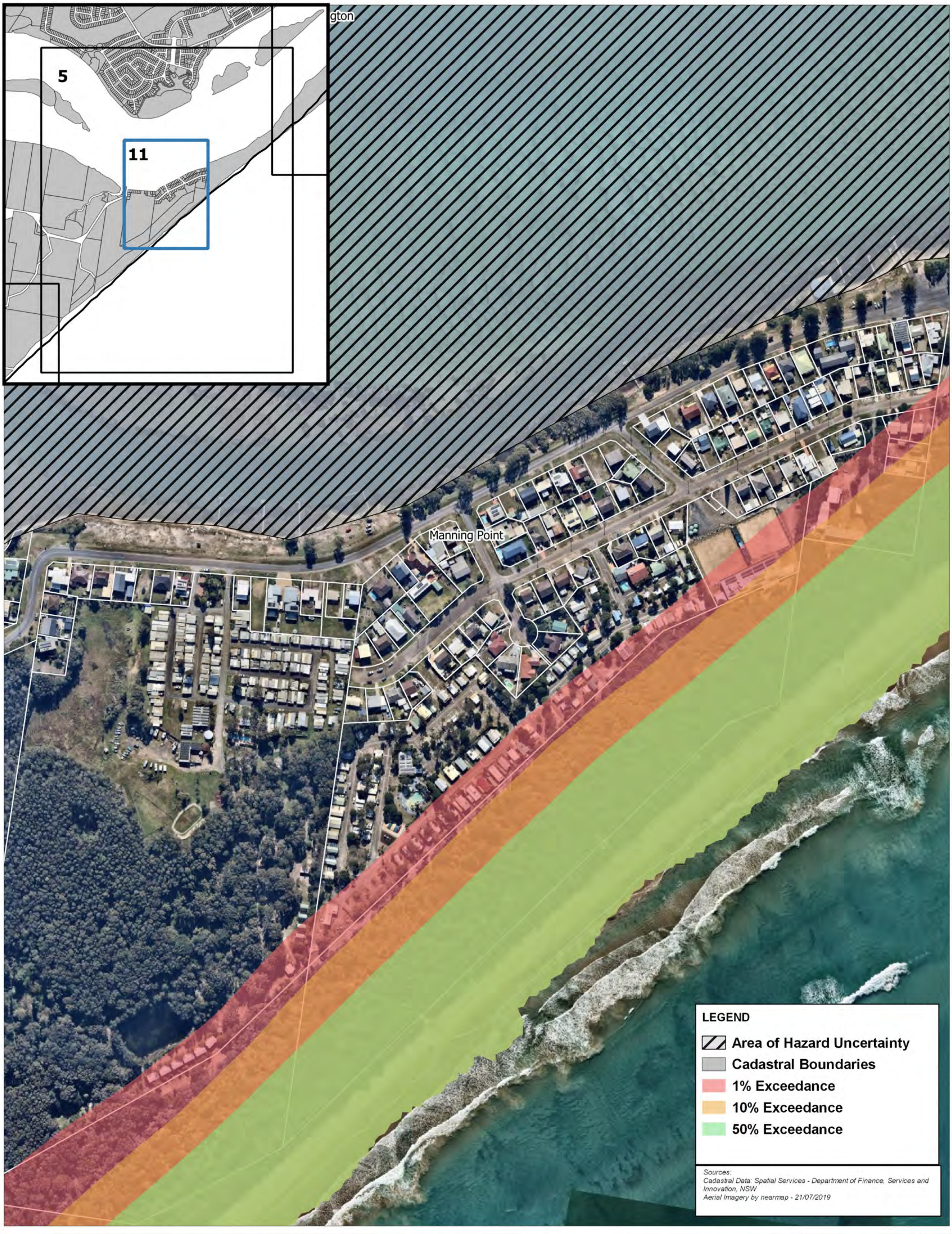
Rev: **A**

N

0 70 140 210 280 m

BMT
www.bmt.org

Filepath: I:\N21005.i.ajs.Old Bar Manning Point CMP\QGZ\COA_017_200207_2020_ZSA_Atlas.qgz



Sources:
Cadastral Data: Spatial Services - Department of Finance, Services and Innovation, NSW
Aerial Imagery by nearmap - 21/07/2019

Title:

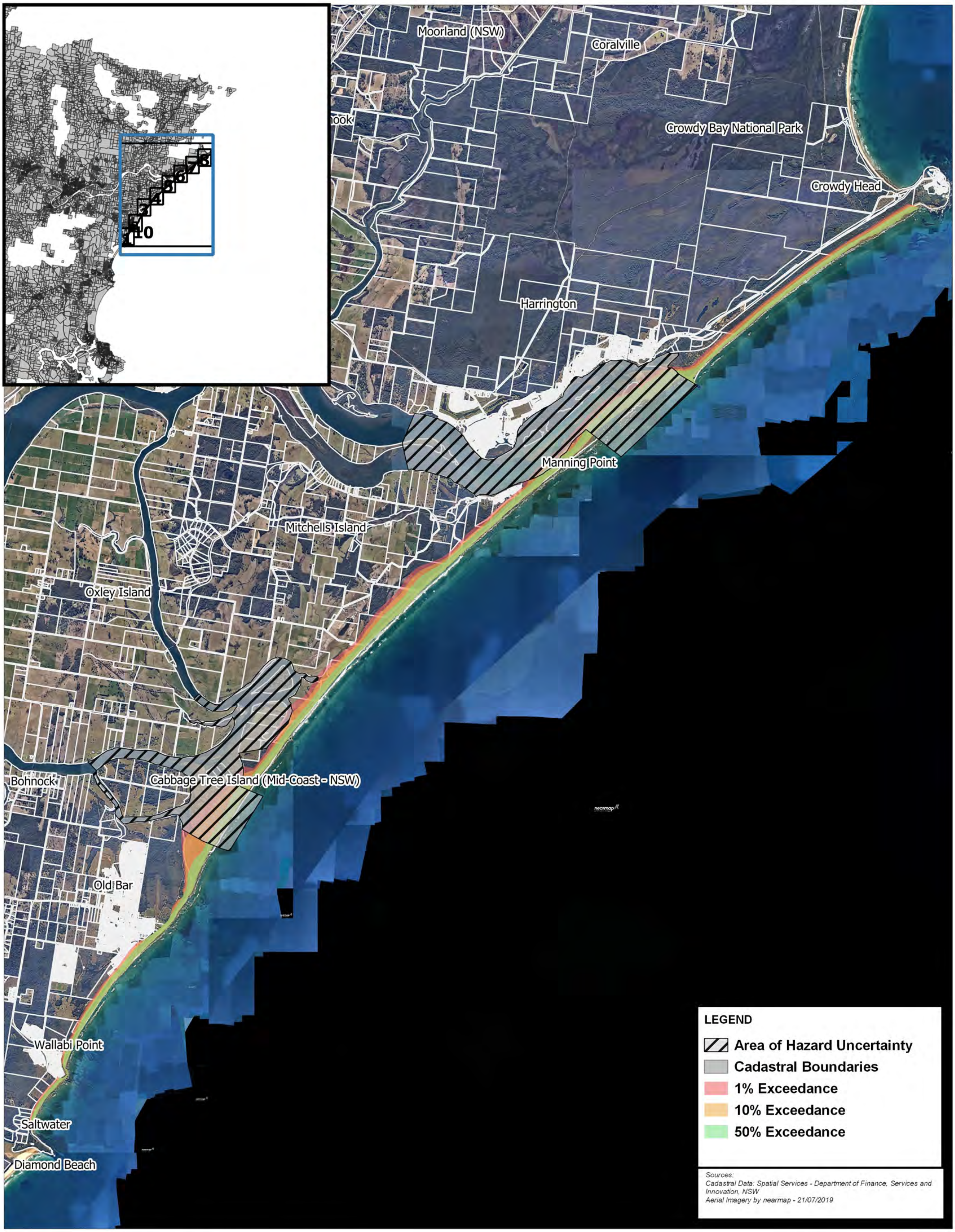
Manning Point Township - 2060 Zone of Slope Adjustment

Figure:
D-11

Rev:
A

BMT
www.bmt.org

Filepath: I:\N21005.i.ajs.Old Bar Manning Point CMP\QGZ\COA_017_200207_2020_ZSA_Atlas.qgz



Sources:
Cadastral Data: Spatial Services - Department of Finance, Services and Innovation, NSW
Aerial Imagery by nearmap - 21/07/2019

Title:

Study Area - 2060 Zone of Slope Adjustment

Figure: **D-12**

Rev: **A**

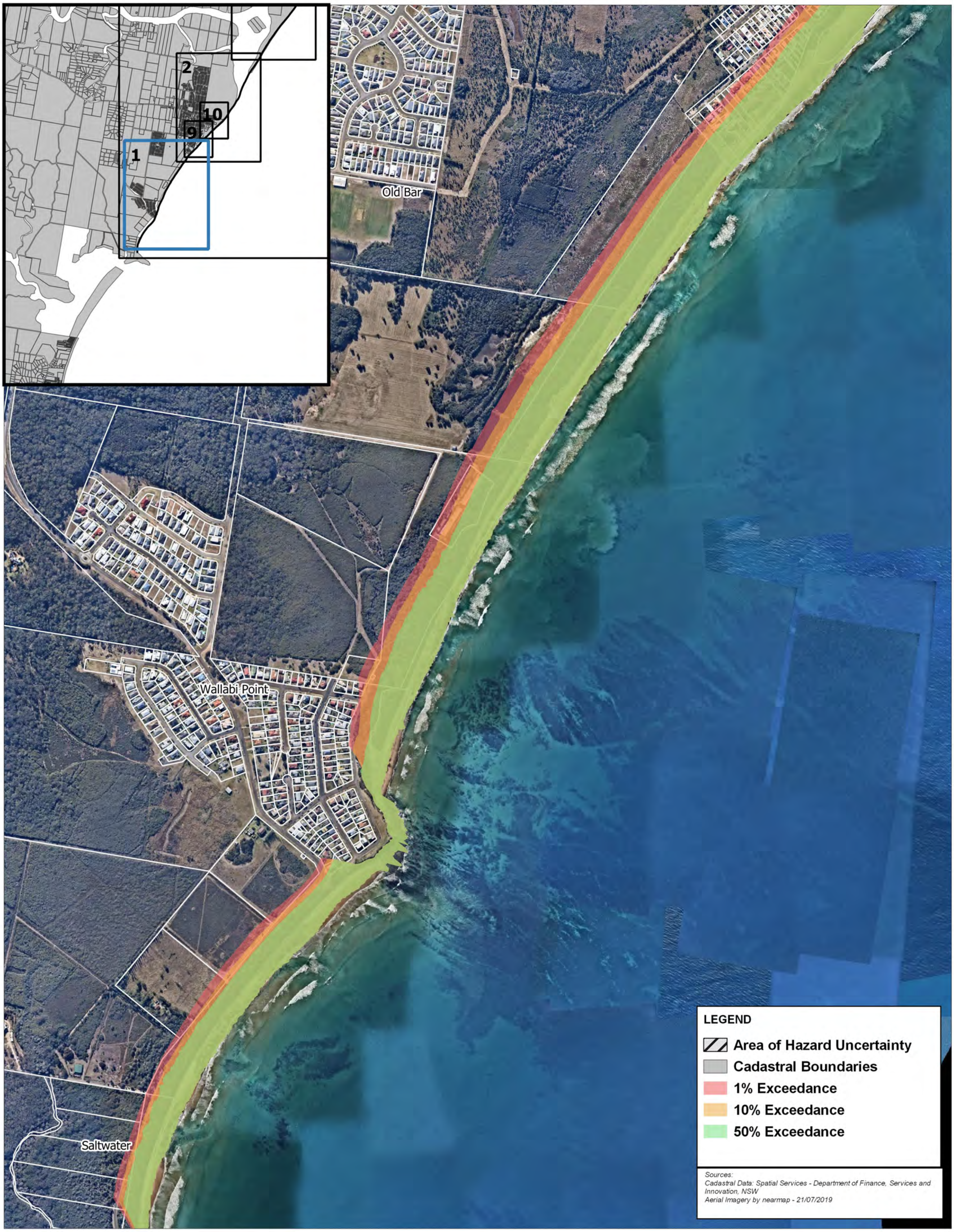
N

0 1000 2000 3000 4000 m

BMT
www.bmt.org

Filepath: I:\N21005.i.ajs.Old Bar Manning Point CMP\QGZ\COA_017_200207_2020_ZSA_Atlas.qgz

Appendix E 2060 Zone of Reduced Foundation Capacity Mapping



Sources:
Cadastral Data: Spatial Services - Department of Finance, Services and Innovation, NSW
Aerial Imagery by nearmap - 21/07/2019

Title:

Wallabi Point - 2060 Zone of Reduced Foundation Capacity

Figure:

E-1

Rev:

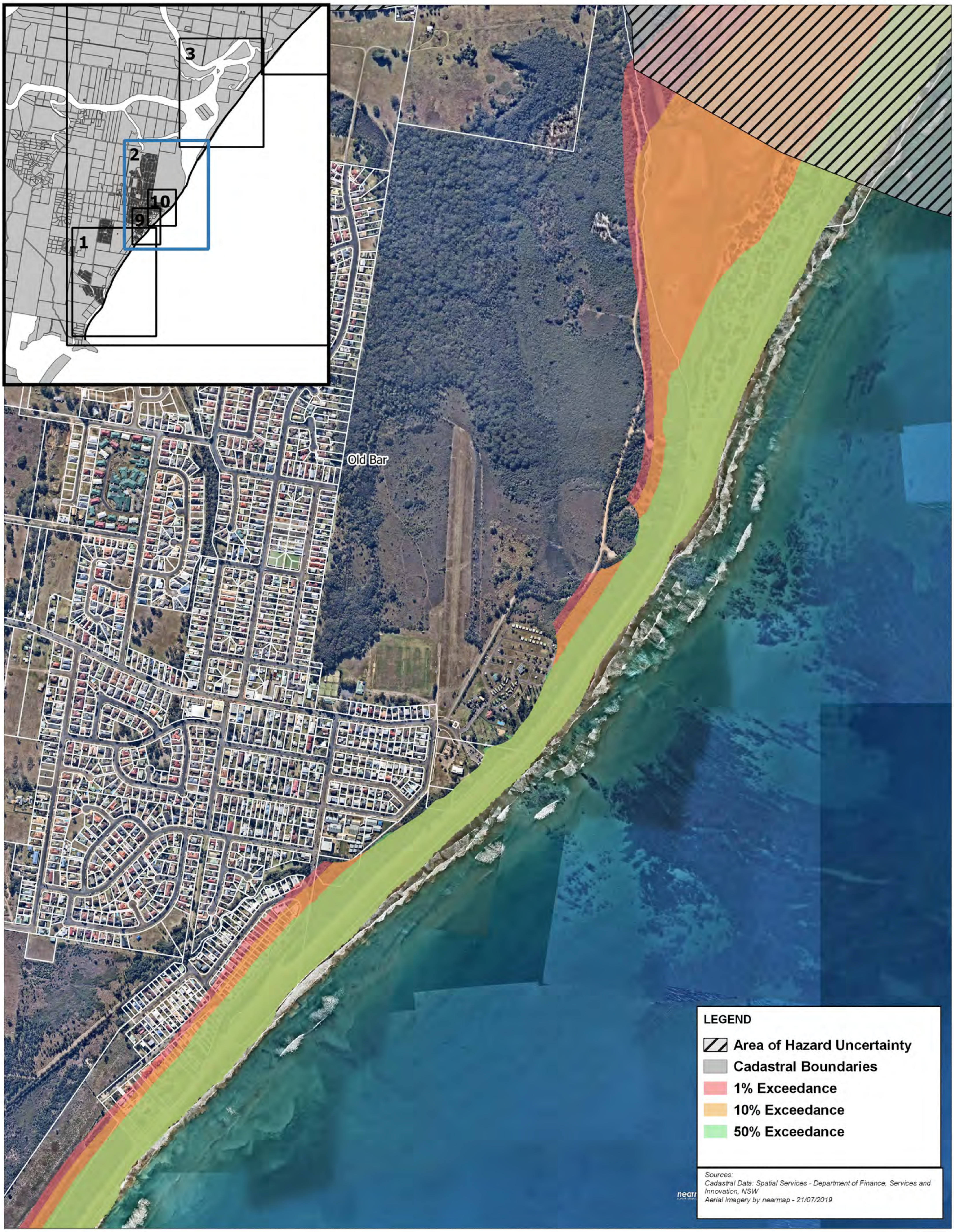
A

N

0 200 400 600 800 m

BMT
www.bmt.org

Filepath: I:\N21005.i.ajs.Old Bar Manning Point CMP\QGZ\COA_017_200207_2060_ZRFC_Atlas.qgz



Sources:
Cadastral Data: Spatial Services - Department of Finance, Services and Innovation, NSW
Aerial Imagery by nearmap - 21/07/2019

Title:

Old Bar - 2060 Zone of Reduced Foundation Capacity

Figure: **E-2**

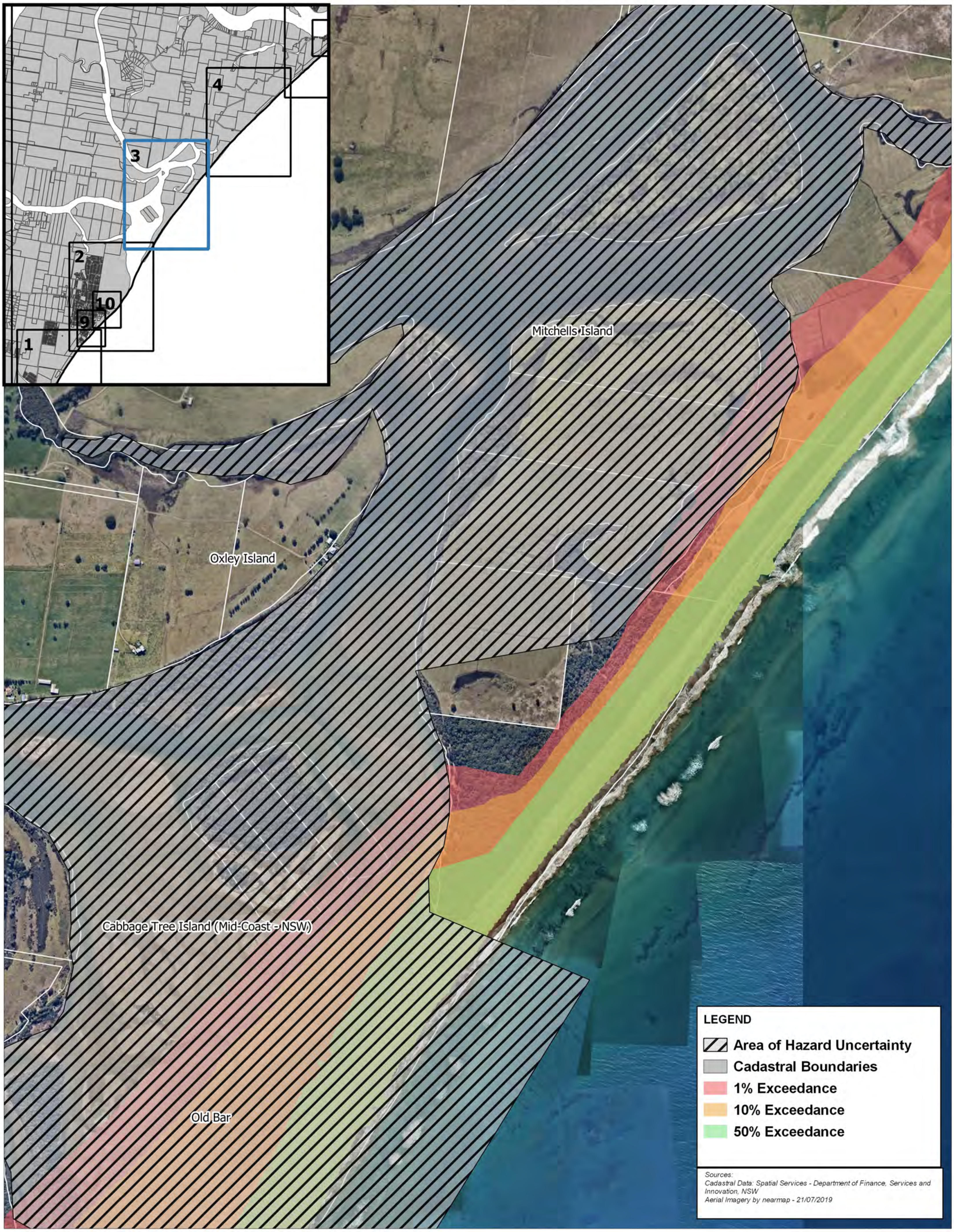
Rev: **A**

N

0 200 400 600 800 m

BMT
www.bmt.org

Filepath: I:\N21005.i.ajs.Old Bar Manning Point CMP\QGZ\COA_017_200207_2060_ZRFC_Atlas.qgz



Sources:
Cadastral Data: Spatial Services - Department of Finance, Services and Innovation, NSW
Aerial Imagery by nearmap - 21/07/2019

Title:

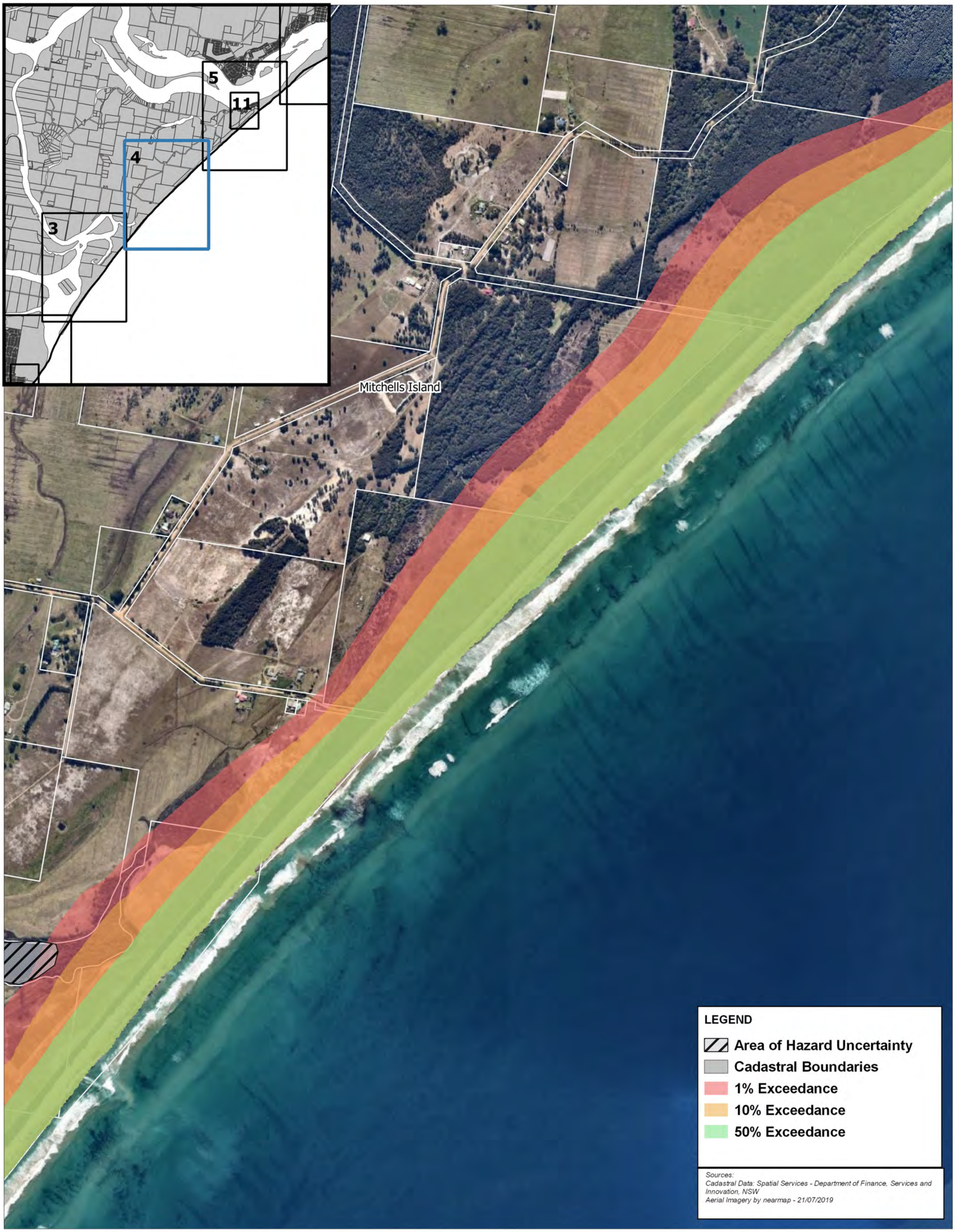
Farquhar Inlet - 2060 Zone of Reduced Foundation Capacity

Figure: **E-3**

Rev: **A**

BMT
www.bmt.org

Filepath: I:\N21005.i.ajs.Old Bar Manning Point CMP\QGZ\COA_017_200207_2060_ZRFC_Atlas.qgz



Sources:
Cadastral Data: Spatial Services - Department of Finance, Services and Innovation, NSW
Aerial Imagery by nearmap - 21/07/2019

Title:
Mitchells Island - 2060 Zone of Reduced Foundation Capacity

Figure: E-4

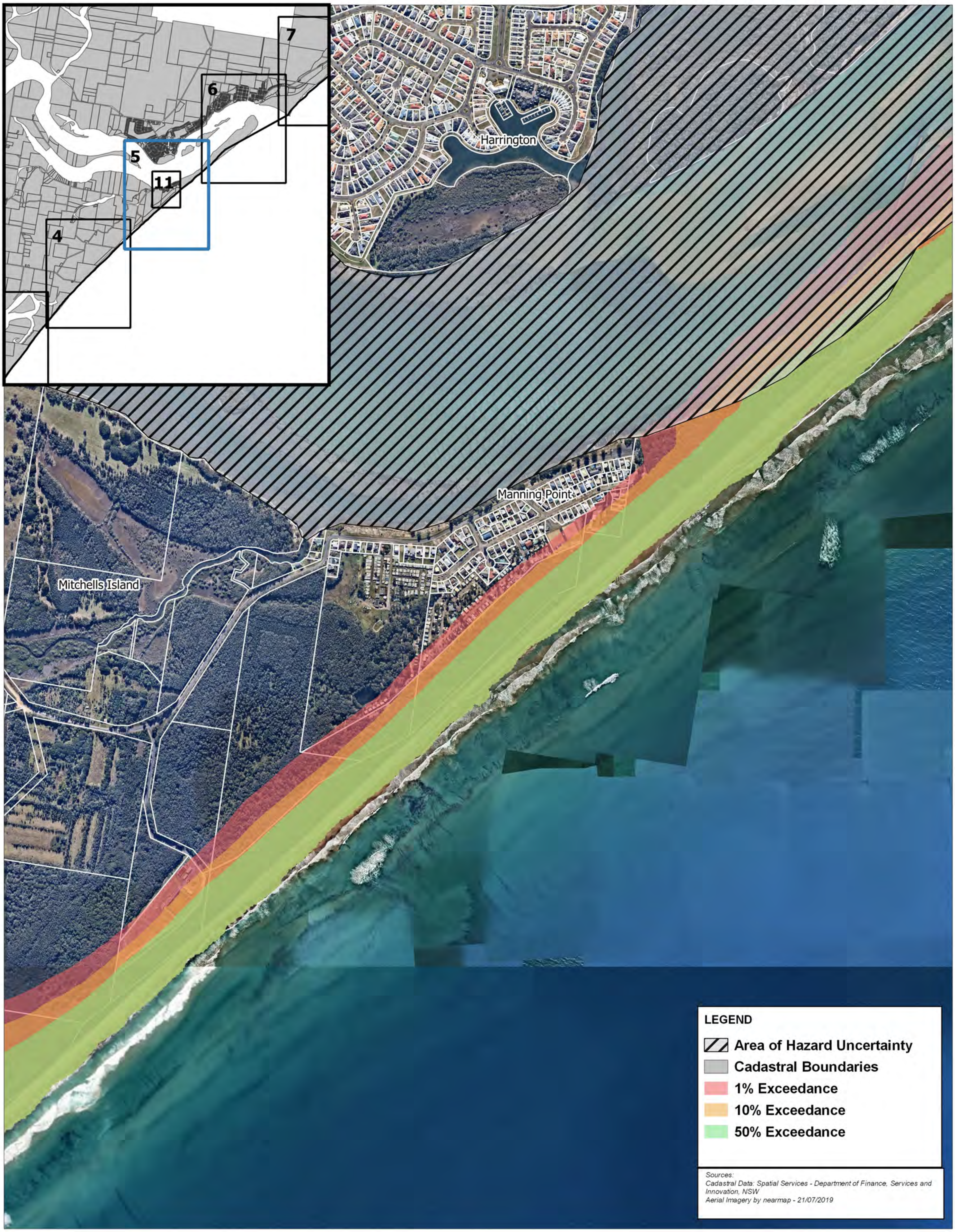
Rev: A

N

0 200 400 600 800 m

BMT
www.bmt.org

Filepath: I:\N21005.i.ajs.Old Bar Manning Point CMP\QGZ\COA_017_200207_2060_ZRFC_Atlas.qgz



Sources:
Cadastral Data: Spatial Services - Department of Finance, Services and Innovation, NSW
Aerial Imagery by nearmap - 21/07/2019

Title:

Manning Point - 2060 Zone of Reduced Foundation Capacity

Figure: **E-5**

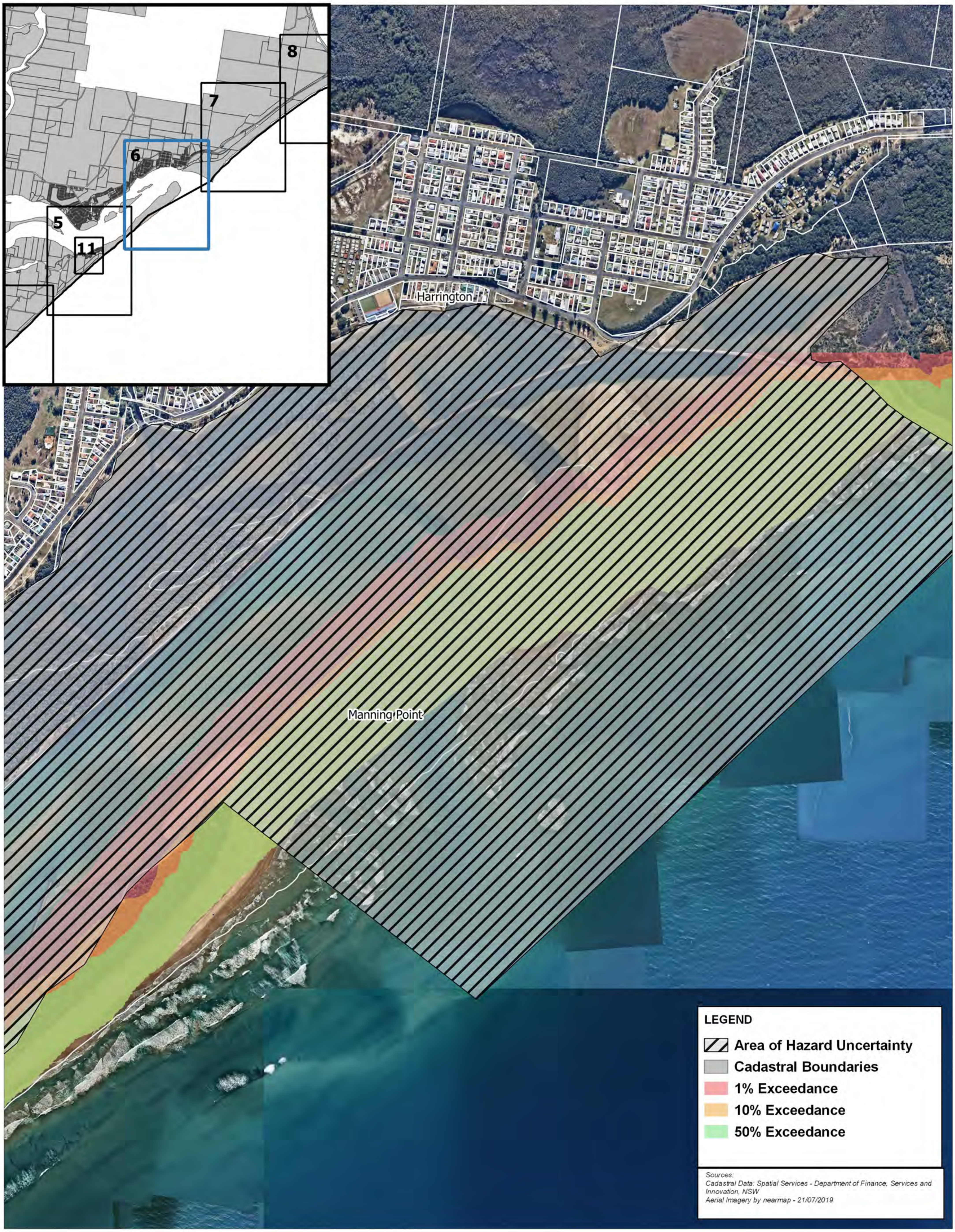
Rev: **A**

N

0 200 400 600 800 m

BMT
www.bmt.org

Filepath: I:\N21005.i.ajs.Old Bar Manning Point CMP\QGZ\COA_017_200207_2060_ZRFC_Atlas.qgz



Sources:
Cadastral Data: Spatial Services - Department of Finance, Services and Innovation, NSW
Aerial Imagery by nearmap - 21/07/2019

Title:

Harrington Entrance - 2060 Zone of Reduced Foundation Capacity

Figure:
E-6

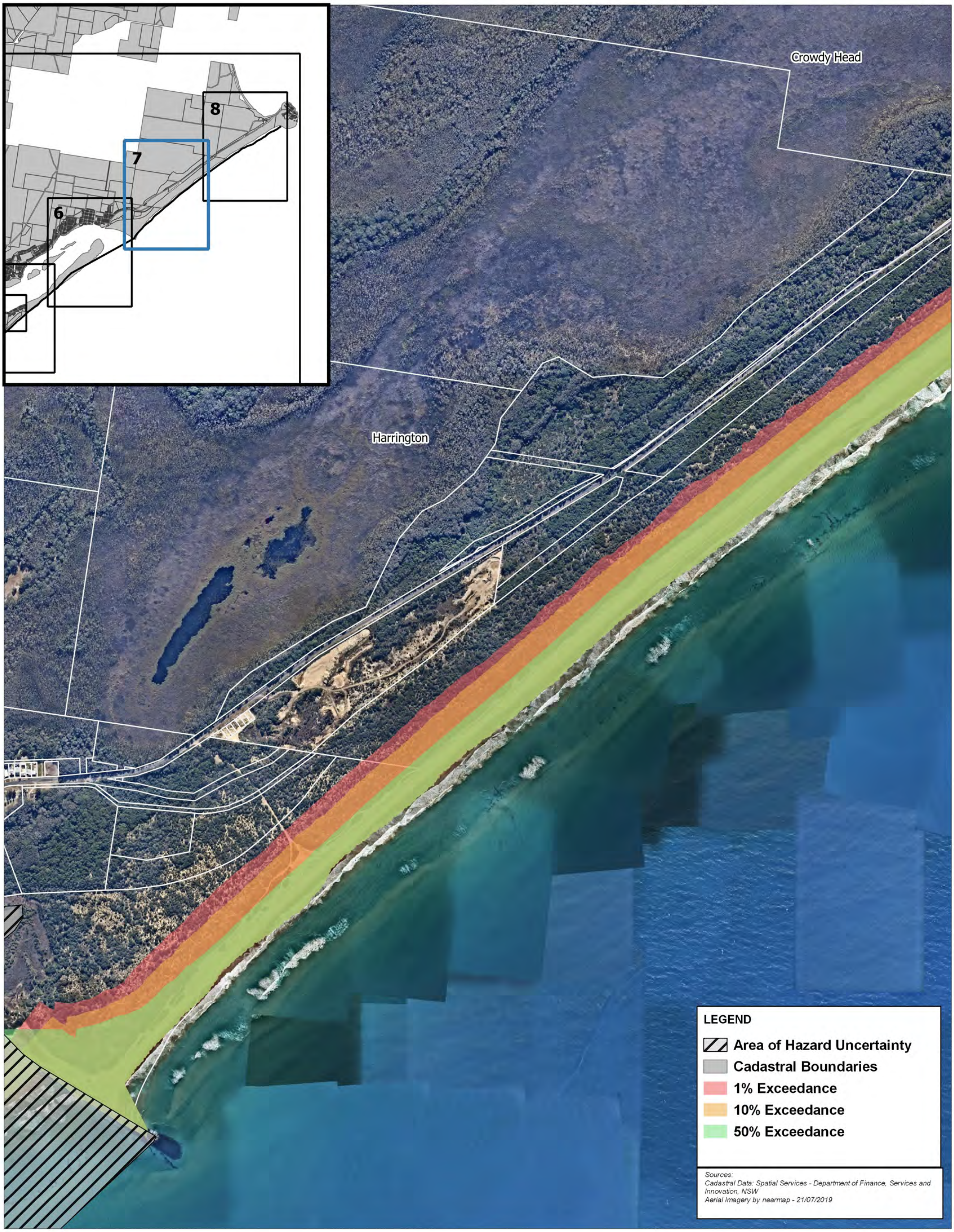
Rev:
A

N

0 200 400 600 800 m

BMT
www.bmt.org

Filepath: I:\N21005.i.ajs.Old Bar Manning Point CMP\QGZ\COA_017_200207_2060_ZRFC_Atlas.qgz



Sources:
Cadastral Data: Spatial Services - Department of Finance, Services and Innovation, NSW
Aerial Imagery by nearmap - 21/07/2019

Title:

Harrington Beach (South) - 2060 Zone of Reduced Foundation Capacity

Figure:
E-7

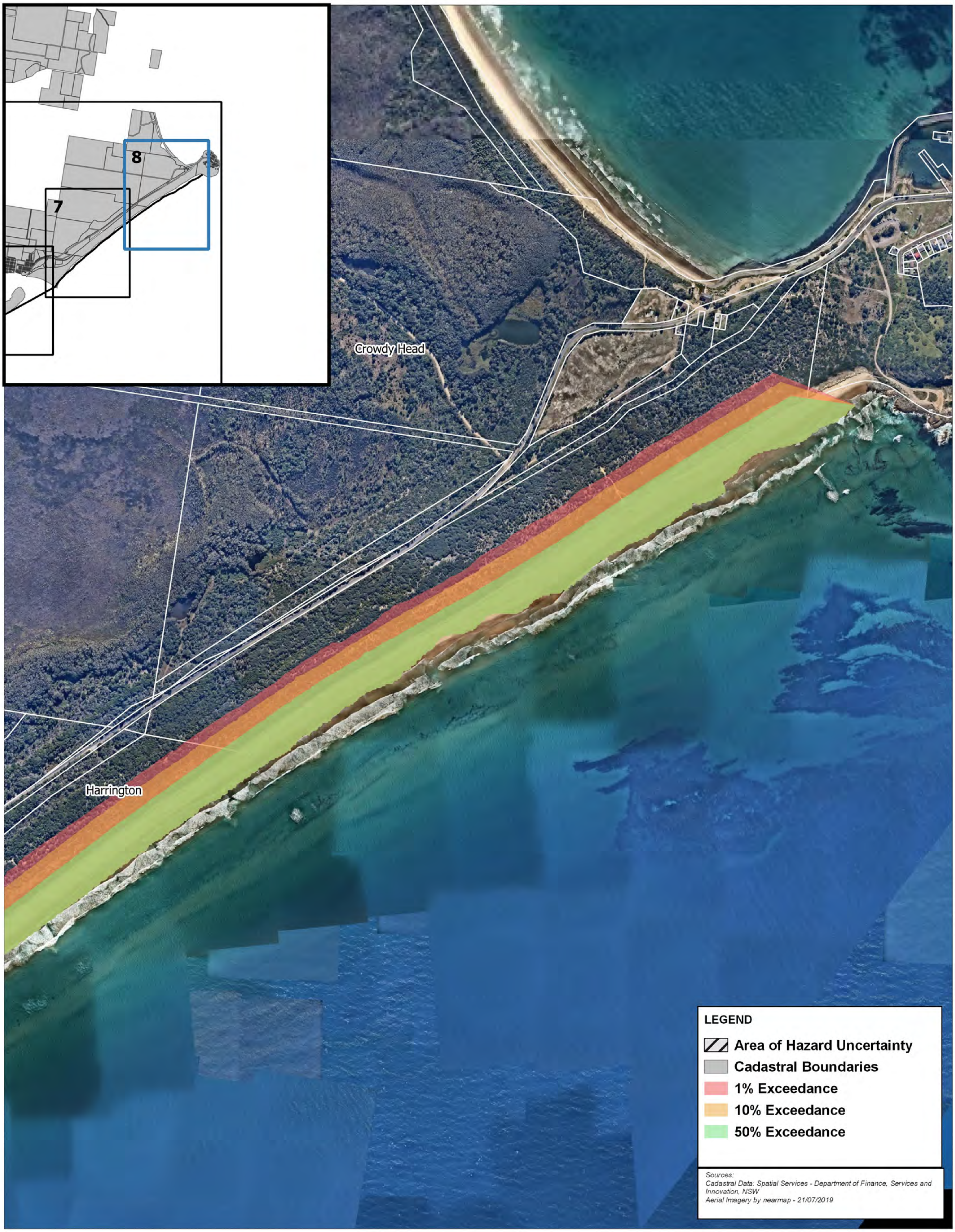
Rev:
A

N

0 200 400 600 800 m

BMT
www.bmt.org

Filepath: I:\N21005.i.ajs.Old Bar Manning Point CMP\QGZ\COA_017_200207_2060_ZRFC_Atlas.qgz



Sources:
Cadastral Data: Spatial Services - Department of Finance, Services and Innovation, NSW
Aerial Imagery by nearmap - 21/07/2019

Title:

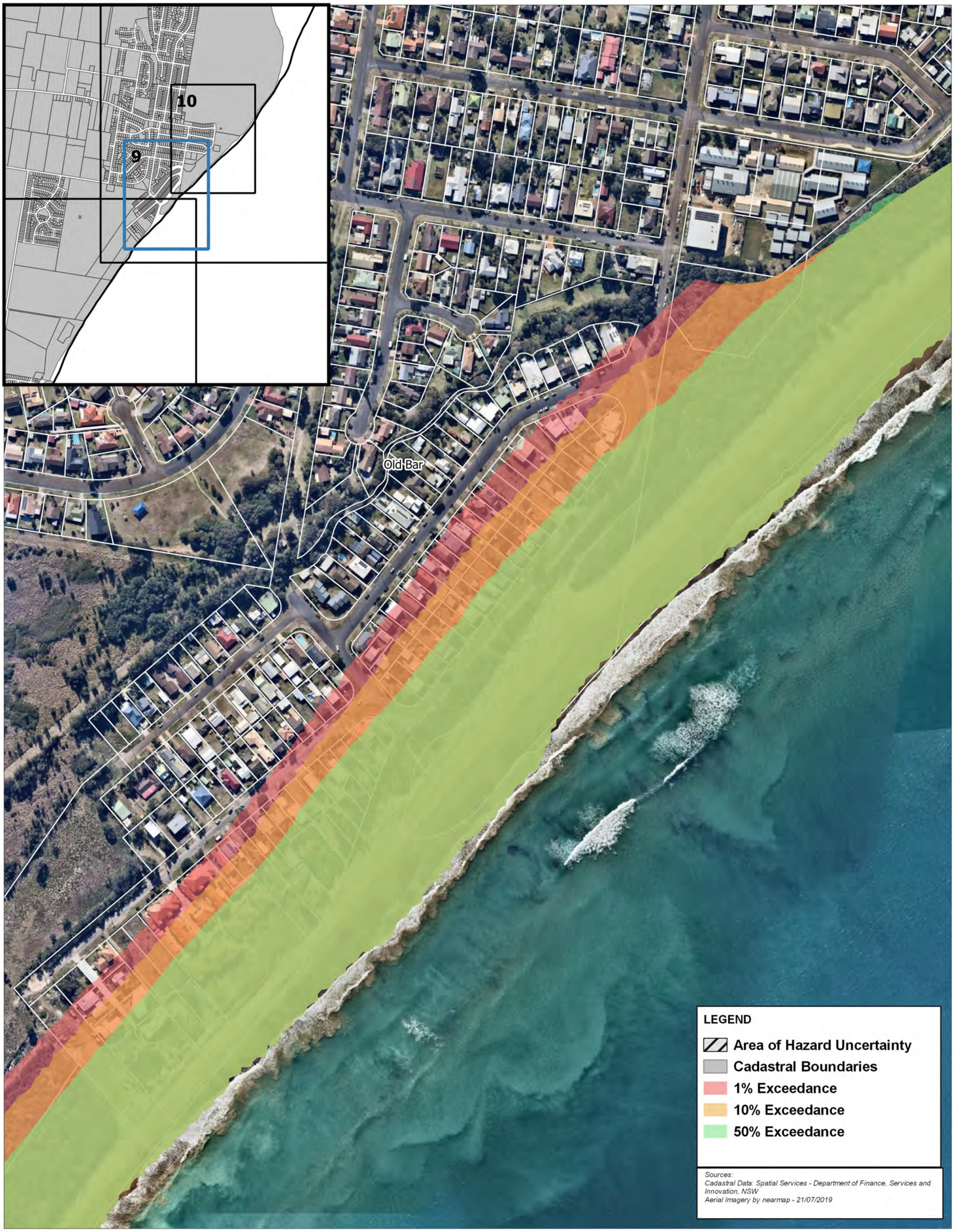
Harrington Beach (North) - 2060 Zone of Reduced Foundation Capacity

Figure:
E-8

Rev:
A

www.bmt.org

Filepath: I:\N21005.i.ajs.Old Bar Manning Point CMP\QGZ\COA_017_200207_2060_ZRFC_Atlas.qgz



Sources:
Cadastral Data: Spatial Services - Department of Finance, Services and Innovation, NSW
Aerial Imagery by nearmap - 21/07/2019

Title:

Old Bar (South) - 2060 Zone of Reduced Foundation Capacity

Figure:
E-9

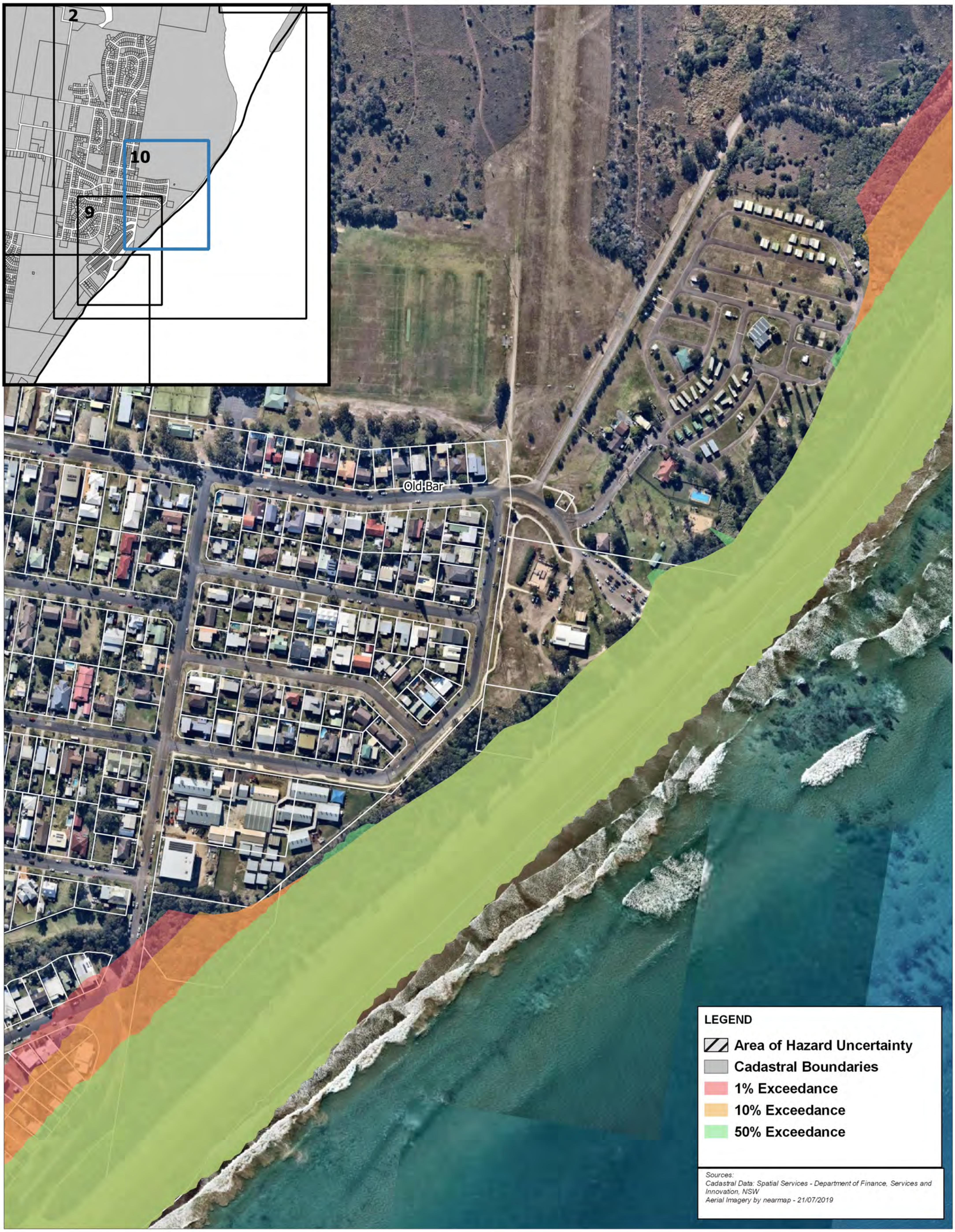
Rev:
A

N

0 70 140 210 280 m

BMT
www.bmt.org

Filepath: I:\N21005.i.ajs.Old Bar Manning Point CMP\QGZ\COA_017_200207_2060_ZRFC_Atlas.qgz



Sources:
Cadastral Data: Spatial Services - Department of Finance, Services and Innovation, NSW
Aerial Imagery by nearmap - 21/07/2019

Title:

Old Bar (North) - 2060 Zone of Reduced Foundation Capacity

Figure: **E-10**

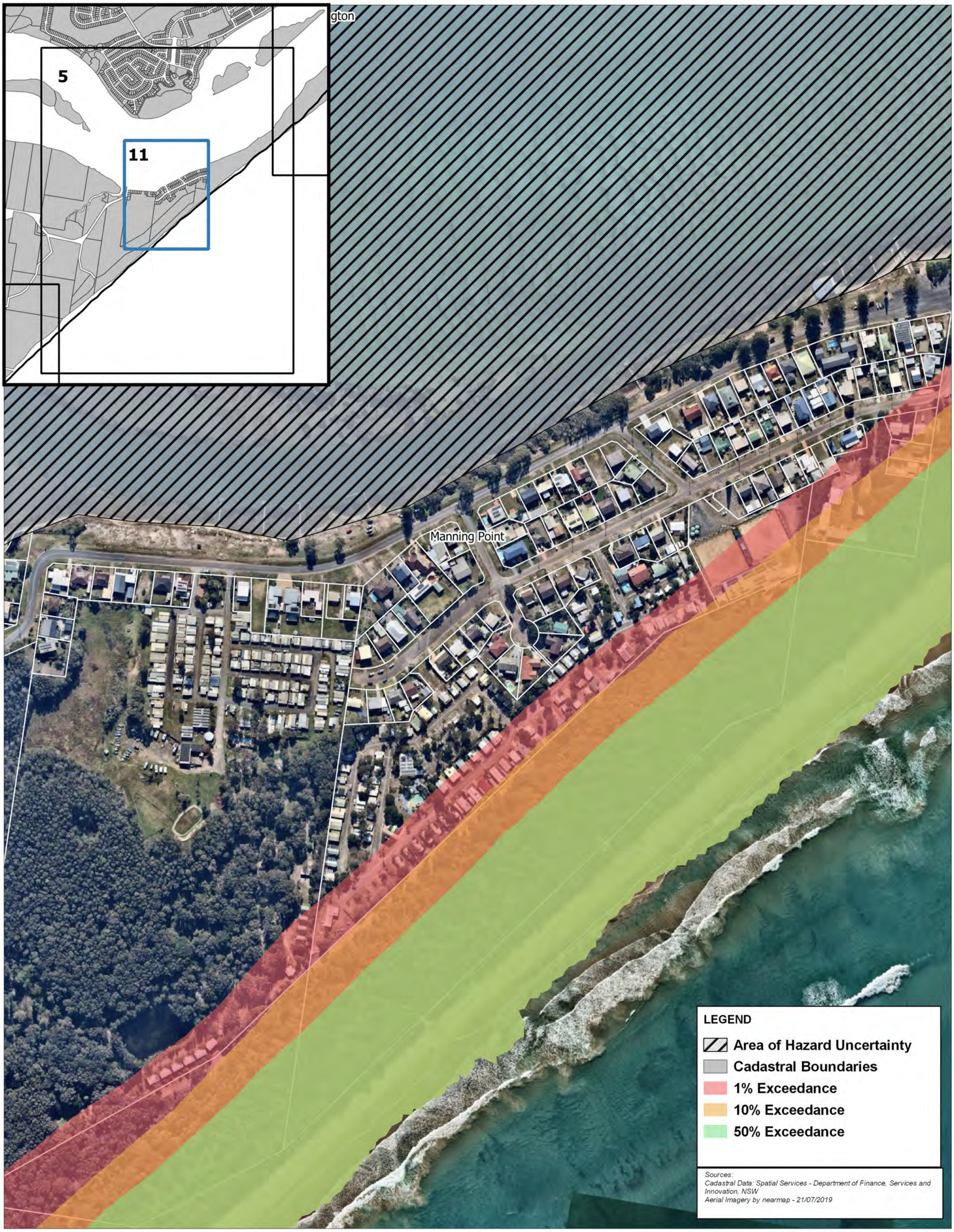
Rev: **A**

N

0 70 140 210 280 m

www.bmt.org

Filepath: I:\N21005.i.ajs.Old Bar Manning Point CMP\QGZ\COA_017_200207_2060_ZRFC_Atlas.qgz



Sources:
Cadastral Data: Spatial Services - Department of Finance, Services and Innovation, NSW
Aerial Imagery by nearmap - 21/07/2019

Title:

Manning Point Township - 2060 Zone of Reduced Foundation Capacity

Figure: **E-11**

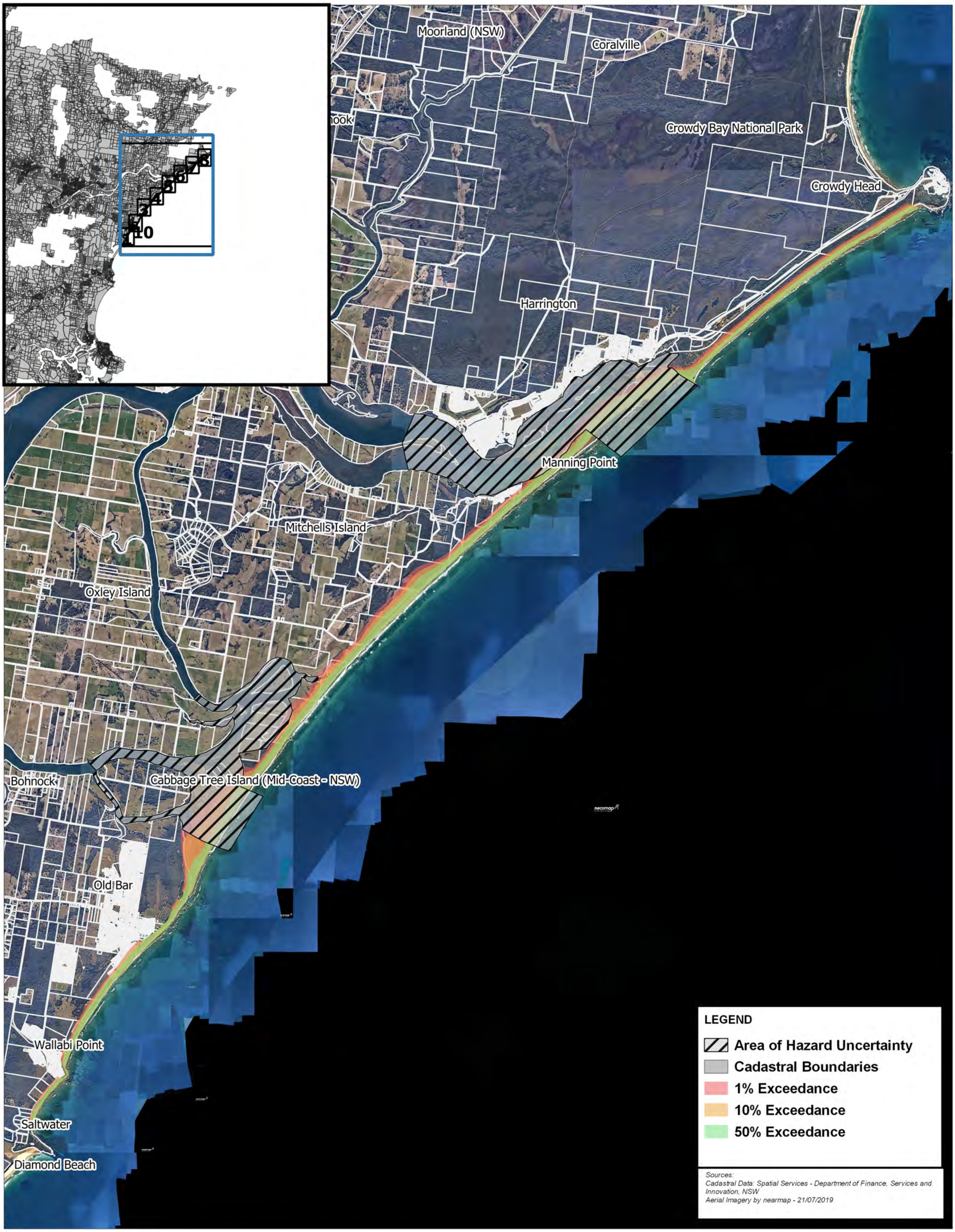
Rev: **A**

N

0 70 140 210 280 m

www.bmt.org

Filepath: I:\N21005.i.ajs.Old Bar Manning Point CMP\QGZ\COA_017_200207_2060_ZRFC_Atlas.qgz



Sources:
Cadastral Data: Spatial Services - Department of Finance, Services and Innovation, NSW
Aerial Imagery by nearmap - 21/07/2019

Title:

Study Area - 2060 Zone of Reduced Foundation Capacity

Figure:

E-12

Rev:

A

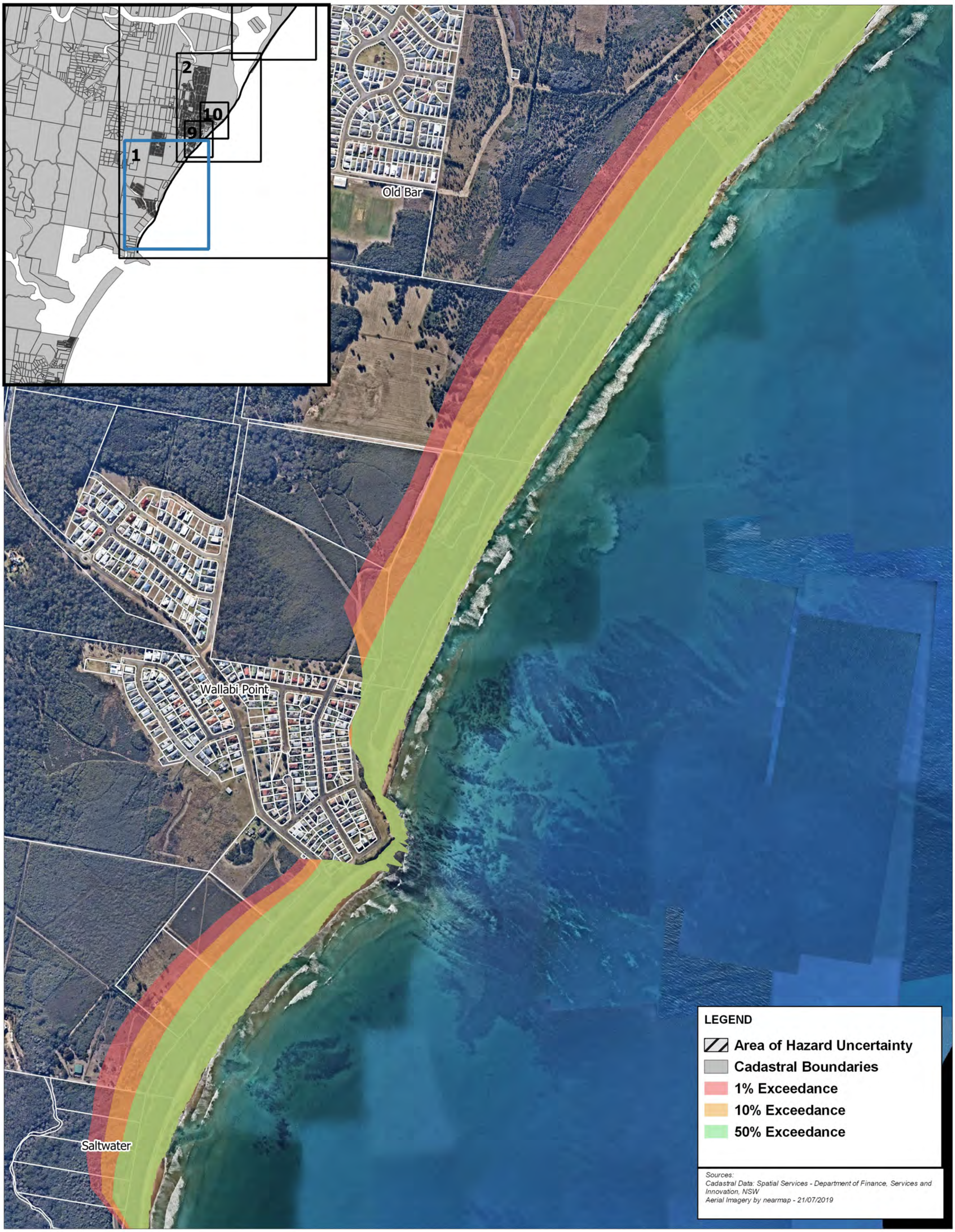
N

0 1000 2000 3000 4000 m

BMT
www.bmt.org

Filepath: I:\N21005.i.ajs.Old Bar Manning Point CMP\QGZ\COA_017_200207_2060_ZRFC_Atlas.qgz

Appendix F 2100 Zone of Slope Adjustment Mapping



Sources:
Cadastral Data: Spatial Services - Department of Finance, Services and Innovation, NSW
Aerial Imagery by nearmap - 21/07/2019

Title:

Wallabi Point - 2100 Zone of Slope Adjustment

Figure: **F-1**

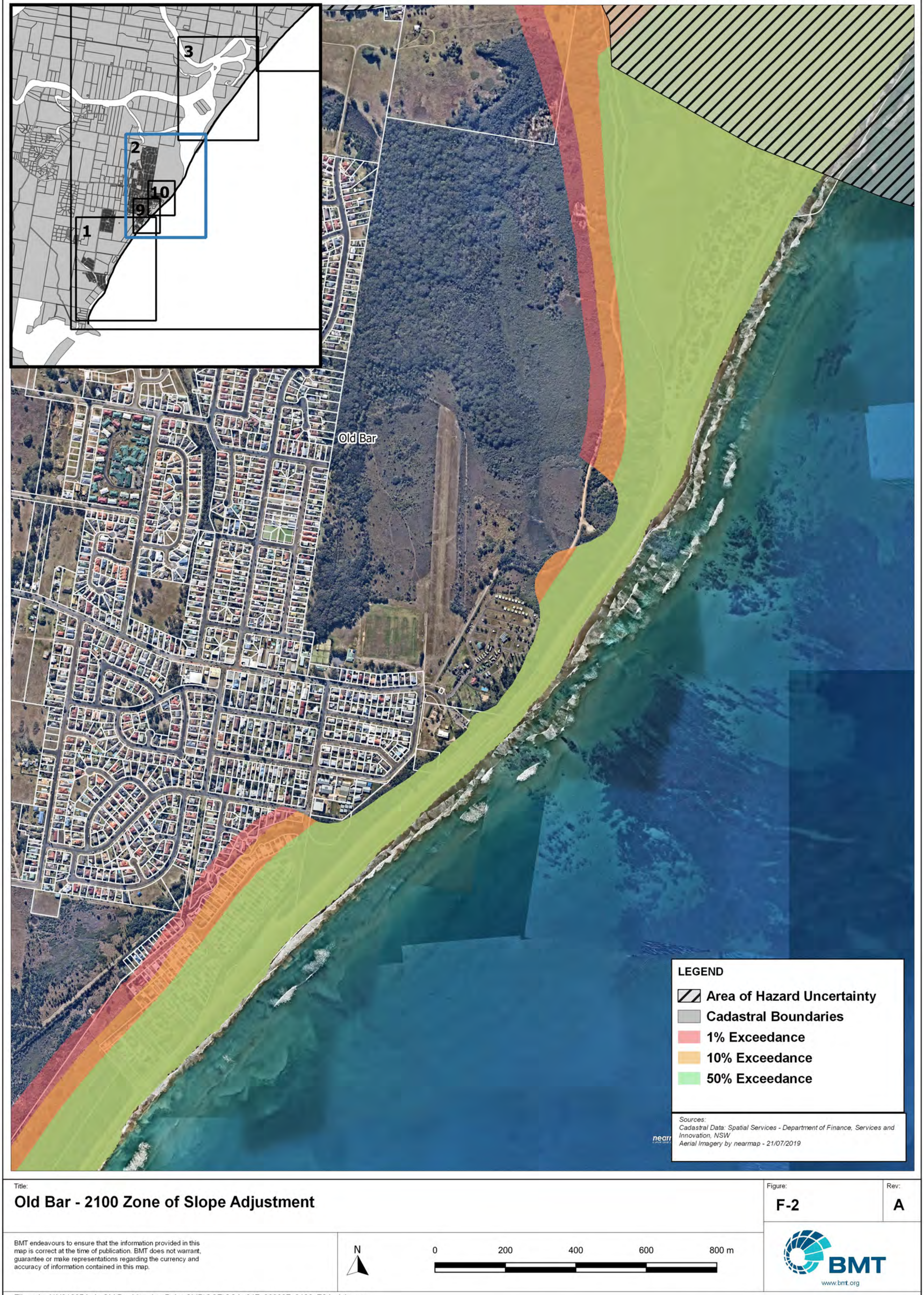
Rev: **A**

N

0 200 400 600 800 m

BMT
www.bmt.org

Filepath: I:\N21005.i.ajs.Old Bar Manning Point CMP\QGZ\COA_017_200207_2100_ZSA_Atlas.qgz



LEGEND

- ▨ Area of Hazard Uncertainty
- ⬜ Cadastral Boundaries
- 🟥 1% Exceedance
- 🟧 10% Exceedance
- 🟩 50% Exceedance

Sources:
Cadastral Data: Spatial Services - Department of Finance, Services and Innovation, NSW
Aerial Imagery by nearmap - 21/07/2019

Title:

Old Bar - 2100 Zone of Slope Adjustment

Figure: **F-2**

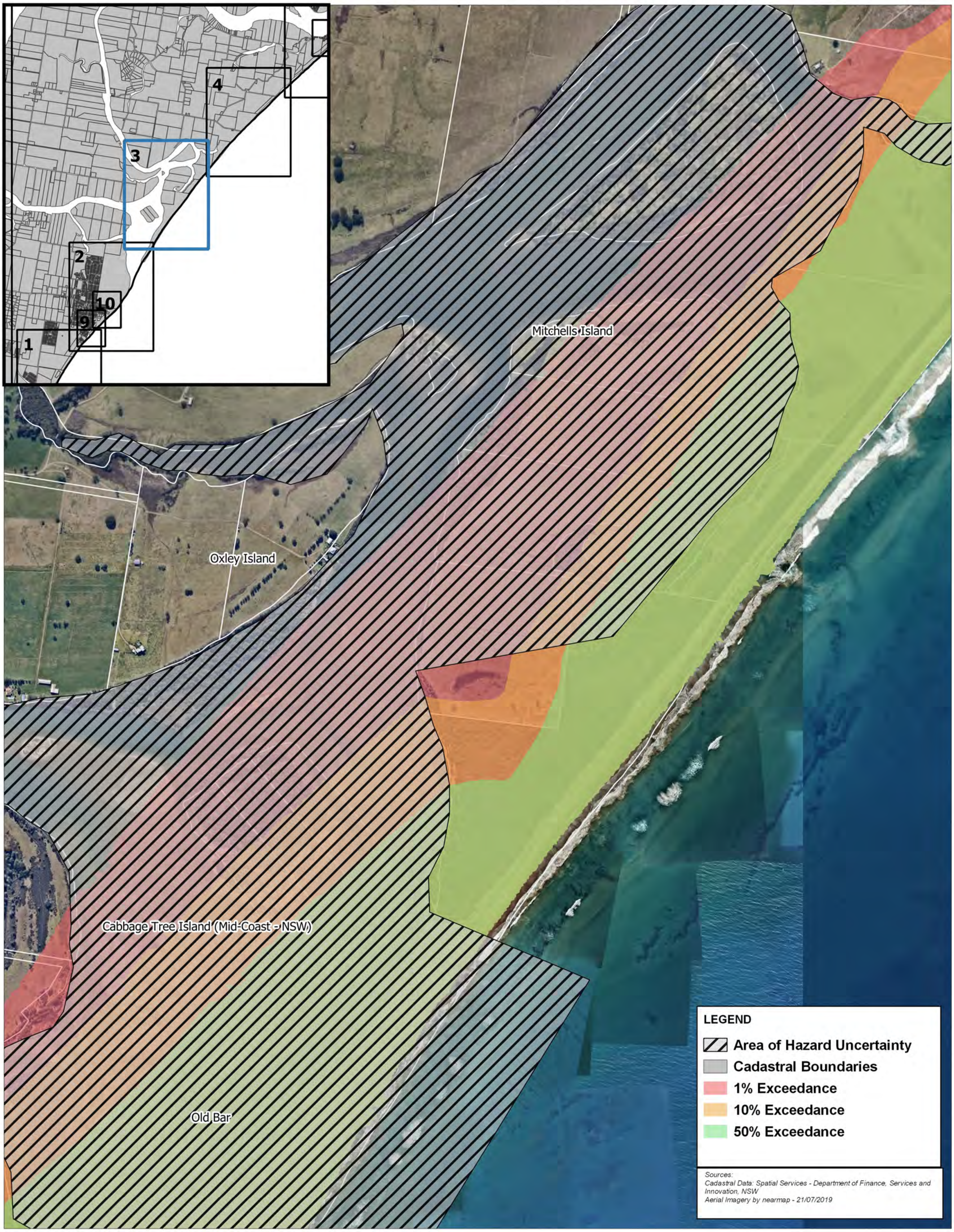
Rev: **A**

N

0 200 400 600 800 m

BMT
www.bmt.org

Filepath: I:\N21005.i.ajs.Old Bar Manning Point CMP\QGZ\COA_017_200207_2100_ZSA_Atlas.qgz



Sources:
Cadastral Data: Spatial Services - Department of Finance, Services and Innovation, NSW
Aerial Imagery by nearmap - 21/07/2019

Title:
Farquhar Inlet - 2100 Zone of Slope Adjustment

Figure: F-3

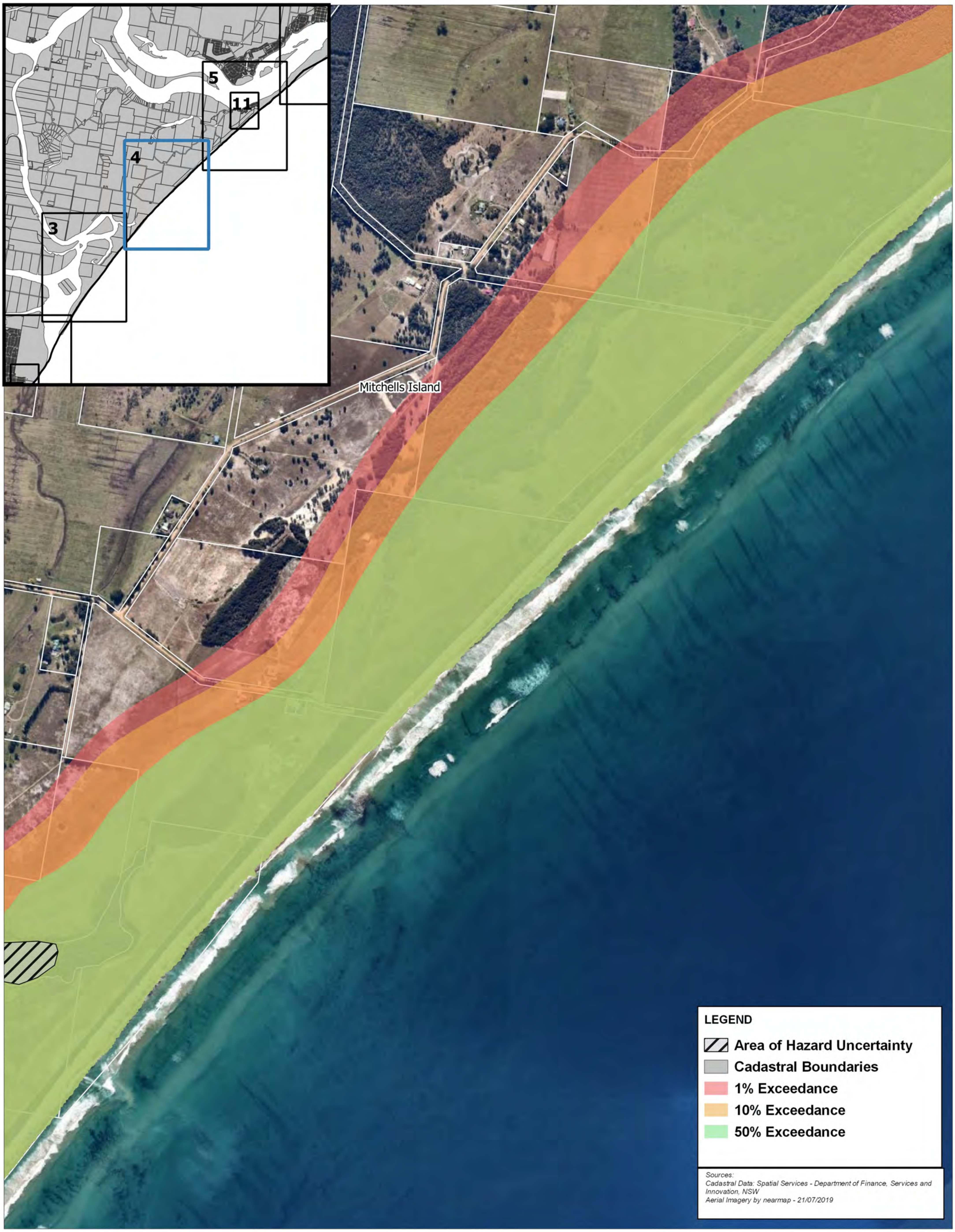
Rev: A

N

0 200 400 600 800 m

BMT
www.bmt.org

Filepath: I:\N21005.i.ajs.Old Bar Manning Point CMP\QGZ\COA_017_200207_2100_ZSA_Atlas.qgz



Sources:
Cadastral Data: Spatial Services - Department of Finance, Services and Innovation, NSW
Aerial Imagery by nearmap - 21/07/2019

Title:
Mitchells Island - 2100 Zone of Slope Adjustment

Figure:
F-4

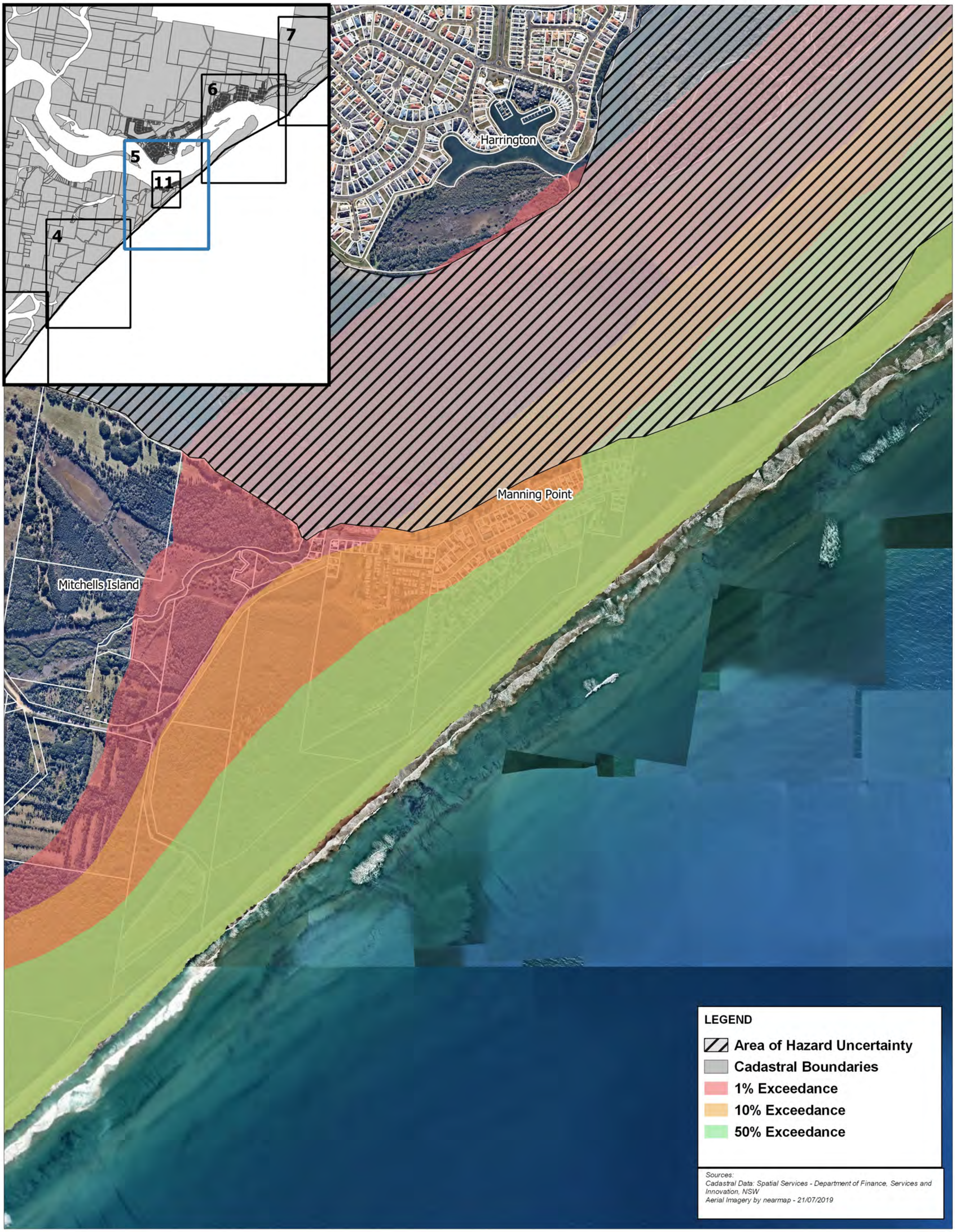
Rev:
A

N

0 200 400 600 800 m

BMT
www.bmt.org

Filepath: I:\N21005.i.ajs.Old Bar Manning Point CMP\QGZ\COA_017_200207_2100_ZSA_Atlas.qgz



Sources:
Cadastral Data: Spatial Services - Department of Finance, Services and Innovation, NSW
Aerial Imagery by nearmap - 21/07/2019

Title:

Manning Point - 2100 Zone of Slope Adjustment

Figure: **F-5**

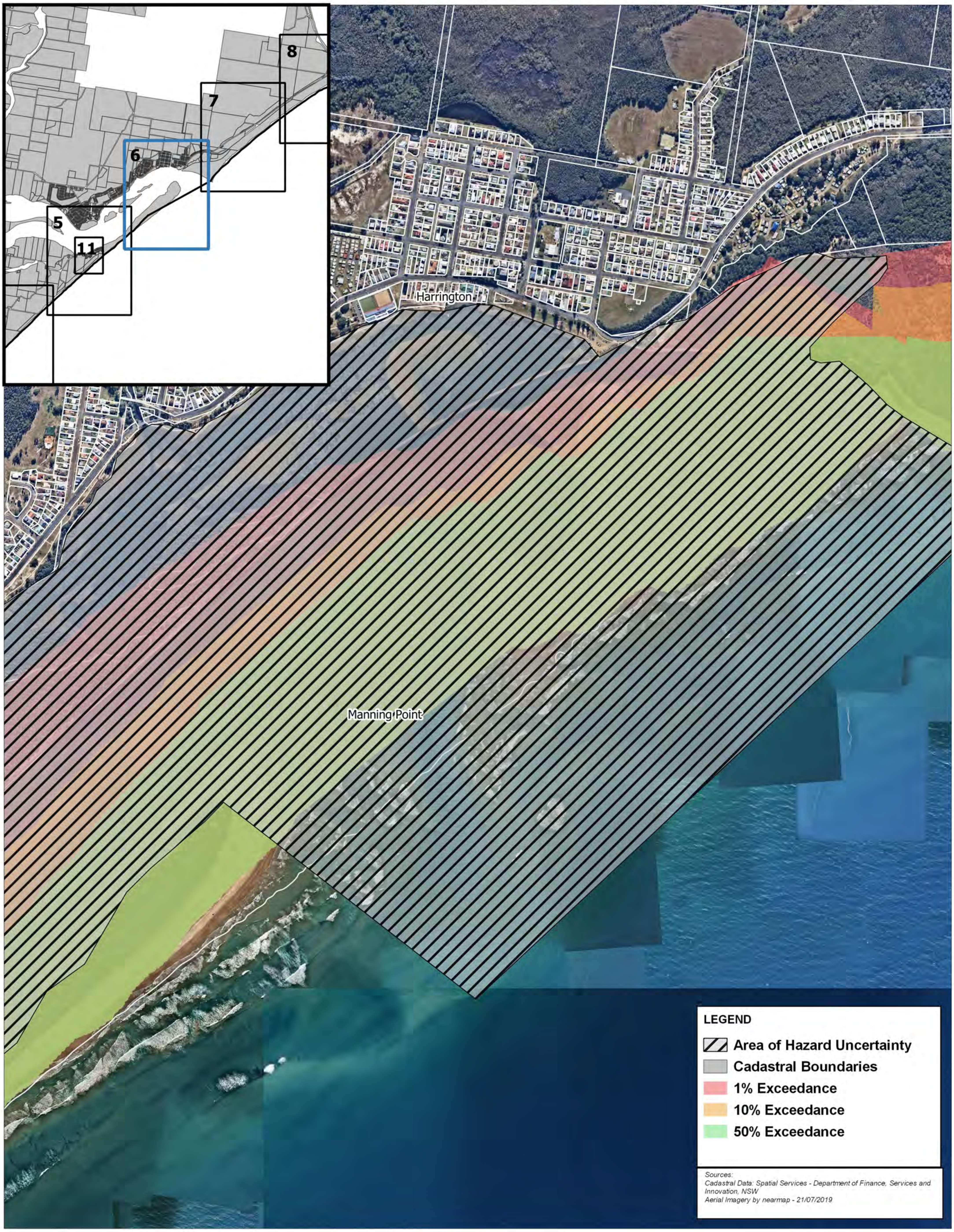
Rev: **A**

N

0 200 400 600 800 m

BMT
www.bmt.org

Filepath: I:\N21005.i.ajs.Old Bar Manning Point CMP\QGZ\COA_017_200207_2100_ZSA_Atlas.qgz



Sources:
Cadastral Data: Spatial Services - Department of Finance, Services and Innovation, NSW
Aerial Imagery by nearmap - 21/07/2019

Title:

Harrington Entrance - 2100 Zone of Slope Adjustment

Figure: F-6

Rev: A

N

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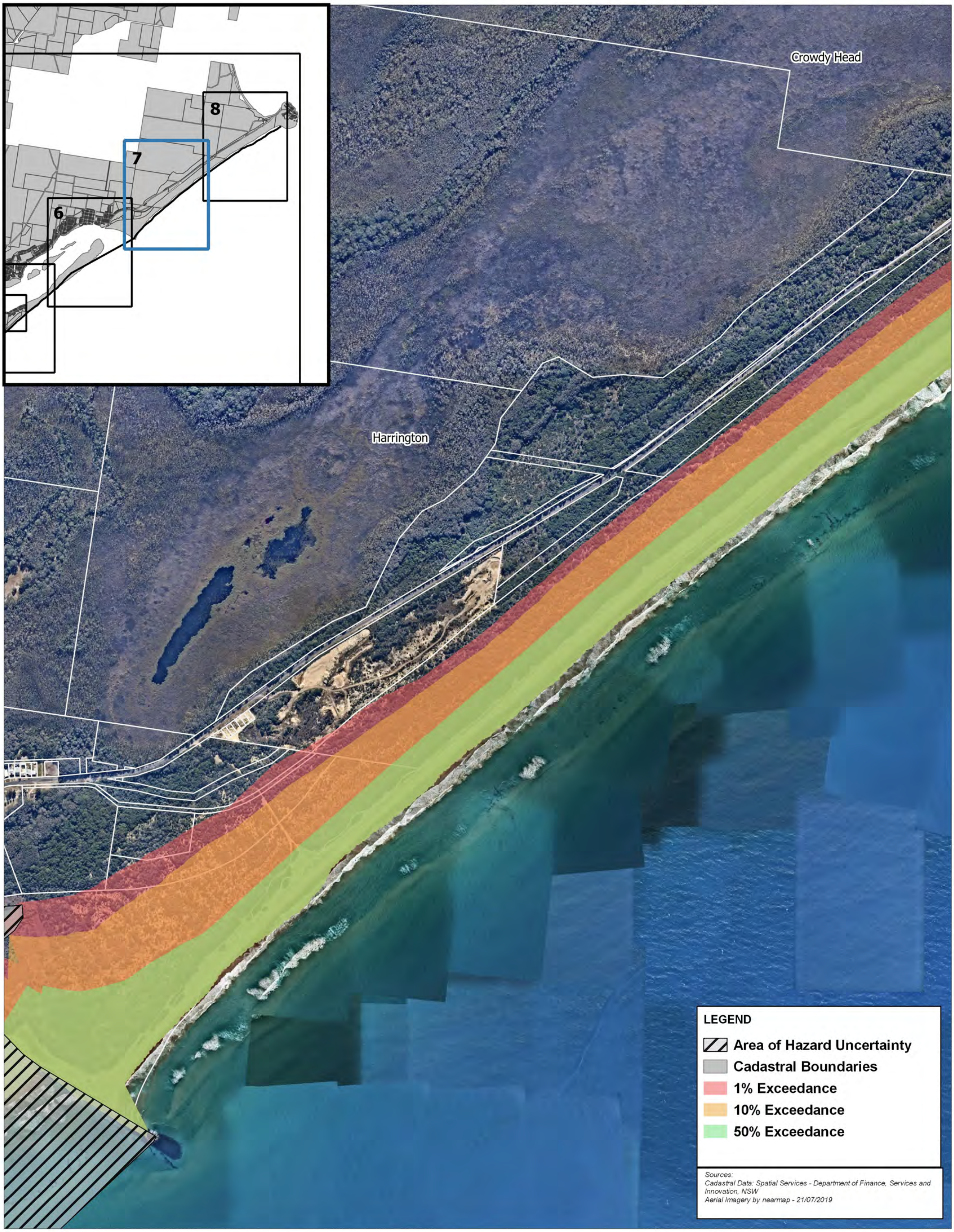

Sources:
Cadastral Data: Spatial Services - Department of Finance, Services and Innovation, NSW
Aerial Imagery by nearmap - 21/07/2019

Title:

Harrington Beach (South) - 2100 Zone of Slope Adjustment

Figure: **F-7**

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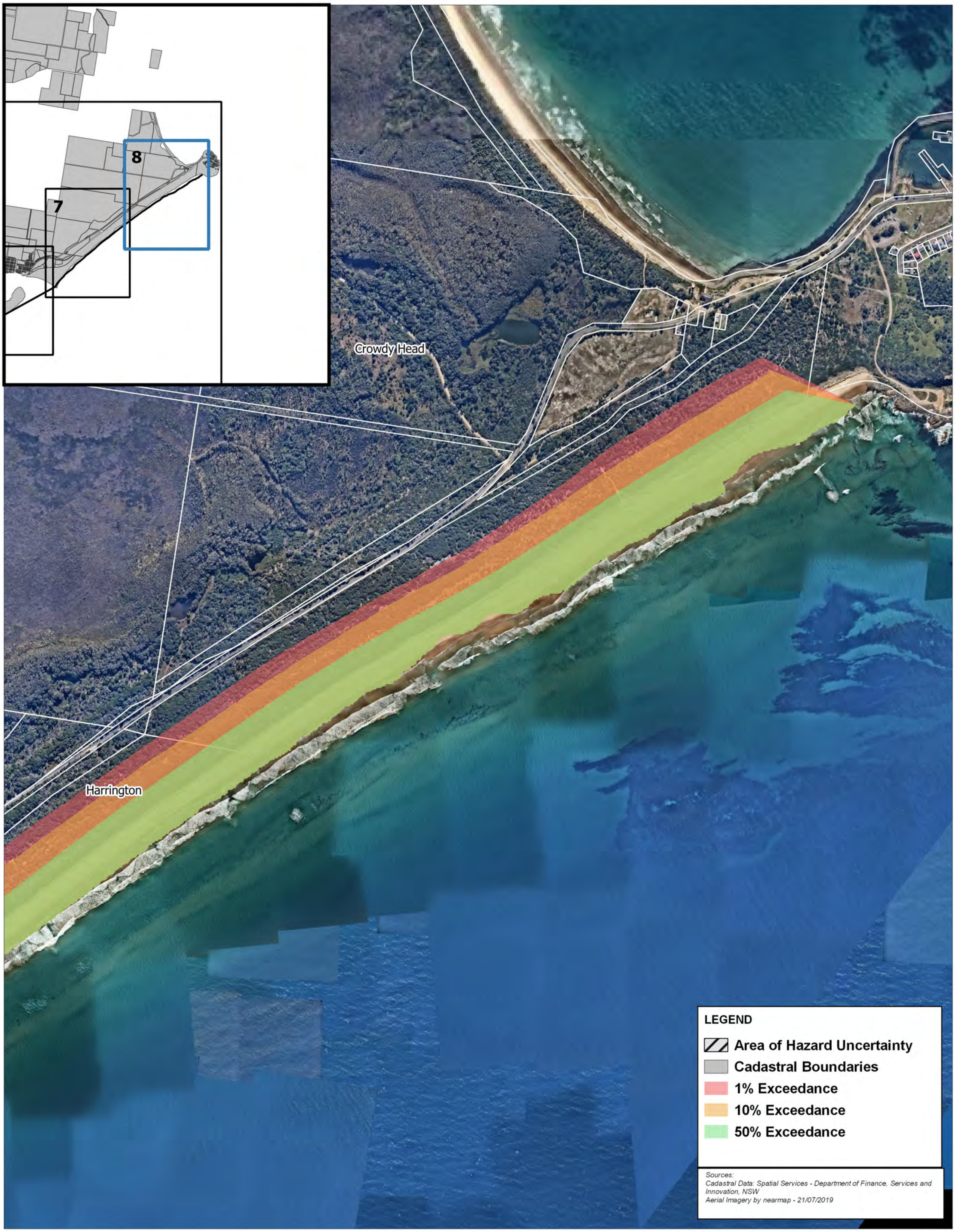

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Cadastral Data: Spatial Services - Department of Finance, Services and Innovation, NSW
Aerial Imagery by nearmap - 21/07/2019

Title:

Harrington Beach (North) - 2100 Zone of Slope Adjustment

Figure: **F-8**

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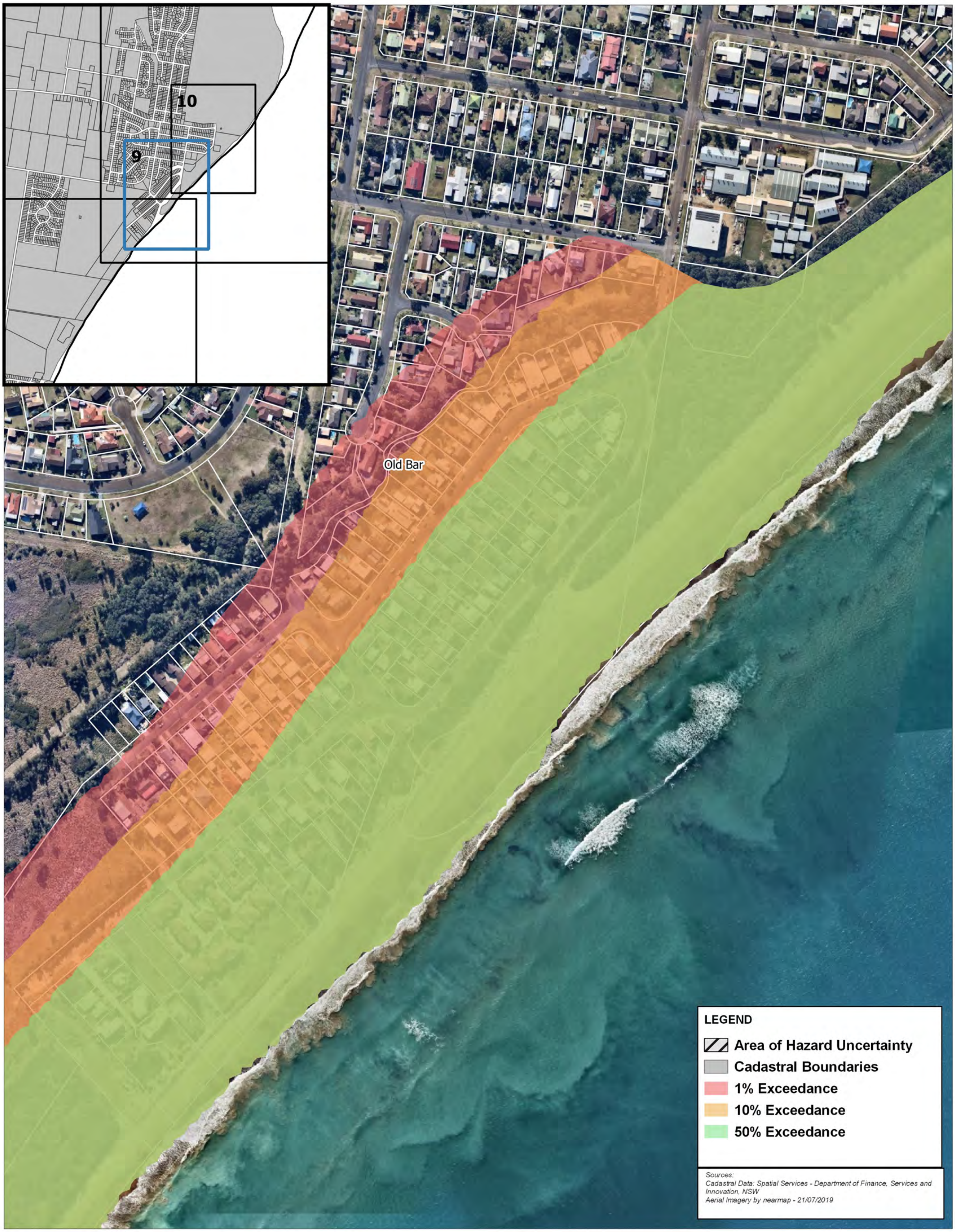

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Aerial Imagery by nearmap - 21/07/2019

Title:

Old Bar (South) - 2100 Zone of Slope Adjustment

Figure:
F-9

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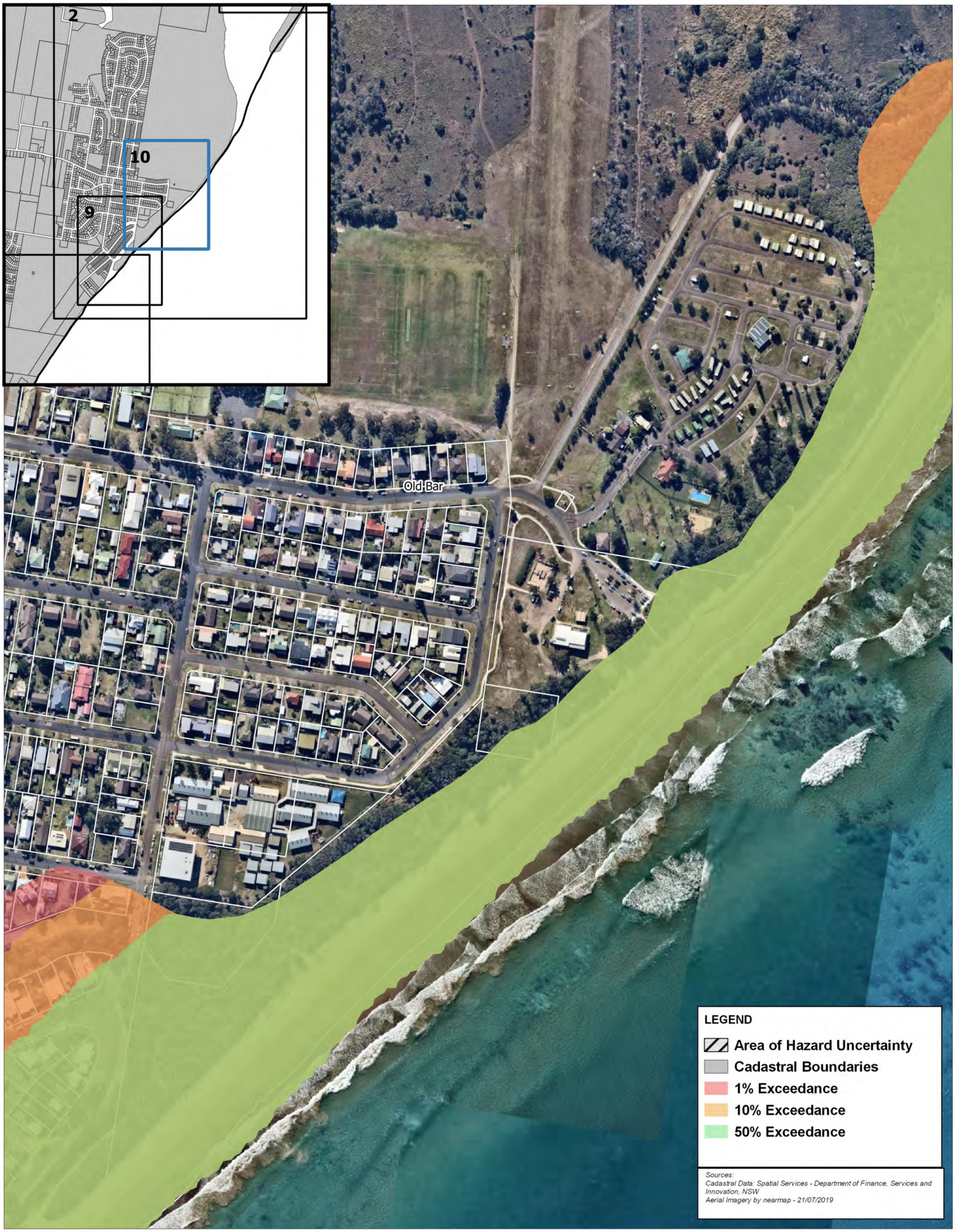

Sources:
Cadastral Data: Spatial Services - Department of Finance, Services and Innovation, NSW
Aerial Imagery by nearmap - 21/07/2019

Title:
Old Bar (North) - 2100 Zone of Slope Adjustment

Figure: **F-10**

Rev: **A**

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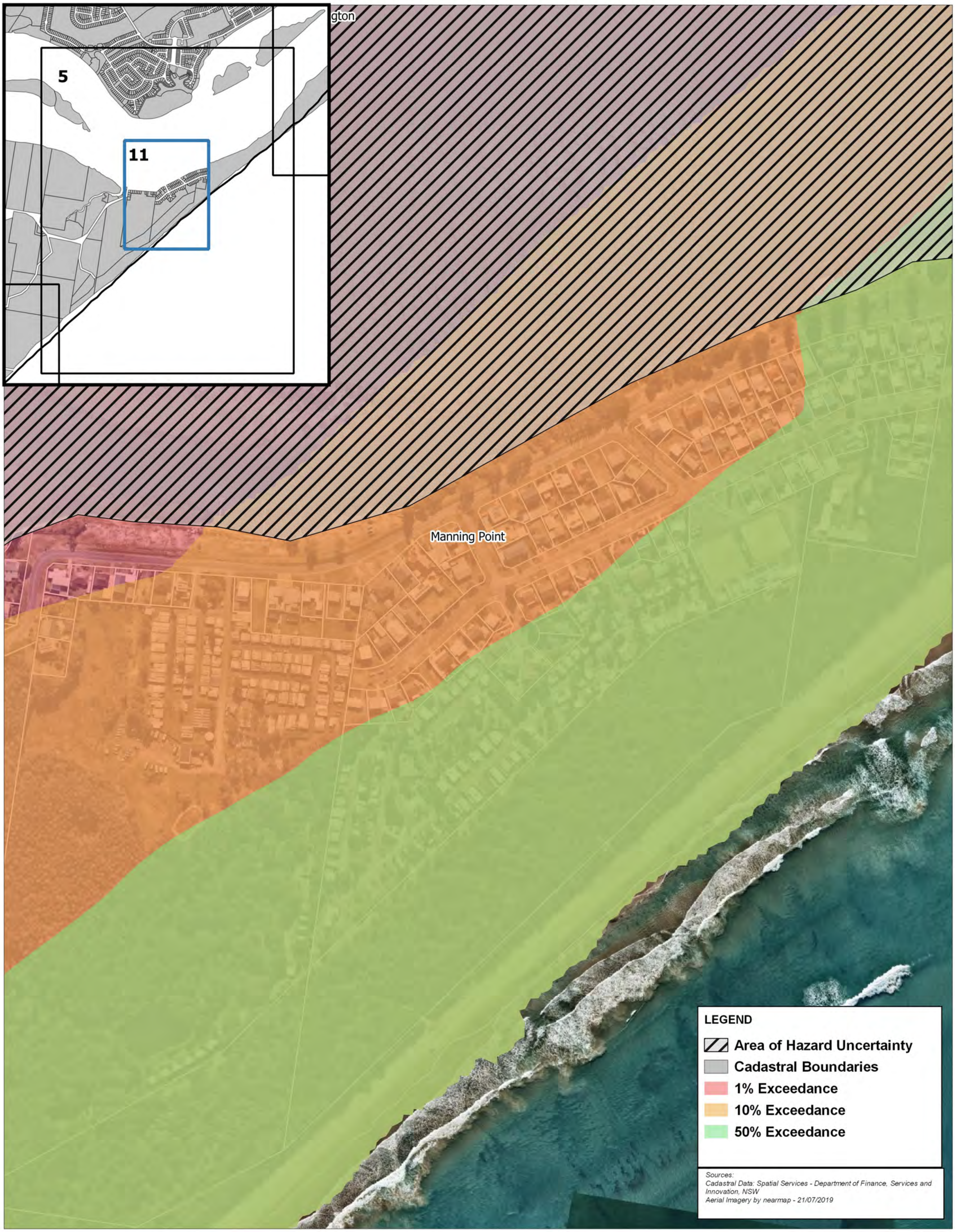

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Cadastral Data: Spatial Services - Department of Finance, Services and Innovation, NSW
Aerial Imagery by nearmap - 21/07/2019

Title:

Manning Point Township - 2100 Zone of Slope Adjustment

Figure: **F-11**

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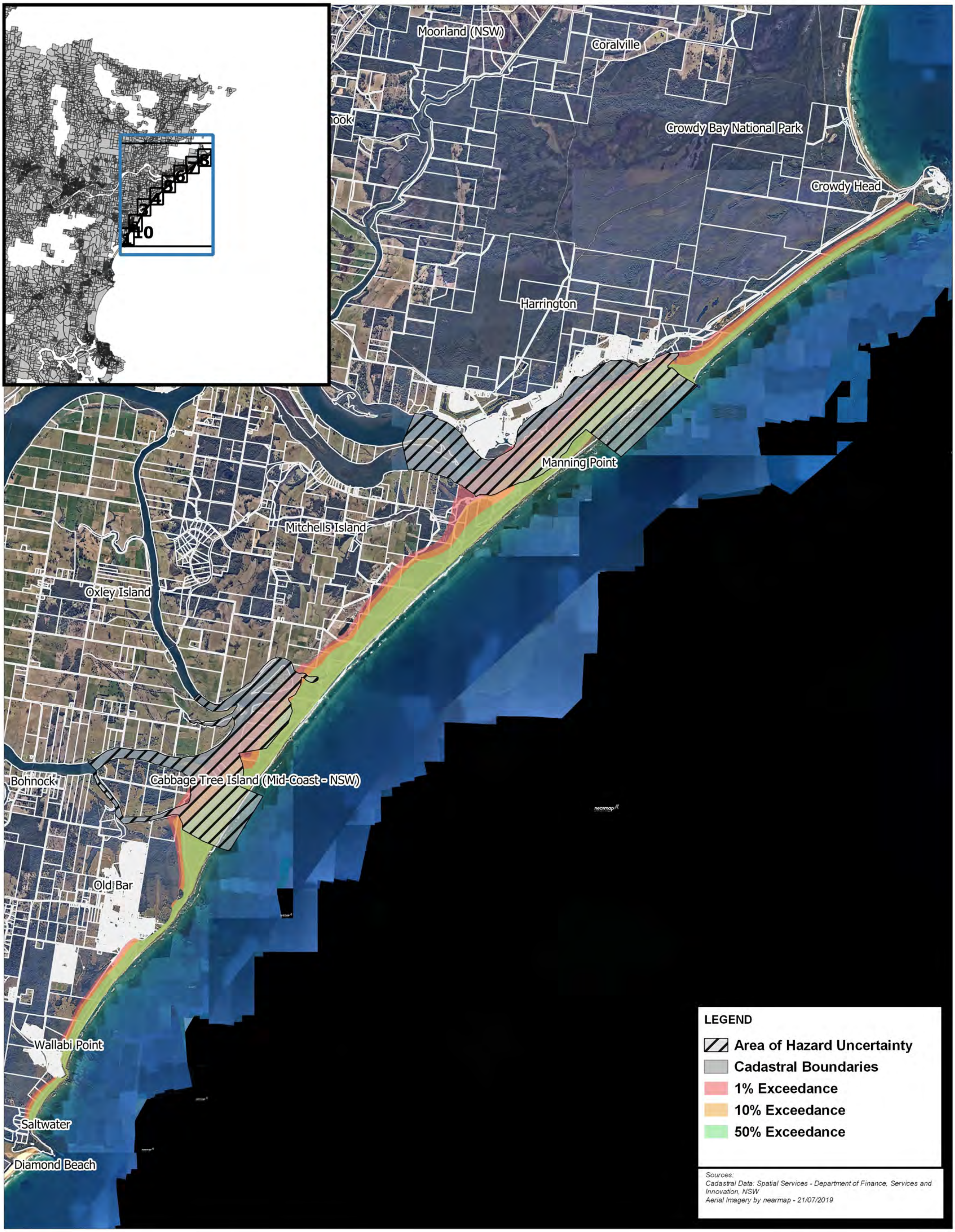

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Cadastral Data: Spatial Services - Department of Finance, Services and Innovation, NSW
Aerial Imagery by nearmap - 21/07/2019

Title:

Study Area - 2100 Zone of Slope Adjustment

Figure: **F-12**

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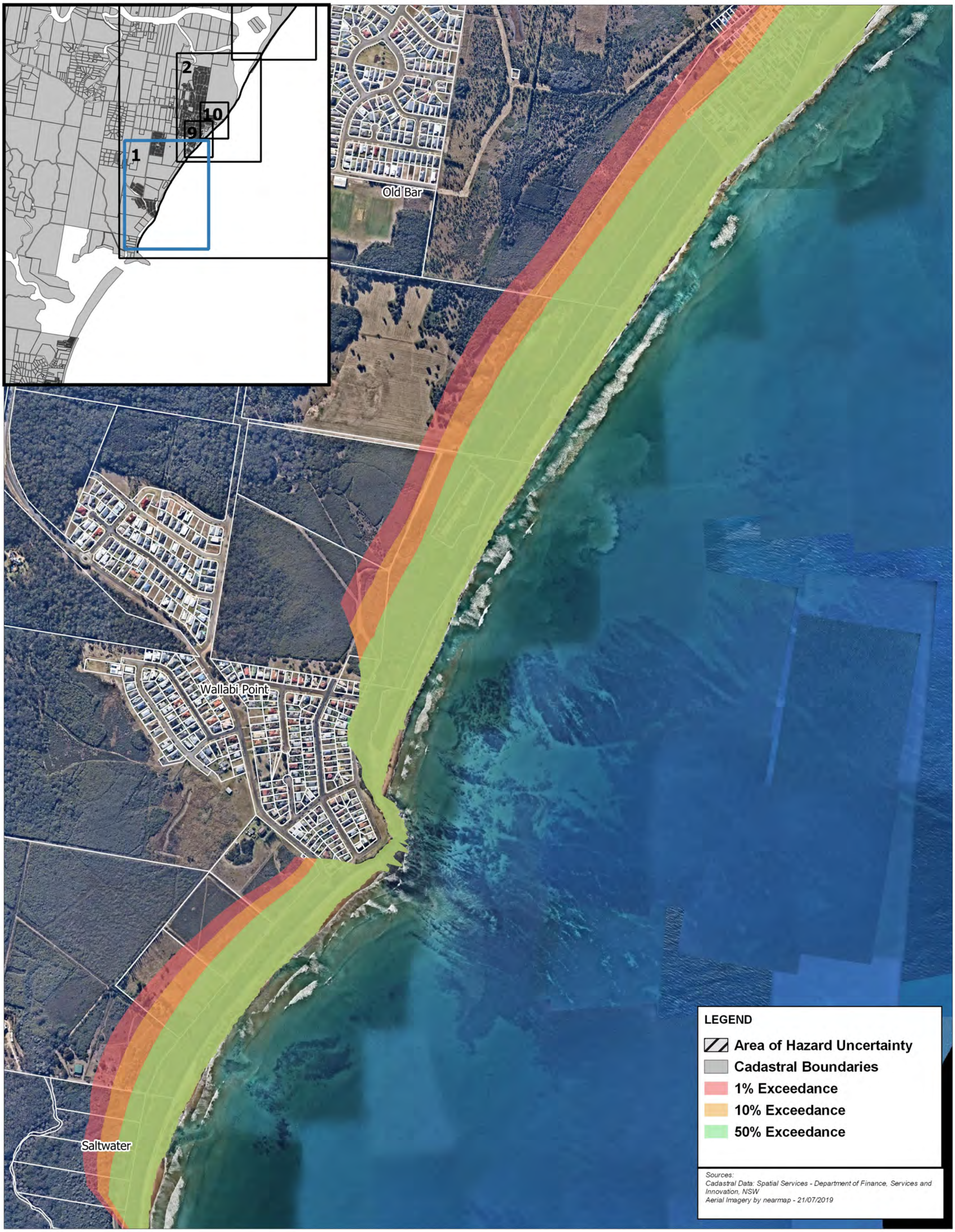
Appendix G 2100 Zone of Reduced Foundation Capacity Mapping



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Aerial Imagery by nearmap - 21/07/2019

Title:

Wallabi Point - 2100 Zone of Reduced Foundation Capacity

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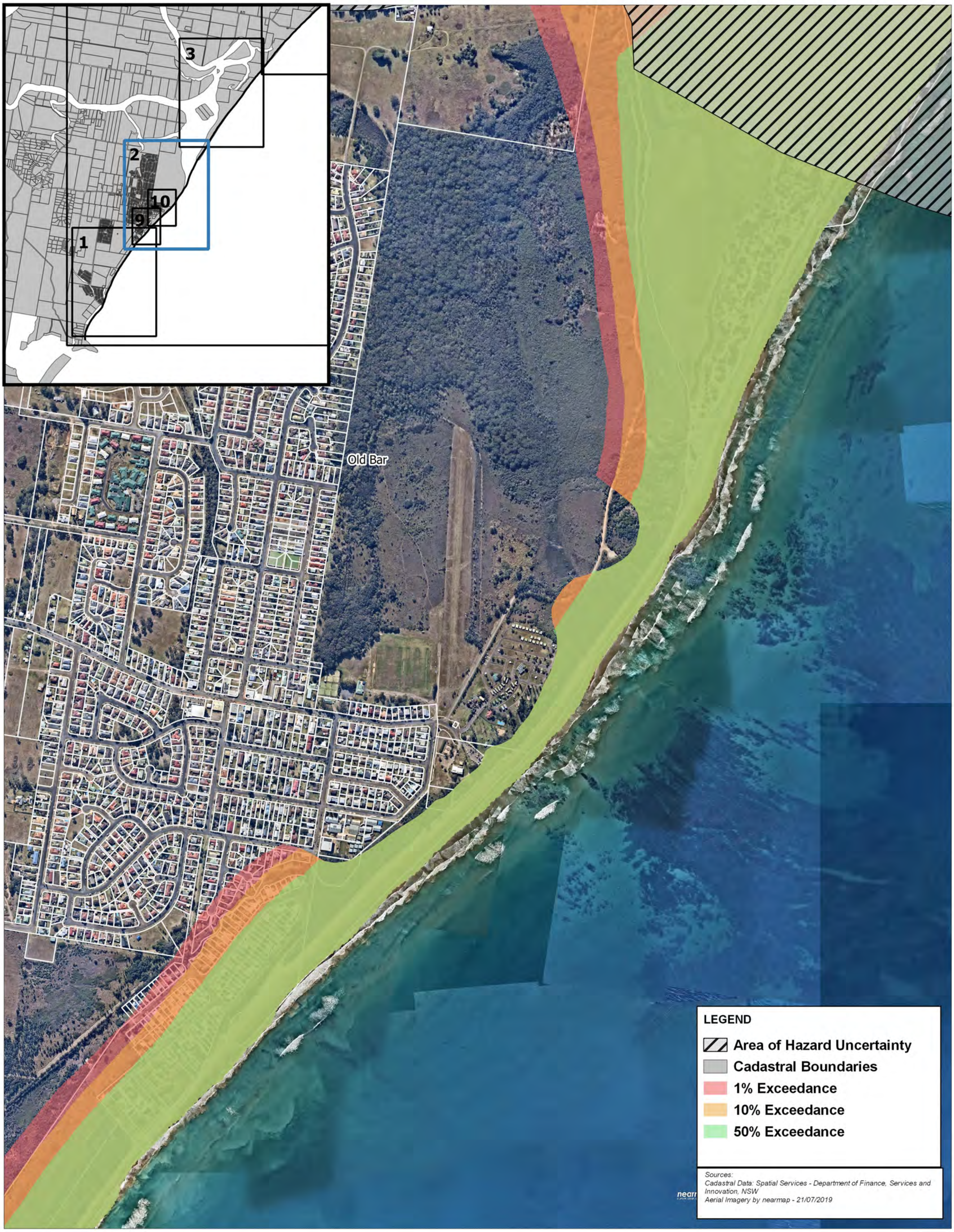

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Aerial Imagery by nearmap - 21/07/2019

Title:
Old Bar - 2100 Zone of Reduced Foundation Capacity

Figure:
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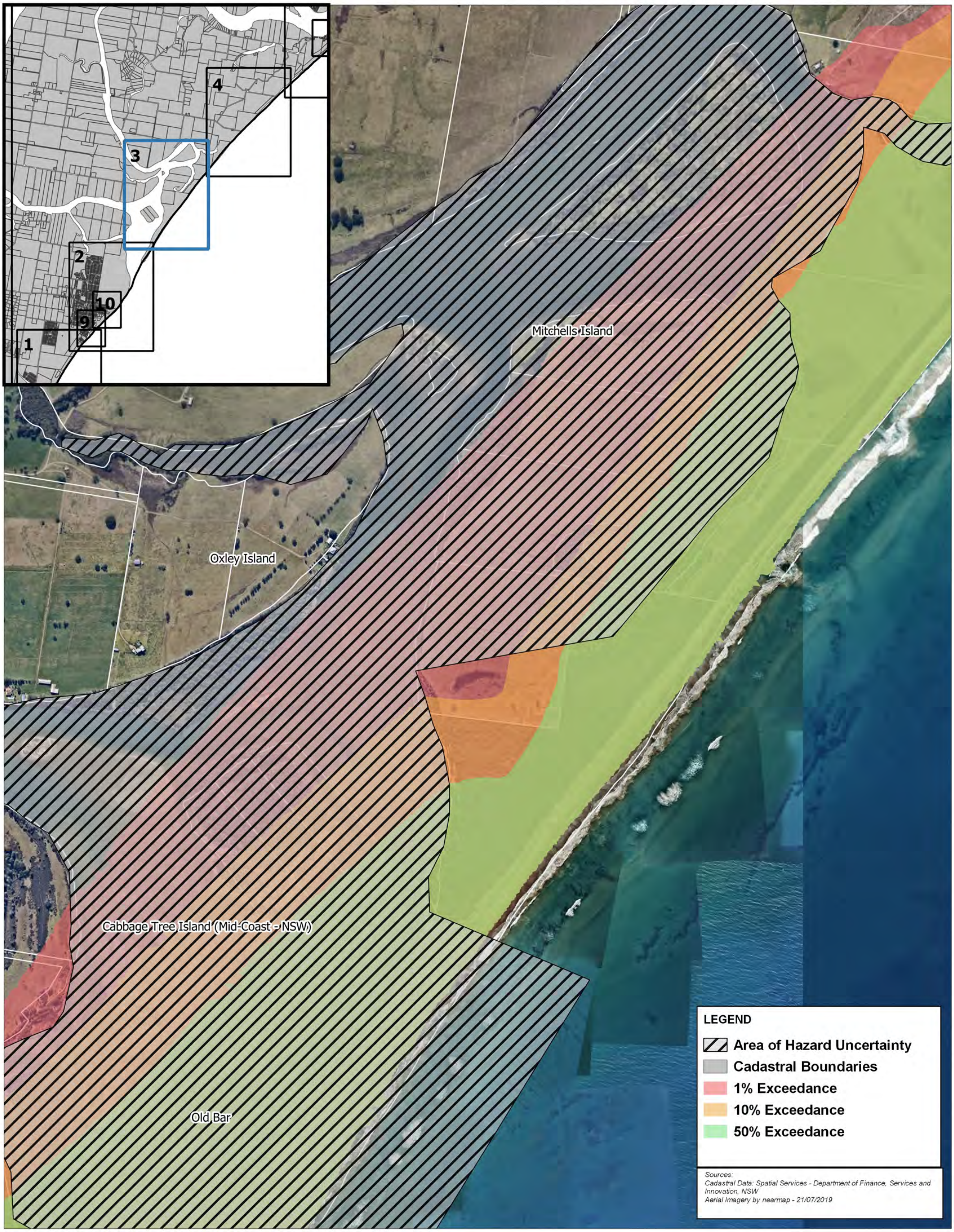

Sources:
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Aerial Imagery by nearmap - 21/07/2019

Title:

Farquhar Inlet - 2100 Zone of Reduced Foundation Capacity

Figure:

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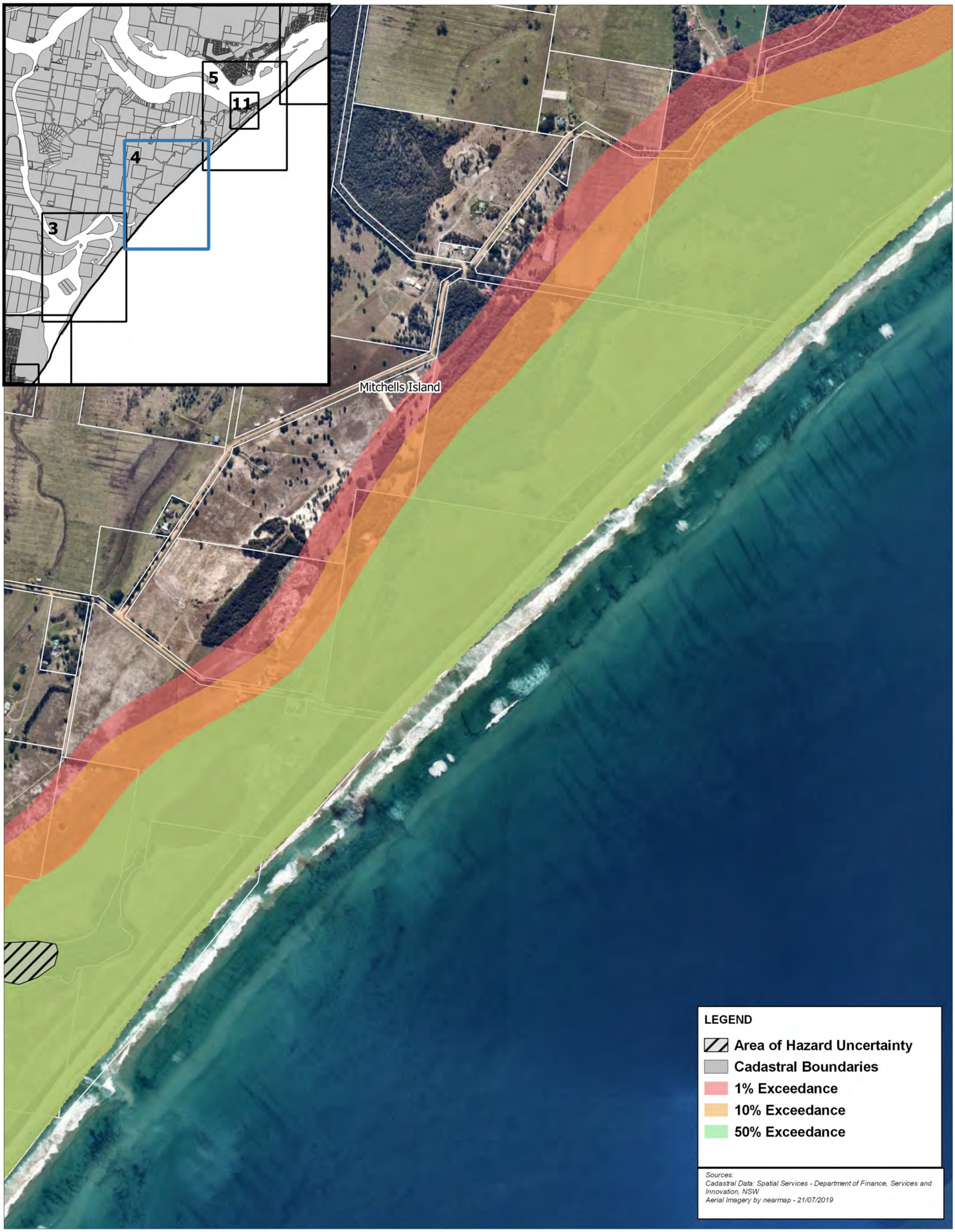

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Aerial Imagery by nearmap - 21/07/2019

Title:
Mitchells Island - 2100 Zone of Reduced Foundation Capacity

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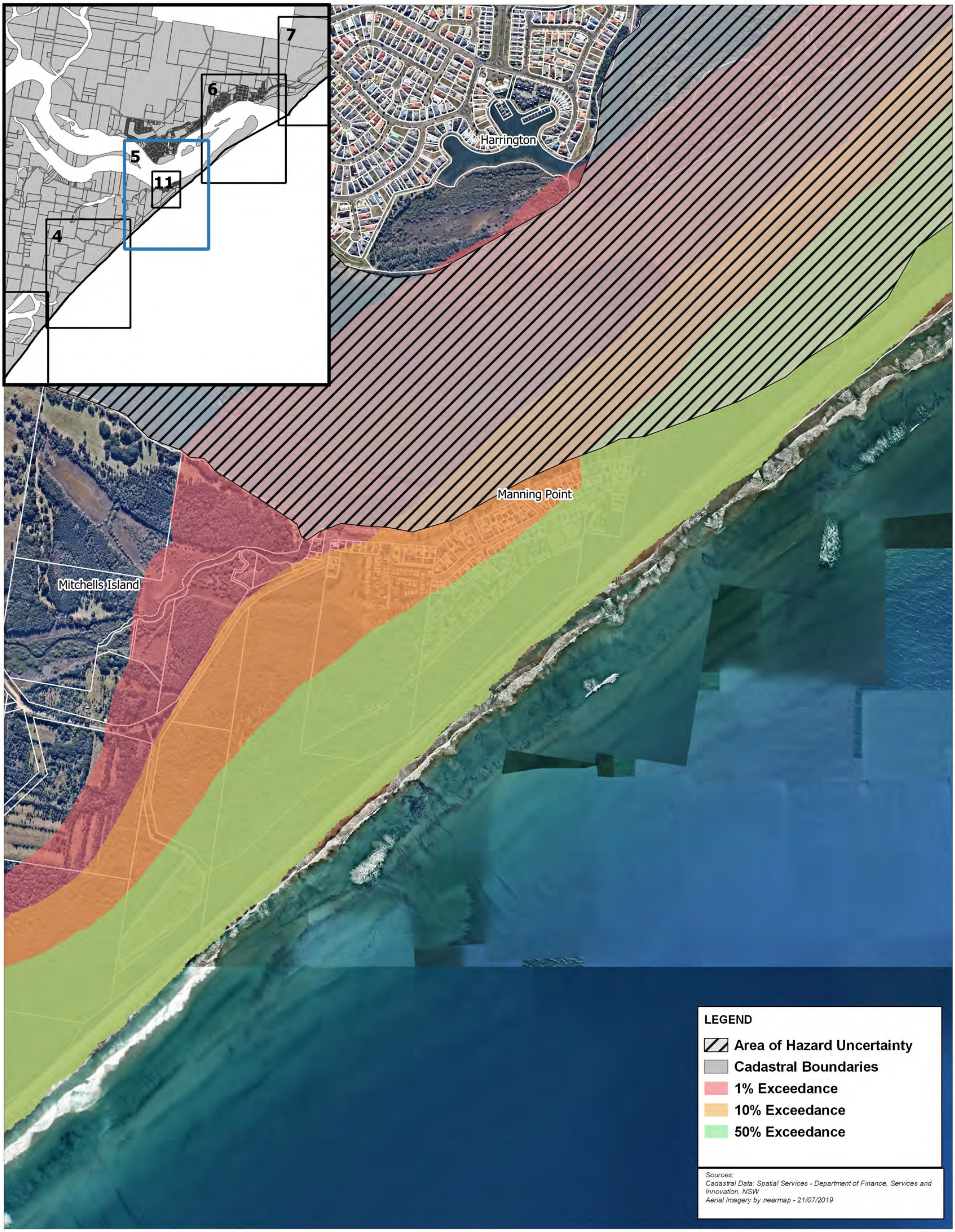

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Aerial Imagery by nearmap - 21/07/2019

Title:

Manning Point - 2100 Zone of Reduced Foundation Capacity

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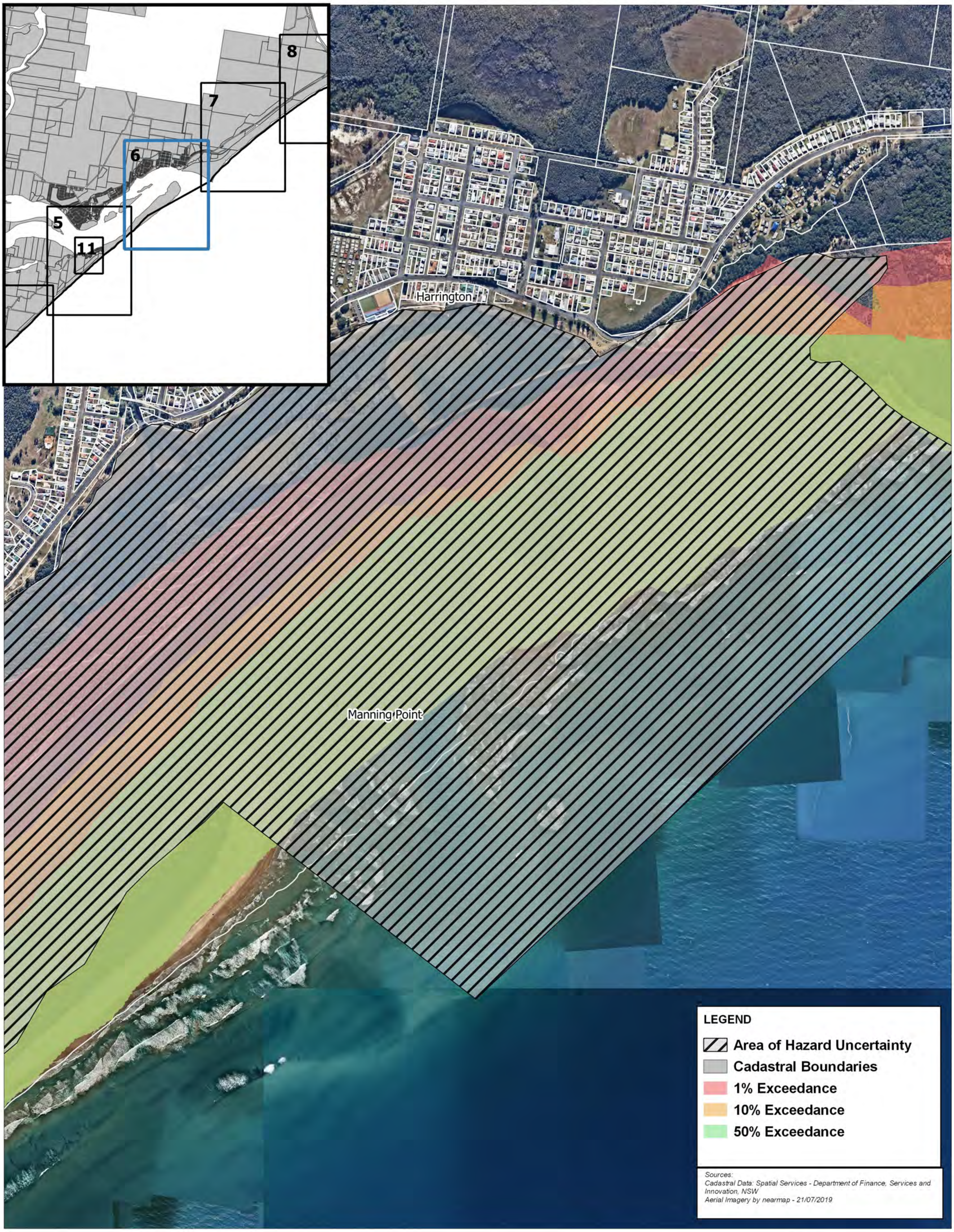

Sources:
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Aerial Imagery by nearmap - 21/07/2019

Title:

Harrington Entrance - 2100 Zone of Reduced Foundation Capacity

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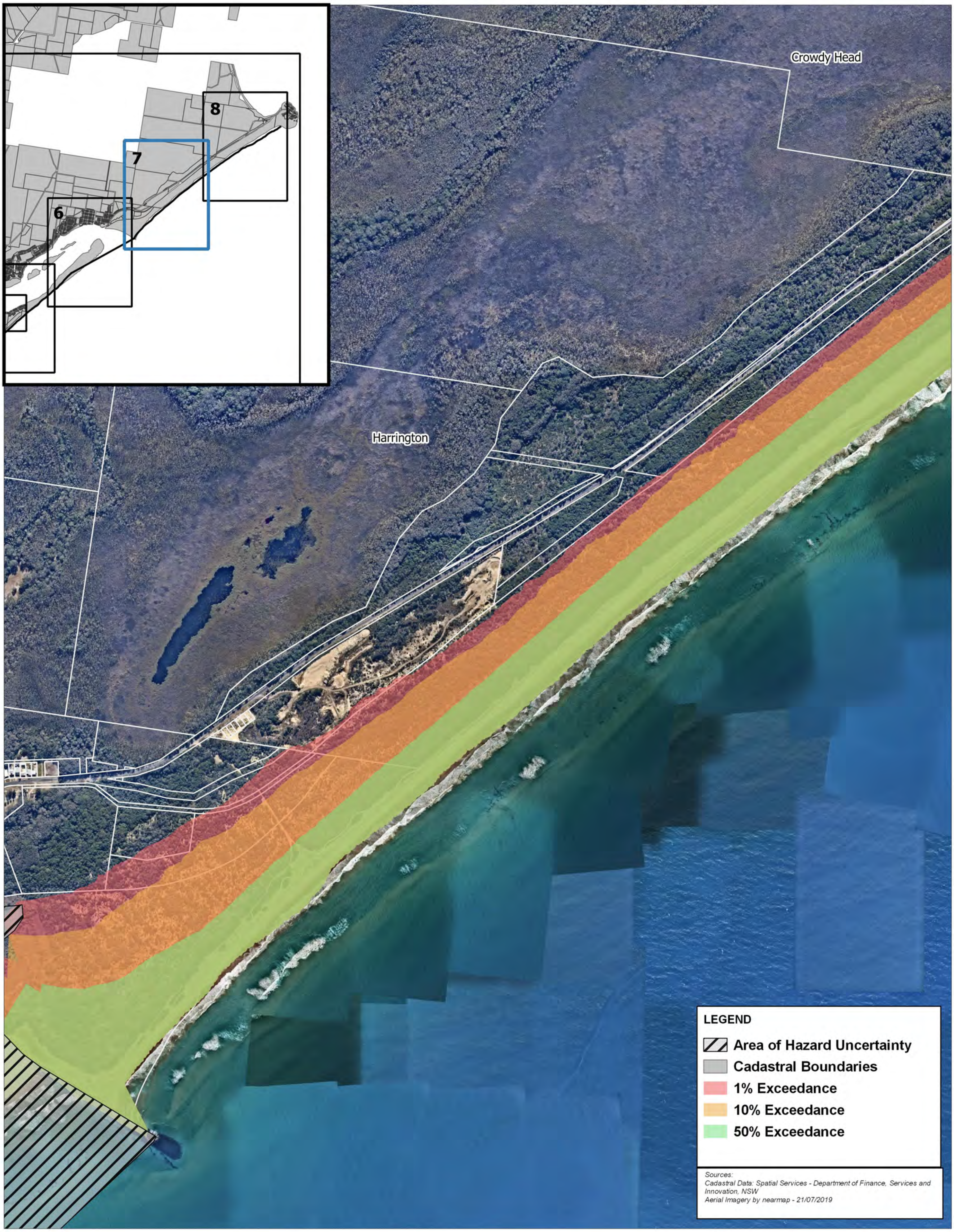

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Cadastral Data: Spatial Services - Department of Finance, Services and Innovation, NSW
Aerial Imagery by nearmap - 21/07/2019

Title:

Harrington Beach (South) - 2100 Zone of Reduced Foundation Capacity

Figure: **G-7**

Rev: **A**

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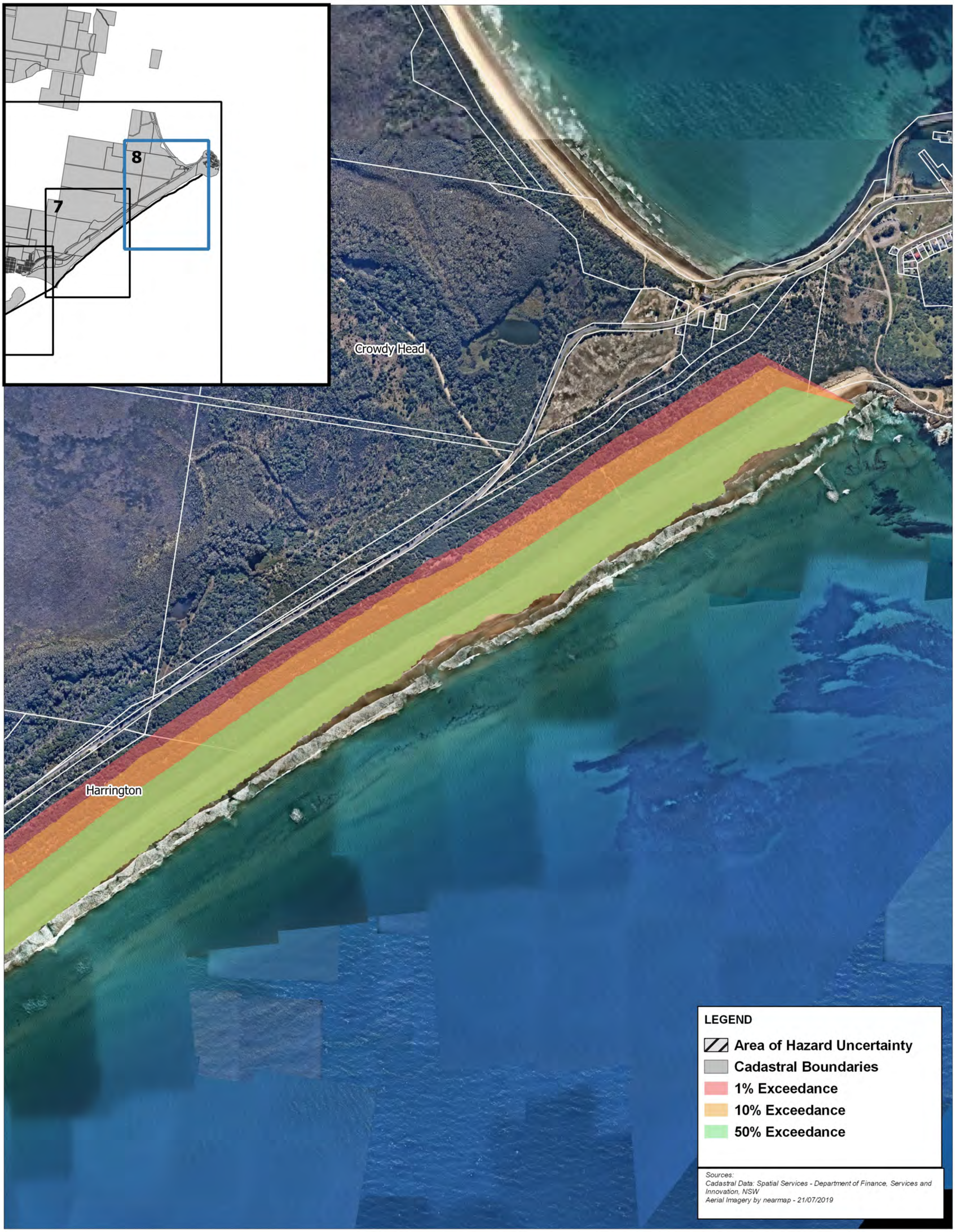

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Aerial Imagery by nearmap - 21/07/2019

Title:

Harrington Beach (North) - 2100 Zone of Reduced Foundation Capacity

Figure:
G-8

Rev:
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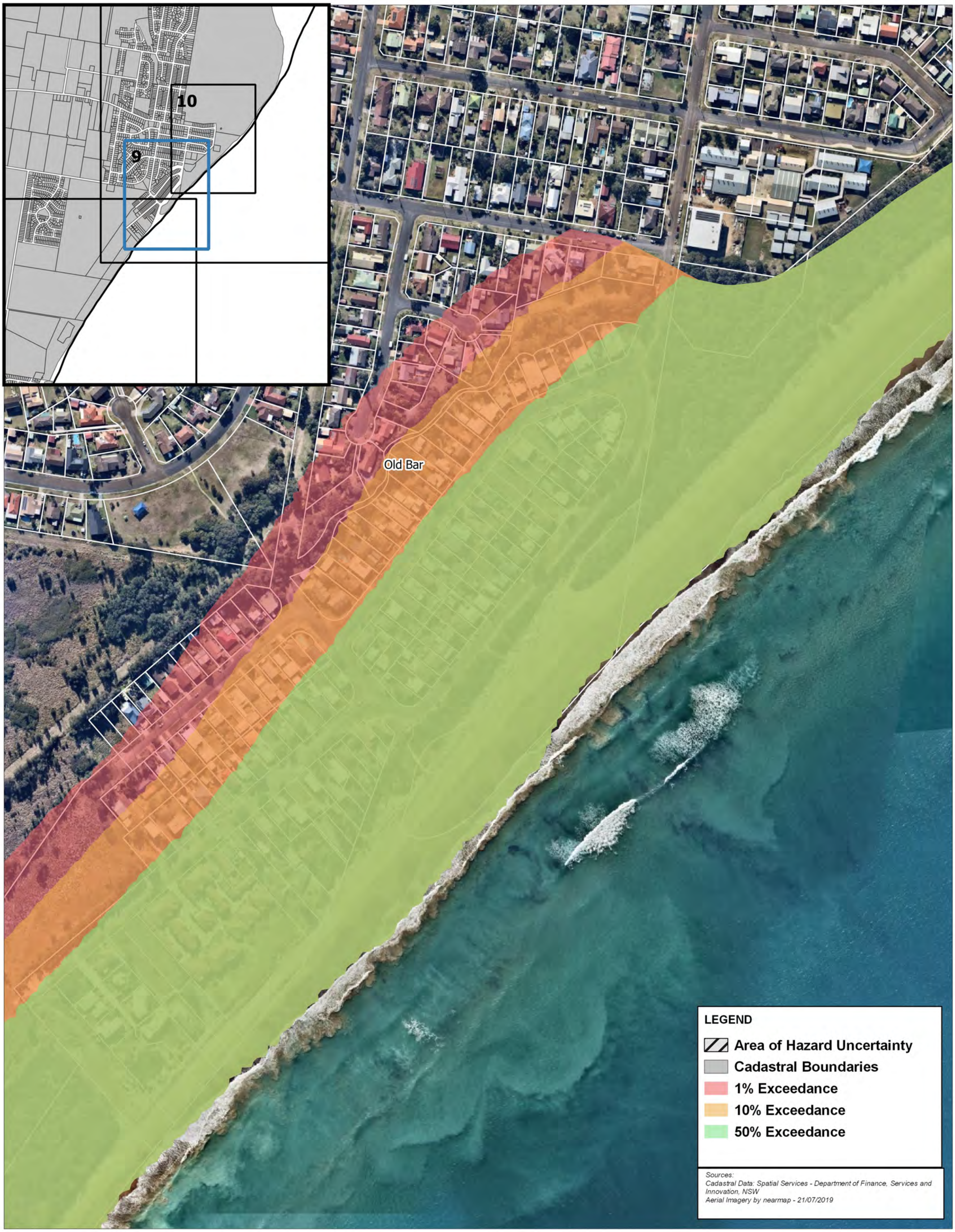

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Aerial Imagery by nearmap - 21/07/2019

Title:

Old Bar (South) - 2100 Zone of Reduced Foundation Capacity

Figure:
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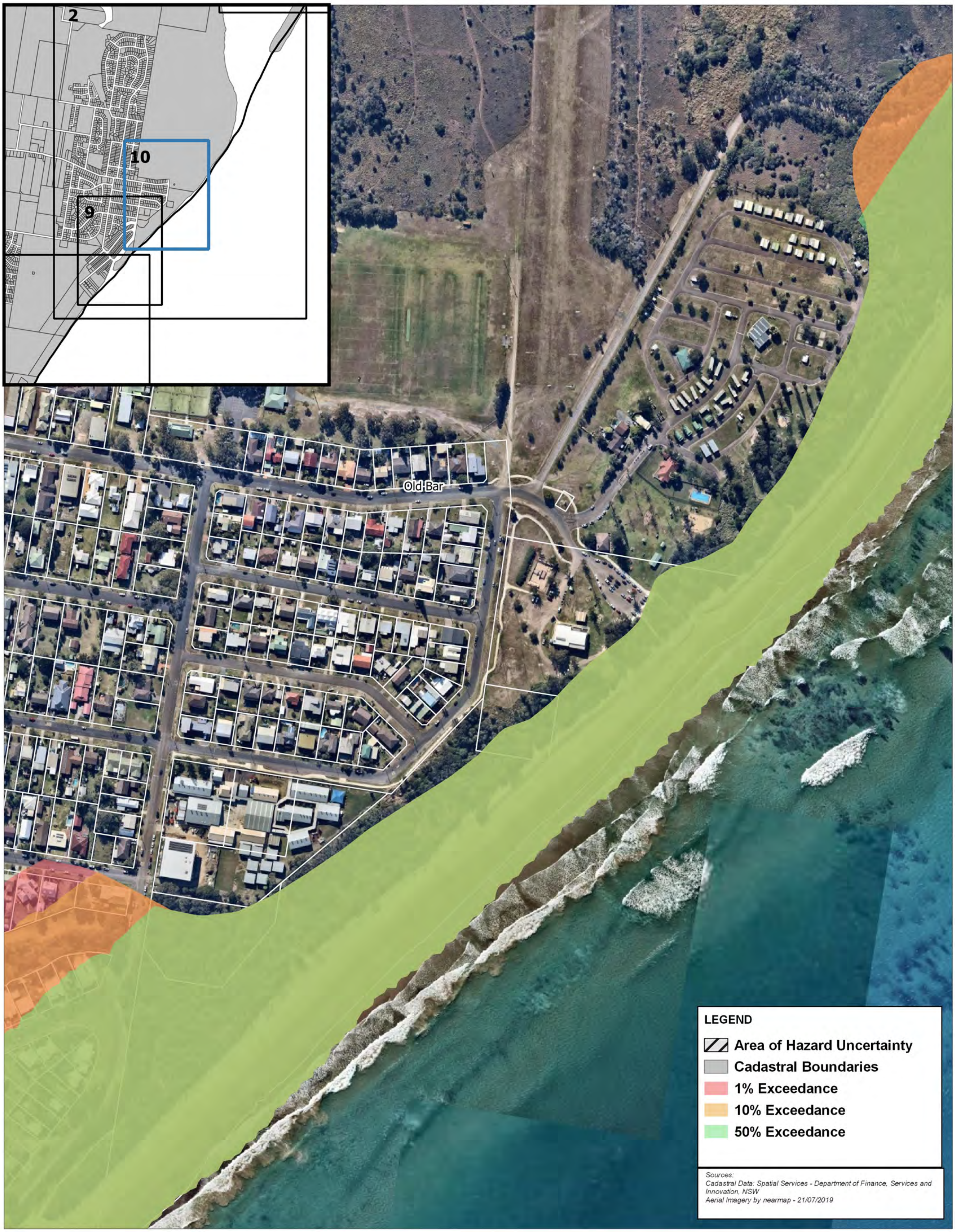

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Aerial Imagery by nearmap - 21/07/2019

Title:
Old Bar (North) - 2100 Zone of Reduced Foundation Capacity

Figure: **G-10**

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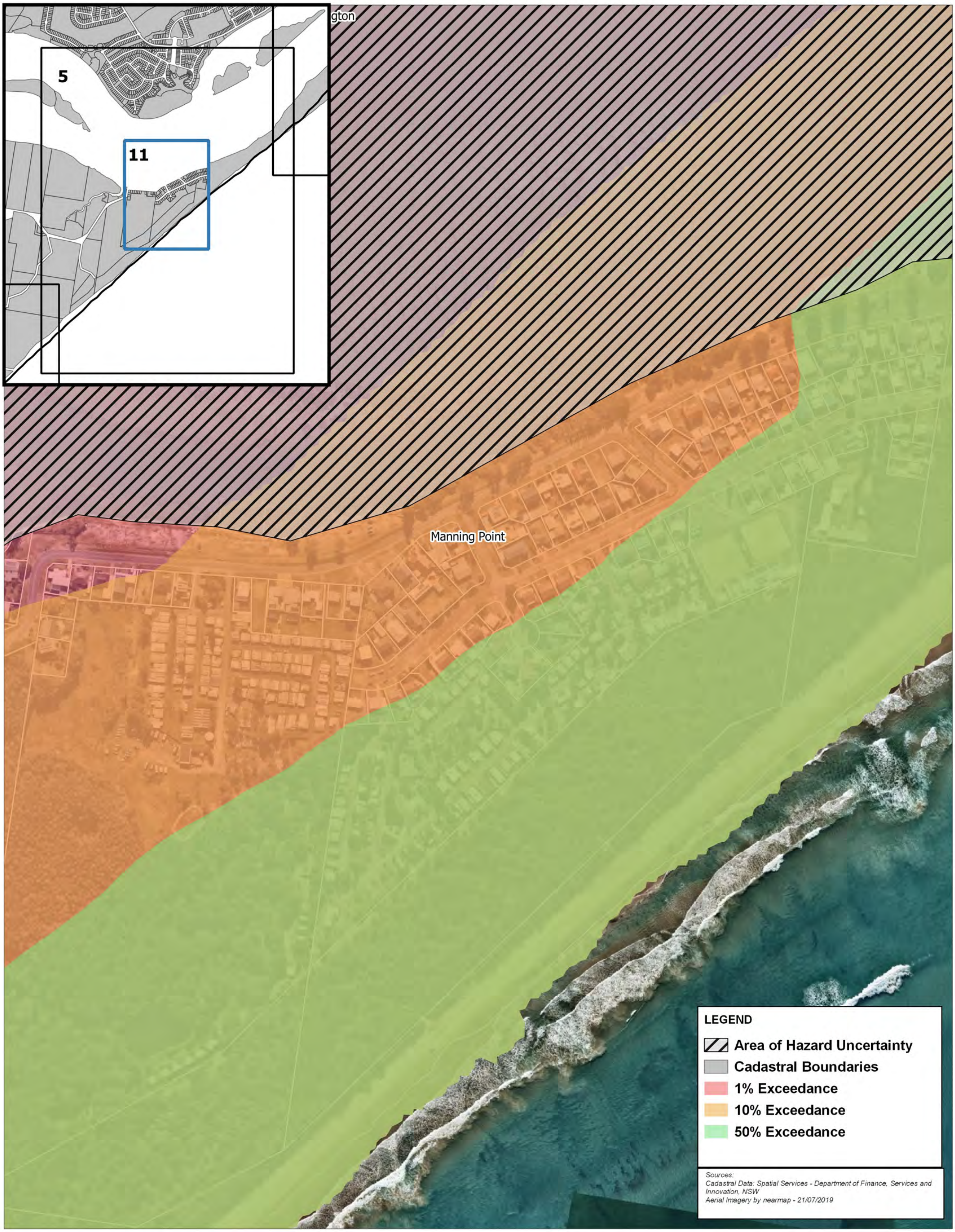

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Aerial Imagery by nearmap - 21/07/2019

Title:

Manning Point Township - 2100 Zone of Reduced Foundation Capacity

Figure: G-11

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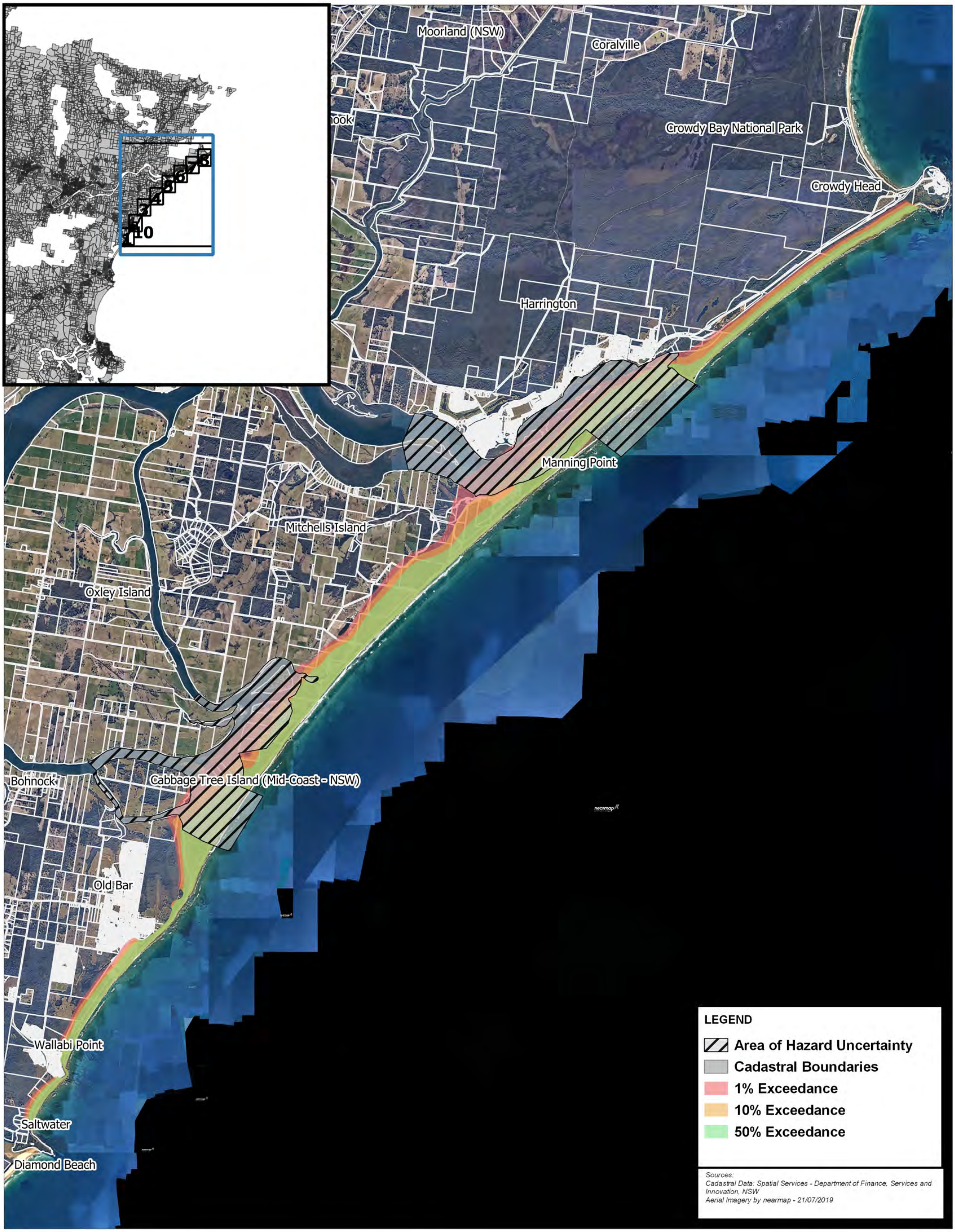

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Title:

Study Area - 2100 Zone of Reduced Foundation Capacity

Figure: G-12

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Appendix H Minutes of Expert Panel Modelling Workshop

Meeting Notes

From:	Paul Donaldson & BMT Project Team (TD, MB, DM)	To:	Mid Coast Council (AS, TD)
Meeting Date:	5 July 2019	CC:	NSW Office of Environment and Heritage (NK, SY, DH, MK)
Subject:	**Meeting Summary: Proposed Hazard Mapping Workshop for Old Bar Beach Coastline**		

Minutes

Agenda

(1) Workshop introduction

(2) Old Bar work to date – overview

(3) Hazard mapping approach / framework

(4) Hazard mapping parameters for Old Bar

(5) Incorporation of varied geotechnical conditions

(6) Hazard mapping outputs for Old Bar

(7) Wrap up

Workshop Participants

- Paul Donaldson, BMT
- Toby Devlin, BMT
- Madeline Broadfoot, BMT
- Andrew Staniland, MCC
- Thomas Doyle, MCC
- Neil Kelleher, DPIE (Regional)
- Stuart Young, DPIE (Regional)
- David Hanslow, DPIE (Science)
- Michael Kinsella, DPIE (Science)

BMT consultancy (BMT), Mid Coast Council (MCC), Dept. of Planning, Industry & Environment (DPIE)

Agreed Actions

- MCC to provide BMT with (DPIE) seamless marine LiDAR product for coastline.
- Up-to-date analysis of shoreline trends and sediment budget to be completed, based on photogrammetry records. MCC / Tom Doyle suggested to lead this new work – with key outputs feeding into model parameters and guiding model setup. MCC and BMT to liaise regarding the practicalities of this new work (who, what, when, how) and implication for project scope.
- BMT to progress with Phase 2 of project, including preliminary model set up. Model to be represent Old Bar coastline in relatively simple terms, although structured such that new coastal processes / sediment budget / coastal geomorphology information can be incorporated for subsequent revisions / uses.
- DPIE to provide BMT with sediment budget terms adopted for the Manning Sediment Compartment (and tertiary/sub-compartments) in the State-wide erosion mapping.
- BMT to submit a variation proposal outlining proposed scope changes consistent with workshop discussions – around new analysis completed to guide model development and mapping.

Workshop Overview

Some key take home messages coming out of the workshop as follows:

- All workshop attendees contributed expert knowledge and demonstrated commitment to delivering good project outcomes, collaboratively.
- There was widespread agreement that a Monte Carlo probabilistic coastal erosion hazard modelling approach for Old Bar coastline is warranted - noting uncertainty, significant risks and public profile of coastline.
- For current project, a ‘fit-for-purpose’ model will be developed that draws on existing information and pragmatic assumptions (at this stage).
- The proposed modelling approach will provide a significant advancement on the existing hazard mapping available. It also goes over an above what was scoped in the original project proposal.
- The technical workshop aimed to agree on a modelling framework and input parameters that would enable Phase 2 work to be completed without any new analysis. The workshop resulted in good guidance to progress preferred modelling option forward.
- DPIE indicated that not enough information was available for several parameters to be agreed upon, and some more technical work is needed.

Workshop Summary and Slides

The following pages document the workshop content presented and matters discussed, as follows:

- Session 1 summary table (Table 1)
- Session 2 summary table (Table 2)
- Workshop slide series (see attached).

If you have any queries or wish to discuss further, please do not hesitate to contact the undersigned.

Many regards, **BMT**	Reviewed by **BMT**
Paul Donaldson Senior Coastal Scientist	**Toby Devlin** Engineer

Table 1 Session 1 Summary

Workshop Item / Session	Summary
Workshop Introduction	• Andrew (MCC) provided an introduction to the project and workshop, highlighted the importance of the project, outlined the need to progress the hazard mapping with a 'fit for purpose' approach, and also welcomed the input from State Govt Science to this project.
Session 1a: Work to Date	**Session outline** • Provided an overview of key coastal work completed to date to inform the workshop discussions. **Outcomes sought** • Set the context to ensure all participants were on the 'same page'. **Key discussion points** • Research work being completed by DPIE Science discussed, along with opportunities to feed into current work and also subsequent revisions. • *Erosion Analysis of the Manning Valley* by MHL (2017) was discussed. Importance of marine delta influence on sediment flux and shoreline behaviour noted. Mitchells Island / Manning Point beach conditions varies over interdecadal timeframes and this relates to entrance conditions (Harrington, Farquhar). • It was also noted that quantitative coastal processes model proposed by MHL (2017) is based on existing information – of which some data is quite old and possibly some rubbery assumptions in past reports. There is a need to assess up-to-date information (photogrammetry). • Value of UQ / GA research noted. • Mitchells Island dune breaching raised as an issue. Limitations of encroachment model to represent barrier breaching processes were raised.
Session 1b: Hazard Mapping Approach / Framework	**Session outline** • Sought guidance and input from participants on a probabilistic approach to modelling erosion hazards, with approach to draw on existing methods and available information (only). **Outcomes sought** • Fit-for-purpose approach agreed on by all and the suite of erosion hazard parameters confirmed. **Key discussion points** • Pros and cons were discussed regarding approaches, with Bruun rule raised as an option to facilitate speedy deliverables. Consensus reached that developing a probabilistic Monte Carlo approach is needed for Old Bar. BMT to pursue capability internally (research and development) and apply to current project with regional guidance / input. • Volumetric encroachment model framework shall be used, based on State Govt / Kinsella et al. approach - but likely simplified. Approach to incorporate fluctuating erosion (current timeframe) and cumulative erosion (future timeframes). • Good to develop an erosion model to represent study coastline through related tertiary compartments and sub-compartments. • If possible, liaise with DPIE science regarding seabed mapping and definition of sub-compartment. Will be good to define these consistent with state government. Timing may not align so this could be something to refine. • Model purpose for current study is to produce coastal erosion planning lines. Mapping outputs required by economists raised – noting yearly outputs / estimates needed for detailed CBA(s). Therefore it would be beneficial to if the erosion model was configured to enable such outputs to be produced at a later stage (e.g. CMP Stage 3 study).

Workshop Item / Session	Summary
	• A ‘fit for purpose’ model will not achieve ‘Roll Royce’ standard at this stage. As long as assumptions and limitations around the model development and input parameters are documented explained, then the ‘simple’ approach will be adequate for the current study (and provide a great improvement on existing work). BMT can assist with further refinements / improvement during the CMP process as an option, if MCC see value in doing so (new engagement). • DPIE participants can be used as a sounding board and provide constructive input. Good to provide key assumptions and approach to group for review – although this makes more work for BMT which will need to be considered. Likely that final report / approach will be reviewed by Government / Council ‘elders’. That’s okay as long as BMT is not working outside of scope.

Table 2 Session 2 Summary

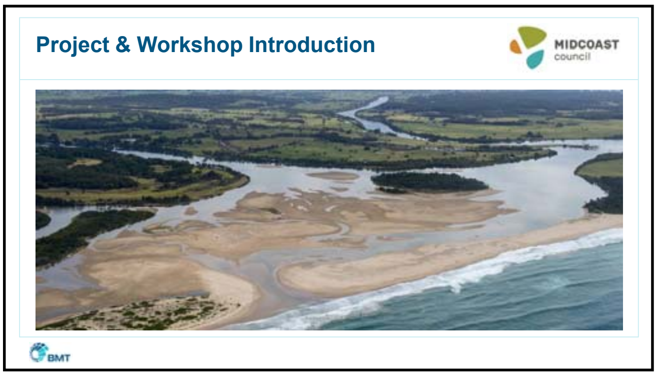
Workshop Item / Session	Summary
Session 2a: Erosion Hazard Parameters	**Session outline** • Sought guidance and input from participants on a probabilistic approach to modelling erosion hazards, with study approach to draw on existing methods and available information (only). **Outcomes sought** • Fit-for-purpose approach agreed on by all and the suite of erosion hazard parameters confirmed. **Key discussion points** • *Fluctuating erosion* – a range of options / possibilities were raised. It was agreed that the fluctuating erosion volumes / probability distribution functions applied to the former OEH State-wide assessment (Kinsella et al paper) will be used, and scaled as appropriate. • Options for scaling fluctuating erosion include: based on existing hazard studies; based on UQ storm cluster EVO MOD work; use wave transformation tool as guide (would need to be provided); or use wave model figure in UQ paper as a guide. Wave model figures from UQ paper agreed to be a reasonable approach for current engagement – noting options available to refine down the track. • An additional option for scaling up the fluctuating erosion component over time was suggested if suitable values can be adopted. This would account for the increased uncertainty. • Need to ensure that any analysis is relative to an *accreted state* as is assumed in the storm demand approach • *Sediment budget* - the range of cumulative erosion terms were discussed in terms of the ability to incorporate all terms based in existing information. Sediment budget values presented in MHL (2017) were raised as an option to guide the net sediment budget flux. Limitations using the MHL report were highlighted – noting nearly 10 years of data post WP (2010) is not accounted for across study area in this report. • Agreed pragmatic approach for Old Bar coastline moving forward is to ‘lump’ gross sediment inputs/outputs (net sediment budget) for current study, until better understanding is available for different sediment budget aspects. • Options to determine net annual sediment budget volumes were identified as follows: • Review WorelyParsons (2010) hazard study to see if sediment budget information is available to use/adopt (without more work).

Workshop Item / Session	Summary
	- Adopt UQ / GA assumptions in academic research (e.g. NSW Coastal Conference paper). - Adopt sediment budget numbers applied in the (former) OEH State-wide erosion mapping across the Manning Sediment Compartment. - Review up to date photogrammetry (up to 2018 information) data to determine net sediment flux - preferred approach by MCC and DPIE. - MCC / DPIE preference to review photogrammetry data to determine budget volumes which will incorporate up to date survey data – and hopefully resolve conjecture and provide insight into behaviour over last decade (e.g. trajectory of trends, influence of external factors e.g. SLR and anthropogenic influences). - It was suggested that MCC / Tom Doyle would lead this new work / analysis – with key outputs guiding model setup and informing input parameters. MCC and BMT to liaise regarding the practicalities of proposed arrangement, associated work (who, what, when, how) and implications for project scope. - Ultimately, BMT will adopted net sediment flux from new photogrammetry work. Important to look at rates of change over time. Steady increase will need to be extrapolated. Fluctuations will provide upper and lower bounds. Trends may be linked to dredging, flooding, possible SLR influence. Need to look at data first before determining approach. - DPIE (regional) suggested that a (reasonable) variation be submitted for consideration relating to new coastal assessment/modelling work; seek review/cross check and incorporate new information, etc. - DPIE to provide BMT with Manning Sediment Compartment sediment budget terms adopted for state-wide assessment which may be used to guide current study (e.g. prelim model setup). - *Depth of Closure / Shoreface* – Relevance of Bruun rule in context of local area (rocky shoreface sediment starved) discussed. Range of results presented from various reports. Need to state adopted values, reasoning and limitations. - *Sea level rise* - we discussed several options. Adopt OEH triangle PDF approach that incorporates all ranges (i.e. all RCPs). Another option is to pick a single RCP to use. Likely ranges reported from 17% to 83%, although range above/below this could be normal distribution or skewed. Tails could be important for higher level scenarios – science getting better on high level scenarios over recent years. Also to consider what MCC policy is now (0.4 and 0.9m) and what this may be in the future after global projections are revised. Suggest adopting former OEH State-wide mapping approach in the first instance. - When selecting a single simulation (from the monte-carlo ensemble), need to consider that this assumes a particular SLR assumption. Will need agreement with MCC that this is appropriate. - Regarding the discussions around *probability distribution functions*, it is agreed that triangular distribution is most appropriate for all parameters unless better information is available (e.g. fluctuating erosion PDF). - *Scaling coefficients*, these will be useful reflecting local variability in terms of wave exposure and the influence of varying geological conditions on erosion behaviour (discussed further below). - Marine delta and coastline interaction were highlighted as important. Consideration is needed around how these complex interactions can be incorporated into new approach. Option put forward include assessing photogrammetric data. Scaling up fluctuating erosion over time. Alternatively, scale up fluctuating erosion over short term to account to inter-decadal variability that is significant over 10 year timeframe but becomes averaged over longer planning horizons.
Session 2b: Incorporating Varied Geological /	**Session outline** - This session considered the potential influence of varying substrate types and landforms on erosion hazards along the Old Bar coastline.

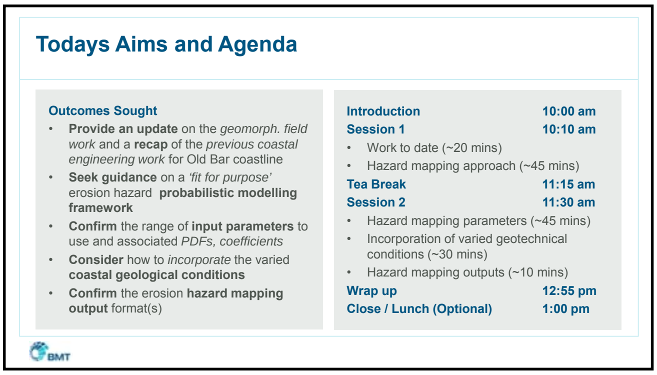
Workshop Item / Session	Summary
Geotechnical Conditions	**Outcomes sought** • Agreed approach to incorporate local/regional coastal geological conditions into the erosion model and mapping method. **Key discussion points** • Geological controls on erosion hazard at Old Bar presented and discussed. The three types of geological control including *(i) erosion limiting bedrock landforms*, *(ii) erosion influencing bedrock outcrops*, and *(iii) partially resistant substrates.* • It was agreed that *erosion limiting bedrock* mapping be used to limit erosion line setback distances in a landward direction. Deeply weathered residual soils and / or extremely weathered cohesive clays substrates will not be treated in numerical model. Rather a 'geotechnical' buffer will be used to capture potential risks around slumping / cliff profile adjustment that may occur when fronting sand buffer eroded (e.g. Old Bar bluff). • *Erosion influencing bedrock outcrops*, such as reefs and rocky shore platforms, shall be accounted for in model by scaling fluctuating erosion term. Existing behaviour of beach behind reef area (e.g. Urana Bombora) shall provide a good guide for scaling coefficient to be adopted. • *Partially resistant substrates* were identified as comprising indurated sands or residual soils. • Residual soils will be treated as described above (geotechnical buffer), where they overlie erosion limiting bedrock landforms. • Indurated sediment will reduce erosion impact and an appropriate coefficient should be scaled to reflect this were possible. It was suggested that the scaling approach used to Lake Cathie may from an appropriate basis to adopt / apply for Old Bar. Advantages with that approach is that it was overseen by State Government. Scaling coefficients were adopted for both the fluctuating and cumulative erosion components, although different approaches were used for each. Fluctuating erosion potential was reduced more than the cumulative erosion component, which was skewed toward a coefficient of 1 with some variability. This nuanced detailed approach would be nice to adopt for Old Bar, if scope allows (to be determined).
Session 2c: Hazard Mapping Outputs	**Session outline** • Scope of hazard mapping agreed to under current contract reviewed (i.e. x3 timeframes, ZSA & ZRFC). • It was noted that a Monte Carlo model would allow (& may warrant) a more nuanced mapping approach (but not under current contract). **Outcomes sought** • Format for presenting revised coastal hazard lines agreed upon. **Key discussion points** • Hazard mapping output should reflect x3 Council planning horizons. • Issues with ZRFC for future timeframes noted, as future dune heights unknow. It may be worth considering representing current ZRFC setbacks based on local dune heights, and then future ZRFC setbacks based on tertiary compartment averaged dune height (for example). Note modifying approaches for different timeframes can be done and likely adds value, but would require addition effort/time. • A range of mapping outputs were presented. MCC likes the look of 'erosion bands' for different AEPs, as per Kinsella et al paper. BMT notes this may require more work that x3 lines scoped (to be discussed). It may be worth discussing mapping pros / cons form a planning perspective with MCC Planning Dept. (Alex)

Erosion Hazard Modelling / Mapping Workshop Old Bar Coastline

Paul Donaldson, Toby Devlin & Madeline Broadfoot
5 July 2019, Newcastle



Project & Workshop Introduction



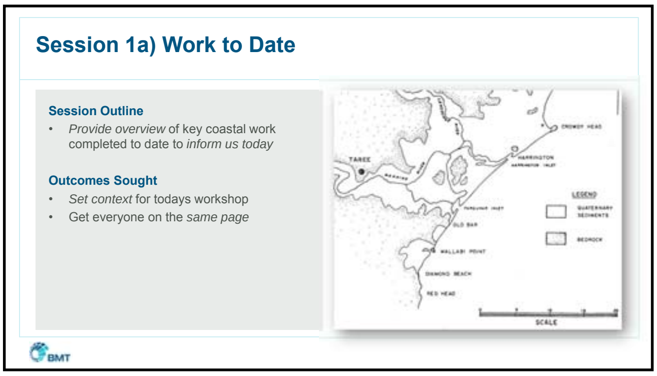
Todays Aims and Agenda

Outcomes Sought

- **Provide an update** on the *geomorph. field work* and a **recap** of the *previous coastal engineering work* for Old Bar coastline
- **Seek guidance** on a *'fit for purpose'* erosion hazard **probabilistic modelling framework**
- **Confirm** the range of **input parameters** to use and associated *PDFs, coefficients*
- **Consider** how to *incorporate* the varied **coastal geological conditions**
- **Confirm** the erosion **hazard mapping output** format(s)

Introduction	**10:00 am**
Session 1	**10:10 am**
• Work to date (~20 mins)	
• Hazard mapping approach (~45 mins)	
Tea Break	**11:15 am**
Session 2	**11:30 am**
• Hazard mapping parameters (~45 mins)	
• Incorporation of varied geotechnical conditions (~30 mins)	
• Hazard mapping outputs (~10 mins)	
Wrap up	**12:55 pm**
Close / Lunch (Optional)	**1:00 pm**

Session 1



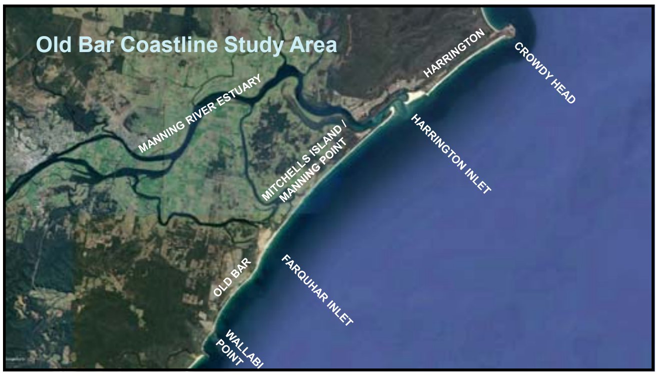
Session 1a) Work to Date

Session Outline

- *Provide overview* of key coastal work completed to date to *inform us today*

Outcomes Sought

- *Set context* for todays workshop
- Get everyone on the *same page*



Old Bar Coastline Study Area

Work to Date - Summary

Coastal Processes & Hazard Assessments
- Old Bar Erosion Study (SKM, 1982)
- Black Head to Crowdy Head Coastline Hazard Definition Study (WP, 2010)
- Risk Assessment to Define Setbacks for Hazards at Old Bar (RHDHV, 2013)
- Old Bar Beach Sediment Tracing (RHDHV, 2016)
- Erosion Analysis of the Manning Valley Coastal Sediment Compartment (MHL, 2017)
- *Old Bar Erosion Hazard Line Review [this study] (BMT, in prep)*

Coastal Geomorphology / Geology Studies
- Old Bar Erosion Study (SKM, 1982)
- Quaternary Geology of the Forster-Tuncurry Coast and Shelf (GSNSW, 1997)
- *Old Bar to Manning Point Coastal Geomorphological Field Study (BMT, 2019)*

Academic Studies
- Research by GA, UQ & others

Data / Mapping
- Coastal Quaternary Geology Mapping (GNSW, 2008)
- Photogram, LiDAR (2013), Bathy (2009), plus recent OEH data (waves, seabed)

BMT

Coastal Processes and Hazard Studies

Black Head to Crowdy Head Coastline Hazard Definition Study (WP, 2010)
- Typical hazard assessment, whole coast
- Historical information reviewed
- Wave modelling, hazard line mapping

Risk Assessment to Define Setbacks for Hazards at Old Bar (WP, 2010)
- 'Risk approach applied', Old Bar town only
- Many hazard lines (v. conservative?)

Erosion Analysis of the Manning Valley Sediment Compartment (MHL, 2017)
- Wholistic review of available information, with sediment compartment approach
- Quantitative coastal processes & sediment budget model proposed (more later)
- Coastline / estuarine dynamics important
- Recent aggressive recession linked to anthropogenic influences

UQ / GA Erosion Studies at Old Bar (many)
- Beach response to storm clusters modelled (up to 2% AEP), no SLR impacts
- Erosion demand from clustered storms w 2% AEP is 25% greater than single events
- Individual storms can generate the same erosion demand as clustered events

This Study… *drawing on the above*

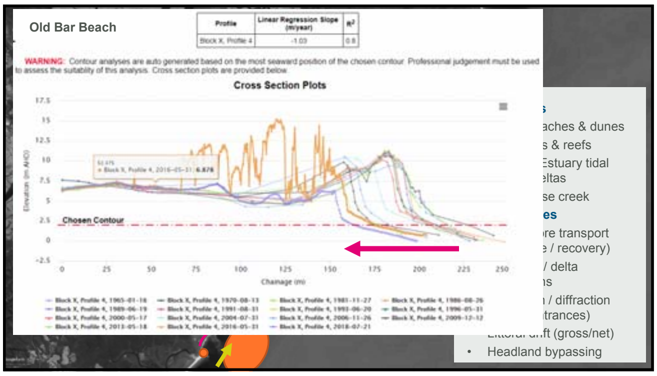
BMT

Coastal Processes

Human Interference
- Harrington training wall (one-way valve)
- Sand mining
- Dredging (one off campaigns & ongoing)

Key Features
- Sandy beaches & dunes
- Headlands & reefs
- Manning Estuary tidal inlets & deltas
- Racecourse creek

Key Processes
- Cross shore transport (storm bite / recovery)
- Coastline / delta interactions
- Refraction / diffraction (reefs / entrances)
- Littoral drift (gross/net)
- Headland bypassing

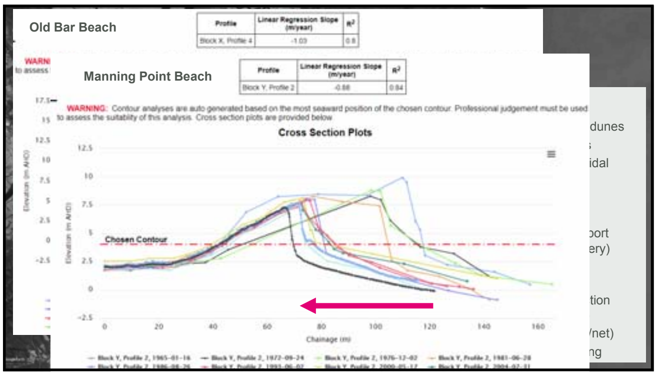


Old Bar Beach

Profile	Linear Regression Slope (m/year)	R²
Block X, Profile 4	-1.03	0.8

WARNING: Contour analyses are auto generated based on the most seaward position of the chosen contour. Professional judgement must be used to assess the suitability of this analysis. Cross section plots are provided below.

Cross Section Plots

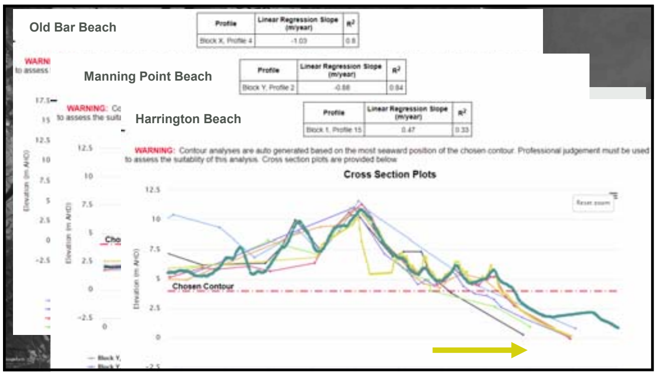


Manning Point Beach

Profile	Linear Regression Slope (m/year)	R²
Block Y, Profile 2	-0.88	0.84

WARNING: Contour analyses are auto generated based on the most seaward position of the chosen contour. Professional judgement must be used to assess the suitability of this analysis. Cross section plots are provided below.

Cross Section Plots

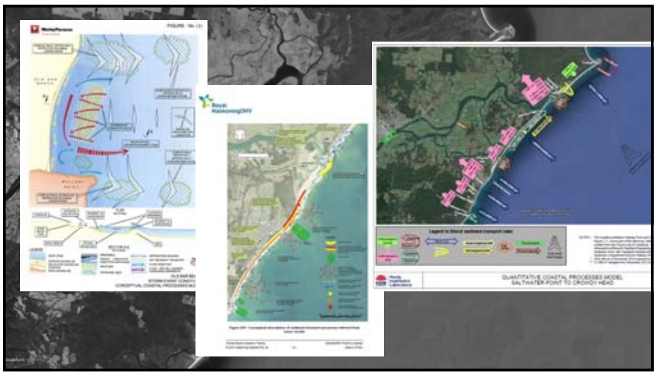


Harrington Beach

Profile	Linear Regression Slope (m/year)	R²
Block 1, Profile 15	0.47	0.33

WARNING: Contour analyses are auto generated based on the most seaward position of the chosen contour. Professional judgement must be used to assess the suitability of this analysis. Cross section plots are provided below.

Cross Section Plots



Coastal Geomorphology and Geology Studies

Old Bar Erosion Study (SKM, 1982)
- Data rich study
- Modern & relic coastal deposits identified, offshore sediments /reef mapped
- Coastal geological conditions shown to be varied, with bedrock below Old Bar beach

Quaternary Geology of the Forster-Tuncurry Coast and Shelf (GSNSW, 1997)
- Quaternary geology sediment compartment research, south of Manning
- Sediment flows / coastal evolution shown
- Tuncurry sediment trap - Negligible supply sand supply into Manning Compartment

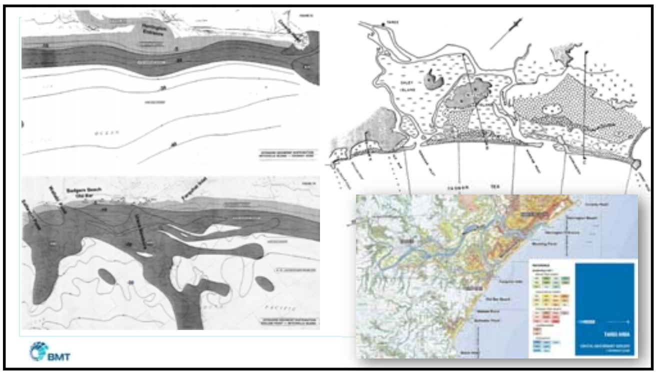
Coastal Quaternary Geology Mapping (GSNSW, 1997)
- Quaternary sediments mapped (1:25k)
- Barrier / estuarine / alluvial sediments mapped, incl. modern & relic sediments

Old Bar to Manning Point Coastal Geomorphological Field Study (BMT, 2019)

Investigations x3:
- (i) walkover, (ii) geophysics, (iii) borehole

Coastal geotechnical conditions:
- Partially resistant substrates (eg indurated)
- Erosion influencing bedrock (eg reefs)
- Erosion limiting bedrock (eg headlands)

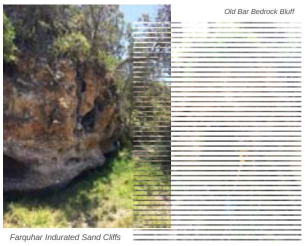
BMT



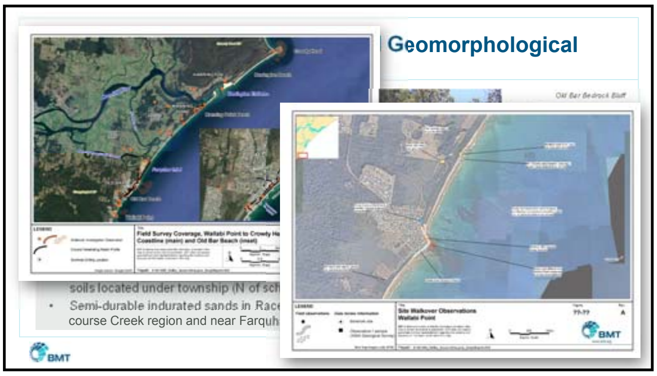
Old Bar to Manning Point Coastal Geomorphological Field Study

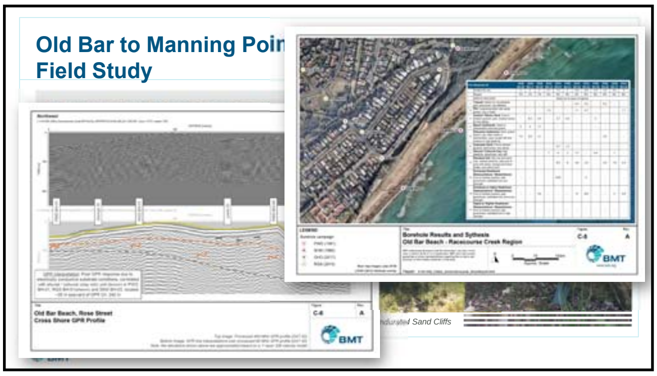
Geomorphology Characterised for Study Coastline and its Segments
- Old Bar
- Farquhar Inlet
- Mitchell's Island / Manning Point
- Harrington Inlet
- Harrington Beach

Key Findings
- Old Bar area is complex (study focus)
- Buried bluff with deep weathered rock / soils located under township (N of school)
- Semi-durable indurated sands in Race-course Creek region and near Farquhar


Old Bar Bedrock Bluff
Farquhar Indurated Sand Cliffs

BMT



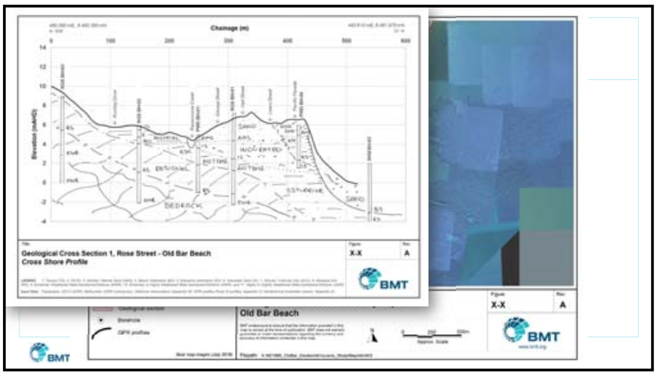


LEGEND
Geological section
Borehole
GPR profiles

Title
Geological Cross Section Locality Map
Old Bar Beach

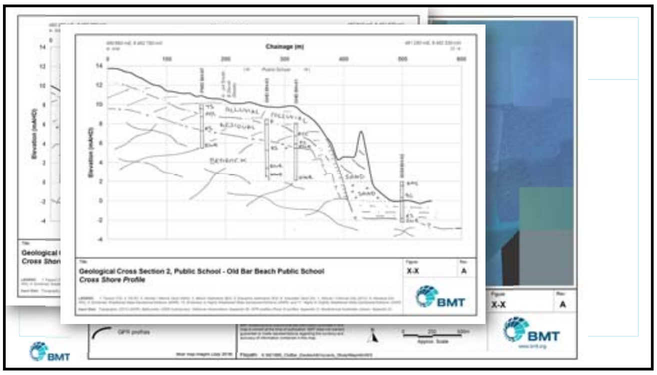
Figure	Rev
X-X	A

Approx. Scale



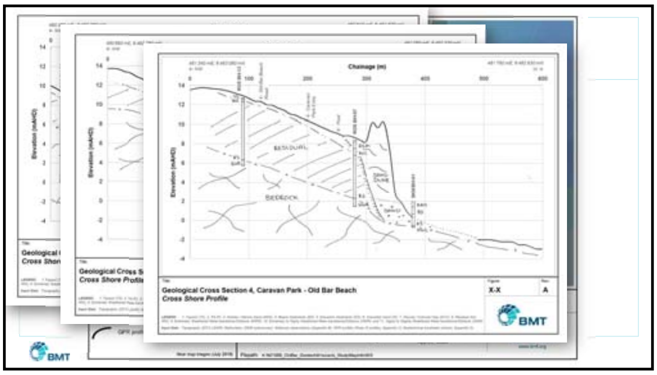
Title
Geological Cross Section 1, Rose Street - Old Bar Beach
Cross Shore Profile

Figure	Rev
X-X	A



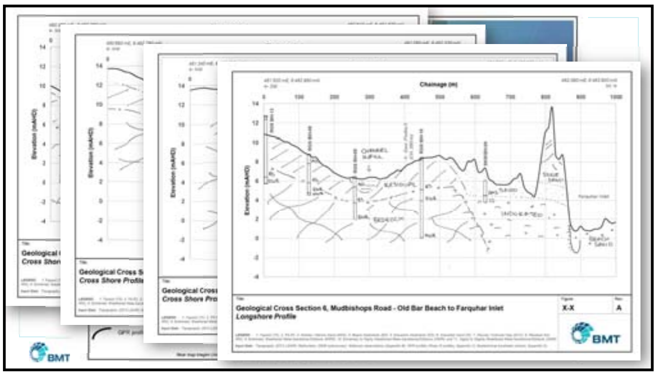
Title
Geological Cross Section 2, Public School - Old Bar Beach Public School
Cross Shore Profile

Figure	Rev
X-X	A



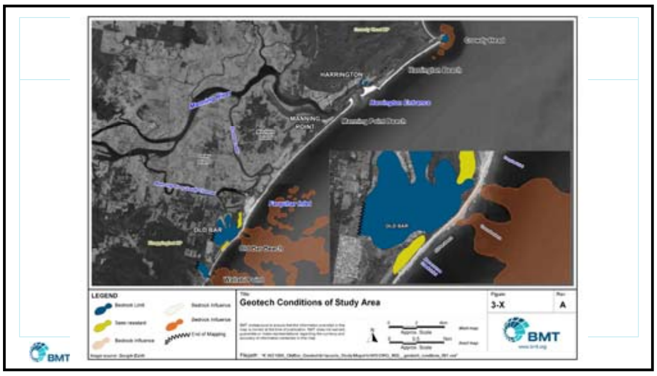
Title
Geological Cross Section 4, Caravan Park - Old Bar Beach
Cross Shore Profile

Figure	Rev
X-X	A



Title
Geological Cross Section 6, Mudbishops Road - Old Bar Beach to Farquhar Inlet
Longshore Profile

Figure	Rev
X-X	A



LEGEND
Bedrock Limit
Semi resistant
Bedrock Influence
Bedrock Influence
Bedrock Influence
End of Mapping

Title
Geotech Conditions of Study Area

Figure	Rev
3-X	A

Approx. Scale

1a) Questions / Comments

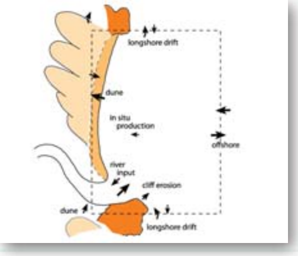
Any burning questions / comments, in the context of the hazard modelling / mapping discussion to follow?

Session 1b) Hazard Mapping Approach / Framework

Session Outline
- *Seek guidance and input* from participants on a probabilistic approach to modelling erosion hazards
- Approach to draw on existing methods and available information (only)

Outcomes Sought
- Fit-for-purpose approach *agreed* on by all
- Suite of erosion *hazard parameters confirmed*

Note
- *'Rolls Royce' modelling can be done, but not under current contract scope*



Existing Information

Hazard Study Data - Various
- Storm Demand (m3/m)
- Historical Recession (m/yr)
- Depth of Closure estimates
- Recession setbacks due to SLR (Bruun)

Sediment Budget Info – MHL Report
- Onshore transport (gross / net)
- Headland bypassing
- Fluvial / catchment input
- Longshore transport (gross / net)
- Aeolian transport
- Delta / coastline exchange

- Anthropogenic influences
  - Dunes reshaping / mining
  - Dredging at Harrington and Farquhar

Geotechnical Info – This Study
- Erodible substrates
- Partially resistant substrates
  - Indurated sediments & residual bedrock
- Erosion resistant substrates
  - Erosion influencing & limiting bedrock

Topography / Bathymetry Data

Sediment Compartments Mapping

Climate Change / Sea Level Rise

NSW Govt. Science Framework (Kinsella et al)

Approach
- Monte Carlo – probabilistic model
- Volumetric encroachment model
- Fluctuating erosion (F) plus cumulative erosion (C)

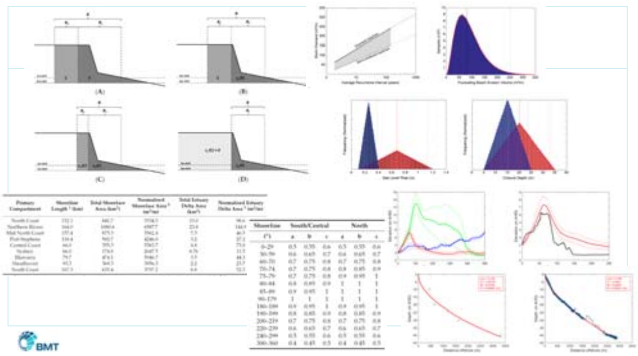
$$V = c_f(F) + c_c(C)$$

Fluctuating Erosion
- Captures beach response to short term change (storm bite, rotation)
- Can be scaled

$$F \sim \Gamma(k,\theta) \equiv Gamma(v, 3, 30.5) \text{ for } 1 \leq v \leq 350$$

Cumulative Erosion
- Captures long term beach response to littoral sediment budget imbalance
- Key terms:
  - *Cross shore and alongshore sed. drift*
  - *Shoreface sink to SLR*
  - *Delta sink to SLR*
  - *Aeolian source/sink*
  - *Barrier washover sink*
  - *Mega rips sink*
  - *Biogenic supply*
  - *River supply*

$$C = (q_s + q_p)t + c_s(V_S) + c_e(V_E) + \left(\frac{V_A + V_O + V_M + V_B + V_R}{t}\right)t$$



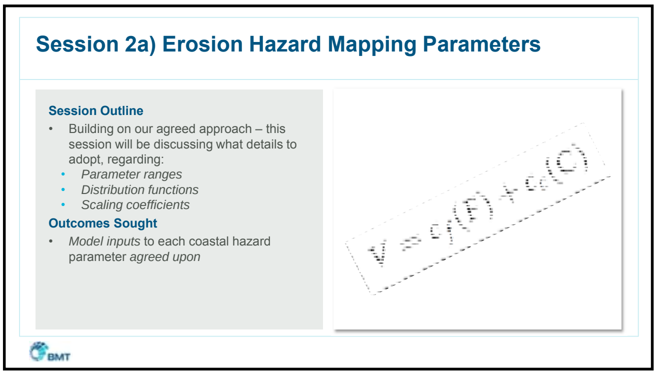
1b) Discussion

What does a *fit-for-purpose* probabilistic approach for modelling / mapping erosion hazards at Old Bar look like?
- **What key parameters are we adopting?**
- **How do these relate to one another?**
- **How do we apply these to Old Bar?**
  - Whole coastline?
  - Coastline segments (what are these, geographically; & how are they represented in the model)?
- Any other matters to consider?

Tea Break

15 minutes

Session 2



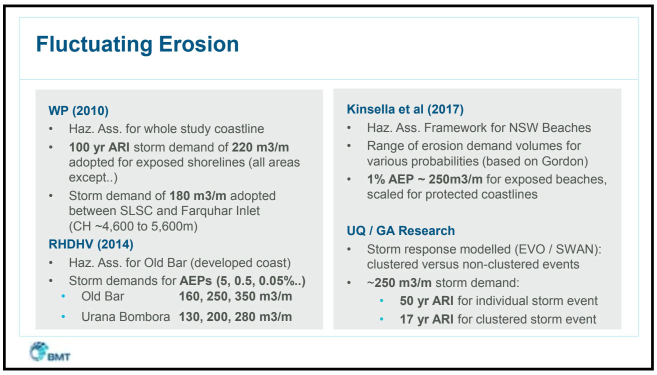
Session 2a) Erosion Hazard Mapping Parameters

Session Outline

- Building on our agreed approach – this session will be discussing what details to adopt, regarding:
  - *Parameter ranges*
  - *Distribution functions*
  - *Scaling coefficients*

Outcomes Sought

- *Model inputs* to each coastal hazard parameter *agreed upon*



Fluctuating Erosion

WP (2010)

- Haz. Ass. for whole study coastline
- **100 yr ARI** storm demand of **220 m3/m** adopted for exposed shorelines (all areas except..)
- Storm demand of **180 m3/m** adopted between SLSC and Farquhar Inlet (CH ~4,600 to 5,600m)

RHDHV (2014)

- Haz. Ass. for Old Bar (developed coast)
- Storm demands for **AEPs (5, 0.5, 0.05%..)**
  - Old Bar **160, 250, 350 m3/m**
  - Urana Bombora **130, 200, 280 m3/m**

Kinsella et al (2017)

- Haz. Ass. Framework for NSW Beaches
- Range of erosion demand volumes for various probabilities (based on Gordon)
- **1% AEP ~ 250m3/m** for exposed beaches, scaled for protected coastlines

UQ / GA Research

- Storm response modelled (EVO / SWAN): clustered versus non-clustered events
- **~250 m3/m** storm demand:
  - **50 yr ARI** for individual storm event
  - **17 yr ARI** for clustered storm event

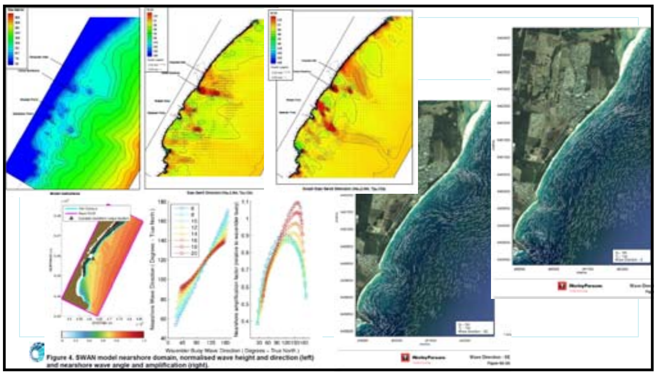
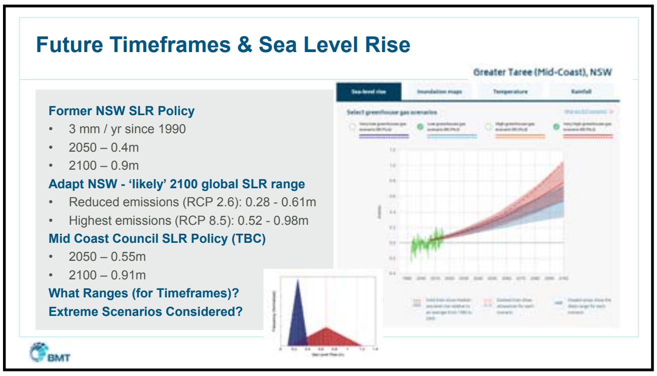


Figure 4. SWAN model nearshore domain, normalised wave height and direction (left) and nearshore wave angle and amplification (right).



Future Timeframes & Sea Level Rise

Former NSW SLR Policy

- 3 mm / yr since 1990
- 2050 – 0.4m
- 2100 – 0.9m

Adapt NSW - 'likely' 2100 global SLR range

- Reduced emissions (RCP 2.6): 0.28 - 0.61m
- Highest emissions (RCP 8.5): 0.52 - 0.98m

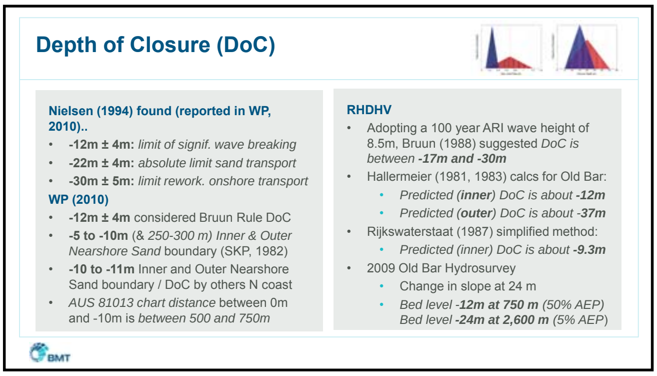
Mid Coast Council SLR Policy (TBC)

- 2050 – 0.55m
- 2100 – 0.91m

What Ranges (for Timeframes)?

Extreme Scenarios Considered?

Greater Taree (Mid-Coast), NSW



Depth of Closure (DoC)

Nielsen (1994) found (reported in WP, 2010)..

- **-12m ± 4m:** *limit of signif. wave breaking*
- **-22m ± 4m:** *absolute limit sand transport*
- **-30m ± 5m:** *limit rework. onshore transport*

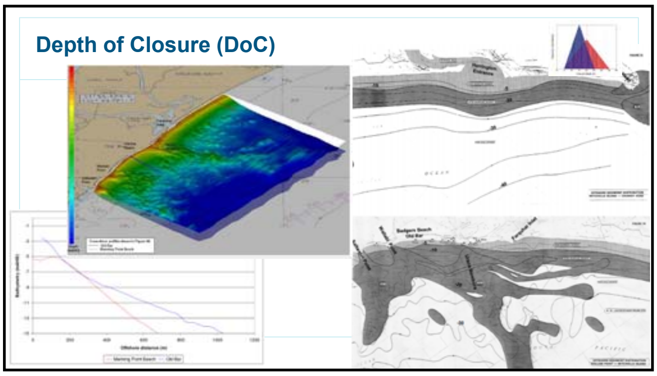
WP (2010)

- **-12m ± 4m** considered Bruun Rule DoC
- **-5 to -10m** (& *250-300 m) Inner & Outer Nearshore Sand* boundary (SKP, 1982)
- **-10 to -11m** Inner and Outer Nearshore Sand boundary / DoC by others N coast
- *AUS 81013 chart distance* between 0m and -10m is *between 500 and 750m*

RHDHV

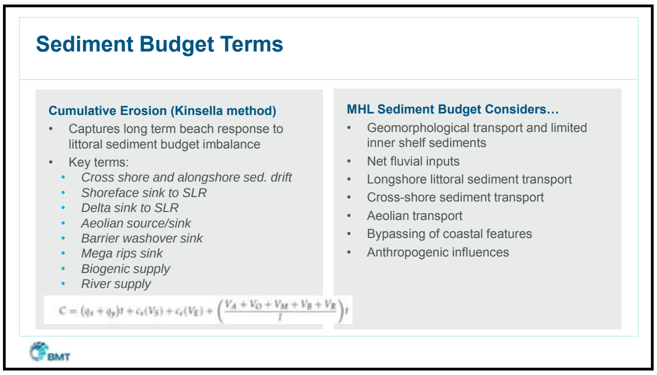
- Adopting a 100 year ARI wave height of 8.5m, Bruun (1988) suggested *DoC is between* ***-17m and -30m***
- Hallermeier (1981, 1983) calcs for Old Bar:
  - *Predicted (**inner**) DoC is about **-12m***
  - *Predicted (**outer**) DoC is about **-37m***
- Rijkswaterstaat (1987) simplified method:
  - *Predicted (inner) DoC is about **-9.3m***
- 2009 Old Bar Hydrosurvey
  - Change in slope at 24 m
  - *Bed level **-12m at 750 m** (50% AEP) Bed level **-24m at 2,600 m** (5% AEP)*

BMT



Depth of Closure (DoC)

BMT



Sediment Budget Terms

Cumulative Erosion (Kinsella method)

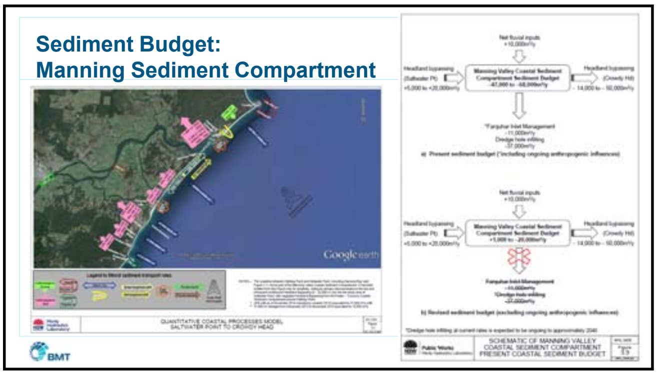
- Captures long term beach response to littoral sediment budget imbalance
- Key terms:
  - *Cross shore and alongshore sed. drift*
  - *Shoreface sink to SLR*
  - *Delta sink to SLR*
  - *Aeolian source/sink*
  - *Barrier washover sink*
  - *Mega rips sink*
  - *Biogenic supply*
  - *River supply*

$$C=(q_s+q_g)t+c_s(V_S)+c_f(V_E)+\left(\frac{V_A+V_O+V_M+V_B+V_R}{t}\right)t$$

MHL Sediment Budget Considers…

- Geomorphological transport and limited inner shelf sediments
- Net fluvial inputs
- Longshore littoral sediment transport
- Cross-shore sediment transport
- Aeolian transport
- Bypassing of coastal features
- Anthropogenic influences

BMT



Sediment Budget: Manning Sediment Compartment

BMT

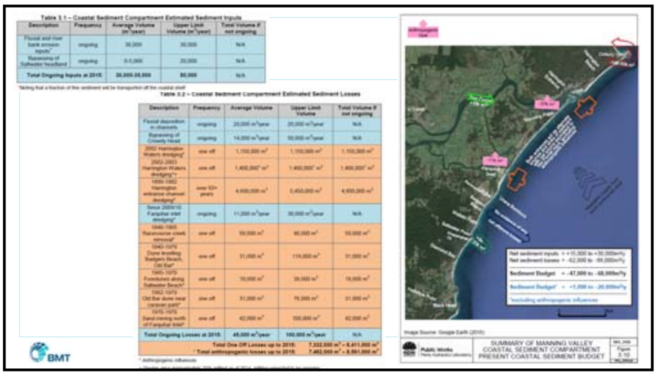
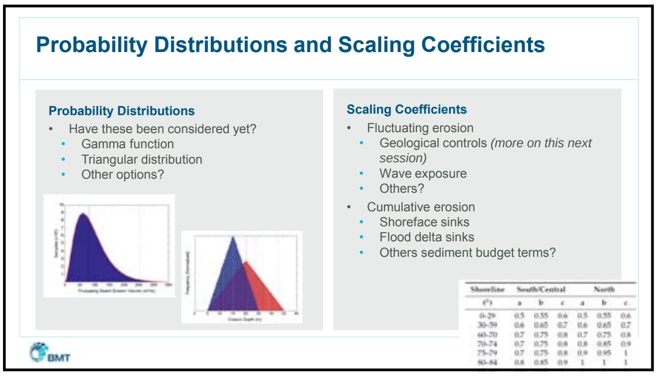


Table 3.1 – Coastal Sediment Compartment Estimated Sediment Inputs

Table 3.2 – Coastal Sediment Compartment Estimated Sediment Losses

BMT



Probability Distributions and Scaling Coefficients

Probability Distributions

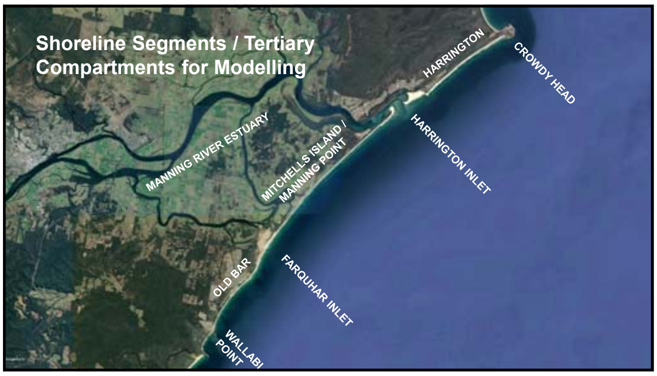
- Have these been considered yet?
  - Gamma function
  - Triangular distribution
  - Other options?

Scaling Coefficients

- Fluctuating erosion
  - Geological controls *(more on this next session)*
  - Wave exposure
  - Others?
- Cumulative erosion
  - Shoreface sinks
  - Flood delta sinks
  - Others sediment budget terms?

Shoreline	South/Central			North		
(°)	a	b	c	a	b	c
0-29	0.5	0.55	0.6	0.5	0.55	0.6
30-39	0.6	0.65	0.7	0.6	0.65	0.7
60-70	0.7	0.75	0.8	0.7	0.75	0.8
70-74	0.7	0.75	0.8	0.8	0.85	0.9
75-79	0.7	0.75	0.8	0.9	0.95	1
80-84	0.8	0.85	0.9	1	1	1

BMT

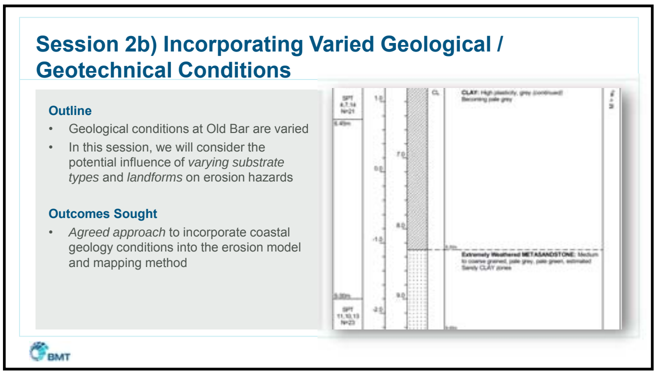


Shoreline Segments / Tertiary Compartments for Modelling

2a) Discussion

Based on *existing information* and *expert judgment…*

- For each **input parameter**, what are we adopting in terms of:
  - Parameter **ranges**?
  - **Distribution functions**?
  - Scaling **coefficients**?
- How are we considering the Hazard Assessment storm demand estimates with respect to Kinsella's fluctuating erosion term?
- How are we applying MHL sediment budget to Kinsella's cumulative erosion terms?



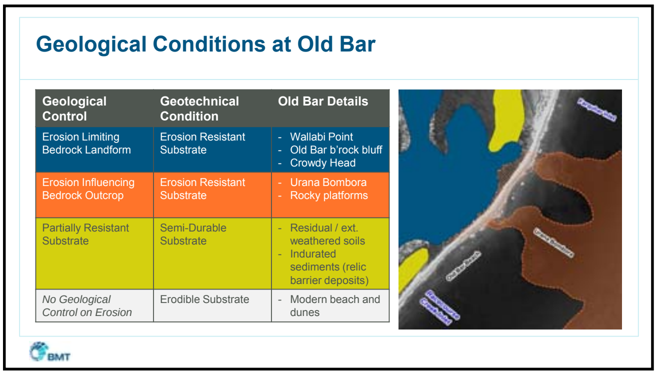
Session 2b) Incorporating Varied Geological / Geotechnical Conditions

Outline

- Geological conditions at Old Bar are varied
- In this session, we will consider the potential influence of *varying substrate types* and *landforms* on erosion hazards

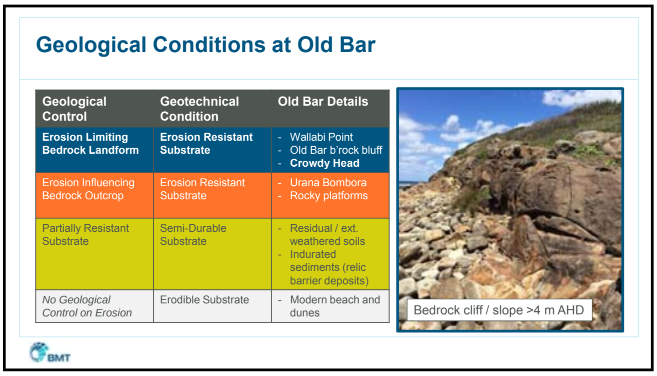
Outcomes Sought

- *Agreed approach* to incorporate coastal geology conditions into the erosion model and mapping method



Geological Conditions at Old Bar

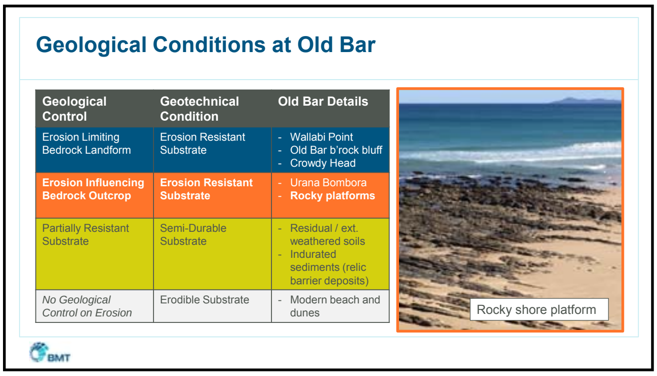
Geological Control	Geotechnical Condition	Old Bar Details
Erosion Limiting Bedrock Landform	Erosion Resistant Substrate	- Wallabi Point - Old Bar b'rock bluff - Crowdy Head
Erosion Influencing Bedrock Outcrop	Erosion Resistant Substrate	- Urana Bombora - Rocky platforms
Partially Resistant Substrate	Semi-Durable Substrate	- Residual / ext. weathered soils - Indurated sediments (relic barrier deposits)
No Geological Control on Erosion	Erodible Substrate	- Modern beach and dunes



Geological Conditions at Old Bar

Geological Control	Geotechnical Condition	Old Bar Details
Erosion Limiting Bedrock Landform	**Erosion Resistant Substrate**	- Wallabi Point - Old Bar b'rock bluff - **Crowdy Head**
Erosion Influencing Bedrock Outcrop	Erosion Resistant Substrate	- Urana Bombora - Rocky platforms
Partially Resistant Substrate	Semi-Durable Substrate	- Residual / ext. weathered soils - Indurated sediments (relic barrier deposits)
No Geological Control on Erosion	Erodible Substrate	- Modern beach and dunes

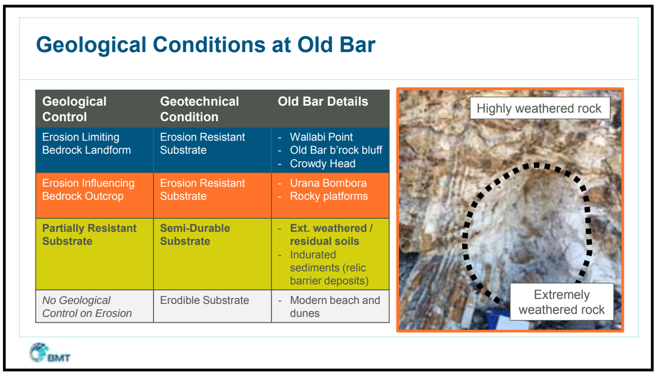
Bedrock cliff / slope >4 m AHD



Geological Conditions at Old Bar

Geological Control	Geotechnical Condition	Old Bar Details
Erosion Limiting Bedrock Landform	Erosion Resistant Substrate	- Wallabi Point - Old Bar b'rock bluff - Crowdy Head
Erosion Influencing Bedrock Outcrop	**Erosion Resistant Substrate**	- Urana Bombora - **Rocky platforms**
Partially Resistant Substrate	Semi-Durable Substrate	- Residual / ext. weathered soils - Indurated sediments (relic barrier deposits)
No Geological Control on Erosion	Erodible Substrate	- Modern beach and dunes

Rocky shore platform

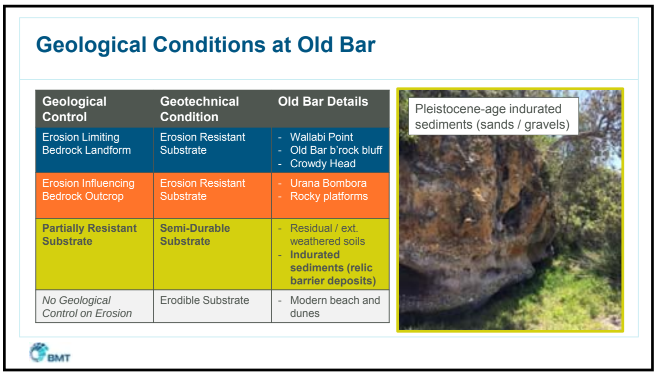


Geological Conditions at Old Bar

Geological Control	Geotechnical Condition	Old Bar Details
Erosion Limiting Bedrock Landform	Erosion Resistant Substrate	- Wallabi Point - Old Bar b'rock bluff - Crowdy Head
Erosion Influencing Bedrock Outcrop	Erosion Resistant Substrate	- Urana Bombora - Rocky platforms
Partially Resistant Substrate	**Semi-Durable Substrate**	- **Ext. weathered / residual soils** - Indurated sediments (relic barrier deposits)
No Geological Control on Erosion	Erodible Substrate	- Modern beach and dunes

Highly weathered rock

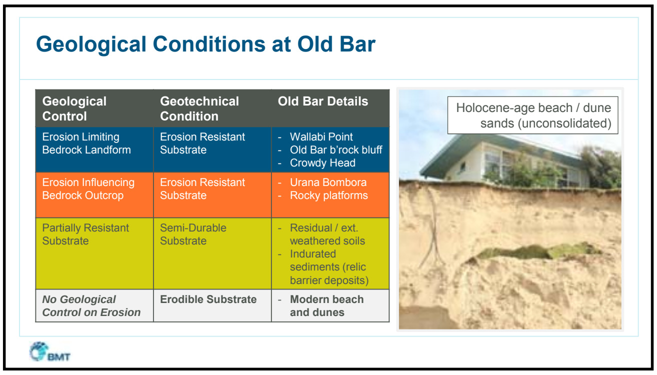
Extremely weathered rock



Geological Conditions at Old Bar

Geological Control	Geotechnical Condition	Old Bar Details
Erosion Limiting Bedrock Landform	Erosion Resistant Substrate	- Wallabi Point - Old Bar b'rock bluff - Crowdy Head
Erosion Influencing Bedrock Outcrop	Erosion Resistant Substrate	- Urana Bombora - Rocky platforms
Partially Resistant Substrate	**Semi-Durable Substrate**	- Residual / ext. weathered soils - **Indurated sediments (relic barrier deposits)**
No Geological Control on Erosion	Erodible Substrate	- Modern beach and dunes

Pleistocene-age indurated sediments (sands / gravels)



Geological Conditions at Old Bar

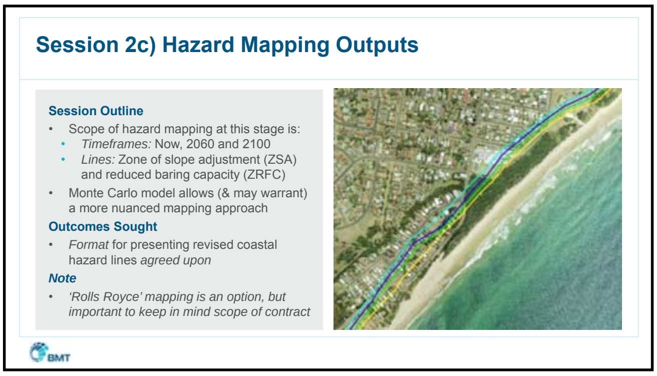
Geological Control	Geotechnical Condition	Old Bar Details
Erosion Limiting Bedrock Landform	Erosion Resistant Substrate	- Wallabi Point - Old Bar b'rock bluff - Crowdy Head
Erosion Influencing Bedrock Outcrop	Erosion Resistant Substrate	- Urana Bombora - Rocky platforms
Partially Resistant Substrate	Semi-Durable Substrate	- Residual / ext. weathered soils - Indurated sediments (relic barrier deposits)
No Geological Control on Erosion	**Erodible Substrate**	- **Modern beach and dunes**

Holocene-age beach / dune sands (unconsolidated)

2b) Discussion

Based on *existing information* and *expert judgment*…

- **How do we treat the following geological conditions:**
  - **Erosion limiting bedrock landforms (e.g. Old Bar bluff)?**
  - **Erosion influencing bedrock landforms (e.g. *Urana Bombora*)?**
  - **Partially resistant substrates (*indurated sediment*, exposed *cohesive clay bedrock slopes*)?**
- *Possible options* include:
  - Suitable *scaling coefficients*
  - *Mapping methods (geotechnical buffer, clip lines to bedrock etc)*



Session 2c) Hazard Mapping Outputs

Session Outline

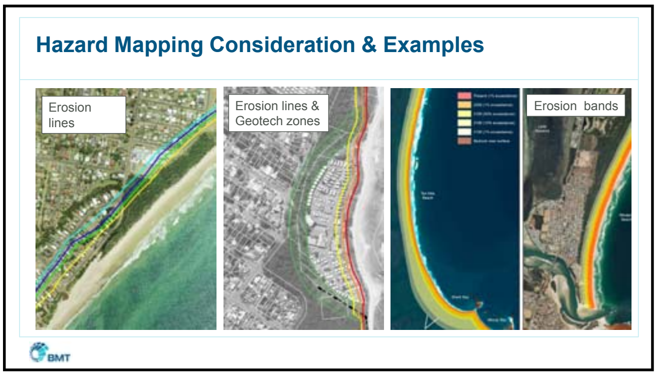
- Scope of hazard mapping at this stage is:
  - *Timeframes:* Now, 2060 and 2100
  - *Lines:* Zone of slope adjustment (ZSA) and reduced baring capacity (ZRFC)
- Monte Carlo model allows (& may warrant) a more nuanced mapping approach

Outcomes Sought

- *Format* for presenting revised coastal hazard lines *agreed upon*

Note

- *'Rolls Royce' mapping is an option, but important to keep in mind scope of contract*

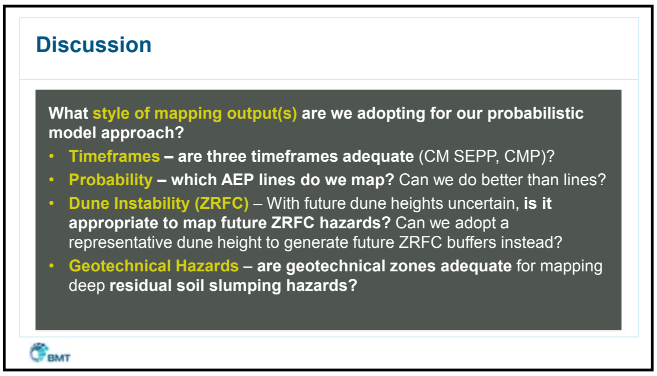


Hazard Mapping Consideration & Examples

Erosion lines

Erosion lines & Geotech zones

Erosion bands

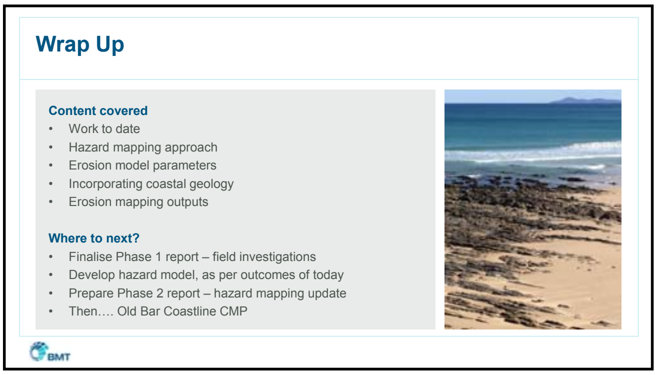


Discussion

What style of mapping output(s) are we adopting for our probabilistic model approach?

- **Timeframes – are three timeframes adequate** (CM SEPP, CMP)?
- **Probability – which AEP lines do we map?** Can we do better than lines?
- **Dune Instability (ZRFC)** – With future dune heights uncertain, **is it appropriate to map future ZRFC hazards?** Can we adopt a representative dune height to generate future ZRFC buffers instead?
- **Geotechnical Hazards – are geotechnical zones adequate** for mapping deep **residual soil slumping hazards?**

Wrap Up



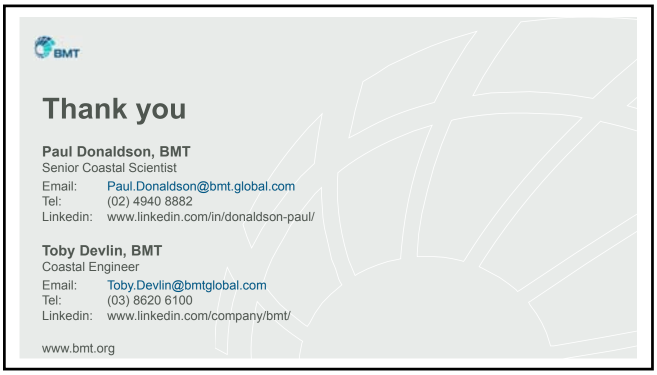
Wrap Up

Content covered

- Work to date
- Hazard mapping approach
- Erosion model parameters
- Incorporating coastal geology
- Erosion mapping outputs

Where to next?

- Finalise Phase 1 report – field investigations
- Develop hazard model, as per outcomes of today
- Prepare Phase 2 report – hazard mapping update
- Then…. Old Bar Coastline CMP



Thank you

Paul Donaldson, BMT
Senior Coastal Scientist
Email: Paul.Donaldson@bmt.global.com
Tel: (02) 4940 8882
Linkedin: www.linkedin.com/in/donaldson-paul/

Toby Devlin, BMT
Coastal Engineer
Email: Toby.Devlin@bmtglobal.com
Tel: (03) 8620 6100
Linkedin: www.linkedin.com/company/bmt/

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Appendix I Old Bar to Manning Point Coastal Geomorphological Field Study (BMT, 2020)

Old Bar to Manning Point Coastal Geomorphological Field Study (BMT, 2020)

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Old Bar to Manning Point Coastal Geomorphological Field Study

Reference: R.N21005.001.02_OldBar_Geotech_Study.docx
Date: February 2020
Preliminary Draft Report
Confidential

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BMT Commercial Australia Pty Ltd
126 Belford Street
Broadmeadow NSW 2292
Australia
PO Box 266
Broadmeadow NSW 2292

Tel: +61 2 4940 8882
Fax: +61 2 4940 8887

ABN 54 010 830 421

www.bmt.org

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Project Manager:	Paul Donaldson
Author:	Paul Donaldson
Client:	Mid Coast Council
Client Contact:	Andrew Staniland
Client Reference:	

Synopsis: **This document outlines the coastal geomorphology field investigation of Old Bar Beach region on the NSW Mid North Coast. The study applied a suite of field investigations, which are documented within this report. A description of the geomorphic conditions surveyed across the Wallabi Point to Crowdy Head coastline is presented in the context of coastal erosion hazards and risks. Geological cross sections are provided for Old Bar.**

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1				PD	
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DISTRIBUTION

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1 Introduction

1.1 Preamble

The sandy coastline spanning from Wallabi Point to Crowdy Head (the Old Bar study region) on the Mid North Coast of NSW is exposed to significant coastal erosion hazards, with the Old Bar and Manning Point beaches experiencing some of the highest recession rates in the state. Residential land, community assets and other infrastructure is highly exposed to erosion impacts, as demonstrated in 2008 when three foreshore houses were demolished at southern end of Old Bar due to erosion impacts.

A wide range of technical investigations have been undertaken over several decades. Field surveys in the early 1980's found the coastal geological conditions to be varied in the vicinity of Old Bar (SKM, 1982). More recently a suite of coastal processes and erosion investigations have been completed (e.g. WP, 2010; RHDHV, 2014; MHL, 2017), with several coastal engineering hazard studies estimating future erosion hazard extents using methods that assuming that beach is backed by erodible sand. For some time, there has been a general recognition that variable geotechnical conditions at Old Bar may to potentially limit future erosion and recession hazards (e.g. bedrock behind the beach), although these conditions have been poorly understood.

In response to the geological unknowns at Old Bar Beach, Mid Coast Council (Council) has initiated this current coastal geomorphology field investigation to help resolve the uncertainty regarding coastal geology and associated erodibility within the Old Bar to Manning Point region.

1.2 Aims and objectives

The objective of this coastal geomorphological field study is to identity and characterise geotechnical conditions that may influence coastal erosion and shoreline recession hazards across the Old Bar study region, through a literature review and field survey program. More specifically, this study aims to analyse and interpret the existing and new data sources in the context of coastal erosion risks and provide practical recommendations on how to refine coastal erosion and recession hazards estimations that reflect the varying geomorphic conditions of the region.

1.3 Scope of work

BMT was engaged by Council to undertake a field investigation and information review to characterise the onshore geomorphic conditions across the Wallabi Point to Crowdy Head coastline. The agreed field program comprised a ‘three pronged’ approach that extended to a:

- Geomorphological site walkover (field) assessment,
- Ground penetrating radar (GPR) coastal geology survey; and
- Geotechnical borehole drilling investigation of the subsurface conditions, which includes the production of engineering logs.

This report presents a summary of the field investigations and literature review. Standalone field investigation reports are documented within the technical appendices to this study, which should be read in parallel with this summary report.

STUDY AREA

Wallabi Point to Crowdy Head

MANNING SEDIMENT COMPARTMENT

Black Head to Crowdy Head

Image source: Google Earth

Title:

Locality Map, Old Bar Study Region and the Manning Sediment Compartment

N

0 3.75 7.5km

Approx. Scale

Figure:

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A review of coastal geoscience literature and information was undertaken to understand the existing knowledge on the coastal geomorphology, geological and geotechnical conditions of the study region. Table 1-1 lists the information sources that have been reviewed through this process, which extended to the following information types:

- State Government technical reports
- Consultant technical reports
- Field survey data, including borehole investigations and geological maps
- Academic literature

Appendix A documents the outcomes of the literature and information review. Key information relating to the regional geological framework, geotechnical coastal geomorphology conditions of the site, and corresponding coastline processes are documented within this report.

1.4 Report structure

The document is set out in the following sections:

Chapter 2	Outlines the physical characteristics of the study region and study sites, and presents an overview of the geological controls on coastal erosion.
Chapter 3	Provides an overview of the field survey approach and then summarises key aspects and outcomes of each field investigation.
Chapter 4	Synthesises the outcomes of the site surveys and background analysis undertaken for this study.
Chapter 5	Presents a summary of this technical study and provides a set of recommendations for consideration.
Chapter 6	Contains a list of references used during this study.
Appendix A	Documents the review of geoscience literature and information.
Appendix B	Documents the geomorphological field walkover assessment.
Appendix C	Documents the GPR survey in detail, including the survey objectives, methodology, data processes and analysis and survey results.
Appendix D	Documents an overview of the borehole investigation undertaken by Regional Geotechnical Solutions (RGS), and provides synthesis of available borehole information collected through this and past studies
Appendix E	Provide the RGS geotechnical borehole drilling results, including the geotechnical boreholes logs.
Appendix F	Provide the borehole drilling results from past studies (PWD, 1981; SKM 1982)

Table 1-1 Summary of information and literature reviewed for this study

Year	Author	Name	Information Type
1969	GSNSW	Manning River Flood Mitigation: Old Bar Entrance, Sources of Breakwater Stone	State Government technical report
1970	GSNSW	Hastings 1:250,000 Geological Series (Sheet SH/65-14)	Field survey (geological map)
1981	PWD	Old Bar Sewerage: Appendix A - Borehole Information	Field survey (boreholes)
1982	SKM	Old Bar Coastal Erosion Study (Draft): Chapter 3 – Geomorphological – Geological Assessment	Consultant technical report
1987	GSNSW	Tamworth-Hastings 1:250,000 Metallogenic Map (SH/65 13-14, SI/65 1-2)	Field survey (geological map)
1994	Roy *et al.*	Wave Dominated Coasts [chapter], in Coastal Evolution: Late Quaternary Shoreline Morphodynamics [book]	Academic literature
1997	GSNSW	Quaternary Geology of the Forster-Tuncurry Coast and Shelf Southeast Australia	State Government technical report
2001	Roy *et al.*	New South Wales Estuaries: Their Origin and Evolution	Academic literature
2008	GSNSW	Taree Area (1:25,000 and 1:100,000) Coastal Quaternary Geology Mapping	Field survey (geological map)
2009	NSW OEH	Single beam offshore bathymetry survey, Old Bar	Field survey (marine survey)
2010	Worley Parsons	Black Head to Crowdy Head Coastline Hazard Definition Study Volume 1: Report	Consultant technical report
2010	Worley Parsons	Greater Taree Coastline Management Study	Consultant technical report
2012	NSW LPI	LiDAR onshore topographic survey	Field survey (land survey)
2013	Worley Parsons	Draft Coastal Zone Management Plan	Consultant technical report
2013	RHDHV	Old Bar Beach Coastal Protection Structure Design Investigation	Consultant technical report
2014	RHDHV	Risk Assessment to Define Appropriate Development Setbacks and Controls in Relation to Coastline Hazards at Old Bar	Consultant technical report
2014	RHDHV	Addendum to Coastal Zone management Plan for Old Bar	Consultant technical report
2016	GA	Ground Penetrating Radar Data – Old Bar Beach Survey	Field survey (geophysical data)
2016	Nichol *et al.*	A Framework for Modelling Shoreline Response to Clustered Storm Events: A Case Study from Southeast Australia	Academic literature
2016	RHDHV	Old Bar Beach Sediment Tracing	Consultant technical report
2017	MHL	Erosion Analysis of the Manning Valley Coastal Sediment Compartment	Consultant technical report
2018	GA	ESRI StoryMap: Coastal Erosion, Understanding Cause, Response and Impact	Federal Government technical report
2018	Gravois *et al.*	The Effects of Storm Clustering on Storm Demand and Dune Recession at Old Bar NSW	Academic literature

2 Background

2.1 Study area context

2.1.1 Overview

Spanning north from Wallabi Point towards Crowdy Head, the Old Bar and Manning Point coastline region is situated approximately midway between Sydney and Coffs Harbour, on the Mid North Coast of NSW. The study region has a population that is rapidly expanding, which includes the coastal settlements of Old Bar, Manning Point and Harrington. The southeast facing coastline beaches have been subject to coastal hazard over several decades, including significant storm erosion events and rapid shoreline recession that resulted in foreshore dwelling being removed from Old Bar due to coastal erosion impacts since 2008.

2.1.2 Regional geology

Bedrock Geology

The bedrock geology of the Manning River region is located within the Hasting Block of the Lachlan Fold Belt. The 250:000 geology sheet for Hastings indicates that the study region is underlain by the Koorainghat Beds (Old Bar region) and the Byabbara Beds both comprising lithic sandstone, siltstone, greywacke, shale and mudstone (NSW Geological Survey, 1970; 1987).

The coastal bedrock geology of the region is characterised by sandstone, siltstone and conglomerate headlands (CoastAdapt, 2016). Rock exposures show the bedrock units to be upturned (~sloping to vertical bedding) across the study site, which is reflective of the low grade metamorphism that has influenced the region. Thick and resistant sandstones outcrop at Crowdy Head, whereas subvertical interbedded siltstones and sandstones (minor) are exposed at Wallabi Point, which are strongly cleaved and faulted in placed.

The geology has a strong influence on the topography of the rocky landforms. The regional scale northwest – southeast trend in the bedrock folding/faulting system is reflected in the orientation of the rocky coastal landforms (e.g. Wallabi Point, Urana Bombora).

Onshore Quaternary Geology

Coastal Quaternary geological mapping (1:25,000 scale) of the Taree Area by the NSW Geological Survey identified a range of coastal sediment types across the study area (see Figure 2-1). Mapped sedimentary landforms are varied in terms of sediment type, age, and origin. These sediments include both ‘modern’ Holocene-age sediments and ‘relic’ Pleistocene-age sediments, which have been laid down in a variety of depositional environments, including ‘coastal barrier’. ‘estuarine plain’ and ‘alluvial plain’ systems.

Quaternary sediments south of the Old Bar occur within a relatively narrow geographic area that is constrained by a bedrock compartment. The distribution of sediments is significantly more extensive north of Old Bar, with a wide range of sediments types mapped throughout lower Manning River estuarine plain region. These two contrasting onshore sedimentary setting are reflected in earlier mapping presented in SKM (1982).

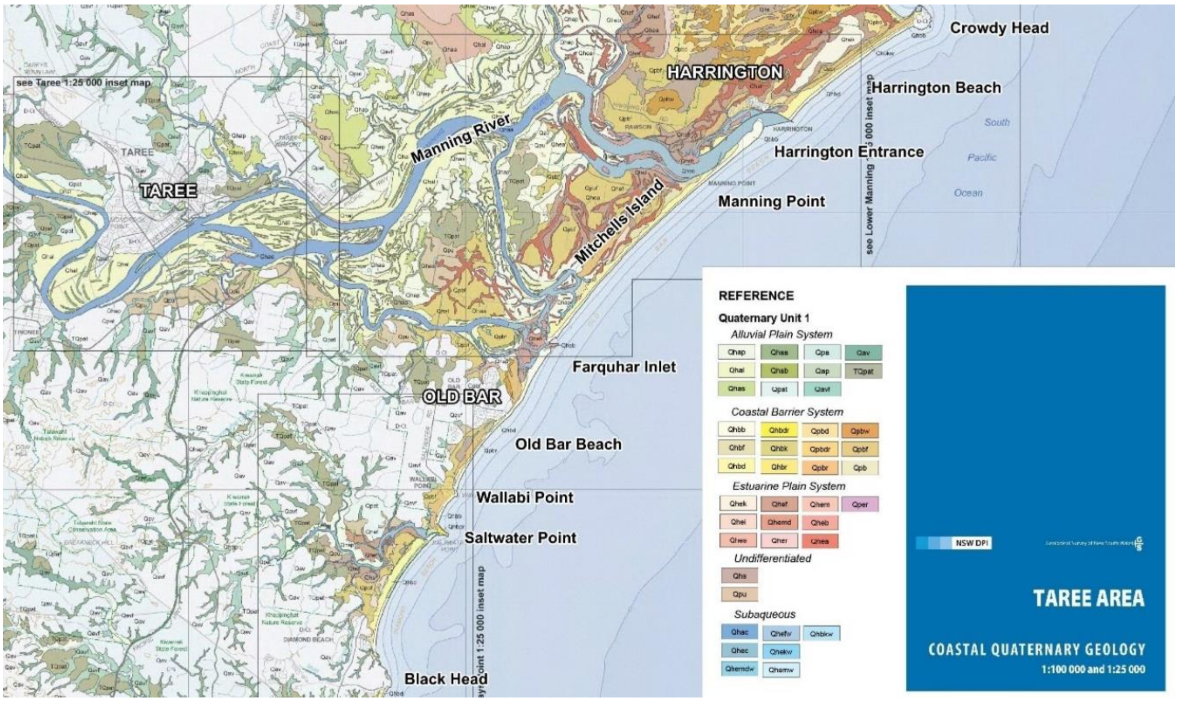


Figure 2-1 Coastal Quaternary Geology

Offshore Sediments

Offshore bathymetry surveys and sediment sampling by SKM (1982) has shown that the shoreface sediments are discontinuous along coastline, with extensive rocky reefs occurring at Urana Bombora offshore of Old Bar and attached to Wallabi Point. Offshore sediment mapping by SKM (1982) shows that the inner-shelf deposits have been largely transported onshore, with and no significant offshore sand body/sheet found and nearshore (shoreface) sands occurring along the coastal margin only (MHL, 2017).

River and estuarine channel sediment sampling indicate that marine delta sediments extend some 5 km upstream of the Harrington Entrance, and 2 - 3 km upstream of the Farquhar Inlet (SKM, 1982).

2.1.3 Geomorphological framework

The coastal morphology of the Old Bar study region is varied. It includes long sand beaches with tall and narrow barrier dunes in places, local occurrences of bedrock terrain behind the beach, vast extents of offshore rocky reef and a relatively sediment starved shelf. Relic coastal deposits occur behind the beaches and an extensive estuarine plain system is associated with the Manning River Estuary. Two tidal inlets dissect the sandy coastline at Farquhar and Harrington Inlet. Harrington Inlet is the primary estuary entrance positioned between the Manning Point and Harrington, which is artificially trained and remains permanently open to the ocean. Farquhar Inlet is the secondary tidal inlet, located immediately north of Old Bar township. Its entrance condition is intermittently closed to the ocean.

The coastline region is exposed to a moderate to high energy wave climate typically of the NSW and receives waves predominantly from the southeast. Offshore rocky reefs influence wave action arriving at the shore in places, through wave refraction and shoaling processes, particularly at Urana

Bombora located offshore of Old Bar. The extensive areas of reef indicate that the shoreface is somewhat starved of sediment.

The link between the coastline and estuary settings is both dynamic and important. Lage deltas occur within Farquhar and Harrington tidal inlets. The Manning River Estuary is subject to periods of flood, which flush the entrance shoals and delta sands into the littoral zone. Over time, sediment migrates back into the channel entrance through wave and tide action (MHL, 2017).

At Farquhar Inlet, entrance breakout channels have occurred naturally across a wide coastline region spanning Old Bar and Mitchells Island. The entrance condition is currently managed through artificial breakouts. Harrington Inlet remains permanently open, after becoming artificially trained in early 1900’s. Large and dynamic entrance sand bar and shoals develop within the Harrington Inlet, which influence the tidal channel geometry within the entrance region.

For this purpose of this report, the study area spanning from Wallabi Point to Crowdy Head is described under the following five (interconnected) coastline sectors (shown in Figure 2-2):

- **Old Bar Beach**, spanning northward from Wallabi Point to Farquhar Inlet.
- **Farquhar Inlet** region,
- **Mitchells Island / Manning Point Beach**, spanning between the two tidal inlets to the Manning River
- **Harrington Inlet**, and
- **Harrington Beach**, extending northward from northern Harrington Inlet Breakwater to Crowdy Head.

Figure 2-2 Wallabi Point to Crowdy Head Coastline Sectors

2.1.4 Manning Valley Sediment Compartment

The Old Bar study area is located within the Manning Coastal Sediment Compartment, which is a 'secondary level' sediment compartment that extends north from Black Head to Crowdy Head (see Table 2-1 for summary of the 'coastal sediment compartment' concept). The Manning sediment compartment receives negligible supply of sediment from the downdrift Tuncurry Sediment Compartment (Roy et al., 1994). Much of the available sand is being fed into the Manning River entrances to form extensive flood tide deltas (CoastAdapt, 2016).

There is also limited sediment being delivered to the shoreline from the shelf, with large extents of rocky reef mapped immediately offshore of Old Bar. As such the compartment is relatively starved of sediment. This is demonstrated by the common occurrences of a narrow Holocene-age coastal barrier deposits and Pleistocene age sediments exposed in the eroding shoreline.

The Manning sediment compartment is rated 4 out of 5 in terms of erosion sensitivity, due to significant erosion already occurring at Old Bar Beach and Manning Point Beach (CoastAdapt, 2016). Various technical studies have attributed the rapid historical shoreline recession to a significant sediment sink within the sediment compartment. Although various interpretations are available, the sediment sink has been most recently attributed to anthropogenic influences (dredging, groyne construction; MHL, 2017).

Table 2-1 Coastal Sediment Compartment Concept

TEXT BOX: Coastal Sediment Compartment Concept

'Coastal sediment compartments' is a concept used to divide the coastline into discrete geographic units that share physical attributes such as geology, landforms, coastal sediment flows and nearshore coastal processes. For this reason, sediment compartments are useful for coastal management and climate adaptation purposes.

Coastal sediment compartments can be mapped at different scales, typically including primary, secondary and tertiary levels, where:

- *Primary compartments* are defined by large landforms (headlands, rivers), and can be used to guide large scale engineering works and long term strategic plans
- *Secondary compartments* are defined by sediment movement on the shoreface within and between beaches, and are at a suitable scale to guide regional planning and engineering decisions
- *Tertiary compartments* often comprise individual beaches and are characterised by sediment movement within the nearshore. Tertiary level compartments are suitable for detailed impact studies and local management plan in vulnerable areas

In New South Wales, the concept of coastal sediment compartments is embedded within the *Coastal Management Act 2016,* which recognises the important of sediment movement on a regional scale.

Source: CoastAdapt (2016a), Thom, B (no date)

2.1.5 Coastal erosion hazard assessments

The coastal erosion issues at Old Bar Beach and surrounding coastline has been investigated through a number of technical studies, including:

- Old Bar Coastal Erosion Study (SKM, 1982)

- Black Head to Crowdy Head Coastline Hazard Definition Study (WP, 2010)
- Risk Assessment to Define Appropriate Development Setbacks and Controls in Relation to Coastline Hazards at Old Bar (RHDHV, 2014)
- Old Bar Beach Sediment Tracing (RHDHV, 2014)
- Erosion Analysis of the Manning Valley Coastal Sediment Compartment (MHL, 2014)
- Coastal Erosion, Understanding Cause, Response and Impact [ESRI StoryMap] (GA, 2016)

These information sources have been reviewed in detail in Appendix A and are briefly summarised herein. SKM (1982) undertook a suite of investigations that included extensive field surveys. Their study report is rich in data and details many aspects that relate to the coastal geology and its influence on erosion susceptibility.

WP (2010) presents a coastal engineering hazard assessment for the former Taree Local Government Area (including Wallabi Point to Crowdy Head), which includes a review of historical records, coastal processes modelling, and the production of erosion hazard lines. Although the study acknowledges that the coastal geotechnical conditions may be varied for Old Bar, the hazard line modelling assumes the coastal fringe is comprised of sand. Similarly, the RHDHV (2014) presents a series of hazard lines that assumes the backing land is erodible, while recognising that bedrock may be present. RHDHV (2016) undertook sediment tracing to investigate sediment transport pathways, with the aim to identify the process (sediment sink) that is driving rapid shoreline recession at Old Bar.

MHL (2017) completed a wholistic review of existing information through the lens of a sediment compartment framework. This report describes the importance of understanding the geological framework for places such as Old Bar Beach; details the wide range of past anthropogenic influences on the sediment budget; and presents a quantitative coastal processes / sediment budget model for the region. MHL (2017) highlights that negligible supply of sediment from the inner shelf; demonstrates the link between the coastline and estuary environment form a sediment movement perspective; and ultimately concludes that anthropogenic factors are responsible for observed long-term and recently accelerated beach recession. The reader is referred to this excellent report for further information on the coastal processes and sediment budget framework of the Manning River Sediment Compartment.

GA (2016) summarises of a body of academic research undertaken at Old Bar Beach within an online platform [story book], which focusses on erosion impacts from storm clustering. This work included coastal processes modelling and the production of hazard lines. Erosion response modelling accounted for depth to bedrock below the beach face and corresponding volumes of sediment available to be eroded. It is not clear if the back beach bedrock controls were incorporated into the assessment.

In summary, a range of technical coastal erosion hazard work has been completed for Old Bar including the production of three sets of erosion hazard lines. There is broad acknowledgment that the aggressive shoreline recession is in response to a sediment sink, and also that the potential for future erosion may be limited by geological factors at Old Bar. While SKM (1982) provides a good account of the geological variability at Old Bar and surrounds. a key aim for this study is to further explore the coastal geological conditions at a scale that can be used to guide future erosion hazard estimations and mapping.

2.2 Geological controls on coastal erosion

2.2.1 Erosion processes

Erodible shorelines are subject to coastal erosion from wave action which usually results in shoreline recession. During severe storms or a series of storms in succession, increased wave heights and elevated ocean levels result in wave attack of the beach berm and foredune region. Storm events generate high transport rates of sand both:

- Onshore/Offshore, with sand eroded from the beach face and transported to the nearshore seabed to form a sand bar roughly parallel to the shoreline (this is usually considered reversible with onshore transport returning sand in ambient conditions); and
- Alongshore, either upcoast or downcoast depending on wave direction, with gradients in the transport rates leading to medium/longer term erosion or accretion (this can be irreversible under some conditions).

The result is erosion on the beach face and dune that may pose a hazard to back beach land and assets. The short term storm related cross shore sediment transport and longshore drift occur simultaneously. The extent of storm erosion that will occur under the same set of offshore water level and wave conditions may vary for several factors. This is because the volume of erosion relates also to:

- The occurrence, location and strength of rip current cells, which promote seaward transport of sediment and may allow larger waves access to the beach face, resulting in further localised beach erosion;
- The state of the beach (eroded / accreted both above and below sea level) immediately prior to the storm (i.e. as a result of several storms in succession);
- Geomorphological factors that modify local wave conditions and sediment movement patterns during a storm event, including adjacent headlands and nearby rocky reefs; and
- Geotechnical properties of the shoreline substrate, noting that some shoreline types (e.g. bedrock) are fully resistant to wave erosion and other are partially resistant to wave action (relative to unconsolidated beach and dune sands).

Beaches constantly fluctuate across a range (or envelope) of positions, from a fully accreted to extremely eroded beach state. This concept is defined as ‘beach fluctuation zone’ in *Coastal Management Act 2016*. On average, stable shorelines exhibit a form of dynamic equilibrium. That is following periods of large-scale short term erosion, the beach will tend to restore itself over time to an average or accreted state during favourable wave conditions. This recovery involves the shoreward return of sediment from nearshore and/or, where the erosion resulted from longshore losses, a sand supply from updrift that exceeds the transport downdrift.

On beaches that are in long term 'dynamic equilibrium', the amount of sand that returns to the beach is equal to the amount eroded during the storm. However, at beaches experiencing long term recession, not all the sediment eroded may be returned and the eroded dune escarpment will move landward on average over time. This is usually related to a sand supply deficit, like that experienced at Old Bar and Manning Point Beaches.

In summary, there are a range of processes and factors that influence shoreline response to storm activity and prevailing coastal processes. Beaches fluctuate across a range (or envelope) of shoreline positions, with some experiencing a long term dynamic equilibrium state, and others showing long term recession due to a deficit in the sediment budget. Shorelines with diverse geomorphological conditions may be more resistant to erosion processes in some instances, where bedrock outcrops will influence wave dissipation and erosion potential. In other instances, the backbeach areas comprise sediments/substrates that are erodible, but more resistant to wave action than sands. These geologically diverse shoreline types typically exhibit a narrower envelope of natural change (i.e. a narrower ‘beach fluctuation zone’).

2.2.2 Geological substrate factors that influence erosion potential

As outlined above, beach behaviour and erosion response to storm events can be strongly influenced by geomorphic setting and local geotechnical conditions. Coastal hazard assessments of beaches with complex geomorphic settings may overestimate erosion setback distances in the absence of site specific geotechnical information. Where present, the following geological characteristics can limit the potential for erosion at a site:

- *Erosion limiting bedrock landforms* that form an erosion control boundary. Erosion limiting bedrock landforms comprise erosion resistant rocky surfaces that rise 4 metres above mean sea level. Such features include tall bedrock cliffs exposed along the active shoreline and sloping rocky surfaces behind a beach that may be buried below dune sands (e.g. a buried bedrock bluff). Where present, these features should be considered resistant to wave erosion on planning timeframes (see Figure 2-3).
- *Erosion influencing bedrock outcrops/subcrops* that reduce erosion potential through wave dissipation processes but will not stop erosion altogether. Such features comprise erosion resistant rocky surfaces within the supra-, inter-, or sub-tidal zone such as a nearshore a rocky reef (submerged or emergent) that front a sandy beach, and/or sandy dunes perched on top of a sub-horizontal rocky platform/surface (see Figure 2-4).
- *Partially resistant coastal substrates* that are vulnerable to erosion from wave action on planning timeframes, but the potential for erosion is relatively less than that of unconsolidated beach/dune sands (under the same set of water level and wave conditions). The partially resistant substrates may include for example, semi-consolidated (Pleistocene-age) sediments (gravels, clays, indurated sands) and/or residual soil profiles (see Figure 2-5).

The current study has employed a range of field investigation methods to identify the presence, nature and distribution of the above listed geological factors that may influence coastal erosion hazards across each four study sites. A summary of the field investigation methods undertaken is provided in Chapter 3 and a description of study site coastal geological conditions is provided in Chapter 4.

Figure 2-3 Coastal rocky cliff: Erosion limiting bedrock landform example

Figure 2-4 Low lying rock exposures (top: submerged rocky reef; bottom: emergent rocky shore platform): Erosion influencing bedrock examples

Figure 2-5 Indurated gravel-sands (relic Pleistocene-age coastal sediments): Partially-resistant coastal substrate example

2.2.3 Approaches to assessing erosion hazards for geologically diverse coastlines

Erosion hazard assessments can be undertaken through either a deterministic or probabilistic modelling framework. Put simply:

- *Deterministic* methods apply single value variables to calculate a single erosion setback distance or storm bite volume that represents a 1 in 100-year storm event, for example. Deterministic methods can be prone to over- or under-estimating erosion hazard impacts, and especially so if considerable levels of uncertainty are associated with one or many of the input variables.
- *Probabilistic* methods provide a more flexible approach to estimating erosion hazards that can overcome the inherent uncertainty in understanding the influence of coastal processes, sediment budget and geotechnical parameters on the erosion potential of a site. Probabilistic methods allow a range (or distribution) of values for each input variable to be assigned.

Erosion limiting bedrock landforms can be applied as a single variable control in the deterministic assessment of erosion hazards. For example, erosion setback estimates will be constrained in a landward direction by the occurrence (and mapping) of an erosion limiting bedrock landform (Figure 2-6 for example).

The influence of *erosion influencing bedrock outcrops/subcrops* and/or *partially-resistant coastal substrates* on erosion hazard potential is less certain and will vary depending on site specific characteristics. For example, the influence of a rocky reef on the erosion potential is dependent on several factors e.g. submerged or emergent outcrop, reef size, proximity to the shoreline. Likewise, *partially-resistant coastal substrates* will respond differently to storm wave action depending on the relative erodibility/stability of the material. Indurates sands for example is likely to be less erodible than unconsolidated beach sands, but more erodible than a cohesive clay residual soil profile. The variability in these geological characteristics, and the uncertainty surrounding their influence on erosion potential, means they would be best incorporated into the assessment of erosion hazards through a probabilistic modelling approach.

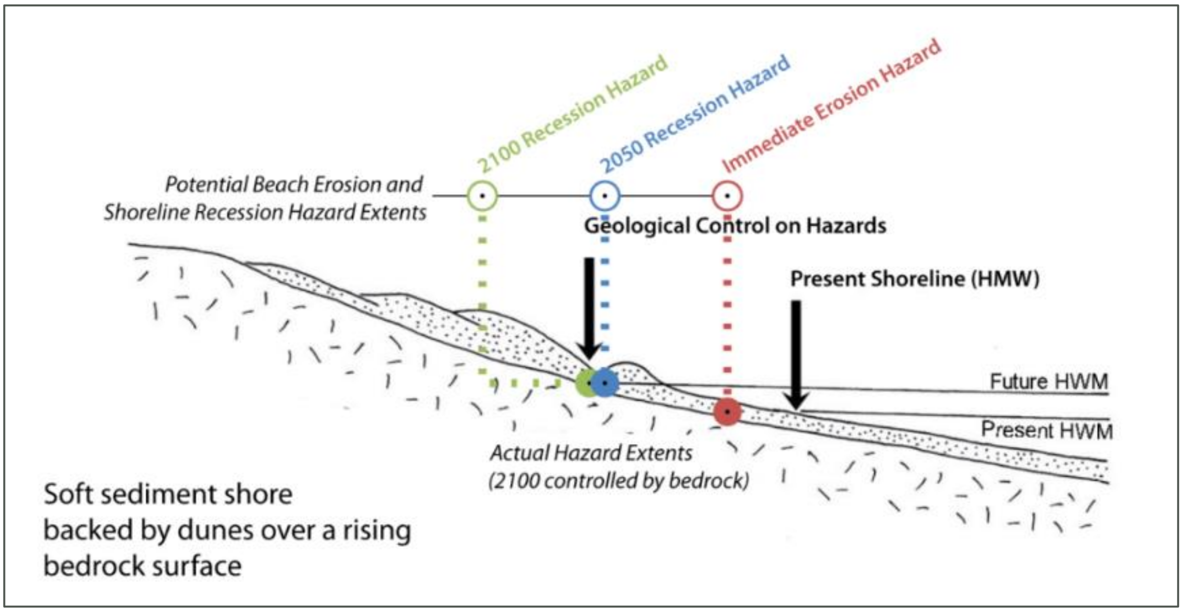


Figure 2-6 Influence of ‘erosion limiting landform’ on hazard setback estimations

3 Coastal Geomorphology Field Assessment

3.1 Field study overview and scope

A detailed field investigation was required to characterise the coastal geomorphology of the Old Bar coastline study region, and its associated geotechnical conditions. A 'three pronged' approach was adopted, which extended to the following survey methods:

- Geomorphological site walk over (field) assessment,
- GPR coastal geology survey, and
- Geotechnical borehole drilling investigation.

Figure 3-1 shows the ground extents covered by the field program, with a summary of each survey and its key findings provided below (Sections 3.2 to 3.4). Detailed documentation of the literature review and a description of each field investigation are provided within the technical appendices to this report. A synthesis of the geological characteristics that relate to coastal erosion and recession hazards for the Old Bar region coastline is provided in Chapter 4.

3.2 Field walkover assessment summary

3.2.1 Overview

A geomorphological site walkover investigation was undertaken across the Old Bar coastline region. This survey aimed to document the coastal geomorphology, substrate types and their corresponding geotechnical characteristics, in addition to any other coastal erosion related features/conditions that could be observed from the ground.

3.2.2 Methods

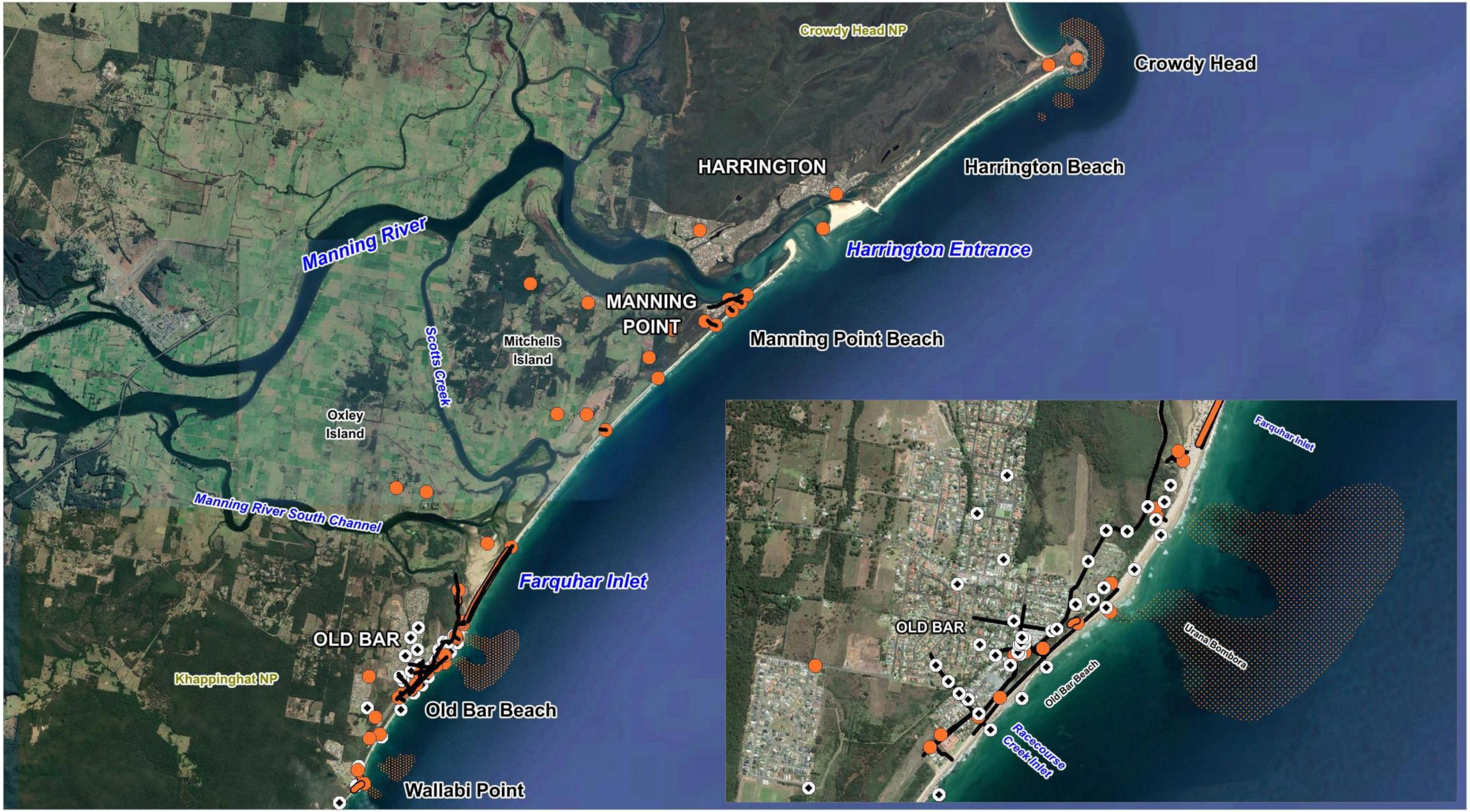
The walk over investigation was completed by a coastal geoscientist over a total of three days (November 2018; February 2019). The site investigation covered most foreshore areas publicly accessible by foot between Saltwater Point and Crowdy Head, backing reserves and roadways. Visual inspection was made from vantage points where foot access was not possible.

Site observations were sketched on a field map (see Figure 3-2), with corresponding locations recorded on a hand-held GPS. A desktop assessment of available aerial imagery, topography (including LiDAR digital elevation model), bathymetry and published geological maps was also completed to help contextualise the site observations.

3.2.3 Results

Field walkover observations and desktop interpretations were digitised in GIS, with finding documented in a series of maps and field photographs (see Figure 3-3 and Figure 3-2, for example). Appendix B provides a more detailed description of the walkover survey observation and outputs.

A brief summary of the key findings for each beach segment along the study areas are provided below:



LEGEND

● Walkover Investigation Observation

Ground Penetrating Radar Profile

◆ Borehole Drilling Location

Image source: Google Earth

Title:

Field Survey Coverage, Wallabi Point to Crowdy Head Coastline (main) and Old Bar Beach (inset)

N

0 2 4km
Approx. Scale
Main map

0 0.5 1km
Approx. Scale
Inset map

Figure: **3-1**

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www.bmt.org

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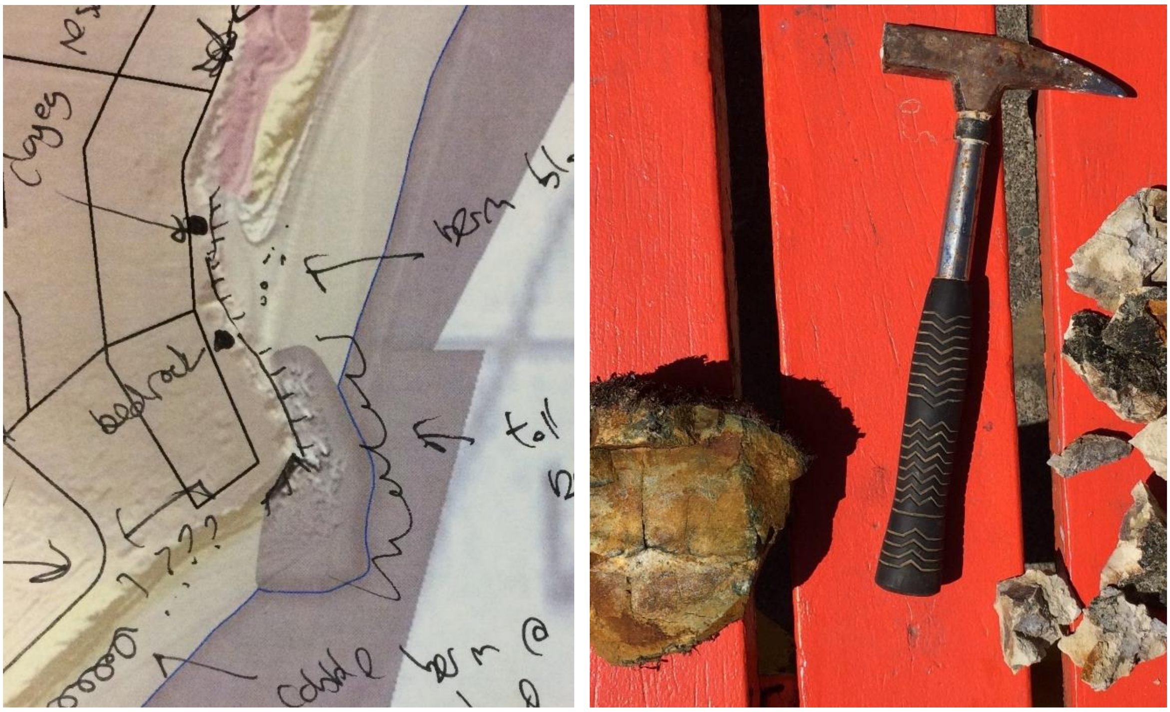


Figure 3-2 Field mapping example from Wallabi Point (left) and rock sample collection from Old Bar Beach dune and intertidal / reef area (right)

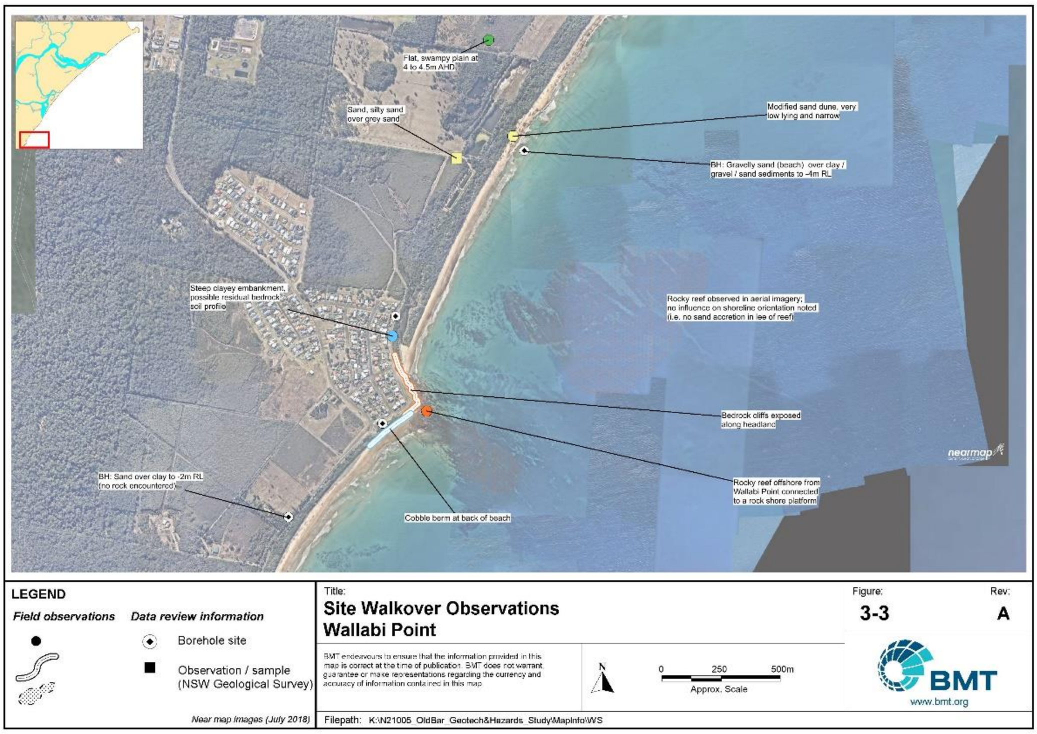


Figure 3-3 Example site walk over observations map (see Appendix B for further details)

Old Bar Beach

Key site observations regarding the coastal morphology and geological conditions at Old Bar Beach, described here to span some 4.2 km north from Wallabi Point towards Farquhar Inlet, are summarised below:

- *Wallabi Point* is a rocky headland comprised of weathered siltstone bedrock, that adjoins with shore platform and rocky reef offshore. The elongate rocky landform exhibits a NW-SE orientation. A clear break in topographic slopes delineates the sand – rock interface at the end of the beach.
- The *Old Bar Beach* sandy coastline comprises two parts, including a sandy beach that sweeps for ~3.6 km between Wallabi Point and Urana Bombora, and a shorter beach section that separates the Urana Bombora from the steep backing coastal slopes for some 800 metres. Gravels are common along the lower beach profile.
- The *narrow sandy beach and dunes* that sweep north of Wallabi Point are located within a minor bedrock embayment. A narrow area of relic coastal and estuarine sediments occur landward of the shoreline. The sediments are inferred as Pleistocene age from the leached surface sands and elevated (~5 m AHD) estuarine plain occurring landward of Racecourse Creek.
- *Racecourse Creek* drains a minor sediment infilled bedrock embayment. A sharp change in the creek orientation is indicative of the bedrock slopes that occur adjacent to the outside bend of this small waterway. A gradual rise in topography landward of the coastline is indicative of the change in substrate from coastal sediment to bedrock terrain.
- A *topographic rise* occurs along the coast between the Old Bar Public School and Caravan Park, adjacent to the rocky Urana Bombora. The morphology of the coastal profile is suggestive of a buried bedrock slope that is fringed by sand dunes. Rock (siltstone) exposures in an old quarry near to the Surf Club support this interpretation.
- Tall vegetated transgressive dunes, fronted by a large erosion escarpment extend northward of the Caravan Park towards Farquhar Inlet, along the ‘northern dunes’ region.

Farquhar Inlet

Forming the secondary tidal inlet to the Manning Estuary, Farquhar Inlet spans for some 2 km between the Old Bar Beach northern dune region and Mitchells Island. Some key site observations from this region are summarised below:

- Farquhar Inlet encompasses an extensive coastline and estuary area, with a sandy marine delta and entrance shoals extending into Manning River Channel South and Scotts Channel
- Relic indurated sediments that form Pleistocene shoreline extend along the southern margin of the inlet, which stand as +5 meter tall cliffs in places. The sediments are somewhat durable, but still exposed to channel scour as indicated by the undercut profile observed in places.
- The tidal inlet was completely closed during the site visit, with a wide and continuous beach berm that was partially vegetated separating the estuarine waterway from the open ocean.

- The sandy beach berm fronting the inlet had a high gravel content within the lower beach profile, consistent with beach conditions observed elsewhere.

Mitchells Island / Manning Point Beach

Key site observations regarding the coastal morphology and geological conditions at Mitchells Island / Manning Point Beach, described here to span some 9 km north from Farquhar Inlet to Harrington Inlet, are summarised below:

- The shoreline is characterised by a long straight high energy sandy beach, backed by a narrow sand dune that is tall in places (e.g. Manning Point region)
- A prominent erosion escarpment is observed along the back of this beach segment for much of its length
- A low lying estuarine plain complex forms much of Mitchell Island, which extends behind the shoreline for some 5.5 km toward the Manning River. A gravel quarry is located on the crest of a sandy ridge that parallels the modern shoreline some 500m landward of the coastline. This feature is mapped as a Pleistocene-age barrier dune (NSW Geological Survey, 2009)
- A narrow sandspit extends northward of the Manning Point township towards the Harrington Inlet. The spit has well developed dune vegetation along most of its length. The spit is very narrow and reduces to some 30 m wide near to the southern training wall.

Harrington Inlet

Harrington Inlet forms the primary estuary inlet to the Manning River, with a coastline entrance that spans for some ~2.5 km between the Southern Training Wall and the Northern Breakwater. Some key site observations from this region are summarised below:

- The northern training wall and breakwater form a dominant structure controlling the location of the Harrington Inlet. A bedrock topographic rise located behind the rock wall is located in the vicinity of the Harrington township. While this natural feature is no longer part of the active coastal system, it likely formed a geological control on the entrance location prior the training wall / breakwater being constructed.
- Extensive sand bar / shoal development within the entrance influences the location of the entrance channel at any point in time. The formation and distribution of the sand shoals are dependent on many interrelated processes (waves, tides, floods, sediment budget).
- The entrance shoals form part of an extensive marine delta system, which connects with the tide delta and associated tidal channel that extends upstream of the entrance; and the ebb tide delta deposits that extends offshore into the littoral zone.
- During early 2019, a large and wide subaerial sand bar infilled the entrance region adjacent the northern breakwater. The main tidal channel was positioned within the middle reach of the entrance region at this time.

Harrington Beach

Key site observations regarding the coastal morphology and geological conditions at Harrington Beach, which spans some 5.5 km from the Harrington Inlet towards the from north from Farquhar Inlet to Harrington Inlet, are summarised below:

- A wide sandy beach and dune system forms the Harrington Beach shoreline segment. A wide estuarine plain complex occurs landward of the continuous dune barrier.
- The Harrington Beach shoreline sits seaward of the sand shoals within the Harrington Inlet. This indicates that the breakwater traps sediment moving northwards around the structure from littoral drift. The breakwater has been previously described as a 'one-way' valve for this reason.
- A submerged rocky reef is located near to the shore, towards Crowdy Head. A depositional foreland (salient) feature has formed in the lee of this reef indicates that it influences wave refraction patterns (and littoral drift) locally.
- Crowdy Head is a prominent rocky headland feature at the northern end of the beach. This feature forms the downdrift boundary to the study area and Manning Sediment Compartment. A clear break in topographic slopes delineates the sand – rock interface at the foot of the headland.

3.3 Ground penetrating radar (GPR) survey summary

3.3.1 Overview

A GPR survey of the subsurface geological conditions was completed across the townships of Old Bar and Manning Point, which we highlighted as the primary areas of interest for Council. The objective of the survey was to investigate the subsurface geological conditions and vulnerability to coastal erosion of the target beaches, by imaging the subsurface sedimentary system and depth to bedrock where possible. The GPR survey completed for this study by BMT was designed to complement a prior GPR survey completed by Geoscience Australia (GA), which was incorporated into investigation.

3.3.2 Methods

The GPR investigation was undertaken over a two-day period in November 2018. GPR profiles were collected from accessible beach and backbeach locations were where conditions were considered to be potentially suitable for GPR. Data was acquired with a Mala Ground Explorer GPR system with a 450 MHz and 80 MHz shielded antennas (see Figure 3-4). Positioning information was measured with an RTK GPS system. Cross cutting transects oriented parallel and perpendicular to the shore were collected where possible (see Figure 3-1).

Figure 3-4 GPR data collection (vehicle towed), Farquhar Inlet

GPR data collected for this study was processed in the *ReflexW* software package. A series of signal processing steps were applied to reduce the noise, improve the geological reflection signals, account for topographic variations and determine depth information. The processed GA GPR data was accessed and analysed also.

An assessment of all GPR profiles was undertaken to determine the best profiles for further analysis Line interpretations were then sketched over a selection of GPR profiles, and cross referenced against the site observations. Key GPR findings were digitised in GIS.

Preliminary GPR results helped to design the borehole investigation survey. For example, boreholes were placed where (a) potential bedrock reflections were noted below sand dunes areas, or (b) in areas where poor GPR signals were returned that indicate the presence of a non-sandy substrate (and possible bedrock / residual soils). Borehole measurements were subsequently used to refine the GPR interpretations.

3.3.3 Results

Geophysical findings were documented as a series sketched GPR profiles (see Figure 3-5 example) and interpretations maps (see Figure 3-6 example). These survey outputs are provided in Appendix C, along with a more detailed description of the GPR field surveys, analysis and interpretations.

A summary of the key GPR findings are provided below:

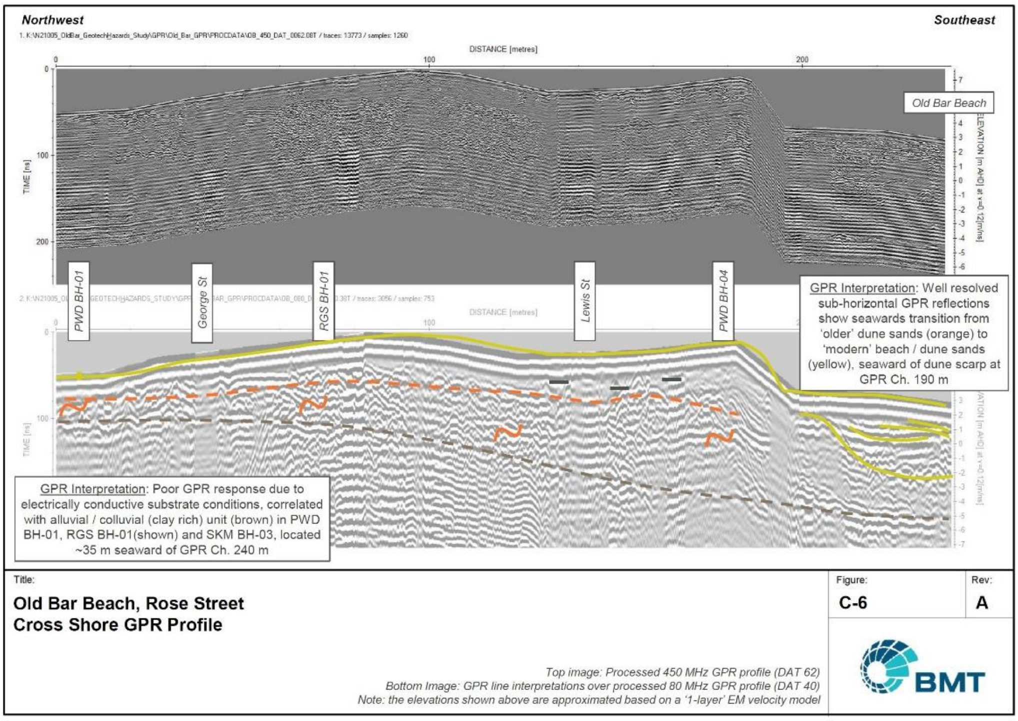


Figure 3-5 Example GPR profile with line interpretations and notes (see Appendix C for further details)

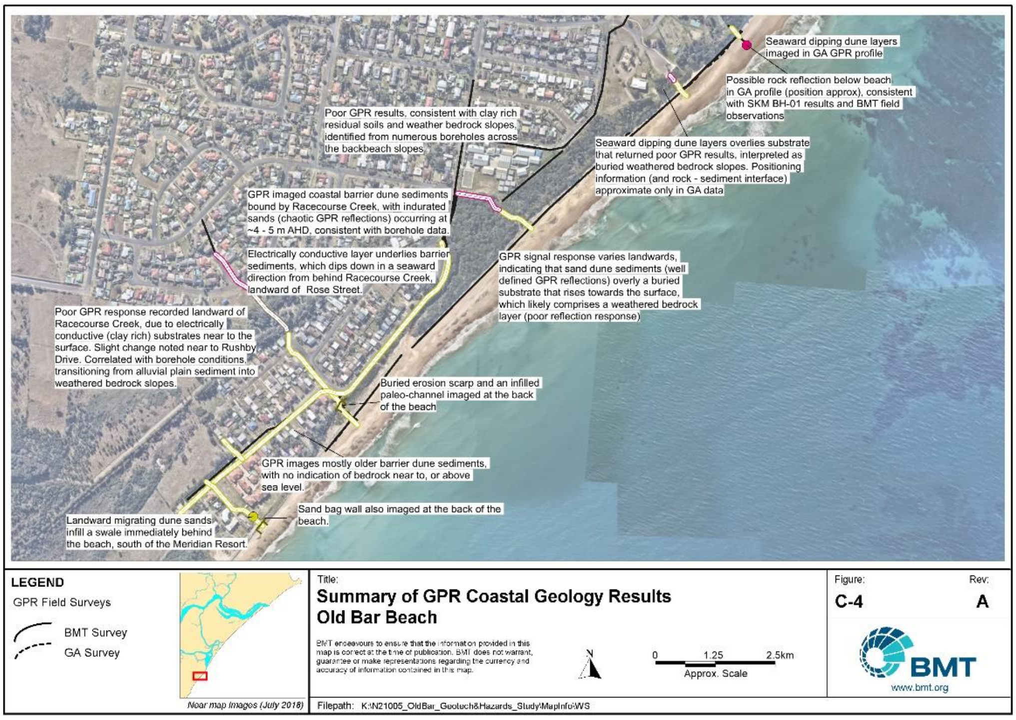


Figure 3-6 Example GPR interpretation map (see Appendix C for further details)

Old Bar Beach

- Various substrates types were identified including coastal barrier deposits, modern (Holocene) and relic (Pleistocene) sediments, plus areas with electorally conductive material that indicate weathered bedrock or clay rich estuarine/alluvial sediments substrates
- The interface between the modern dune sands and relic coastal deposits within the Racecourse Creek region was identified. Indurated sediments were also imaged at elevations of around ~5 m AHD within the relic coastal deposits.
- A clear change in substrate was identified within the residential areas behind Racecourse Creek. Subsequent targeted borehole drilling identified the areas of estuarine/alluvial sediment infill, and areas of bedrock terrain.
- The boundary between the modern dunes and weathered bedrock slopes in the vicinity of the Public School and Caravan Park were identified with the GPR. A modern barrier dune was found to fringe a relic bedrock bluff. The nature of the weathered bedrock profile was subsequently investigated by targeted borehole drilling (residual soil thickness, rock strength etc).
- The geological boundary between the relic dunes / indurated sediments and weathered bedrock slopes was mapped in the ‘northern dunes’ region with GPR, including along Mudbishops Point Road and along a beach accessway.

Farquhar Inlet

- GPR imaged a tall modern (Holocene-age) sand dune to overlie relict (Pleistocene-age) indurated barrier sediments in the vicinity of the 4WD beach access adjacent to Farquhar Inlet A relic entrance channel was imaged below the modern beach in this region.
- The GPR survey found no indication of bedrock near to, or above sea level, adjacent to the Farquhar Inlet.

Mitchells Island / Manning Point Beach

- GPR shows that the barrier dune at Mitchells Island and Manning Point is comprised of modern sand dunes, with no indication of bedrock identified from the surveyed profiles

3.4 Geotechnical borehole survey summary

3.4.1 Overview

A targeted borehole investigation was undertaken for this study across the Old Bar Beach region, with a focus on the townships of Old Bar and Wallabi Point where bedrock is known or expected to occur within the coastal zone. The objective of the survey was to investigate the subsurface geotechnical conditions at priority locations, including depth to bedrock. A secondary objective was to confirm the GPR interpretations and investigate those areas that were found to be unsuitable for GPR.

Existing borehole records for the Old Bar region were also complied as part of this study.

3.4.2 Methods

Targeted borehole survey (RGS, 2019)

The borehole drilling was undertaken by RGS over the period of two field days for this study. The survey involved the drilling of boreholes with a truck mounted drill rig (see Figure 3-7). Standard penetrometer tests were carried out at 1.5 m intervals to assess shear strength and density. A total of 16 borehole were undertaken, including:

- Wallabi Point - 2 boreholes
- Old Bar Beach in the vicinity of Racecourse Creek – 6 boreholes
- Old Bar township, in the vicinity of the school, surf club and caravan park – 7 boreholes
- Old Bar Beach, in the northern dune areas (towards Farquhar Inlet) – 1 borehole

Geotechnical logs were recorded for each borehole, in accordance with current Australian Standards.

Existing borehole information (PWD, 1981; SKM,1982; GHD, 2017)

Existing borehole information from past field investigation were collated and analysed as part of this study, including the borehole investigations documented in: a stormwater planning and design investigation (11 boreholes) by PWD (1981); a coastal geomorphology and erosion study (13 boreholes) by SKM (1982); and a geotechnical assessment of the Old Bar Public School (4 boreholes) by GHD (2017). Geotechnical logs for the GHD survey were documented in accordance with current Australian Standards, whereas the 1980's records were not. Nonetheless, the PWD (1981) and SKM (1982) do provide some useful information on the nature of the subsurface conditions at the respective survey location.

Together, these three additional datasets extended across:

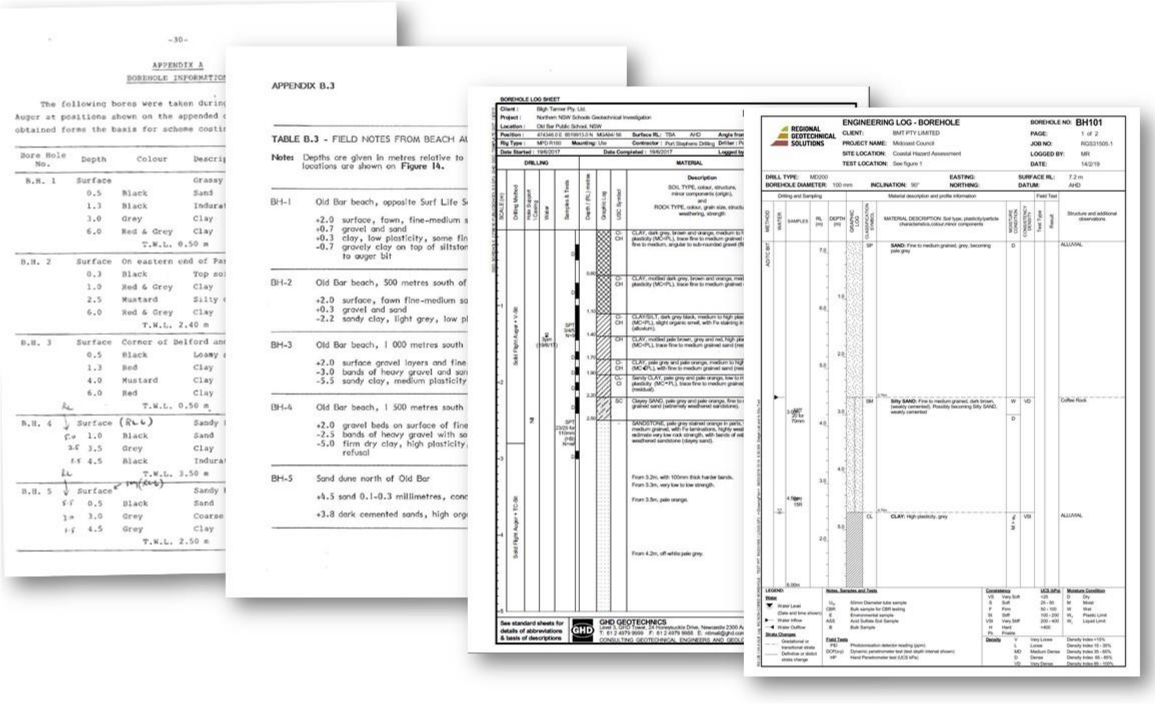
- Wallabi Beach – 1 borehole
- Old Bar Beach foreshore – 8 boreholes
- Old Bar beach, in the vicinity of Racecourse Creek – 5 boreholes
- Old Bar township, in the vicinity of the school, surf club and caravan park – 11 boreholes
- Old Bar Beach, in the northern dune areas (towards Farquhar Inlet) – 3 boreholes

Borehole Compilation

Geotechnical information relating to the 44 boreholes from all four investigations were documented in single dataset in spreadsheet format. Location information was provided in map form only for PWD (1981), SKM (1982) and GHD (2017). Borehole maps from these studies were georeferenced in GIS to determine the easting and northing of each borehole location (see Figure 3-1 for a map of all boreholes).

A review of the consolidated borehole dataset was then undertaken to synthesis the geotechnical information into a consistent format that would facilitate geological interpretation. Expert judgment was applied to undertake this task.

Figure 3-7 Borehole Drilling by RGS at Wallabi Point



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APPENDIX A

BOREHOLE INFORMATIO

The following bores were taken durin
Auger at positions shewn on the appended
obtained forms the basis for scheme costi

Bore Hole No.	Depth	Colour	Descri
B.H. 1	Surface		Grassy
	0.5	Black	Sand
	1.3	Black	Indura
	3.0	Grey	Clay
	6.0	Red & Grey	Clay
		T.W.L. 0.50 m	
B.H. 2	Surface	On eastern end of Pa	
	0.3	Black	Top so
	1.0	Red & Grey	Clay
	2.5	Mustard	Silty
	6.0	Red & Grey	Clay
		T.W.L. 2.40 m	
B.H. 3	Surface	Corner of Belford an	
	0.5	Black	Loamy
	1.3	Red	Clay
	4.0	Mustard	Clay
	6.0	Red	Clay
		T.W.L. 0.50 m	
B.H. 4	Surface		Sandy
	1.0	Black	Sand
	3.5	Grey	Clay
	4.5	Black	Indura
		T.W.L. 3.50 m	
B.H. 5	Surface		Sandy
	0.5	Black	Sand
	3.0	Grey	Coarse
	4.5	Grey	Clay
		T.W.L. 2.50 m	

APPENDIX B.3

TABLE B.3 - FIELD NOTES FROM BEACH A

Note: Depths are given in metres relative to
locations are shown on **Figure 14.**

BH-1 Old Bar beach, opposite Surf Life S
+2.0 surface, fawn, fine-medium s
+0.7 gravel and sand
+0.3 clay, low plasticity, some fin
-0.7 gravely clay on top of siltston
to auger bit

BH-2 Old Bar beach, 500 metres south of
+2.0 surface, fawn fine-medium sa
+0.3 gravel and sand
-2.2 sandy clay, light grey, low pl

BH-3 Old Bar beach, 1 000 metres south
+2.0 surface gravel layers and fine
-3.0 bands of heavy gravel and san
-5.5 sandy clay, medium plasticity

BH-4 Old Bar beach, 1 500 metres south
+2.0 gravel beds on surface of fine
-2.5 bands of heavy gravel with sa
-5.0 firm dry clay, high plasticity
refusal

BH-5 Sand dune north of Old Bar
+4.5 sand 0.1-0.3 millimetres, conc
+3.8 dark cemented sands, high org

BOREHOLE LOG SHEET
Client : Bligh Tanner Pty. Ltd.
Project : Northern NSW Schools Geotechnical Investigation
Location : Old Bar Public School, NSW
Position : 474346.0 E 6519913.0 N MGA94 56 Surface RL: TBA AHD
Rig Type : MPD R100 Mounting: Ute Contractor : Port Stephens Drilling
Date Started : 19/6/2017 Date Completed : 19/6/2017

GHD GEOTECHNICS

REGIONAL GEOTECHNICAL SOLUTIONS
ENGINEERING LOG - BOREHOLE
CLIENT: BMT PTY LIMITED
PROJECT NAME: Midcoast Council
SITE LOCATION: Coastal Hazard Assessment
TEST LOCATION: See figure 1
BOREHOLE NO: BH101
PAGE: 1 of 2
JOB NO: RGS31505.1
LOGGED BY: MR
DATE: 14/2/19
DRILL TYPE: MD200
BOREHOLE DIAMETER: 100 mm
INCLINATION: 90°
EASTING:
NORTHING:
SURFACE RL: 7.2 m
DATUM: AHD

Figure 3-8 Example Old Bar borehole records from various sources

Substrate types outlined in RGS (2019) were adopted where appropriate (e.g. 'Alluvial / Colluvial Clay'), with some minor modifications made as deemed appropriate (e.g. 'Alluvial Indurated Sand' changed to 'Indurated Sand', as the indurated sands are considered to be coastal in origin). Several new substrate types were also developed and assigned to the dataset which represent geological conditions that were not encountered by RGS (2019) (e.g. 'Estuarine Sediments').

Borehole records were used to guide geological interpretation and geotechnical characterisation of Old Bar. Borehole data that comply with current geotechnical standard (GHD, 2017; RGS, 2019) were adopted with confidence, whereas 1980's survey information was used as a guide only.

3.4.3 Results

Synthesis and analysis of existing borehole information was produced the following key outputs:

- Description of substrate types;
- Development of a borehole dataset and summary maps; and
- Assessment of substrate conditions and strength across the study region.

These key outputs are summarised below and detailed further in Appendix D. The targeted borehole campaign completed for this study by RGS (2019) is documented in Appendix E. A record of the other geotechnical borehole information compiled for this study is presented in Appendix F.

Substrate types

The geological conditions identified within the Old Bar borehole dataset are described to comprise the following 11 substrate types:

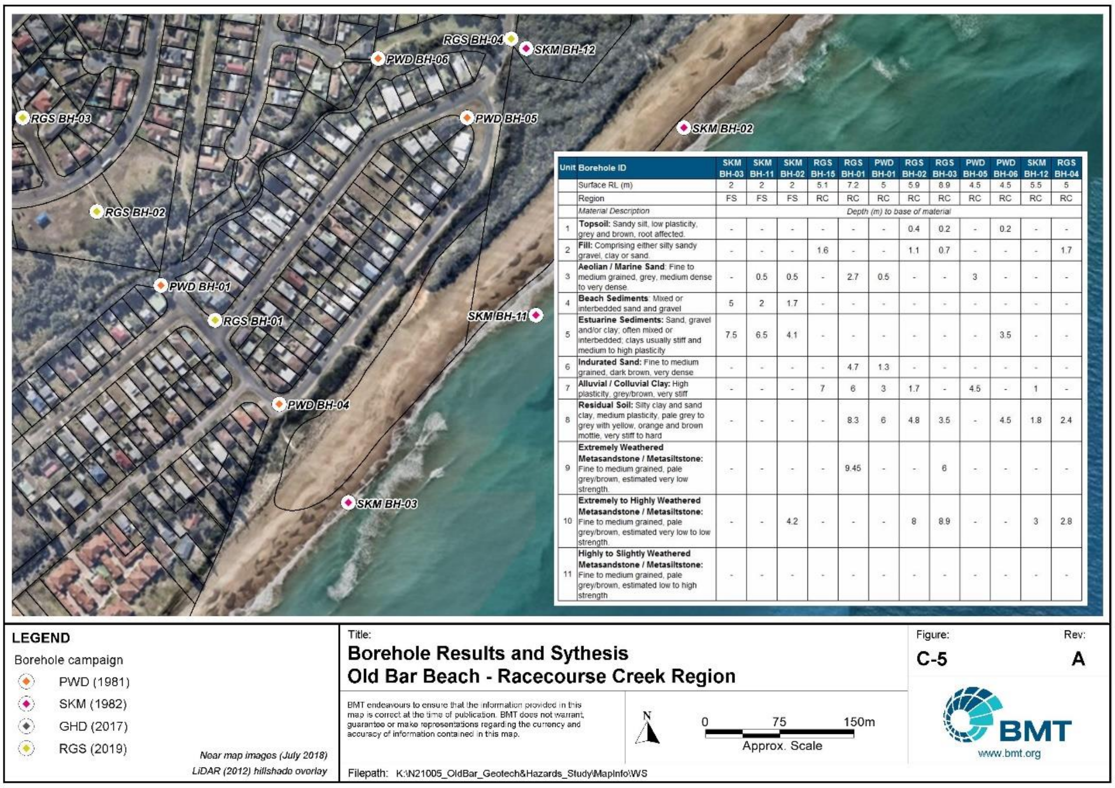
- **Unit 1 - Topsoil:** Sandy silt, low plasticity, grey and brown, root affected
- **Unit 2 - Fill:** Comprising either silty sand, gravel, clay or sand
- **Unit 3 - Aeolian / Marine Sand:** fine to medium grained, grey, medium dense to very dense
- **Unit 4 - Beach Sediments:** mixed or interbedded sand and gravel
- **Unit 5 - Estuarine Sediments:** sand, gravel and/or clay, often mixed or interbedded (either sandy clay, clayey sand or clay and gravel), with clays usually stiff and medium to high plasticity
- **Unit 6 - Indurated Sand:** Fine to medium grained, dark brown, very dense, cemented in places
- **Unit 7 - Alluvial / Colluvial Clay:** High plasticity, grey/brown, very stiff
- **Unit 8 - Residual Soil:** Silty clay and sandy clay, medium plasticity, pale grey to grey with yellow, orange and brown mottle, very stiff to hard
- **Unit 9 - Extremely Weathered Metasandstone / Metasiltstone:** Fine to medium grained, pale grey/brown, estimated very low strength
- **Unit 10 - Extremely to Highly Weathered Metasandstone / Metasiltstone:** Fine to medium grained, pale grey/brown, estimated very low to low strength
- **Unit 11 - Highly to Slightly Weathered Metasandstone / Metasiltstone:** Fine to medium grained, pale grey/brown, estimated low to high strength

Borehole dataset and maps

The borehole compilation dataset and corresponding summary maps show the range of geotechnical conditions experienced across the Old Bar Beach investigation area. In summary:

- Bedrock was encountered along the margins of *Wallabi Point*. This substrate information will be good for identifying the geological transition between rocky slopes and adjoining beach/dune areas.
- At *Old Bar Beach*, bedrock slopes were identified close to the coastline between the Public School and Caravan Park, indicating that areas of higher topography near to the coast form a buried bedrock bluff. A mix of coastal and estuarine sediments (including indurated sands) were encountered within both the Racecourse Creek and Northern Dune region.

Figure 3-9 presents an example of the borehole summary map for the Racecourse Creek region.



Unit	Borehole ID	SKM BH-03	SKM BH-11	SKM BH-02	RGS BH-15	RGS BH-01	PWD BH-01	RGS BH-02	RGS BH-03	PWD BH-05	PWD BH-06	SKM BH-12	RGS BH-04
	Surface RL (m)	2	2	2	5.1	7.2	5	5.9	8.9	4.5	4.5	5.5	5
	Region	FS	FS	FS	RC	RC	RC	RC	RC	RC	RC	RC	RC
	Material Description	*Depth (m) to base of material*											
1	**Topsoil:** Sandy silt, low plasticity, grey and brown, root affected.	-	-	-	-	-	-	0.4	0.2	-	0.2	-	-
2	**Fill:** Comprising either silty sandy gravel, clay or sand.	-	-	-	1.6	-	-	1.1	0.7	-	-	-	1.7
3	**Aeolian / Marine Sand**: Fine to medium grained, grey, medium dense to very dense.	-	0.5	0.5	-	2.7	0.5	-	-	3	-	-	-
4	**Beach Sediments**: Mixed or interbedded sand and gravel	5	2	1.7	-	-	-	-	-	-	-	-	-
5	**Estuarine Sediments:** Sand, gravel and/or clay; often mixed or interbedded; clays usually stiff and medium to high plasticity	7.5	6.5	4.1	-	-	-	-	-	-	3.5	-	-
6	**Indurated Sand:** Fine to medium grained, dark brown, very dense	-	-	-	-	4.7	1.3	-	-	-	-	-	-
7	**Alluvial / Colluvial Clay:** High plasticity, grey/brown, very stiff	-	-	-	7	6	3	1.7	-	4.5	-	1	-
8	**Residual Soil:** Silty clay and sand clay, medium plasticity, pale grey to grey with yellow, orange and brown mottle, very stiff to hard	-	-	-	-	8.3	6	4.8	3.5	-	4.5	1.8	2.4
9	**Extremely Weathered Metasandstone / Metasiltstone:** Fine to medium grained, pale grey/brown, estimated very low strength.	-	-	-	-	9.45	-	-	6	-	-	-	-
10	**Extremely to Highly Weathered Metasandstone / Metasiltstone:** Fine to medium grained, pale grey/brown, estimated very low to low strength.	-	-	4.2	-	-	-	8	8.9	-	-	3	2.8
11	**Highly to Slightly Weathered Metasandstone / Metasiltstone:** Fine to medium grained, pale grey/brown, estimated low to high strength	-	-	-	-	-	-	-	-	-	-	-	-

LEGEND

Borehole campaign

- ◆ PWD (1981)
- ◆ SKM (1982)
- ◆ GHD (2017)
- ◆ RGS (2019)

Near map images (July 2018)
LiDAR (2012) hillshade overlay

Title:
Borehole Results and Sythesis
Old Bar Beach - Racecourse Creek Region

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

Filepath: K:\N21005_OldBar_Geotech&Hazards_Study\MapInfo\WS

Figure: C-5
Rev: A

Figure 3-9 Example GPR profile with line interpretations and notes (see Appendix C for further details)

Substrate conditions and strength

The substrate strength of materials encountered across the Old Bar coastal region varied, as measured within the RGS (2019) and GHD (2017) borehole records. For the purpose of assessing coastal erosion risks over planning timeframes (~100 years), the strength of geological materials at Old Bar can be broadly classified as:

- **Erodible substrates** – which includes a variety of unconsolidated sediments that can be readily eroded by wave action and transported elsewhere by coastal processes (Units 3, 4, 5 and 7)
- **Partially resistant (semi erodible) substrate** – which encompass a wide variety of materials types and strengths that can be eroded by wave action over planning timeframes (Units 6, 8 and 9), but the erosion potential of such materials is relatively less than say unconsolidated sands. The relative resistance to wave erosion processes vary between substrate types captured within this classification type.
- **Erosion resistant substrate** – which forms hard bedrock landforms (comprised of Units 10 and 11) that will provide either a landward limit to erosion potential (tall cliffs, sloping bluffs), or reduce erosion potential through wave dissipation processes (rocky reefs, shore platforms).

4 Coastal Geology and Erosion Sensitivity at Old Bar to Manning Point

4.1 Overview

Stretching northward of Wallabi Point to Crowdy Head, the study region comprises a diverse range of sandy and rocky shoreline types, including coastline beaches, barrier dune systems that include relic Pleistocene-age and modern Holocene-age sediments, two major tidal inlets to a large estuarine system (the Manning River), and a diversity of rocky landforms including coastal headlands, buried bedrock bluffs and offshore reefs.

Geologically, the southern coastline region has formed within narrow bedrock embayment that spans between Wallabi Point and Old Bar. The bedrock terrain of this area is formed from meta-sandstones and meta-siltstones, which demonstrate variably weathered substrate conditions. Northwards of Old Bar, the study coastline beaches front an extensive estuarine plain that extends past Crowdy Head.

The diversity of coastal landforms along the study region coastline, and the range of corresponding geotechnical conditions, will influence how erosion hazards manifest over current and future timeframes. This chapter synthesises the key field investigation findings with site specific descriptions provided for the Old Bar Beach (Section 4.2.1), Farquhar Inlet (Section 4.2.2), Mitchells Island / Manning Point Beach (Section 4.2.3), Harrington Inlet (Section 4.2.4) and Harrington Beach (Section 4.2.5) shoreline segments. Site descriptions focus on the geomorphic attributes that may influence the coastal erosion related hazards from a coastal geotechnical standing point[1].

A series of geological cross sections are also presented for the Old Bar Beach township (Section 4.3), which is a key focus of the current investigation. These profiles bring together the field investigations completed for this study, which demonstrate the varied geotechnical conditions experienced across the Old Bar region.

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[1] Noting there are several other important geomorphic factors that will influence beach behaviour coastal erosion hazard which are not a focus of this study, including coastal processes, sediment flows/budgets and sea level rise response.

4.2 Coastal geomorphology by beach sector

4.2.1 Old Bar Beach

Table 4-1 Coastal Geomorphology Summary: Old Bar Beach Sector

Coastal Geology Component	Details – Old Bar Beach Sector
Landforms and geology	**Coastal geology** • Rocky landforms comprised of interbedded meta-siltstones and meta-sandstones, with upturned (sub-vertical) bedding • Modern (Holocene-age) coastal barrier deposits fringe the coastline. These deposits represent a 'receded barrier' type, as per geological model for wave dominated barriers in Roy et al. (1994). • Relic (Pleistocene-age) coastal barrier and estuary deposits are common behind the beach • The shoreface is starved of sediment, with no discernible sand body / sheet located offshore **Key landforms** • Wallabi Point rocky headland • Racecourse Creek • Buried rocky bluff at Old Bar • Rocky reefs at Urana Bombora • Sandy beach and dunes (coastal barrier system)
Geomorphic history and processes	**Geomorphic history** • During last sea level highstand (120,000 years ago), coastal deposits were laid down within a narrow bedrock embayment spanning Wallabi Point to Old Bar. The bedrock slopes occurring at Old Bar possibly formed a coastal headland at this time. • Since that time, soil forming processes have led to the formation of indurated sediments within the relic coastal deposits, and the development of a variable weathered profiles across bedrock terrain, which include deep residual soils in places • As sea levels rose to near present levels some 7,000 years ago, modern coastal deposits were laid down along the present day coastline. Historical shoreline records indicate that much of these coastal deposits have since been eroded. A relatively narrow barrier of modern beach and dune sediments remain along the coastal margin. **Contemporary geomorphic processes** • Coastal processes interact with extensive rocky reefs at Wallabi Point and Old Bar, which reduce wave action locally and influences littoral sediment transport patterns • Historical records indicate that sediment budget (deficit) conditions and prevailing coastal processes are driving a shoreline recession along the sand beaches (see MHL, 2017 for details). • While some minor undercutting and block failure may occur locally at Wallabi Point, no significant change is expected to occur to the headland cliffs over planning timeframes • As sand buffer fronting the buried bluff at Old Bar becomes eroded, there may be an initial cliff recession / slopes adjustment response due to residual soils being impacted by wave action.

Coastal Geology Component	Details – Old Bar Beach Sector
Geotechnical conditions and erosion sensitivity	**Erosion resistant substrate** • *Erosion limiting bedrock landforms* are encountered at: (i) Wallabi Point in the form of a bedrock headland on the coast; (ii) backbeach bedrock slopes landwards of Racecourse Creek (vicinity of Rushby Drive); and (iii) Old Bar bedrock bluff (between the Public School and north of the Caravan Park), which is concealed by coastal dunes at this stage • *Erosion influencing bedrock landforms* occur as rocky shore platforms and adjoining reefs areas associated with Wallabi Point, and rocky subtidal to intertidal reef at Urana Bombora that extends landwards beneath the beach and dunes areas to join with buried bedrock bluff **Partially resistant (semi erodible) substrate** • *Residual soils profiles* that have developed from parent bedrock material occur across all bedrock terrain areas, including at Wallabi Point and Old Bar. Residual soil thickness varies considerably, with the deepest residual layers encountered near in the vicinity of the Surf Club. • *Indurated sediments* were found to occur at around 5 m AHD across areas of Pleistocene-age coastal barrier deposits in the vicinity of Racecourse Creek and adjacent the southern Farquhar Inlet foreshore. An outcrop of relic Pleistocene-age coastal barrier deposits comprising cemented sands and gravels likely became indurated through the process of podzolization and precipitation of cements from ground water flows (e.g. Brooke et al., 2017). **Erodible substrates** • Unconsolidated sediments in the form of erodible beach and dune deposits extend along the entire sandy coastline. Beach sediments are mostly sandy but contain some gravels.

4.2.2 Farquhar Inlet

Table 4-2 Coastal Geomorphology Summary: Farquhar Inlet Sector

Coastal Geology Component	Details – Farquhar Inlet Sector
Landforms and geology	**Coastal geology** • Modern (Holocene-age) coastal beach barrier and marine delta deposits • Relic (Pleistocene-age) coastal barrier deposits, adjacent to the inlets southern foreshore (Mudbishops Point Road) **Key landforms** • Intermittently closed and open tidal inlet (flood tide delta, sand bar/berm tidal channels) • Indurated sand cliff along the southern inlet foreshore
Geomorphic history and processes	**Geomorphic history** • During last sea level highstand, coastal deposits (sands/gravels) were laid down along the northern margins of the Old Bar bedrock bluff/slopes, which became indurated over time. • In the Holocene (modern geological times), Farquhar Inlet formed as a secondary tidal inlet to the Manning River Estuary. Marine sands were worked onshore to develop a flood tide delta over time. • Entrance flows in Farquhar Inlet periodically erode the relic indurated sand cliff adjacent to Old Bar. **Contemporary geomorphic processes** • Farquhar Inlet / marine delta acts as both a sediment source and sink. • Vast volumes of marine sand become progressively deposited in the flood tide delta from tide and wave action. Over extended dry periods, the estuary entrance condition becomes closed • During periods of flood, the marine delta sands becoming flushed out and deposited within the active littoral zone. • The entrance inlet condition has been linked to position of the adjacent shoreline. This is not surprising, considering the sediment flows / budget links between the coastline beaches and estuary inlets, as demonstrated in MHL (2017)
Geotechnical conditions and erosion sensitivity	**Erosion resistant substrate** • No erosion resistant substrate occurs within the Farquhar Inlet region **Partially resistant (semi erodible) substrate** • *Indurated sediments* occur as vertical sand cliffs along the southern marine of the inlet, adjacent to Mud Bishops Point Road. **Erodible substrates** • Unconsolidated sediments in the form of beach berm and marine delta deposits occur along the Farquhar Inlet coastline.

4.2.3 Mitchells Island / Manning Point Beach

Table 4-3 Coastal Geomorphology Summary: Mitchells Island / Manning Point Beach Sector

Coastal Geology Component	Details – Mitchells Island / Manning Point Beach Sector
Landforms and geology	**Coastal geology** • Modern (Holocene-age) coastal barrier deposits fringe the coastline. These deposits represent a ‘receded barrier’ type, as per geological model for wave dominated barriers in Roy et al. (1994) • Manning River estuarine plain is located landwards of the beach. This system forms a ‘mature riverine estuary’ type, as per geological model for NSW estuaries by Roy et al. (2001) • Mitchells Island deltaic estuarine deposits include relic (Pleistocene-age) coastal barrier and estuary deposits • The shoreface is starved of sediment, with no discernible sand body / sheet located offshore **Key landforms** • Sandy beach and dunes (coastal barrier system) • Deltaic estuarine plain located behind the active beach/dune system, which includes a complex of coastal and estuarine deposits
Geomorphic history and processes	**Geomorphic history** • During previous sea level highstand, coastal deposits were laid down parallel to the modern coastline some 500 metres landward of the present position. Landward of here, barrier estuary deposits were formed across the former Manning River Estuary • In the Holocene (modern geological times), a coastal barrier deposit formed along the current coastline. The Manning River estuary floodplain continued to infill over this period • Similar to Old Bar, the historical shoreline records show that much of modern barrier dune sediments have been eroded. A relatively thin fringe of beach and dune sediments remain along the coastal margin **Contemporary geomorphic processes** • Prevailing coastal processes and the sediment budget conditions are driving a progressive landward recession of the sandy shoreline (see MHL, 2017 for details)
Geotechnical conditions and erosion sensitivity	**Erosion resistant substrate** • No erosion resistant substrate occurs within the Mitchells Island / Manning Point Beach sector **Partially resistant (semi erodible) substrate** • No partially resistant substrates (e.g. indurated sands or residual soils) were documented near to the coast **Erodible substrates** • Unconsolidated beach and dune barrier deposits occur along the Mitchells Island and Manning Point Beach coastline.

4.2.4 Harrington Inlet

Table 4-4 Coastal Geomorphology Summary: Harrington Inlet Sector

Coastal Geology Component	Details – Harrington Inlet Sector
Landforms and geology	**Coastal geology** • Modern (Holocene-age) marine delta **Key landforms** • Permanently (artificially) open tidal inlet (sandy shoals, entrance channels, flood tide delta)
Geomorphic history and processes	**Geomorphic history** • In modern geological times (Holocene), Harrington Inlet formed as a primary entrance to the Manning River Estuary. • Over time, progressive deposition of the marine sands led to the development of the flood tide delta and entrance bar/shoals • Fluvial processes also delivered sediments to the entrance region • Entrance morphology and sediment budget become significantly altered by anthropogonic activities over the past century or so, through construction of the Harrington training wall (circa 1900) and breakwater extension (1920s); plus numerous entrance dredging campaigns for navigation and land reclamation purposes (see MHL, 2107 for a summary) **Contemporary geomorphic processes** • Entrance conditions are very dynamic and respond to interaction of waves, tides and floods. Entrance bar/shoals and channel undergo morphology undergo constant change • Inlet / marine delta acts as periodic sediment source and sink, although net sink due to past dredging activities • Breakwater interrupts southerly littoral transport, but permits northerly littoral transport (acts as a 'one wave valve') • See MHL (2017) for details re: coastal processes and sediment budget
Geotechnical conditions and erosion sensitivity	**Erosion resistant substrate** • No erosion resistant substrate occurs within active coastal zone, although a topographic high at Harrington is formed of erosion resistant bedrock • The entrance training wall is a substantial rock structure that acts as erosion resistant substrate (i.e. erosion will not progress landward of this structure) **Partially resistant (semi erodible) substrate** • No partially resistant substrates were documented near to the coast (i.e. indurated sands or residual soils were not observed). **Erodible substrates** • Erodible sediments in the form of mobile entrance bars / sand shoals and marine delta deposits occur within the Harrington Inlet.

4.2.5 Harrington Beach

Table 4-5 Coastal Geomorphology Summary: Harrington Beach Sector

Coastal Geology Component	Details – Harrington Beach Sector
Landforms and geology	**Coastal geology** • Modern (Holocene-age) coastal barrier deposits fringe the coastline. These deposits represent a 'stationary barrier' type, as per geological model for wave dominated barriers in Roy et al. (1994) (although prior to human interventions, the coastline would have represented a 'receding barrier' type) • Relic (Pleistocene-age) coastal barrier and estuary deposits are common behind the beach • Sandstone landforms are present (noting the bedrock geology differs from the Old Bar Beach sector) **Key landforms** • Sandy beach and dunes (coastal barrier system), that forms an extensive tombolo with Crowdy Bay Beach • Crowdy Head headland • Rocky reefs (isolated) • Deltaic estuarine plain located behind the beach/dune system, including Crowdy Lagoon
Geomorphic history and processes	**Geomorphic history** • Modern coastal barrier deposits were deposited along current coastline orientation, which impounded the backing lagoon area. **Contemporary geomorphic processes** • Beach and dunes experience cyclic erosion and recovery • Net northerly littoral transport • Historical records show that that Harrington Beach is building seawards, due to positive sediment budget associated with the breakwater influences • Breakwater interrupts gross southerly littoral transport, resulting in net accretion. Also, periodic flood events deliver Harrington Inlet delta sands into active littoral system of Harrington Beach (see MHL, 2017 for details)
Geotechnical conditions and erosion sensitivity	**Erosion resistant substrate** • *Erosion limiting bedrock landforms* encountered at: Crowdy Head in the form of a tall, round sandstone headland. • *Erosion influencing bedrock landforms* occur as rocky shore platforms and adjoining reefs areas associated with Crowdy Head. • Rocky subtidal reefs offshore of Harrington Beach influences local wave refraction, resulting in the development of a sandy foreland / bulge coastline feature in its lee **Partially resistant (semi erodible) substrate** • No partially resistant substrates (i.e. indurated sands or residual soils) were documented near to the coast **Erodible substrates** • Unconsolidated sediments in the form of beach and dune deposits extend along Harrington Beach

4.3 Old Bar geological cross sections

A series of six geological cross section have been prepared for the Old Bar Beach sector. These are (as mapped in in Figure 4-1):

- **Rose Street cross shore profile** (geological section 1; Figure 4-2);
- **Old Bar Public School cross shore profile** (geological section 2; Figure 4-3);
- **Hall Street longshore profile** (geological section 3; Figure 4-4);
- **Caravan Park cross shore profile** (geological section 4; Figure 4-5);
- **Northern Dunes cross shore profile** (geological section 5; Figure 4-6); and
- **Mudbishops Point Road longshore profile** (geological section 6; Figure 4-7).

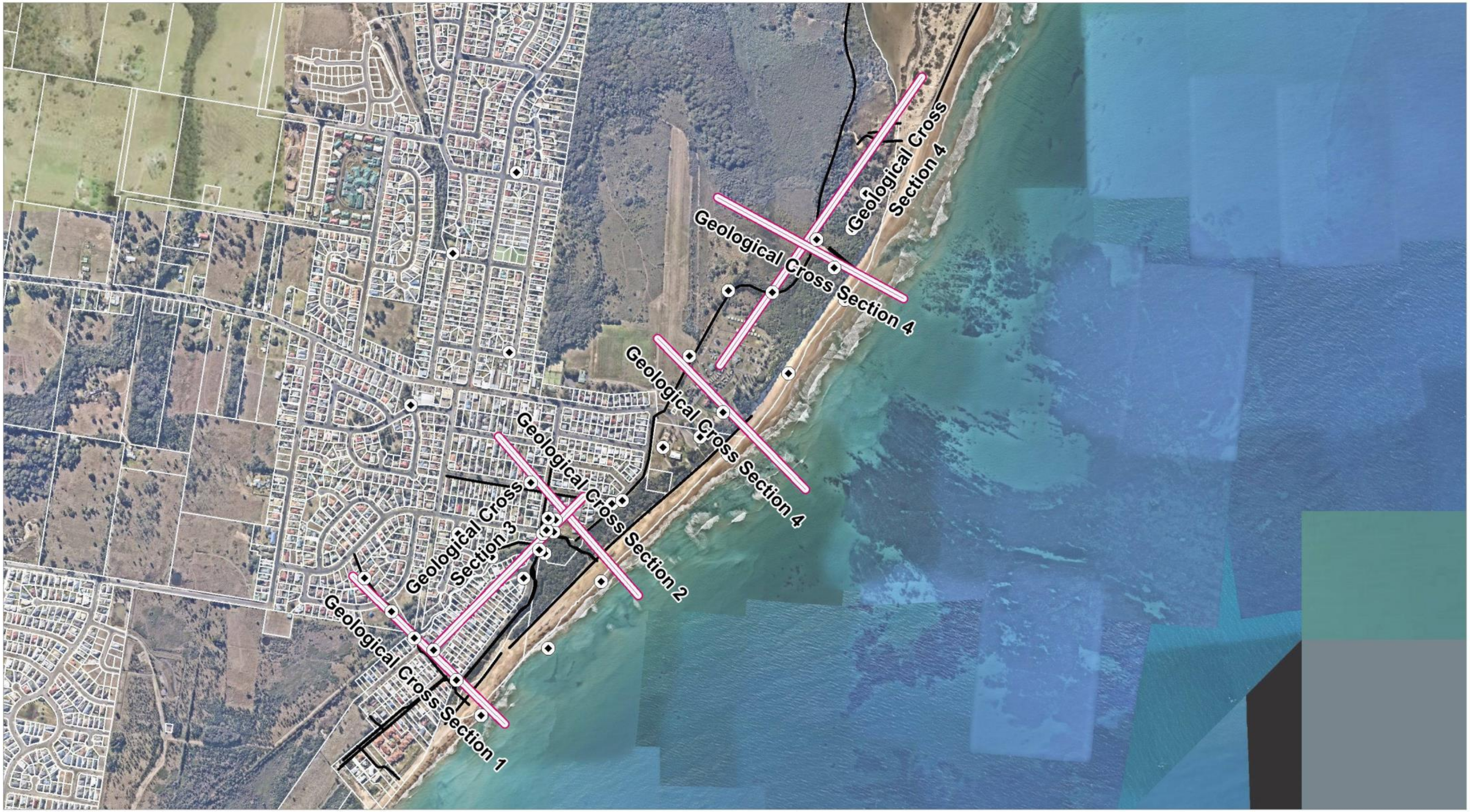
These cross sections have been prepared by synthesising and interpreting the following datasets:

- Available *topographic and bathymetric information* (2013 LiDAR elevation information by NSW LPI, and 2009 single beam bathymetry by NSW OEH)
- *Walk over observations* completed for this study, which included some surface sediment sampling
- *GPR information* collected from various sources and analysed for this study
- *Borehole information* collected from various sources and analysed for this study

Together, these geological sections characterise the variability in coastal geological conditions in three dimensions across the Old Bar region, which is shows to encompass the following landforms types and geotechnical substrates:

- An **erosion limiting bedrock bluff that underlies the Old Bar township** near to the coast. The seaward margin of the bedrock bluff is concealed by a narrow fringe of coastal dunes (e.g. Figure 4-3). Field investigations have shown this feature to extend along the coast northwards of the bend in Racecourse Creek (Figure 4-4) to part way down Mudbishops Point Road (Figure 4-7).
- An **erosion influencing bedrock shore platform and reef that extend seaward Old Bar**, which connects the buried bedrock bluff with the Urana Bombora. Part of this bedrock feature is concealed by overlying beach and dune sediments (Figure 4-5).
- **Partially erosion resistant residual soils which overlying the onshore bedrock areas** / slopes. The thickness of the residual soils varies across the study site, with deep residual profile encountered across the Surf Club region (Figure 4-5).
- **Partially erosion resistant indurated sands located up to ~5 m AHD within the relic barrier dunes deposits**, in the vicinity of Racecourse Creek and also adjacent to Farquhar Inlet (Figure 4-2, Figure 4-7).

All of the above described landform and substrate types will be more resistant to erosion that unconsolidated beach sands. As such, existing erosion hazard assessments that have assumed the beach and backbeach area to comprise sandy substrate only will have most likely overestimates the level of erosion risk across these areas.



LEGEND

▭	Geological section
◈	Borehole
⌒	GPR profiles

Near map images (July 2018)

Title:

Geological Cross Section Locality Map
Old Bar Beach

Figure:

4-1

Rev:

A

N

0 250 500m

Approx. Scale

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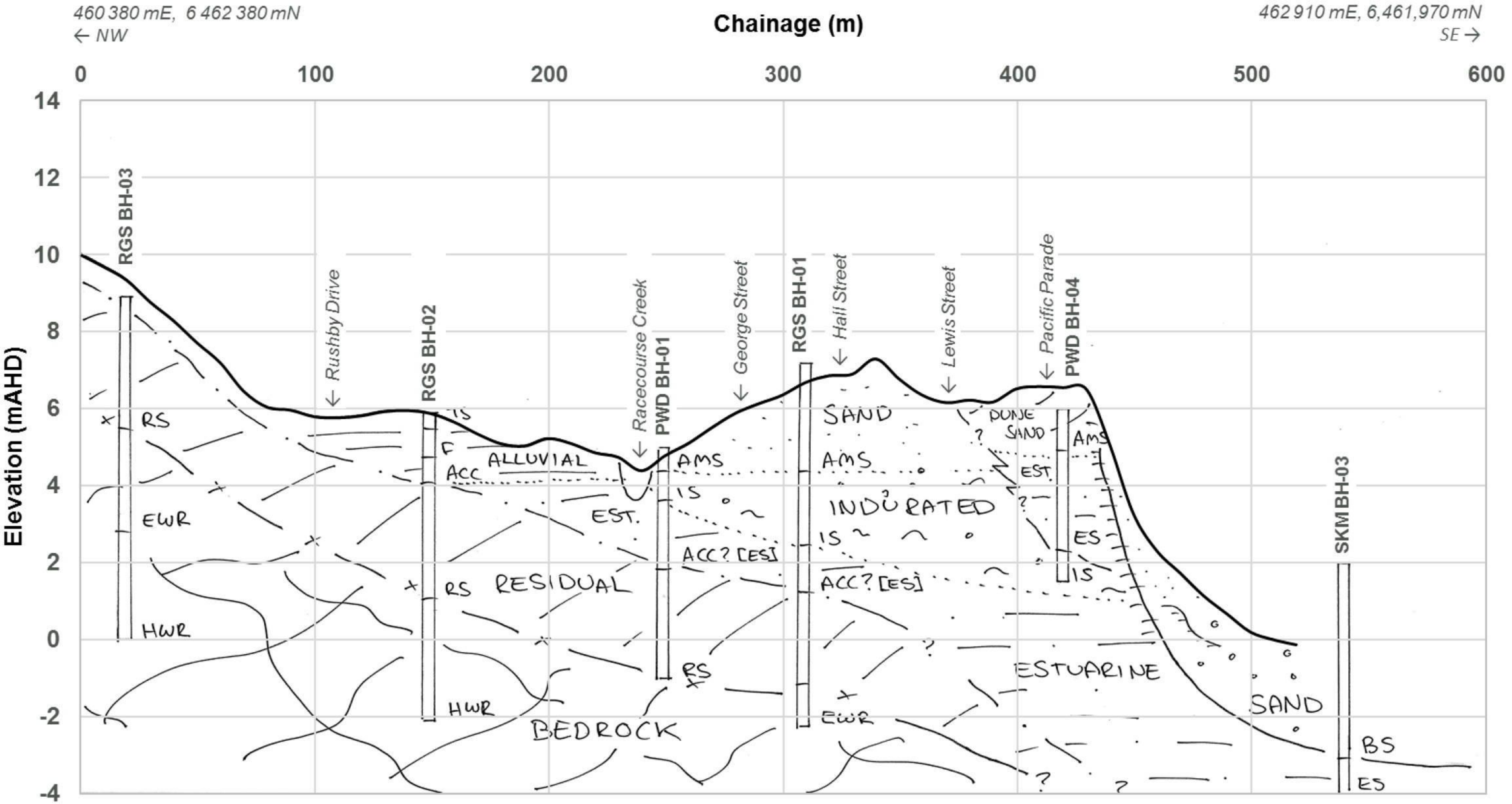


Title:

Geological Cross Section 1, Rose Street - Old Bar Beach

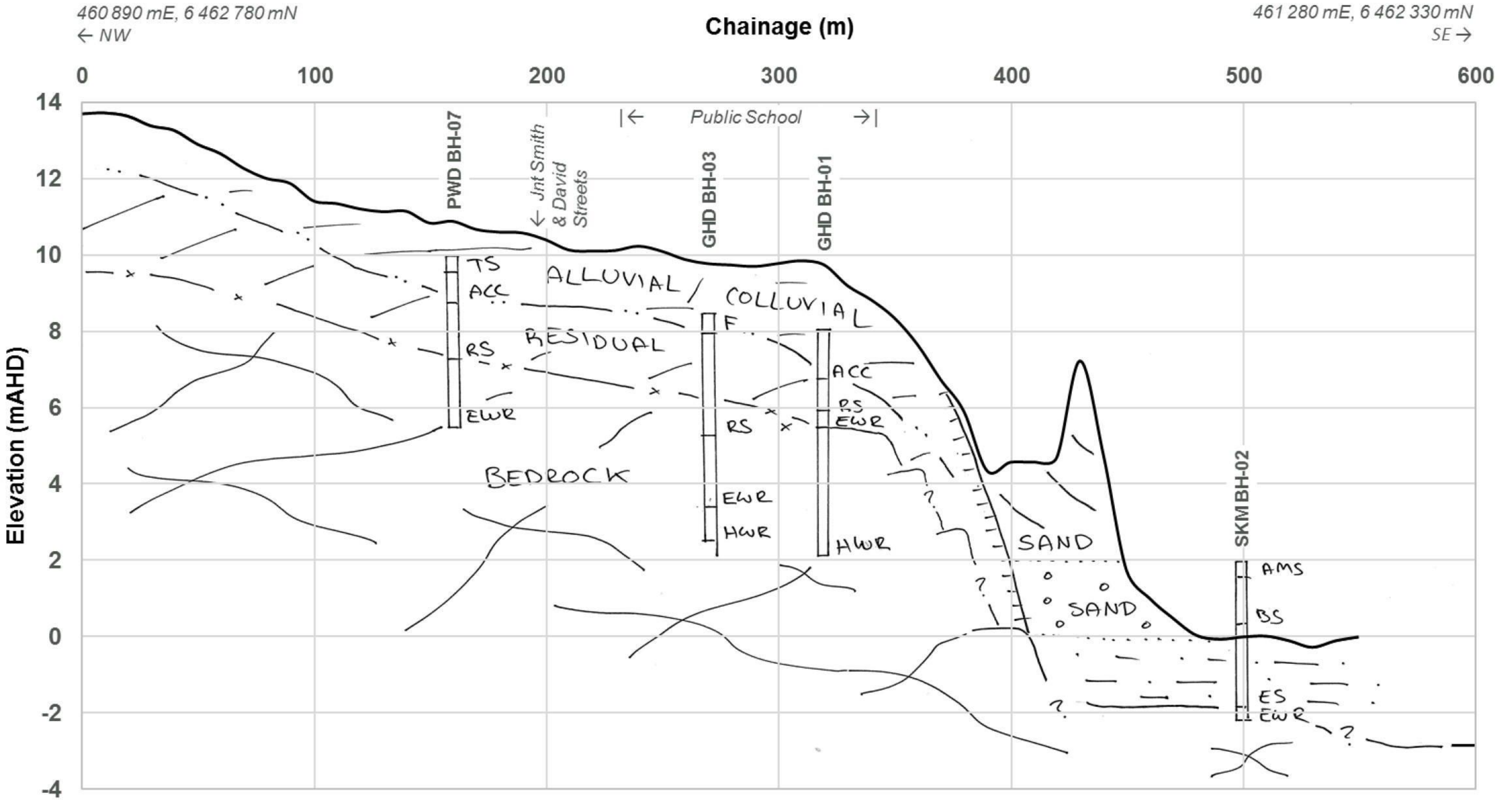
Cross Shore Profile

Figure:
4-2

Rev:
A

LEGEND *1. Topsoil (TS); 2. Fill (F); 3. Aeolian / Marine Sand (AMS); 4. Beach Sediments (BS); 5. Estuarine Sediments (ES); 6. Indurated Sand (IS); 7. Alluvial / Colluvial Clay (ACC); 8. Residual Soil (RS); 9. Extremely Weathered Meta-Sandstone/Siltstone (EWR); 10. Extremely to Highly Weathered Meta-Sandstone/Siltstone (HWR); and 11. Highly to Slightly Weathered Meta-Sandstone/Siltstone (SWR).*

Input Data *Topography (2013 LiDAR); Bathymetry (2009 hydrosuvey); Walkover observations (Appendix B); GPR profiles (Rose St profiles, Appendix C) Geotechnical boreholes (shown, Appendix D)*



Title:

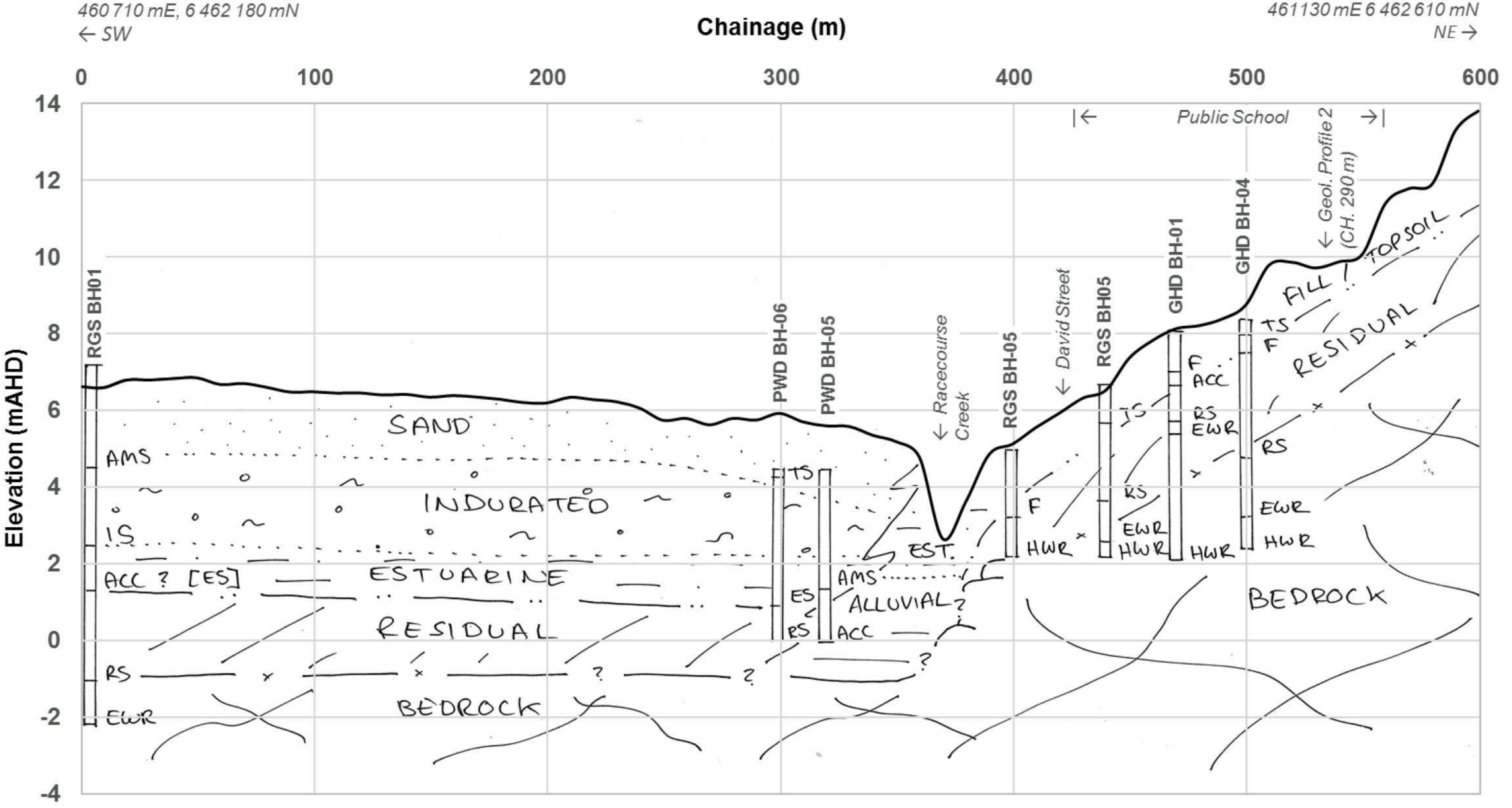
Geological Cross Section 2, Public School - Old Bar Beach Public School
Cross Shore Profile

Figure:
4-3

Rev:
A

LEGEND 1. Topsoil (TS); 2. Fill (F); 3. Aeolian / Marine Sand (AMS); 4. Beach Sediments (BS); 5. Estuarine Sediments (ES); 6. Indurated Sand (IS); 7. Alluvial / Colluvial Clay (ACC); 8. Residual Soil (RS); 9. Extremely Weathered Meta-Sandstone/Siltstone (EWR); 10. Extremely to Highly Weathered Meta-Sandstone/Siltstone (HWR); and 11. Highly to Slightly Weathered Meta-Sandstone/Siltstone (SWR).

Input Data Topography (2013 LiDAR); Bathymetry (2009 hydrosuvey); Walkover observations (Appendix B); GPR profiles (Rose St profiles, Appendix C) Geotechnical boreholes (shown, Appendix D)



Title:

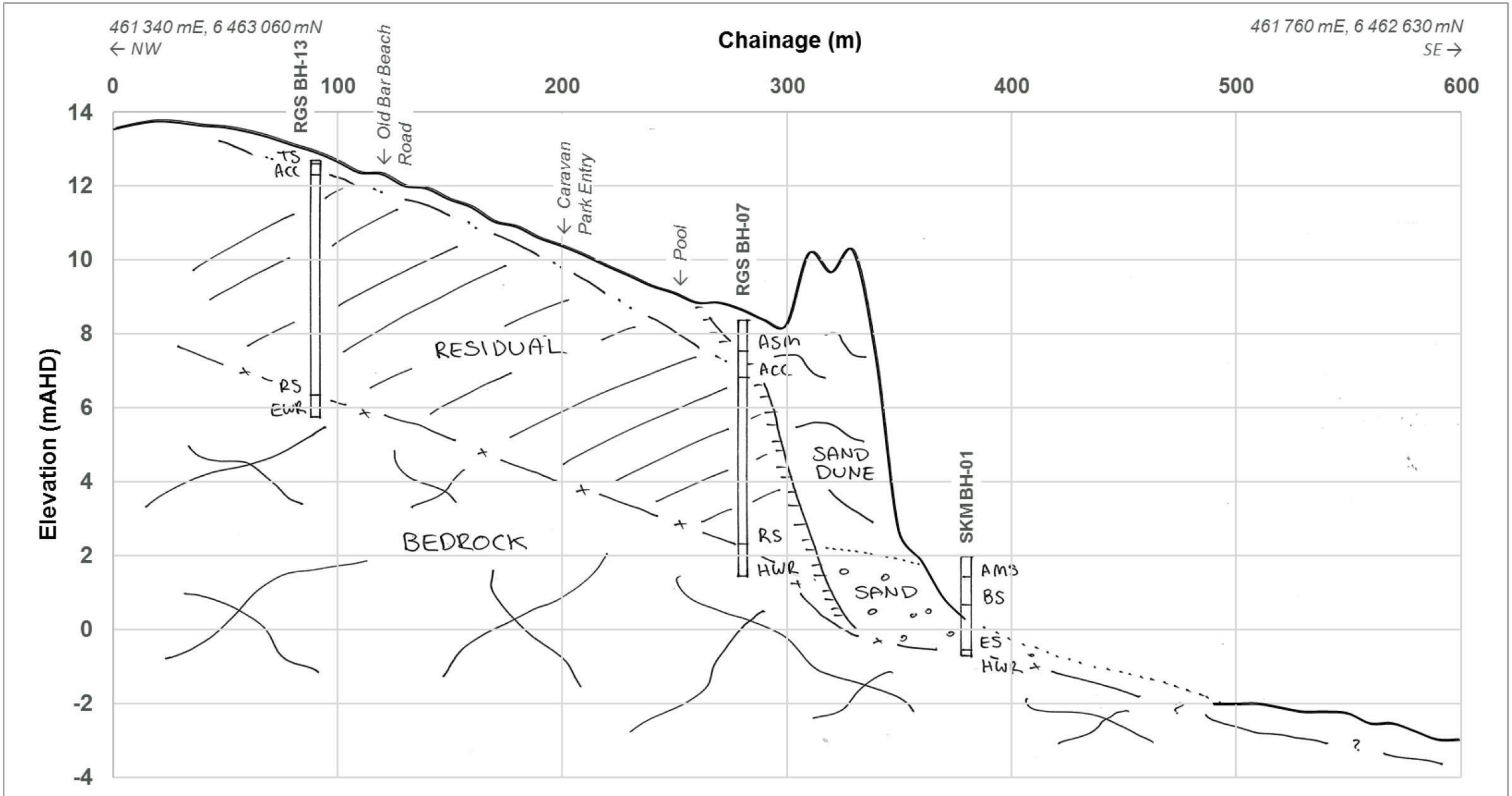
Geological Cross Section 3, Hall Street - Old Bar Beach
Longshore Profile

Figure: **4-4**

Rev: **A**

LEGEND *1. Topsoil (TS); 2. Fill (F); 3. Aeolian / Marine Sand (AMS); 4. Beach Sediments (BS); 5. Estuarine Sediments (ES); 6. Indurated Sand (IS); 7. Alluvial / Colluvial Clay (ACC); 8. Residual Soil (RS); 9. Extremely Weathered Meta-Sandstone/Siltstone (EWR); 10. Extremely to Highly Weathered Meta-Sandstone/Siltstone (HWR); and 11. Highly to Slightly Weathered Meta-Sandstone/Siltstone (SWR).*

Input Data *Topography (2013 LiDAR); Bathymetry (2009 hydrosuvey); Walkover observations (Appendix B); GPR profiles (Rose St profiles, Appendix C) Geotechnical boreholes (shown, Appendix D)*



Title:

Geological Cross Section 4, Caravan Park - Old Bar Beach

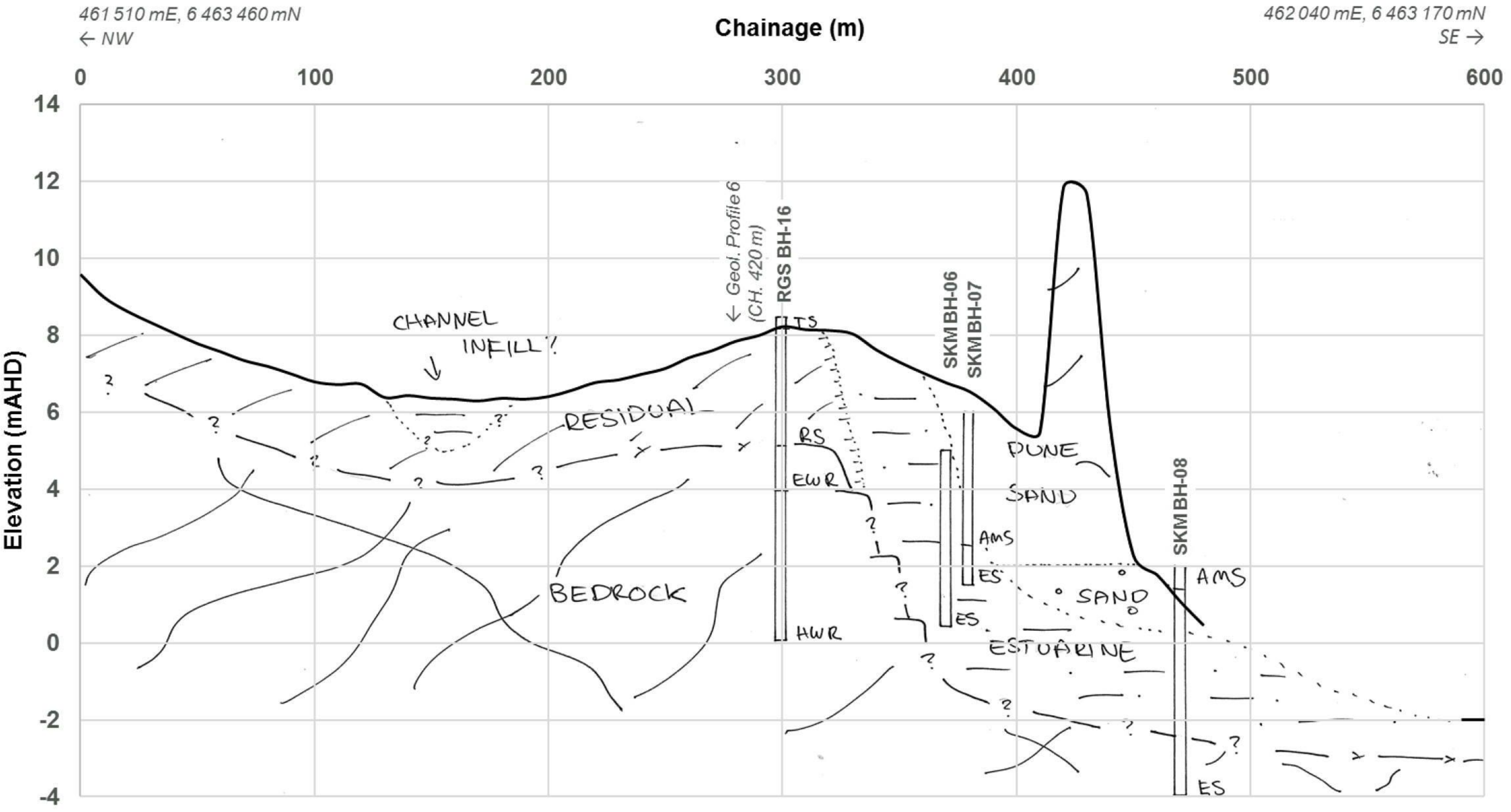
Cross Shore Profile

Figure: 4-5

Rev: A

LEGEND *1. Topsoil (TS); 2. Fill (F); 3. Aeolian / Marine Sand (AMS); 4. Beach Sediments (BS); 5. Estuarine Sediments (ES); 6. Indurated Sand (IS); 7. Alluvial / Colluvial Clay (ACC); 8. Residual Soil (RS); 9. Extremely Weathered Meta-Sandstone/Siltstone (EWR); 10. Extremely to Highly Weathered Meta-Sandstone/Siltstone (HWR); and 11. Highly to Slightly Weathered Meta-Sandstone/Siltstone (SWR).*

Input Data *Topography (2013 LiDAR); Bathymetry (2009 hydrosuvey); Walkover observations (Appendix B); GPR profiles (Rose St profiles, Appendix C) Geotechnical boreholes (shown, Appendix D)*



Title:

Geological Cross Section 5, Northern Dunes - Old Bar Beach

Cross Shore Profile

Figure: 4-6

Rev: A

LEGEND *1. Topsoil (TS); 2. Fill (F); 3. Aeolian / Marine Sand (AMS); 4. Beach Sediments (BS); 5. Estuarine Sediments (ES); 6. Indurated Sand (IS); 7. Alluvial / Colluvial Clay (ACC); 8. Residual Soil (RS); 9. Extremely Weathered Meta-Sandstone/Siltstone (EWR); 10. Extremely to Highly Weathered Meta-Sandstone/Siltstone (HWR); and 11. Highly to Slightly Weathered Meta-Sandstone/Siltstone (SWR).*

Input Data *Topography (2013 LiDAR); Bathymetry (2009 hydrosuvey); Walkover observations (Appendix B); GPR profiles (Rose St profiles, Appendix C) Geotechnical boreholes (shown, Appendix D)*

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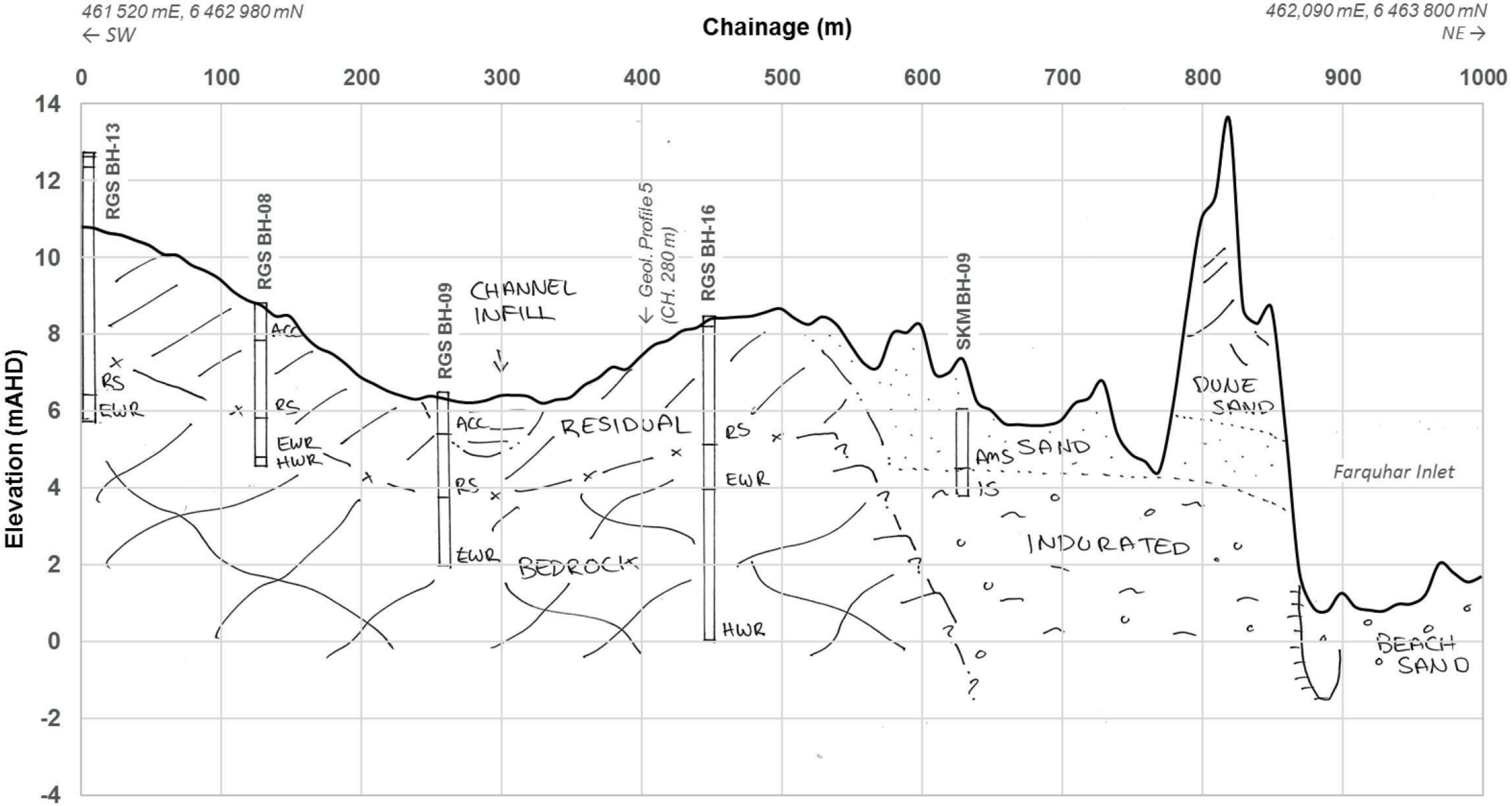


Title:

Geological Cross Section 6, Mudbishops Road - Old Bar Beach to Farquhar Inlet *Longshore Profile*

Figure: **4-7**

Rev: **A**

LEGEND *1. Topsoil (TS); 2. Fill (F); 3. Aeolian / Marine Sand (AMS); 4. Beach Sediments (BS); 5. Estuarine Sediments (ES); 6. Indurated Sand (IS); 7. Alluvial / Colluvial Clay (ACC); 8. Residual Soil (RS); 9. Extremely Weathered Meta-Sandstone/Siltstone (EWR); 10. Extremely to Highly Weathered Meta-Sandstone/Siltstone (HWR); and 11. Highly to Slightly Weathered Meta-Sandstone/Siltstone (SWR).*

Input Data *Topography (2013 LiDAR); Bathymetry (2009 hydrosuvey); Walkover observations (Appendix B); GPR profiles (Rose St profiles, Appendix C) Geotechnical boreholes (shown, Appendix D)*

4.4 Coastal substrate considerations

This study has identified a range of substrate conditions across the coastline region, including modern coastal sediments, relic sedimentary deposits and bedrock substrates with varying rock types and degrees of weathering. The below discusses the erosion sensitivity of substrates encountered across the study region.

4.4.1 Weathered bedrock

Geotechnical borehole records and site observations have identified various degrees of weathered rock across the Old Bar Beach coastal segment, ranging from ‘Residual soils’ (Unit 8) to ‘Highly to slightly weathered metasandstone / metasiltstones’ (Unit 11). It is therefore important to consider how weathered bedrock substrates may behave if / when exposed to coastal processes (e.g. once the fronting sand dune buffer in front of Old Bar is removed from shoreline recession, for example).

Rock exposures at Wallabi Point provide some insight in this regard, as the headland is comprised of interbedded siltstones and sandstones substrates with variable strength like that encountered in boreholes elsewhere. As shown in Figure 4-8 to Figure 4-9, ‘extremely weathered’ materials (~Unit 9) show signs of very localised cliff retreat, whereas highly to slightly weathered materials (~Unit 11) demonstrates a sloping profile that is reflective of a stable rocky coastline.

A single photogrammetry records from Wallabi Point provides some evidence of how the local bedrock geology has evolved over a +50 year period in response to wave exposure. As shown in Figure 4-10, there has been no significant change to the cliff face position since 1963 (~0.03 m/year retreat of the 4 meter contour). It is likely that this cliff face location demonstrates a ~highly weathered conditions (i.e. Unit 10 / Unit 11) on average (e.g. Figure 4-9, top). For this reason, Unit 10 and Unit 11 can be considered to form erosion resistant material over planning timeframes.

Therefore, Units 10 and 11 form *erosion limiting bedrock landforms* where they rise as rocky surfaces above 4 m AHD in the form of bedrock cliffs or buried rocky bluff. Such features should be considered resistant to wave erosion and shoreline recession over planning timeframes, for the purpose of hazard assessment.

4.4.2 Cohesive clay soils (residual, extremely weathered rock)

‘Residual soils’ (Unit 8) and ‘extremely weathered rock’ (Unit 9) demonstrate a cohesive clayey soil substrate with low strength. While it is considered that extreme storms could erode ‘cohesive soil’ material exposed at the shoreline, it would be significantly more resistant to wave action that unconsolidated sands.

While some areas have been found to have deeply weathered ‘cohesive soil’ profiles, it is important to realise that the geotechnical profile of rock/weathered rock areas is variable - as demonsted by the RGS and GHD borehole profiles, and rock exposures presented below. For example, the borehole records alone show a deep ‘residual soil’ and ‘extremely weathered’ rock profile near to the Surf Club (Figure 4-5), however rock exposures in a nearby quarry behind the dunes found ‘highly to slightly weathered’ rock condition (Appendix B).

It is therefore considered that if and when buried rock/weathered rock material becomes exposed at the coastline at some point in the future, that the material strength will not be uniform. Rather such exposures will manifest with:

- Durable material occurring at the toe of the future cliff/slope, thus limiting the opportunity for undercutting (e.g. Figure 4-9) - which is an important factor in the cliff formation and retreat processes; or
- Durable material occurring adjacent to the area of 'cohesive soils' (i.e. along the coast), which would act to arrest any significant cliff retreat.

Where the cohesive clays become exposed at a future cliff face, it is possible that some soil profile adjustment would occur overtime (hillslope processes). There is also the potential for some localised rotational failure due to landslip processes. Again, this impact would likely be restricted geographically due to the non-uniform nature of the weathered material.

It is therefore considered that application of an appropriate 'geotechnical buffer', based on expert judgement, will be an adequate way to capture potential cohesive soil related geotechnical hazards. Such a buffer would be mapped landward of a beach erosion / shoreline recession hazard line, when sandy beach related hazard have been estimated to remove the fronting dune buffer.

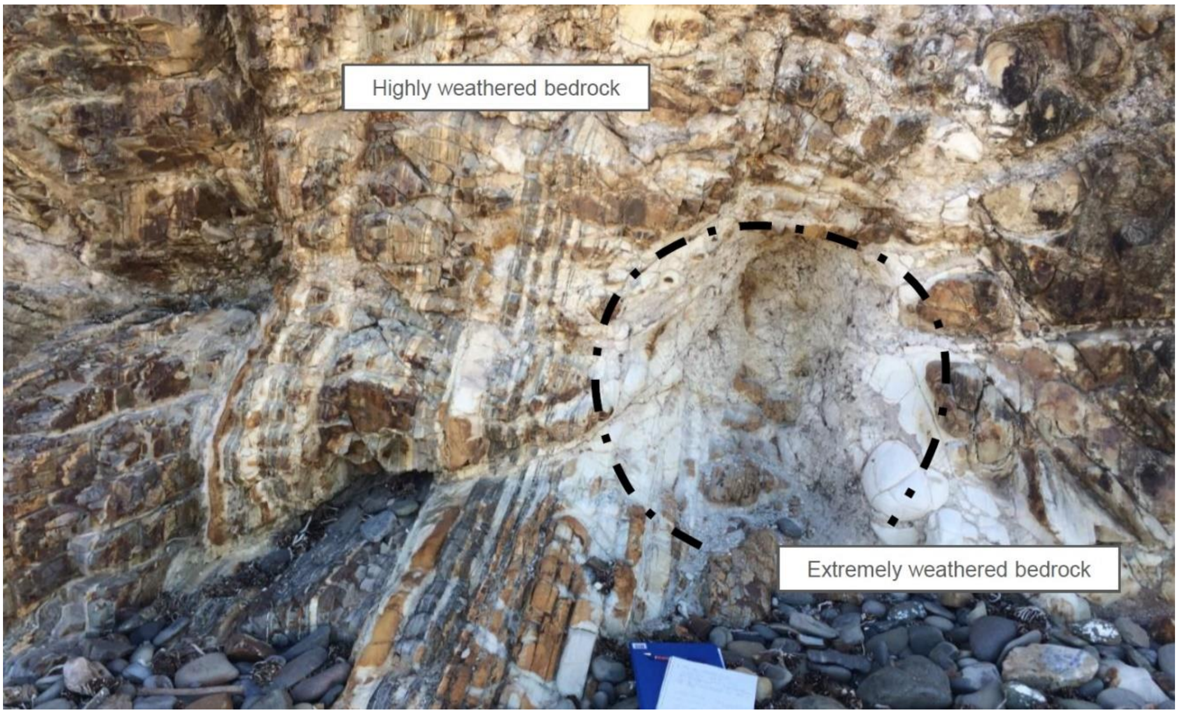
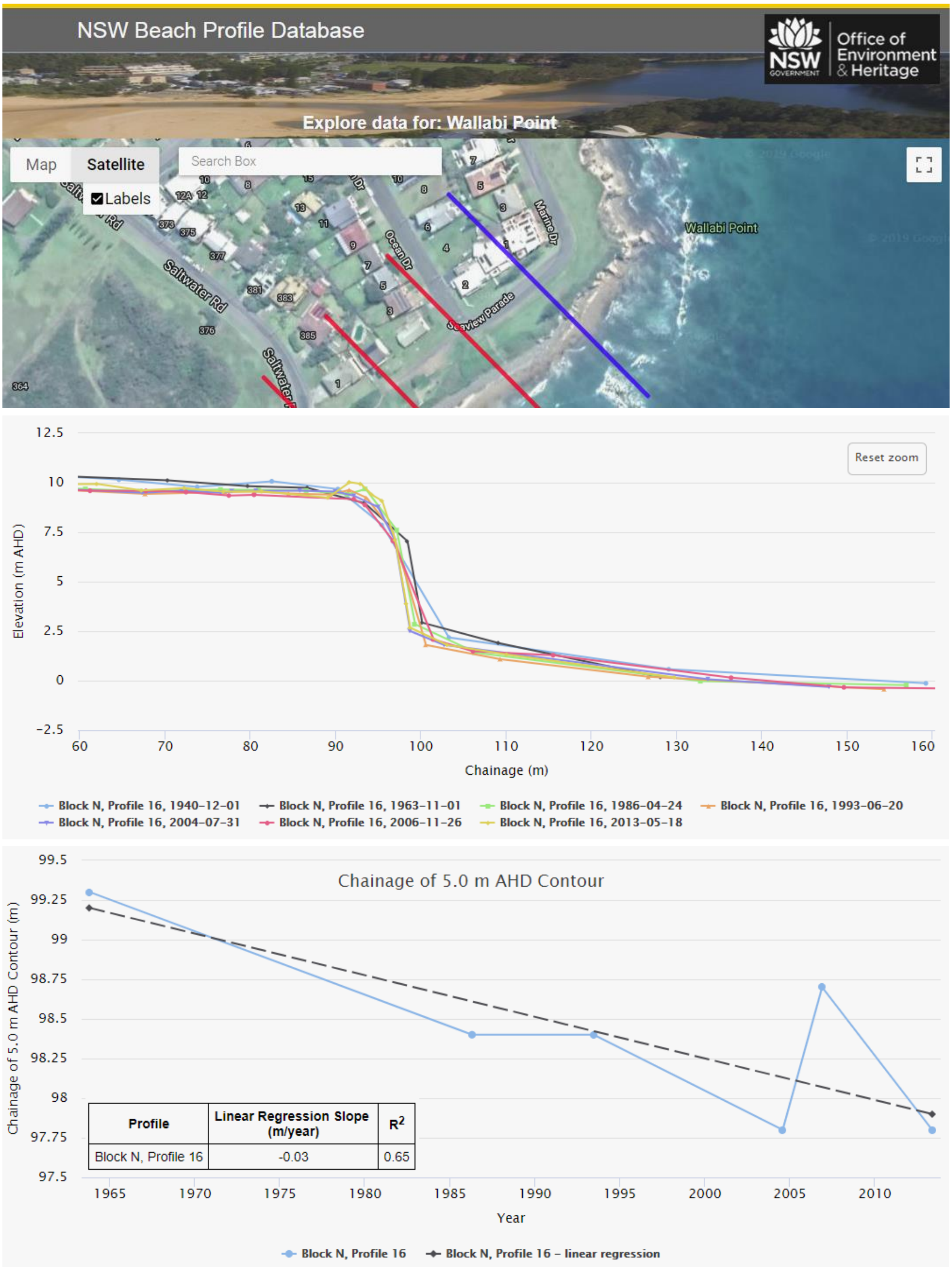


Figure 4-8 Wallabi Point cliff face, showing marginally increased incision (undercutting) of 'extremely weathered bedrock' material

Figure 4-9 Wallabi Point cliff face looking south (top) and north (bottom), showing increased that 'extremely to highly weathered bedrock' has been eroded to forms vertical cliff face, whereas 'highly to slightly weathered bedrock' forms a sloping profile which demonstrates an increased that resilience to wave action

Note: collectively the above three annotated photos from Wallabi Point demonstrate the highly variable degree of weathering that occurs locally within the interbedded meta-siltstones and meta-sandstones of the region



Profile	Linear Regression Slope (m/year)	R^2
Block N, Profile 16	-0.03	0.65

Figure 4-10 Photogrammetry Data from Wallabi Point Headland Cliff (source: NSW Beach Profile Database)

Note: Photogrammetry profile records of Wallabi Point shows negligible cliff face erosion of the highly weathered siltstone / sandstone cliff over historical timeframes

4.4.3 Indurated sediments (coffee rock)

Over geological timescales, sediments may transition from erodible substrates into partially resistant substrates due to processes including the precipitation of mineral or organic cements to form indurated sediments, or sediment compaction to form semi-lithified sediments. Indurated coastal sediments were encountered across the Old Bar Beach sector adjacent to Farquhar Inlet and below the relic sand dunes around Racecourse Creek.

Outcrops of indurated sand and gravel near Mudbishops Point Road (Figure 4-11) have formed a subvertical sand cliff, which require a geological hammer to break off (sand rock) samples. As such, the indurated Pleistocene-age coastal barrier sediments are less vulnerable to erosion processes than their modern counterpart (i.e. unconsolidated Holocene-age dune sands). Thus, indurated sediments form a *partially resistant (semi erodible) substrate*. However, the relative resistance of indurated sediment to wave erosion processes is considerably less than that of cohesive clay soils derived from bedrock.

In general terms, it is also interesting to note that indurated sands occurring along the NSW coastline do not protrude seaward from the surrounding unconsolidated dunes sediments. As such, it may be considered that indurated sediments are equally sensitive to shoreline recession processes as unconsolidated dune sands.

Thus, for the purpose of erosion hazard assessment, indurated sands should be treated as a *partially resistant coastal substrate* when modelling immediate (storm bite related) erosion hazards. However, when modelling long term shoreline recession (due to sediment budget imbalances and sea level rise), it may be prudent to treat indurated sands as an erodible substrate.

Figure 4-11 Indurated sands and gavel exposures at Farquhar Inlet

5 Summary

A field based coastal geomorphology study was conducted to investigate the geological factors that may influence coastal erosion hazards along the Old Bar Beach coastline. This study was initiated by Council in response to ongoing concerns that prior coastal hazard assessment mapping erosion and recession hazard lines that assumed the beach was backed by erodible sand only, while also flagging the potential for variable geological substrates behind the beach.

The geomorphology and geotechnical characteristics of Old Bar Beach coastline was investigated through a detailed review and synthesis of existing geoscientific information, and coupled with a targeted field survey program that comprised a:

- Geomorphological walkover investigation and mapping;
- GPR investigation of the coastal geology and depth to bedrock; and
- Geotechnical drilling and logging of boreholes.

The approach and outcomes from each field survey are detailed in Appendix A to Appendix D. Through these surveys, the geological context and substrate variability of the coastline has been characterised.

For the purpose of guiding future coastal hazard assessments, three broad geological conditions have been identified within the onshore setting that will either exclude or reduce the erosion potential. These geological factors are described as:

- Erosion limiting bedrock landforms;
- Erosion influencing bedrock outcrops/subcrops; and
- Partially resistant coastal substrates.

In summary, *erosion limiting bedrock landforms* were found to occur at Wallabi Point, the Old Bar township and at Crowdy Head. Also, the rising slopes behind Racecourse Creek were also identified as bedrock limiting substrate, along with an isolated topographic high at Harrington. Beach erosion and shoreline recession hazards will not occur landward of the erosion limiting bedrock boundaries (although that land may still be subject to coastal hazards such as wave overtopping, for example).

Erosion influencing bedrock substrates in the form of rocky reefs and shore platforms have been documented in the vicinity of Wallabi Point, Urana Bombora and Crowdy Head. The Urana Bombora was found to extend beneath the adjoining beach and dune sands and connect with the Old Bar bedrock bluff. Low lying bedrock substrates were also identified at around the fringes of the Old Bar bluff and in the vicinity of Racecourse Creek. Erodible sediments/substrates that overlie and/or back these low lying rocky areas are vulnerable to erosion by wave action, however the potential for erosion of these areas is reduced.

Partially resistant coastal substrates were identified overlying and around the fringes of the bedrock slopes at Old Bar as cohesive clay rich soil profiles, which have formed through *in situ* weathering and pedogenic processes acting on the parent bedrock material. These materials are sensitive to erosion, although exposed soils of this nature are not expected to experience any significant erosion hazard and a simply ‘geotechnical buffer’ may appropriately reflect the associated ‘slumping’ geo-hazard.

Semi-durable indurated sediments were identified in some areas, including adjacent the southern foreshore of Farquhar Inlet and beneath the relic dune sands in the vicinity of Racecourse Creek. Pleistocene-age coastal barrier deposits outcropping adjacent to Farquhar Inlet comprise cemented sands and gravels that likely became indurated through the process of podzolization and precipitation of cements from ground water flow (e.g. Brooke et al., 2017). Indurated sediments can become eroded by wave action if/when exposed at the shoreline, however they are partially more resistant to coastal erosion relative to unconsolidated beach and dune sands.

The findings and conclusions of this study are a valuable tool to inform Council decision-making for ongoing coastal management issues. Notably, the outcomes of this study have directly informed the ongoing erosion/recession hazard update works that prepend this report, and provide a valuable addition to considering the erosion potential based on the underlying geology.

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Appendices: Old Bar to Manning Point Coastal Geomorphology Field Study

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BMT Commercial Australia Pty Ltd
126 Belford Street
Broadmeadow NSW 2292
Australia
PO Box 266
Broadmeadow NSW 2292

Tel: +61 2 4940 8882
Fax: +61 2 4940 8887

ABN 54 010 830 421

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Appendix A Coastal Geoscience Literature Review

A.1 Introduction

The available literature regarding coastal geosciences within the Old Bar to Manning Point region has been reviewed to inform the Old Bar to Manning Point Coastal Geomorphological Field Study (this study). The literature review has included the following information sources:

- Geological and geomorphological reports of the study region and surrounds (including Roy et al., 1997; and SKM, 1982);
- Geological mapping datasets, including bedrock geology and coastal Quaternary sediment maps (GSNSW, 1970; 1987; 2008);
- Geological and geotechnical borehole drilling datasets (PWD, 1981; and SKM, 1982);
- Consultant reports on coastal processes, hazards and management (RHDHV, 2013; 2014; 2015; 2016; SKM, 1982; Worley Parsons, 2010a; 2010b; 2013; and MHL, 2017);
- Academic coastal hazard and geoscience literature (i.e. conference and journal papers), including information relating to Old Bar from Bushfire and Natural Hazards CRC (e.g. Davies et al, 2016; and Nichol et al., 2016).

The literature review aimed to collate and document the existing information to help develop an understanding of the coastal geomorphology, geological and geotechnical conditions, along with the respective vulnerability to coastal erosion and shoreline recession hazards.

The below review is intended to complement a detailed literature review by MHL (2017) regarding physical coastal and estuarine processes and sediment budget of the Manning Valley coastal sediment compartment.

A.2 Geological / Geomorphological Information Sources

A.2.1 Manning River Flood Mitigation: Old Bar entrance, sources of breakwater stone (GSNSW, 1969)

In 1969, the Geological Survey of NSW carried out a reconnaissance geological survey to find a suitable quarry stone for the construction of the proposed breakwaters at Farquhar Inlet. A Plan Map of the investigation was produced (see Figure A-1). An abstract summarising the survey is documented within the NSW Geological Survey Digital Imaging of Geological System (accessed April 2019).

A disused road materials quarry at Old Bar (location 1), and the rock forming Wallabi Point (location 2) were examined along with several other sites (see Figure A-1). Both coastline sites (location 1 and 2) were found to be unsuitable for breakwater stone, with no further details provided. Nonetheless, the survey Plan Map forms an early record of bedrock immediately behind the beach at Old Bar, which has not been recognised in prior coastal hazard and management investigations.

The bedrock record at location 1 likely corresponds to the bedrock outcrop recorded in the field walkover investigation (Appendix B).

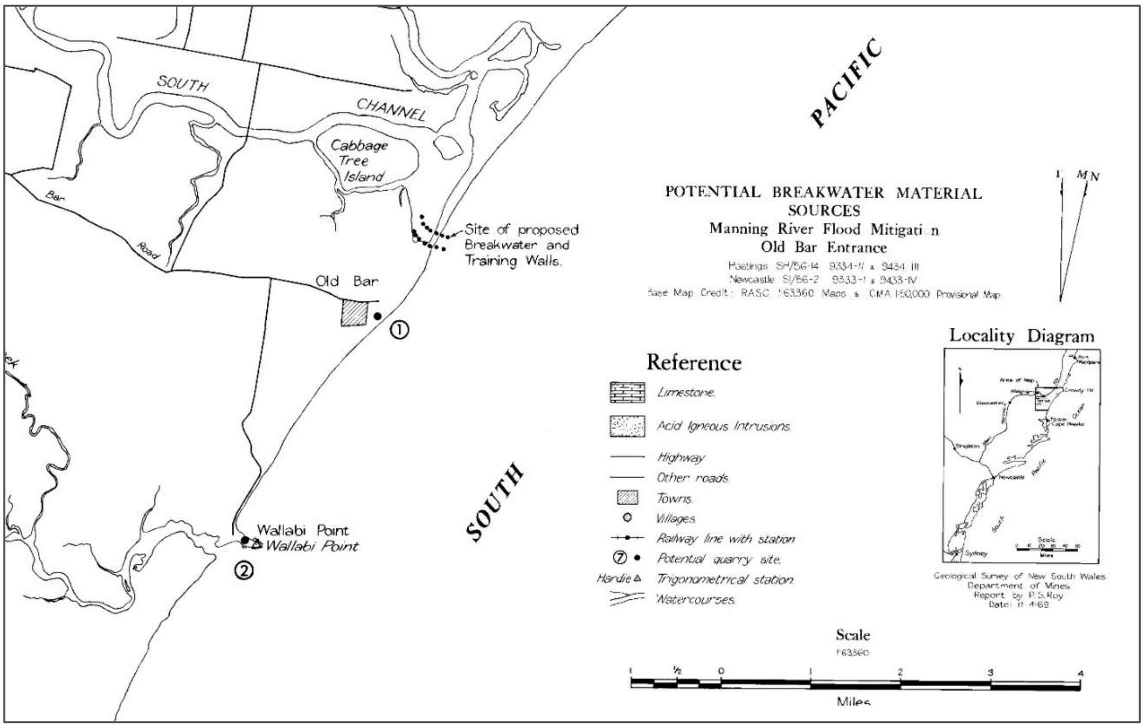


Figure A-1 Potential Breakwater Material Sources, Old Bar Region (source: GSNSW, 1969)

Note: Site 1 ‘disused road material quarry’ located south of Old Bar Surf Club, provides an early site record of bedrock located immediately behind the beach at Old Bar. The proposed breakwater at Farquhar Inlet for flood mitigation purposes, as mapped above, was never constructed.

A.2.2 Old Bar Sewerage: Appendix A - Borehole Information (PWD, 1981)

A borehole survey was completed for the Old Bar region by the Public Works Department (PWD) in 1981. The borehole survey sought information on the subsurface conditions to inform a sewerage system investigation for the township of Old Bar. The geological information formed the basis for the scheme’s costing.

Key points from PWD (1981) borehole survey relevant to the current coastal hazard investigation are summarised below:

- From the 12 boreholes surveys completed, 11 targeted the Old Bar region (see Figure A-2).
- Boreholes were augured to depths ranging between 4.5 to 6 metres.
- Seven (7) boreholes were drilled within the coastline region of Old Bar (around 200 metres from the shore) and the remaining four (4) were spread across the backshore slopes of the township.
- Substrate descriptions provided from the boreholes are very general (e.g. sand, clay, shale; and dry, firm, soft) and not consistent with current Australia Standards for Geotechnical Site Investigations. Nonetheless, the subsurface records provide a good indication of the varying near

surface geological conditions across Old Bar coastal zone, in the vicinity of the township. In summary:

- Sandy sediments were recorded near to the surface in the vicinity of Racecourse Creek;
- Clayey substrates were generally recorded across foreshore slopes and backshore areas. The clay encountered may represent a highly weathered bedrock material / residual soil, or colluvial deposit on sloping terrain;
- ‘Shale’ was recorded in two (2) boreholes, which indicates that durable rock was encountered.

The PWD (1981) borehole information has been mapped in GIS and analysed along with the Geotechnical Borehole Investigation undertaken for this study (see Appendix D for details).

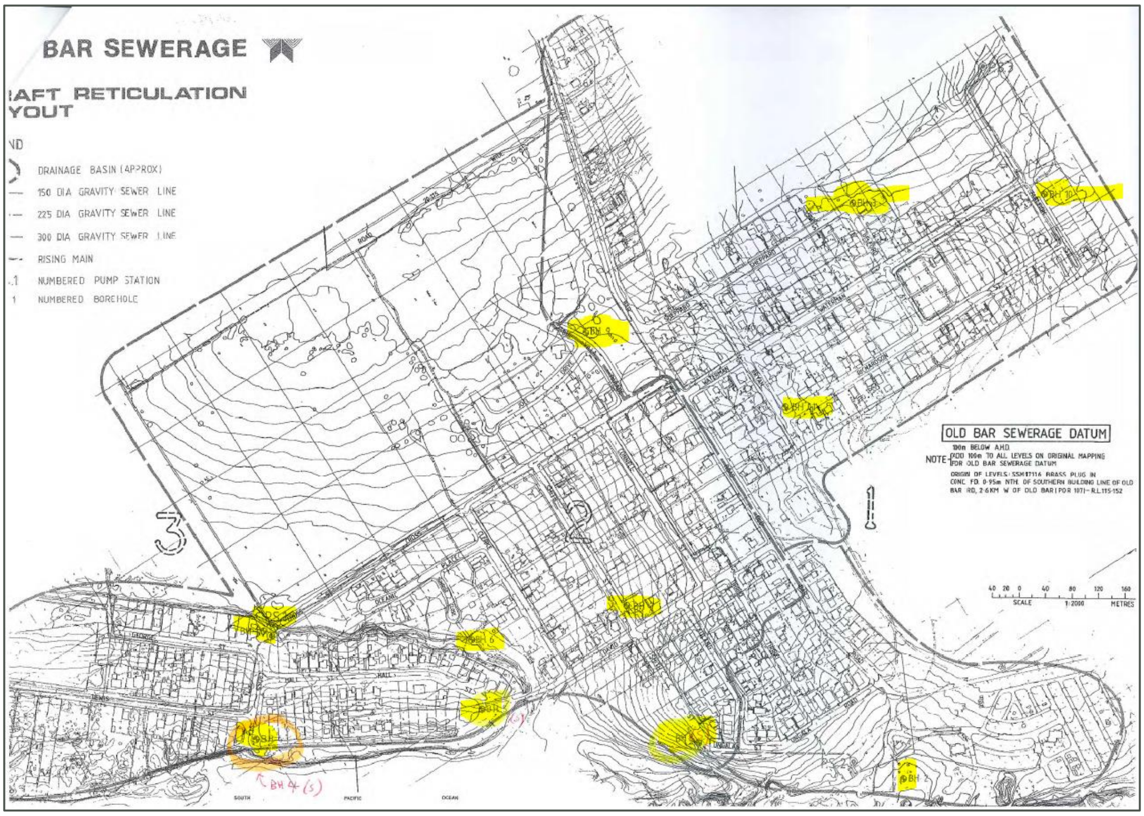


Figure A-2 Old Bar Sewerage: Draft Reticulation Layout, with borehole locations highlighted in yellow (Source: PWD, 1981)

A.2.3 Old Bar Coastal Erosion Study (Draft): Chapter 3 – Geomorphological – Geological Assessment (SKM, 1982)

A draft Coastal Erosion Study was completed for the Old Bar region by Sinclair Knight and Partners (SKP) in 1982. The study completed a geomorphological / geological assessment; photogrammetry analysis of beach condition and change; an analysis of wave, sediment transport and water level conditions; and a conceptual coastal processes model for Old Bar region (spanning Saltwarter Point to Crowdy Head). The SKM study is rich in data and analysis but was never finalised due to what was considered to be unsupported conclusions, according to MHL, 2017 who conducted a critical summary and review; the reader is referred to that report (MHL, 2017) for a holistic overview of the SKM (1982) study.

The geomorphological component of SKM (1982) is relevant to the current investigation. Coastal geoscience context and field survey information documented in that report includes:

- The geological setting of the study region described in terms of:
    - General areas and types of bedrock;
    - Quaternary sedimentary processes in relation fluctuating sea levels; and the
    - Geological characters of the (onshore) embayment sedimentary systems that span from Saltwater Point to Crowdy Head (comprising Pleistocene and Holocene age alluvial, estuarine and beach and dune sediments).
- Geomorphic descriptions of the following 5 distinct shoreline sectors that comprise the study region:
    - (i) Saltwater Point to Farquhar Inlet;
    - (ii) Farquhar Inlet;
    - (iii) Farquhar Inlet to Manning Point;
    - (iv) Harrington Inlet; and
    - (v) Harrington to Crowdy Head.
- An extensive sediment sampling program and associated sediment mapping, that extends to:
    - Beach and dune areas (+15 onshore sediment samples), that were used to produce an onshore geomorphology map of the study region;
    - Offshore areas (+120 marine sediment samples), that were used to produce marine substrate maps delineating the inner nearshore sediment facies, outer nearshore sediment facies, inner shelf sediment facies and areas of rocky reef; and
    - Riverine and estuarine area (+20 channel sediment samples), that were used to map fluvial, estuarine and marine delta deposits within the Manning River Estuary and Farquhar Inlet region.
- Geological borehole records (source undefined) synthesised to produce cross sections across the study region, which shows the cross shore geological profile for:
    - *Mitchells Island / Manning Point Beach* to comprise a narrow Holocene-age coastal barrier backed by a Pleistocene-age barrier dune, that transitions into a wide (~3km) sedimentary infill plain formed of Pleistocene-age sediments. The complex of coastal sediment deposits are underlain by deep ‘estuarine’ clays that extend from -5 m AHD to depths below -30 m AHD.
    - *Harrington Beach* to comprise a narrow Holocene-age coastal barrier, backed by a Pleistocene-age barrier and back barrier sediments, which are both underlain by thick deposits

    of estuarine clay. The elevation and depth of coastal sediments is greater in the northern region, which suggests that over geological timescales the accommodation space and rate sediment supply was greater to the north of Manning River.

- Offshore substrate and sediment distribution maps derived from the extensive offshore sediment sampling program, which shows:
    - The transition from the inner to outer nearshore sands to occur at depths of 5 to 10 metres below mean sea level (~250 to 300 metres offshore in south, and 500 metres offshore in the north);
    - The transition from the outer nearshore sediments and offshore sediments to occur at depths of around 20 to 25 m below sea level, some 1.0 to 1.5 kilometres offshore;
    - Extensive areas of rocky reef in the vicinity of Old Bar township, extending in east to west zones seaward of the surf club (i.e. Urana Bombora, and beyond) and offshore of Wallabi Point.
- No field evidence of extensive offshore sand shoal formation, except in vicinity of the Harrington Entrance where sands were deposited at 40 m below mean sea level.
- Riverine and estuarine channel sediment maps that show marine sourced sediments (flood tide delta) to extend some 5 km upstream of the Harrington Entrance, and 2 - 3 km upstream of the Farquhar Inlet.
- Shallow subsurface borehole (auger) results across the Old Bar township beach and dune areas, that show:
    - Bedrock located below the beach between the Caravan Park and Public School (Surf Club vicinity);
    - Clay and gravel deposits occur below the beach (with no rock encountered) towards Racecourse Creek inlet and further to the south;
    - Orange sands, cemented sands and clay sediments within the ‘sand dune’ area north of Old Bar / south of Farquhar Inlet, associated with the Pleistocene age beach barrier deposits observed by BMT (Appendix B) and outcropping adjacent to Farquhar Inlet.

In summary, the geomorphological and geological assessment reported in the Old Bar Coastal Erosion Study provides detailed context of the range of landforms, distribution of sediment and long term geological history of the area.

Based on the information within SKM (1982), the following points are noted in relation to the coastal erosion vulnerability of the Old Bar region:

- The distribution of onshore sedimentary landforms south of Old Bar are compartmentalised between bedrock hummocks. These sediment infilled bedrock embayments are relatively limited in extent, compared with the wide (geologically mature) estuarine plain that spans north of Farquhar Inlet.

- Bedrock areas are interpreted to extend landwards from Wallabi Point and Old Bar to join with back-beach rocky terrain. The southern limit of bedrock near to the Old Bar Public School is suggested to slope steeply below the beach near Racecourse Creek.
- The geometry of the (onshore) bedrock / sediment interfaces are mapped at a coarse / schematic scale (see Figure A-3). This indicates that coastal erosion will be limited by bedrock terrain in the vicinity of the Old Bar township. More detailed investigation is needed to better understand the nature of this geological boundary and confirm where the sedimentary landforms transition from erodible sediment into resistant rocky terrain.
- Isolated bedrock landforms are mapped near or adjacent to the coast at Saltwater Point, Harrington and Crowdy Head. Rocky hills at Mitchells Island and Oxley Island are also mapped within the estuarine floodplain region.
- The geographic extent of modern (Holocene-age) beach and dune sediments across the study area is relatively minor in comparison to the more extensive Pleistocene-age barrier deposits and alluvial/estuarine sediments that extend across the Manning River Estuary floodplain region. Also, the modern dunes are very narrow at Old Bar and along Mitchells Island / Manning Point Beach

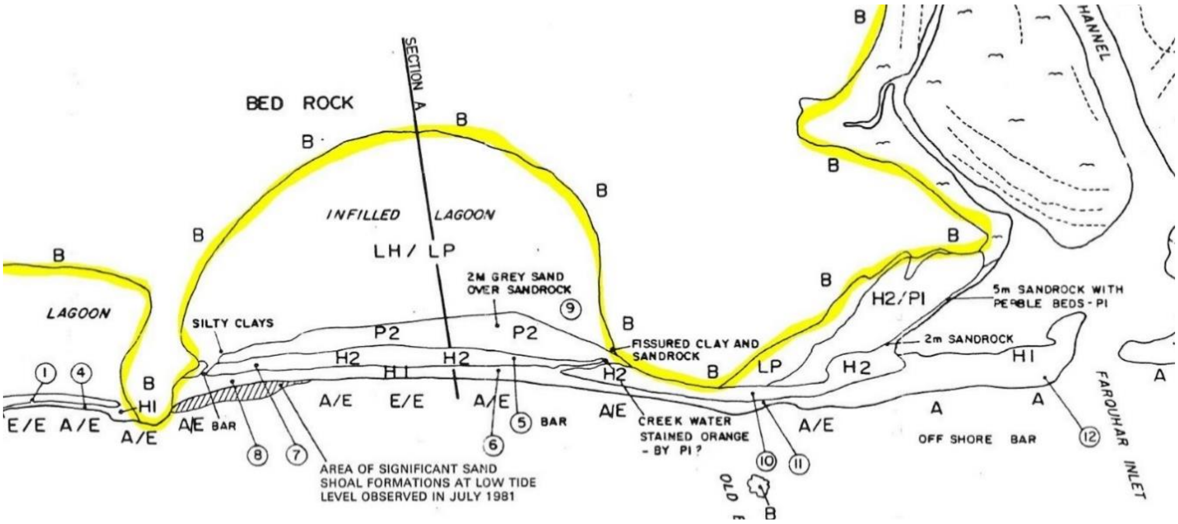


Figure A-3 Geomorphology of the Sedimentary Deposits at Old Bar, with 'B' denoting bedrock (modified from SKM,1982)

A.2.4 Bedrock Geological Mapping (GSNSW, 1970; 1987)

The geology of the Manning River region is located within the Hasting Block of the Lachlan Fold Belt, which comprises moderately hard metamorphic and igneous rocks (Chapman et al., 1982, in GSNSW, 2008). The bedrock geology has been mapped at a regional scale across the Old Bar study area of the present investigation through various mapping exercises, including:

- Hastings 1:250,000 Geological Series (Sheet SH/65-14), prepared by the Geological Survey of NSW in 1970; and

- Tamworth-Hastings 1:250,000 Metallogenic Map (SH/65 13-14, SI/65 1-2), prepared by the Geological Survey of NSW in 1987.

The 250:000 geology sheet for Tamworth-Hastings indicates that the study region is underlain by Carboniferous-age Koorainghat Beds (Old Bar region) and the Byabbara Beds (Crowdy Head), which form low grade metamorphic sedimentary sequences comprising lithic sandstone, siltstone, greywacke, shale and mudstone. These rocks are folded and faulted in places and trend (strike) in a southeast-northwest orientation, consistent with the geological structure of the region (e.g. Manning Fault System). Bedrock terrain is overlain by extensive deposits of coastal, estuarine and alluvial sediments (sand, silt, clay) within the Manning River estuarine plains.

Both the 1970 and 1987 regional scale geological maps indicate that bedrock terrain is located near to coast and Old Bar and Wallabi Point, with isolated bedrock landforms at Crowdy Head, Harrington. Tertiary-age gravel sediments are mapped at Mitchells Island and Oxley Island. More local scale investigations have shown these gravel deposits to comprise relic alluvial terraces that cap bedrock topographic highs (GSNSW, 2008).

A.2.5 Quaternary Geology of the Forster-Tuncurry Coast and Shelf Southeast Australia (Roy et al., 1997)

A research project led by the Geological Survey of NSW investigated the coastal geology and sedimentary evolution of the Forster-Tuncurry Sediment Compartment, which is located immediately south of the Manning Sediment Compartment. The detailed report describes coastal processes, coastal morphology, sediment types, sediment sources and the geological history of the Forster-Tuncurry coastal barrier system. The study synthesises an extensive geological dataset compiled from government, industry and academic studies, which applied a range of field methods (drilling, geophysics, sedimentology, mapping, dating).

The study identifies three main types of modern (Holocene-age) coastal sand deposits occurring in the study region (spanning the Tuncurry and Wallis Sediment Compartments), including:

- Coastal barrier deposits;
- Marine tidal delta deposits (and associated features); and
- Shelf sand bodies (or SBB).

Key physical processes and characteristics relating to the deposition and evolution of these features are also identified, including:

- Sea level change (including post glacial sea level rise);
- Coastal geological settings (such as embayment shape/accommodation space, shoreface slope, headland features);
- Sediment budgets (sand sources, sand sinks); and
- Prevailing coastal processes and sand flows (cross shore, alongshore sediment transport; see Figure A-4).

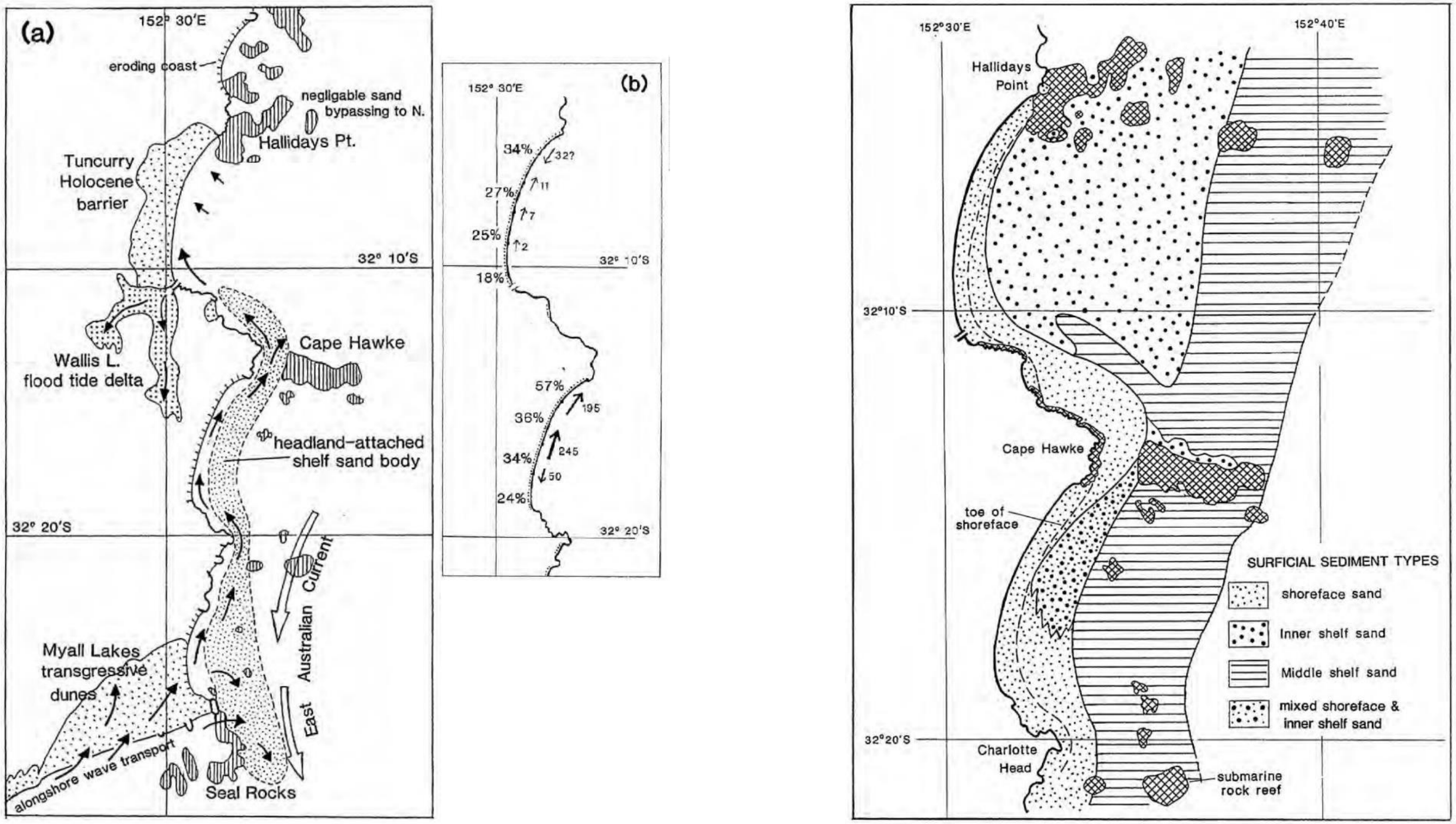


Figure A-4 Forster – Tuncurry Shelf Coastal Geology, showing (left - inset a) Holocene-age sediments and transport pathways; (left – inset b) wave energy and littoral sediment transport (x1000 m/yr); and (right) shelf sediment types and distribution (modified from Roy et al., 1997).

Note (left) the negligible sand bypassing to the north of Hallidays Point, and hence insignificant littoral sediment supply to the Manning Compartment.

Note (right) extensive shoreface and inner shelf sediments that provide continued onshore supply of sediment to Tuncurry shoreline.

The study region is characterised by two contrasting barrier systems (and sediment compartments), located either side of Cape Hawke Headland. In the north, the Tuncurry embayment is infilled with a wide barrier complex made up of several of prograded barriers deposits that span multiple sea level highstands (Pleistocene and Holocene). The extensive coastal plain represent a prolonged period of accretion (prograded barrier), which has been occurred due to a large accommodation space, and consistent sediment supply (sourced from adjoining low gradient sandy shelf and downdrift SSB) over geological times.

South of the Cape Hawke Headland, the Wallis embayment hosts a contrasting barrier morphology and history, with stacked barrier deposits (transgressive dunes) that have built up over past and present sea levels. A longshore transport system operates at this barrier deposit, and with no accommodation space remaining for the sediment, then sand bypassing occurs. A large headland attached SSB occurs on a relatively steeply sloping shoreface immediately offshore and downdrift (toe of the Cape Hawke) of the shoreline.

Detailed analysis on the sediment budget and shoreline evolution of the Tuncurry and Wallis Sediment Compartments by Roy et al (1997) provides valuable insight to contrasting coastal processes and sediment compartment characteristics, and the resultant coastal morphologies. This is very relevant to understanding coastal morphodynamics in a broader NSW wide context.

In relation to the Manning Sediment Compartment, the report identifies important geological characteristics of the region that have implications for Old Bar Beach and surrounds. In summary, the Tuncurry Sediment Compartment is characterised by an extensive prograded coastal barrier deposit, and associated wide, low gradient sandy shoreface. The coastal plain has built progressively seawards over the past 7,000 years due to continuous sediment supply from the adjacent shelf and downdrift SSB.

In contrast, the Manning Sediment Compartment has regular rocky reefs outcropping along its shoreface (SKM, 1982), with no discernible shelf sand body remaining, having been expanded from onshore transported in past geological times (MHL, 2017). Roy *et al* (1997) identified that negligible sand bypassing occurs around Hallidays Point, located at the northern boundary of the Forster-Tuncurry Sediment Compartment. This indicates that Manning Sediment Compartment does not receive any significant supply of sand from longshore sediment flows.

The lack of any onshore (shoreface) or longshore (updrift) sediment supply to the Old Bar coastline over geological timeframes has resulted in the relatively narrow Holocene-age barrier dune south of Harrington Inlet.

A.2.6 Taree Area Coastal Quaternary Geology Mapping (GSNSW, 2008)

Detailed geological mapping of the coastal plain regions of NSW coastal zone was undertaken by the Geological Survey of NSW in 2008. Quaternary geology mapping was prepared at a 1:25,000 scale for the north and south coast regions, including the Old Bar to Manning River study area. The mapping delineates sedimentary landform deposits across coastal sand barrier, estuarine and alluvial sedimentary environments. Quaternary sedimentary geological units are classified in detail, based on their geological age and a combination of geomorphology and sediment character. This mapping data for the Old Bar study region was documented in a seamless GIS dataset and the Taree Area 1:100,000 and 1:25,000 Coastal Geological Map series (see Figure A-5).

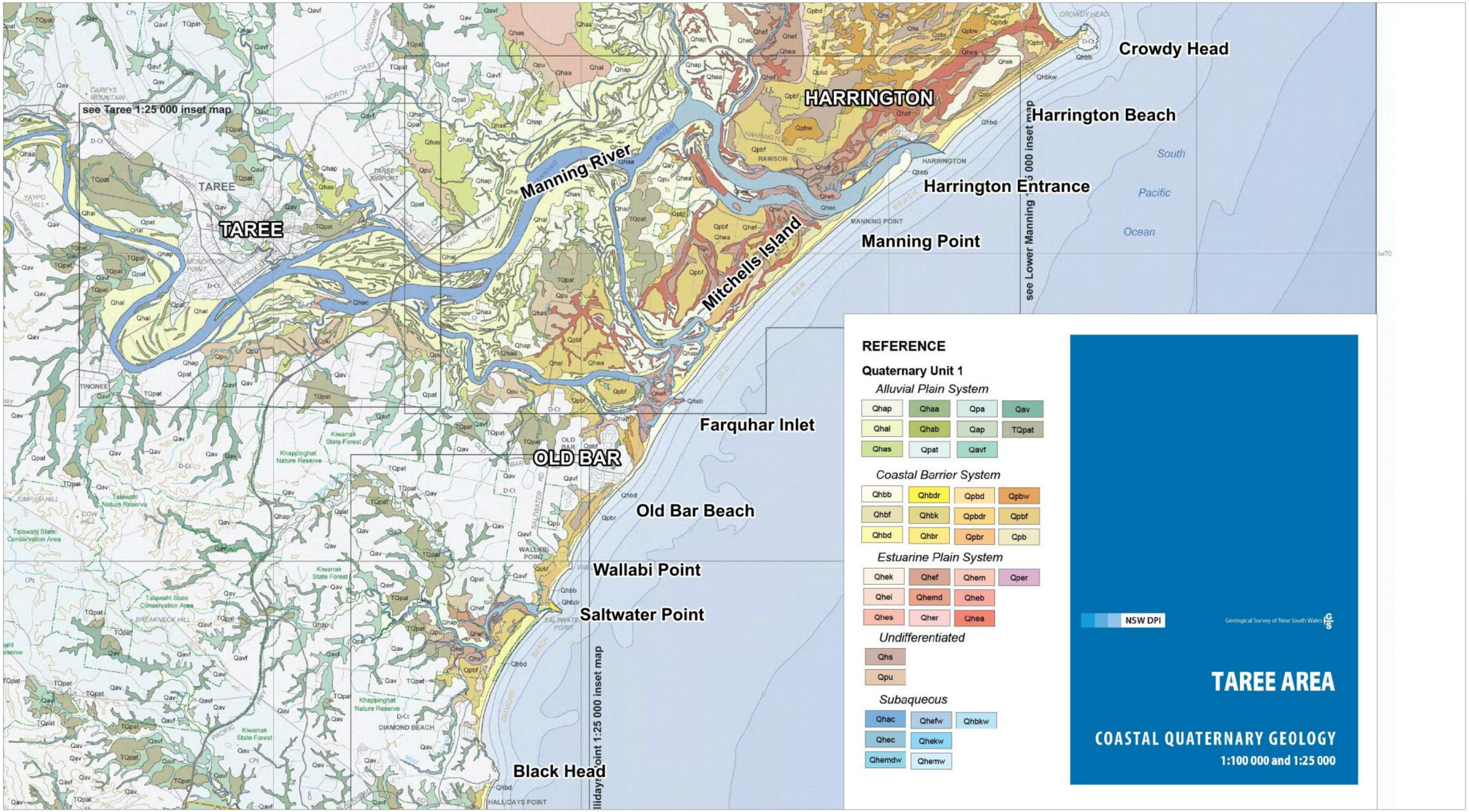
The Taree Area Coastal Quaternary mapping provides an update to the geomorphological maps presented in SKM (1982). Some key observations made in relation to the Quaternary Geology mapping are provided below, with reference to the coastal geological models for wave dominated coastline and NSW estuaries outlined by Roy et al. (1994) and Roy et al (2001) consecutively.

Wallabi Point to Old Bar: Compartmentalised Receding Barrier

- Onshore Quaternary age sedimentary deposits infill a relatively small, bedrock embayment between Old Bar and Wallabi Point. The distribution of mapped sediments (1:25,000 scale) support the interpretation that areas of the Old Bar township, north and west of Racecourse Creek, are located on bedrock terrain. The exact location and nature of the bedrock/sediment interface, and its associated geotechnical characteristics, are not defined at a scale suitable to characterise the limit of erodible coastal substrates.
- The geometry and distribution of these coastal and estuarine sediments include a narrow strip of modern (Holocene-age) beach and dune deposits backed by relic (Pleistocene-age) barrier dune sediments, and lagoon / freshwater sediments
- Bedrock mantling dunes are mapped over Wallabi Point, although no such sediments were observed by BMT during the walkover field investigation (Appendix B).
- Previous reports have identified features and trends that indicate the modern narrow barrier dune south of Old Bar form a receding barrier type (as per Roy et al., 1994 geological scheme of barrier deposits; see Figure A-6, left), including Pleistocene sediments (‘coffee rock’) exposed in an erosion scarp (SKM, 1982), historical trend of progressive erosion and shoreline recession (SKM, 1982; WorleyParsons, 2010a); and an sediment starved shoreface (SKM, 1982; MHL, 2017).

Farquhar Inlet to Crowdy Head: Mature River Estuary

- Manning River estuary comprises a complex of infill sediments, spanning Holocene and Pleistocene that forms an extensive estuarine / river deltaic plain, with common back-swamp areas and relic barrier dune deposits (see Figure A-5).
- The estuarine / riverine channel system is unusual, as it diverges at two locations, to form Oxley Island (south) and Mitchells Island (north). The estuary has two coastal inlets, including Farquhar Inlet (south), which behaves as an Intermittently Closed and Open Lakes and Lagoons (ICOLL); and the Harrington Inlet (north), which is an artificially open entrance.
- Occurrences of bedrock, Tertiary-age terraces, and Pleistocene-age estuarine and barrier deposits are mapped at Oxley Island and Mitchells Islands.
- A modern barrier dune deposit that spans Farquhar Inlet to Harrington Inlet is continuous, yet very narrow in places. This dune is interpreted to form a receding barrier type (see Figure A-6).
- A continuous modern barrier dune stretching north from Harrington Inlet to join with Crowdy Head, is interpreted to form a stable barrier type (see Figure A-6), supported by the northern Harrington breakwater that traps sediments that bypasses the estuary entrance to the north (MHL, 2017).



STUDY AREA

Wallabi Point to Crowdy Head

MANNING SEDIMENT COMPARTMENT

Black Head to Crowdy Head

Image source: NSW Geological Survey

Title:

Coastal Quaternary Geology
1:100,000 Taree Area Map

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Approx. Scale

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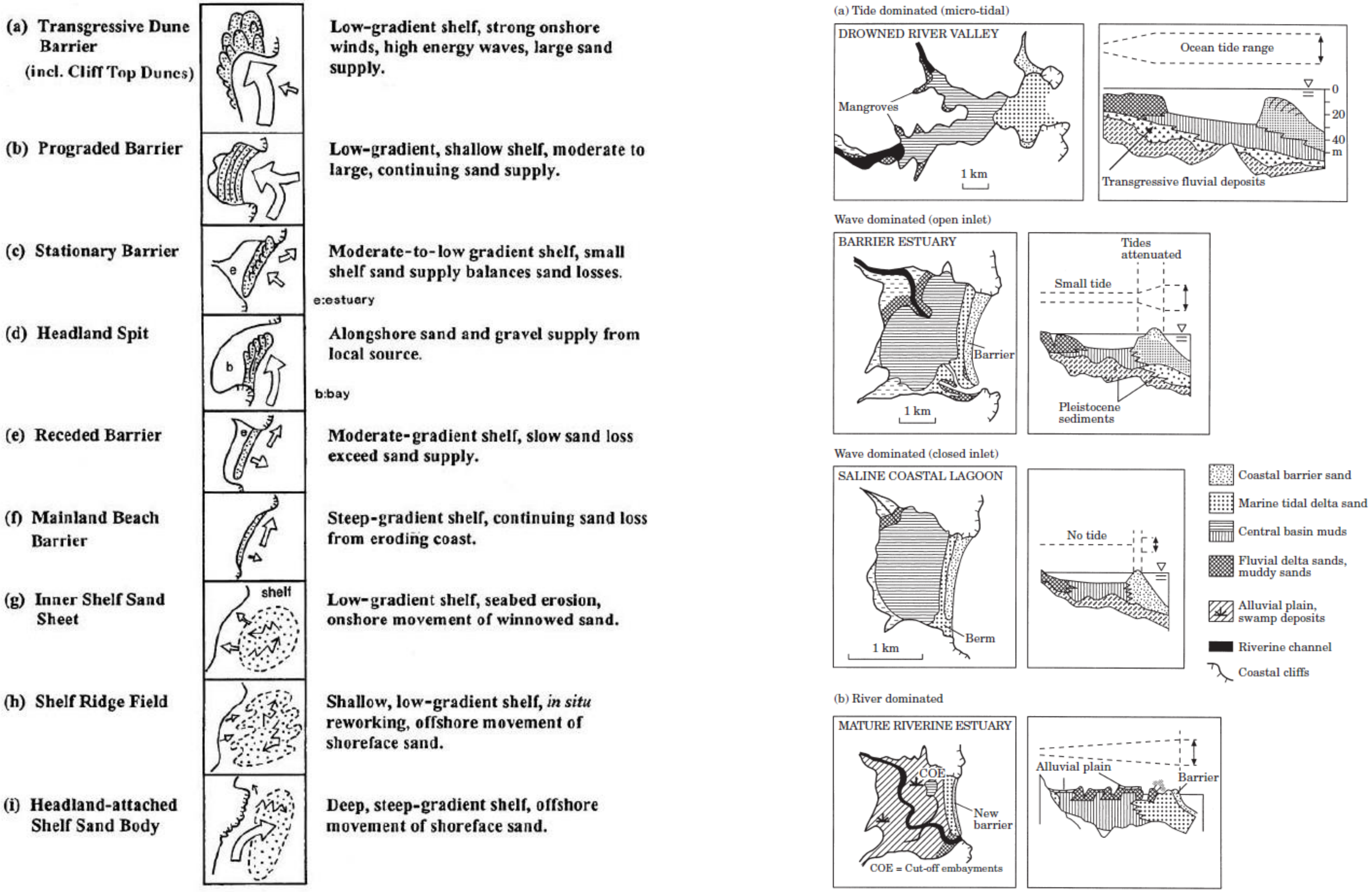


Figure A-6 Geological Models for: (left) Wave Dominated Coastal Barrier Coasts; and (right) NSW Estuary Types (source Roy et al., 1994; Roy et al, 2001), with the Receded Barrier (left) and Mature Riverine Estuary (right) representative of the Old Bar and Manning River Estuary geological framework.

A.2.7 Ground Penetrating Radar Data – Old Bar Beach Survey (GA, 2016)

Geoscience Australia (GA) completed a ground penetrating radar (GPR) survey at Old Bar in 2016 as part of a research initiative. GPR is a geophysical method that can be applied in coastal setting to investigate geological / sedimentological features (see further details in Appendix C). The GA (2016) field investigation aimed to identify and define a minimum thickness for the beach and dune systems, and depth to bedrock, or a pre-Holocene surface that may influence erosion potential.

Coastline areas were surveyed from north of Wallabi Point towards the Farquhar Inlet, with a focus on the beach and dunes near to the Old Bar Surf Club. Data was collected along 13 lines (excluding duplicates), including four shore parallel along the beach and nine shore normal across the beach and dune areas*.* Interpretation of the GPR profiles highlighted the presence of shallow bedrock in the near-shore and upper beach at several locations adjacent to the eroding sections near to the surf club. These results are documented in research papers and reports summarised below (see Nichol et al., 2016; GA, 2018).

The GPR field investigation completed by BMT for the current study (Appendix C) targeted nearshore and backshore areas that were not surveyed by the GA (2016) GPR investigation.

A.3 Coastline Processes, Hazards and Management Studies

A.3.1 Black Head to Crowdy Head Coastline Hazard Definition Study Volume 1: Report (WorleyParsons, 2010a)

A Coastline Hazard Definition Study was prepared by WorleyParsons (2010a) for the former Taree City Council coastline beaches that span from Black Head to Crowdy Head. The purpose of the study was to document the coastal processes operating along the study region, determine the coastal hazards characteristics and map coastal hazard extents.

Technical matters covered in WorleyParsons (2010a) which are relevant to the current study include: historical beach change, coastal processes, sediment budget, erosion / storm demand, shoreline response to sea level rise, geotechnical conditions (onshore/offshore), and coastal erosion hazard and risk profiles. This coastal hazard study provides a range of good information in relation to historic beach change, estuary entrance conditions over time, coastal processes modelling, and sediment budgets.

Table A-1 provides a summary of these above listed components, with specific reference to the Old Bar to Manning Point study region. Table A-2 documents the erosion and recession hazard mapping parameters adopted by WorleyParsons (2010a).

MHL (2017) highlights that while the WorleyParsons (2010a) identified a sediment budget link between the coastline beaches and estuary entrances of the Old Bar region, the hazard study does not consider the influence of past dredging activities on the historical coastline beach behaviour (i.e. progressive recession trend). As discussed further below, MHL (2017) argues that historic and ongoing dredging and removal of sands from the lower Manning River and Farquhar Inlets has created a significant sediment sink, which plays an important role in the observed shoreline recession. MHL (2017) also questions the interpretation provided by WorleyParsons (2010a) that offshore sediment losses from Old Bar Beach occur during storm conditions.

Table A-1 Summary of WorleyParsons (2010a)

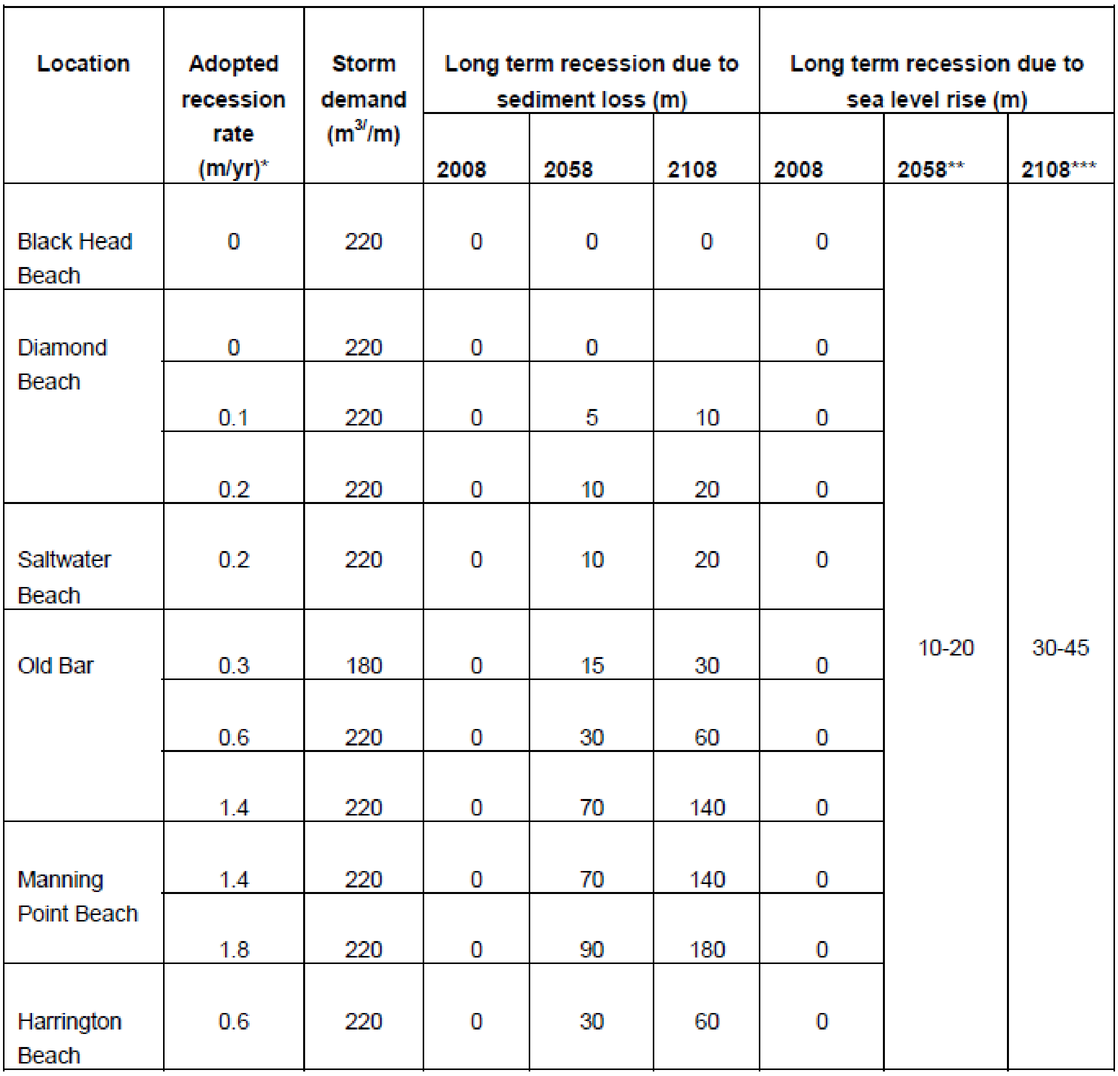
Geomorphology Element	Summary of Key Points from WorleyParsons (2010a)
Historical beach change	• Past studies documenting beach change were reviewed • A photogrammetry (1963/65 – 2006) assessment analysed beach volume (m3/m) and dune scarp changes (m/yr) • Wallabi Beach (referred to as Saltwater Beach): -0.7 m3/m/yr recession (net beach volume loss of 41,000 m3/m); and -0.2 m/yr recession of 5 m contour • Old Bar Beach volume change (south of Farquhar): -3.3 m3/m/yr recession (net beach volume loss of 677,000 m3/m), up to -11 m3/m/yr in central section of beach; • Old Bar Beach dune change (south of Farquhar Inlet): movement of 4 m contour has been variable; -1.4 m/yr at central beach section, -0.5 m/yr vicinity of Racecourse Creek, +0.1m Urana Bombora, and -1.2 m/yr adjacent Farquhar Inlet • Manning Point Beach: -3.5 m3/m/yr recession (net beach volume loss of 1,385,000 m3/m), greatest recession in middle and south up to -12.2 m3/m/yr; Contour movement (3 and 5 m) show net recession in middle and south (up to -1.9 m/yr), and net accretion in the north (up to +2.5 m/yr) • Harrington Beach: +0.8 m3/m/yr net accretion (net beach volume gain of 169,000 m3); 3 m contour movement generally shores seaward movement (rates between 0.3 and 1.0 m/yr), with areas just north of middle receding up to -1.2m/yr.
Sediment budget	• Sediment volume estimates for Manning River tidal inlets of 200,000 m3/m for Farquhar Inlet and Harrington Inlet 300,000 m3/m for Harrington were provided (based on Webb, McKeown & Associated, 1999) • Estuary entrances act as short term sediment sinks, with episodic supply (when marine delta sands scoured during flood/entrance breakout) • Relationship noted between Farquhar Inlet and beach conditions / shoreline orientation (closed conditions associated with eroded south end of Manning Point Beach, accretion of north end of Manning Point Beach, and slower accretion of Harrington Beach; open condition vice versa) • Aeolian sediment losses noted at Harrington Beach • Some gains and losses around Saltwater Point, Wallabi Point and Crowdy Head
Erosion / storm demand	• Storm bite values adapted from literature (Gordon, 1987) • 220 m3/m for open coast beaches; 180 m3/m in lee of Urana Bombora (500 m)
SLR response	• Mid and high level sea level rise (SLR) scenarios were provided for 50 year (2058 - 0.2 and 0.4 m SLR) and 100 year (2108 - 0.6 and 0.9 m SLR) timeframes • Depths of closure levels, and offshore/nearshore slopes were provided • An active beach width of 50 metres was adopted (slope = 1 in 50) to preparing the future recession hazard maps (Brunn Rule calculations)
Geotechnical conditions	• Rock reef mostly continuous between Wallabi Point and Old Bar; reef far less frequent north of Farquhar • Urana Bombora is a significant geological feature, rising above bed level

Geomorphology Element	Summary of Key Points from WorleyParsons (2010a)
	• Urana Bombora may continue inland to shallow depths behind the beach, but backbeach extent bedrock is unknown • Geological/geotechnical conditions outlined in SKM (1982) were summarised, including descriptions of coastline sectors, onshore and offshore sediments and borehole drilling results, noting rock below the beach adjacent to Urana Bombora and clay/gravels under the beach north and south of Old Bar SLSC
Coastal processes	• Wave modelling undertaken for a range of conditions • Wave refraction, littoral drift direction and 'null points' noted along Old Bar to Manning Point • A number of sediment loss mechanisms from the Old Bar Beach compartment are reported • Storm related events are recognised as the dominant driver for significant losses. Rips cells modelled adjacent to Urana Bombora are hypothesised as a sediment loss mechanism – with ~SE storms generating offshore rips that are suggested to transport eroded beach/dune sands offshore • Aeolian sand movement reviewed from past studies • Farquhar Inlet behaviour described, and entrance status documented (1940 – 2009) • A complex relationship appears to exist between the changes to beach erosion patterns of Manning Point Beach, north of Farquhar Inlet, and the southward movement of the closing entrance • Regional coastal processes model is proposed, noting complexity of sediment compartment and dynamic influence of major estuary entrances; and controlling geological feature (headlands, reefs)
Coastal Hazard and Risk	• Coastal erosion hazard line parameters, and setback distances applied to the Old Bar – Harrington Beach are summarised (see Table A-2), for the current and future planning timeframes • Assets affected by the hazard lines are documented, which include residential properties, public roads, community assets (e.g. SLSC) and stormwater/sewer assets

A.3.2 Greater Taree Coastline Management Study (WorleyParsons, 2010b) and draft Coastal Zone Management Plan (WorleyParsons, 2013)

A Coastal Zone Management Study (CZMS) prepared by WorleyParsons (2010b) for the Greater Taree Coastline, provides background for the associated Coastal Zone Management Plan (CZMP) prepared also by WorleyParsons (2013) for the area. These two documents follow on from the Coastline Hazard Study (WorleyPasons, 2010a) summarised above. *No new information on the on the geotechnical / geomorphological characteristics of the Old Bar region is provided in the Coastal Zone Management Study or Plan.* For that reason, a very brief summary of the CZMS and CZMP is provided below, with reference to the Old Bar present study site.

Table A-2 WorleyParsons (2010) Hazard Mapping Components



Location	Adopted recession rate (m/yr)*	Storm demand (m³/m)	Long term recession due to sediment loss (m)			Long term recession due to sea level rise (m)		
			2008	2058	2108	2008	2058**	2108***
Black Head Beach	0	220	0	0	0	0	10-20	30-45
Diamond Beach	0	220	0	0		0		
	0.1	220	0	5	10	0		
	0.2	220	0	10	20	0		
Saltwater Beach	0.2	220	0	10	20	0		
Old Bar	0.3	180	0	15	30	0		
	0.6	220	0	30	60	0		
	1.4	220	0	70	140	0		
Manning Point Beach	1.4	220	0	70	140	0		
	1.8	220	0	90	180	0		
Harrington Beach	0.6	220	0	30	60	0		

The **Greater Taree CZMS** provides a summary of key features, beach characteristics, and coastline processes and hazards for each sandy beach within the former Greater Taree local government area (LGA). A suite of potential management options targeting areas identified at most risk (i.e. Old Bar and Diamond Bay Beach) are also documented. The report evaluates nine (9) coastal erosion options at Old Bar (vicinity of Lewis Street) and identified a revetment as the management approach providing the highest benefit-cost ratio (1.4). Costs for the revetment option were estimated in the 10's of millions of dollars.

The **draft Greater Taree CZMP** was initially prepared for the entire (former) LGA coastline. Council adopted a planned retreat policy stance within the CZMP. Distance triggers were documented to remove or relocate structures and cease use of access roads and services (water, sewer and electricity) to affected properties.

The draft CZMP provides a good succinct summary of the coastal processes operating at each beach (as documented in the 2010 hazard study). This information has also been summarised and critically reviewed by MHL (2017).

A.3.3 Old Bar Beach Coastal Protection Structure Design Investigation (RHDHV, 2013a)

The former Greater Taree Council engaged Royal HaskoningDHV (RHDHV 2013a) to investigate structural solutions to manage threat from the aggressive shoreline recession to Old Bar Beach. The 2km study site spanned north from the Mid Coast Water exfiltration ponds to the Old Bar Surf Club. The study investigated a number of structural solutions, based on a suite of design criteria provided by Council. A rock revetment was the preferred option, to be constructed in three stages in order of priority at a cost in excess of $50 million over a +20 year timeframe. The report describes the proposed coastal engineering design.

Information provided in Appendix D and Appendix E of RHDHV (2013a) are relevant to the current investigation, as summarised below:

Appendix D: Available Borehole Logs for Old Bar Beach

- Borehole logs for Old Bar from various sources (PWD, 1981; SKM, 1982) are reproduced. A synthesis of this information is provided in Appendix D.

Appendix E: Assessment of Recession Trends, Design Wave Heights and Scour Levels

- An updated assessment of long term recession trends for Old Bar was completed by RHDHV, based on photogrammetry data provided by OEH.
- Records from 1940 to 2013 were assessed for the whole time period and also shorted periods of interest. The 4 m AHD dune contour was used to measure beach change.
- Long term plots show the rate of change to be variable and influenced by the creek entrance condition.
- It was concluded that the long term recession rate is in the order of 0.8 m/year in the vicinity of Lewis Street, with estimates more recent rates increasing to around 2.5 m/year.
- Water Research Laboratory (WRL) prepared a letter report that assess design wave heights and scour levels to inform the structure design (WRL, 2013).
- This WRL report is reproduced within Appendix E of RHDHV (2013a).

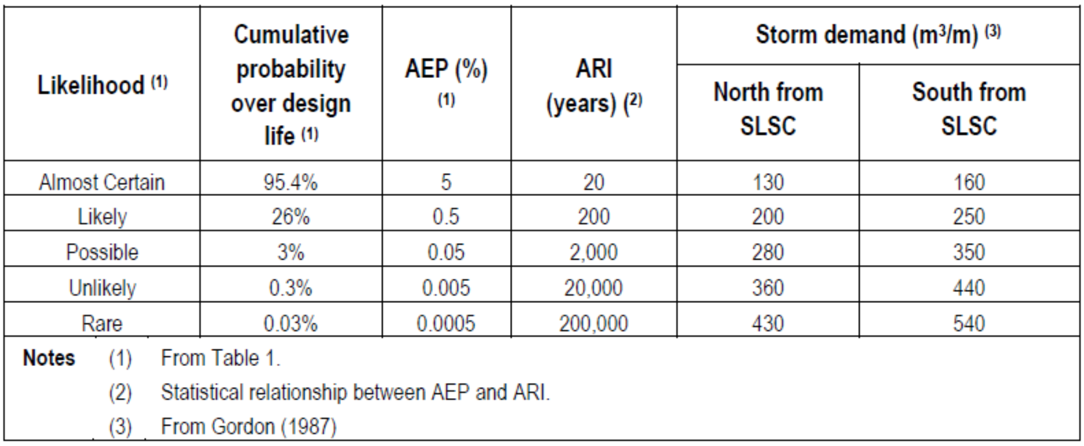
A.3.4 Risk Assessment to Define Appropriate Development Setbacks and Controls in Relation to Coastline Hazards at Old Bar (RHDHV, 2014a)

A coastal engineering report was prepared for the former Greater Taree Council to determine erosion risk setback lines. A key aim of the adopted approach was to account for uncertainty regarding the Old Bar shoreline response to prevailing coastal processes and future sea level rise. The hazard line method mapped the likelihood of erosion impacts to new development structures over a 60 year timeframe.

The Old Bar hazard mapping and risk assessment extended from Wallabi Point to the Caravan Park and assumed no bedrock or coastal protection structures were present. The study identified that the ‘northern’ section of Old Bar located behind the Urana Bombora, to behave differently to the ‘southern’ section of Old Bar. As such, different rates of historical recession and storm erosion demand were applied to the corresponding sections of coastline (e.g. Table A-3). The range of erosion hazard parameters and assigned probabilities adopted for this study are reproduced in Table A-4.

Erosion hazard lines with assigned likelihood estimates were mapped, based on the defined probability input parameters. Recommendations regarding acceptable levels of risk for new development were also provided, which gave consideration to the consequence of erosion impacts.

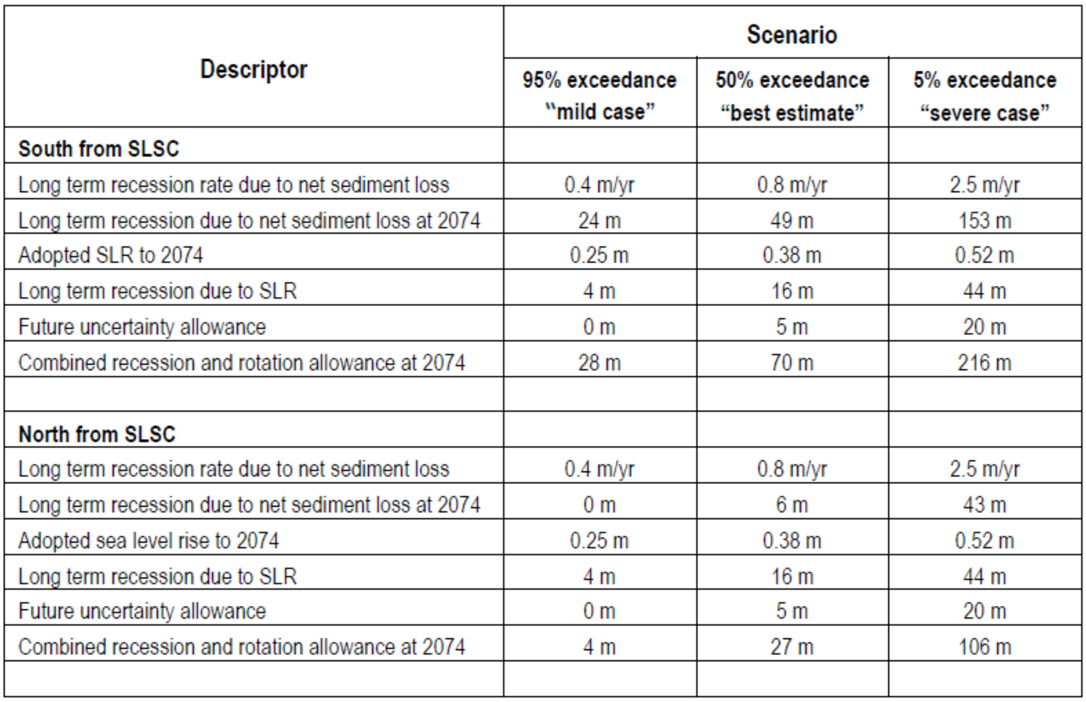
Table A-3 Old Bar storm demand likelihood (source: RHDHV, 2014)



Likelihood (1)	Cumulative probability over design life (1)	AEP (%) (1)	ARI (years) (2)	Storm demand (m^3/m) (3)	
				North from SLSC	South from SLSC
Almost Certain	95.4%	5	20	130	160
Likely	26%	0.5	200	200	250
Possible	3%	0.05	2,000	280	350
Unlikely	0.3%	0.005	20,000	360	440
Rare	0.03%	0.0005	200,000	430	540

Notes (1) From Table 1.
(2) Statistical relationship between AEP and ARI.
(3) From Gordon (1987)

Table A-4 Old Bar recession likelihood summary (source: RHDHV, 2014)



Descriptor	Scenario		
	95% exceedance "mild case"	50% exceedance "best estimate"	5% exceedance "severe case"
South from SLSC			
Long term recession rate due to net sediment loss	0.4 m/yr	0.8 m/yr	2.5 m/yr
Long term recession due to net sediment loss at 2074	24 m	49 m	153 m
Adopted SLR to 2074	0.25 m	0.38 m	0.52 m
Long term recession due to SLR	4 m	16 m	44 m
Future uncertainty allowance	0 m	5 m	20 m
Combined recession and rotation allowance at 2074	28 m	70 m	216 m
North from SLSC			
Long term recession rate due to net sediment loss	0.4 m/yr	0.8 m/yr	2.5 m/yr
Long term recession due to net sediment loss at 2074	0 m	6 m	43 m
Adopted sea level rise to 2074	0.25 m	0.38 m	0.52 m
Long term recession due to SLR	4 m	16 m	44 m
Future uncertainty allowance	0 m	5 m	20 m
Combined recession and rotation allowance at 2074	4 m	27 m	106 m

Note: inverse beach slopes of 15 (mild case), 43 (best estimate) and 84 (severe case) were adopted for Bruun Rule sea level rise recession calculations

A.3.5 Addendum to Coastal Zone Management Plan for Old Bar (RHDHV, 2014b)

An addendum to the draft Greater Taree Coastal Zone Management Plan (WorleyParsons, 2013) was prepared by RHDHV (2014b) for Old Bar (referred to herein as the Old Bar CZMP). The Old Bar CZMP outlines the rock revetment as an alternative approach to manage the long term hazards. The Old Bar CZMP 're-visits' management options for the Old Bar coastline, based on the updated hazard definition, recent investigations, and additional community consultation. This CZMP assumes that the Old Bar township is located on erodible substrate.

A.3.6 Old Bar Beach Sediment Tracing (RHDHV, 2016)

A sediment tracing investigation was completed for Old Bar to improve the understanding of littoral sediment transport processes. The study deployed sand tracer materials at three sites (south: exfiltration ponds; central: surf club; and north; south of Farquhar Inlet), and then subsequently collecting samples for analysis between Wallabi Point and Manning Point Beach. Samples were collected during 5 field visits, over a 14 month period, with sands being collected from the beach, surf zone and nearshore area.

Some key interpretations arising from the study are as follows:

- A predominantly northward littoral drift system operates at Old Bar, with some minor southward drift occurring. This is consistent with the wave climate experienced at Old Bar and its shoreline orientation.
- Sediments bypassing north of Urana Bombora was observed, showing that the reef does not form a complete barrier to longshore sediment flows.
- Longshore drift of sediment north of Farquhar Inlet was observed, showing that some sands bypasses the tidal inlet over a period when the inlet condition was open and migrated southwards during the study period (reported to indicate a closing entrance state).
- Tracer material was recorded at -12 m AHD, indicating that cross shore sediment transport occurs. The short term length of the study was unable to resolve if sands eroded offshore become transported back onshore, as this process occurs over longer timescales; MHL (2017).
- Some red tracer material was collected from Farquhar Inlet, but no yellow or orange material was observed. RHDHV considered this result to indicate that Farquhar Inlet does not act as a significant sediment sink. However, as noted by MHL (2017) sampling from the Farquhar delta region was limited, and therefore unlikely resolved the degree to which eroded Old Bar Beach sands flowed into the inlet region during the investigation period.

A.3.7 Erosion Analysis of the Manning Valley Coastal Sediment Compartment (MHL, 2017)

A detailed review and analysis of coastal processes and erosion characteristics of the Manning Valley Sediment Compartment was completed by MHL in 2017. This study involved: undertaking a review of previous investigation and information; the development of a conceptual quantitative coastal process model for the Manning Valley coastal sediment compartment; a review of past and ongoing practices; and the development of recommendations to better manage the observed erosion.

The study provides a holistic and critical review of relevant coastline and estuary studies, with an aim to provide an improved understanding of the observed beach erosion to better inform coastal management decision making. Central to the study was development of an evidence based coastal process model and the establishment of a quantitative sediment budget for the Manning Valley sediment compartment (see Figure A-7).

Some important physical characteristics highlighted by MHL (2017) for the Manning Valley sediment compartment are as follows:

- The compartment extends across 32 km, from Hallidays Point (Black Head) to Crowdy Head.
- The compartment contains two major tidal inlets to the Manning River Estuary: Farquhar Inlet to the south and Harrington Inlet to the north.
- There is no discernible sand body offshore of the study area, with extensive rocky reefs along the seabed north of Hallidays Point.
- Hallidays Point headland acts as a boundary between any alongshore sediment transport from the southern Forster/Tuncurry coastal sediments compartment (i.e. the Forster/Tuncurry compartment is a sediment sink, with an insignificant supply of sediment flowing north into the Manning Valley compartment).
- As such, Manning Valley compartment shoreline behaviour and position is highly dependent on the local coastal processes and its sediment budget.
- The sediment budget is complicated by a fluctuating marine flood tide delta sediment source and sink dynamic, which comprises intermittent catchment flooding - that delivers sediment to the coastline, and progressive delta infilling and growth – that removes sediment from the coastline.
- The shoreline position is also influenced by short to medium term changes in wave energy and wave direction (beach rotation)

The key physical processes determined to have the most significant influence on sediment flows and shoreline change over planning timeframes are as follows:

- Entrance marine delta dynamics;
- Longshore and cross-shore sediment transport, and
- Anthropogenic influences (i.e. sediment removal via dredging)

A quantitative sediment budget outlined in the report proposes for 126 years (up to 2015) that:

- *Total sediment inputs of approximately 4.4 million* m^3; and a
- *Total system outputs of approximately 11.7 million* m^3, including one off losses (sand mining, dredging); which has resulted in a
- *Net sediment deficit of 7 million* m^3, which correlates reasonably well with the observed long term recession.

Figure A-7 summarises the Manning Valley sediment budget proposed by MHL (2017).

The report advises that the coastal erosion management options proposed thus must be reconsidered given the: (a) improved understanding of the sediment budget; and (b) demonstrated anthropogenic factors responsible for observed long-term and recently accelerated beach recession.

A.3.8 Estuary Studies / Management Plans: Manning River and Farquhar Inlet

While the scope of the current study is focused on the coastline setting of the Old Bar region, it is evident through this literature review process that the coastline and estuary interactions are important for Old Bar from a sediment budget and shoreline response perspective. This sediment interaction have identified in several studies (e.g. WorleyParsons, 2010a; MHL, 2017; Gravois et al., 2018).

MHL (2017) has provided a review of several key estuary management studies and plans, which outline entrance characteristics and past human activities, which form an important component in understanding the Manning Sediment Compartment coastal processes and sediment budget. For reference, the estuarine studies are listed below.

- Manning River Estuary Processes Study (Webb, McKeown & Associates, 1997)
- Proposed Dredging of the Manning River for Harrington Waters Estate, Harrington, Environmental Impact Statement (WBM Oceanics, 2002)
- Farquhar Inlet, Old Bar Entrance Opening Management Plan (WorleyParsons, 2010c)
- Harrington Waters Dredging Project Final Environmental Management Report (Umwelt, 2015)

MHL (2017) provides a summary of the estuary processes and sediment budget parameters outlined in the above. As such, these reports are not reviewed herein.

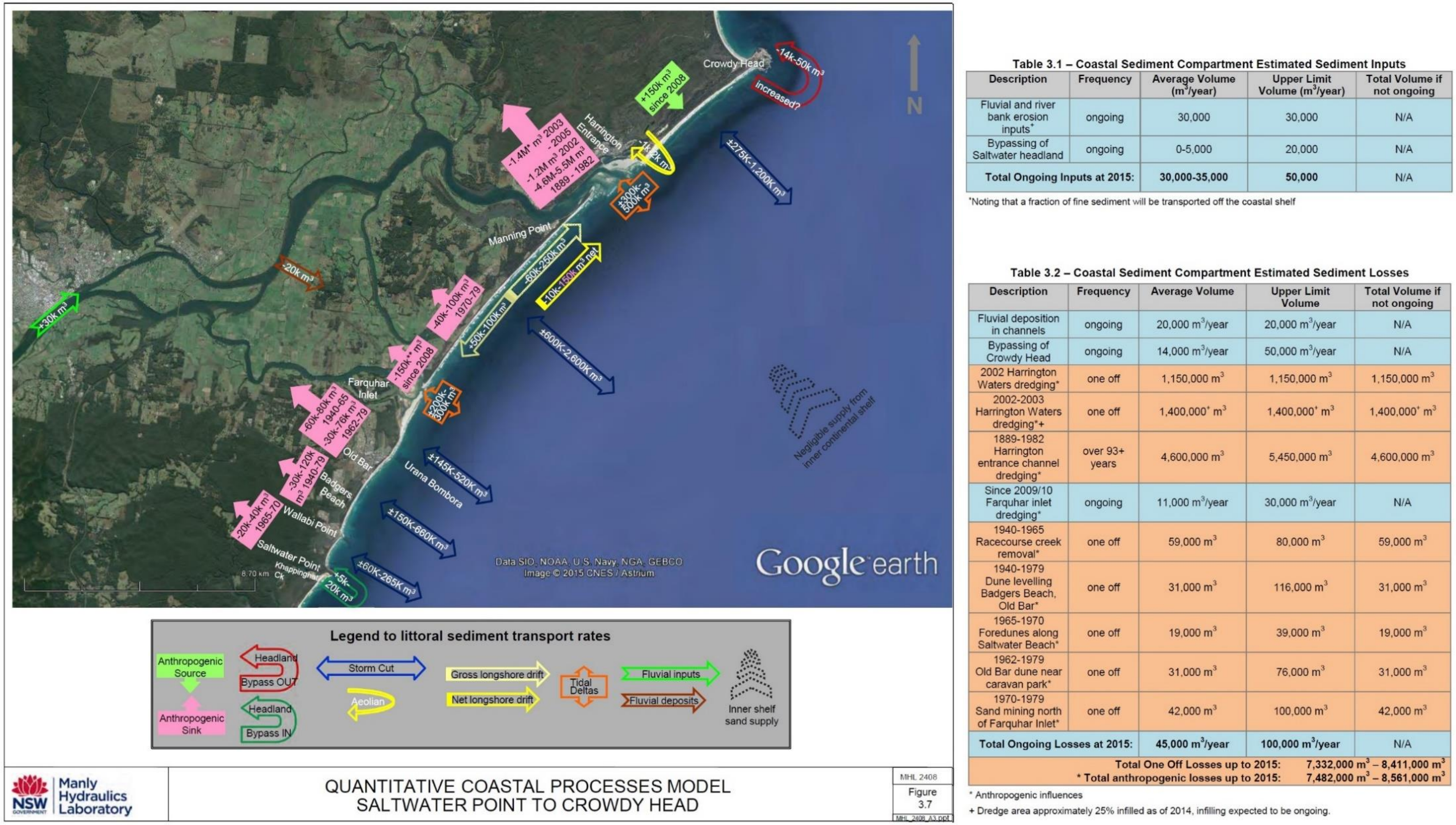


Table 3.1 – Coastal Sediment Compartment Estimated Sediment Inputs

Description	Frequency	Average Volume (m^3/year)	Upper Limit Volume (m^3/year)	Total Volume if not ongoing
Fluvial and river bank erosion inputs^{+}	ongoing	30,000	30,000	N/A
Bypassing of Saltwater headland	ongoing	0-5,000	20,000	N/A
Total Ongoing Inputs at 2015:		**30,000-35,000**	**50,000**	N/A

'Noting that a fraction of fine sediment will be transported off the coastal shelf

Table 3.2 – Coastal Sediment Compartment Estimated Sediment Losses

Description	Frequency	Average Volume	Upper Limit Volume	Total Volume if not ongoing
Fluvial deposition in channels	ongoing	20,000 m^3/year	20,000 m^3/year	N/A
Bypassing of Crowdy Head	ongoing	14,000 m^3/year	50,000 m^3/year	N/A
2002 Harrington Waters dredging*	one off	1,150,000 m^3	1,150,000 m^3	1,150,000 m^3
2002-2003 Harrington Waters dredging*+	one off	1,400,000^{+} m^3	1,400,000^{+} m^3	1,400,000^{+} m^3
1889-1982 Harrington entrance channel dredging*	over 93+ years	4,600,000 m^3	5,450,000 m^3	4,600,000 m^3
Since 2009/10 Farquhar inlet dredging*	ongoing	11,000 m^3/year	30,000 m^3/year	N/A
1940-1965 Racecourse creek removal*	one off	59,000 m^3	80,000 m^3	59,000 m^3
1940-1979 Dune levelling Badgers Beach, Old Bar*	one off	31,000 m^3	116,000 m^3	31,000 m^3
1965-1970 Foredunes along Saltwater Beach*	one off	19,000 m^3	39,000 m^3	19,000 m^3
1962-1979 Old Bar dune near caravan park*	one off	31,000 m^3	76,000 m^3	31,000 m^3
1970-1979 Sand mining north of Farquhar Inlet*	one off	42,000 m^3	100,000 m^3	42,000 m^3
Total Ongoing Losses at 2015:		**45,000 m^3/year**	**100,000 m^3/year**	N/A
Total One Off Losses up to 2015: *** Total anthropogenic losses up to 2015:**				**7,332,000 m^3 – 8,411,000 m^3** **7,482,000 m^3 – 8,561,000 m^3**

* Anthropogenic influences

\+ Dredge area approximately 25% infilled as of 2014, infilling expected to be ongoing.

Figure A-7 Proposed Coastal Processes Model and Sediment Budget for the Old Bar Region, summarised in a map showing of sediment flow paths and rates (left); and tables detailing sediment budget inputs (right top) and losses (right bottom; adapted from MHL, 2017).

A.4 Academic Literature

A selection of the Old Bar specific studies and project outputs by research partners Geoscience Australia (GA) and the University of Queensland (UQ) are summarised in the following sections. This selection of coastal geomorphology and engineering research work was completed under the 'Resilience to Clustered Disaster Events at the Coast: Storm Surge' project (through the Bushfire and Natural Hazard Cooperative Research Centre).

A.4.1 A framework for modelling shoreline response to clustered storm events: A case study from southeast Australia (Nichol et al., 2016)

A framework for modelling shoreline response to clustered storm events at Old Bar Beach is presented in this paper. The study adopts a coastal sediment compartment approach to quantifying the erosion impact of clustered storm events, which incorporates sediment thickness in the upper beach and foredune.

The physical characterises of the study site are characterised based on sediment mapping, landform distribution and subsurface imaging of the buried bedrock surfaces with GPR (Figure A-8). This information was used to characterise local scale variability in sediment distributions that might otherwise have been assumed uniform for shoreline response modelling purposes.

The paper outlines an approach to developing synthetic time series of extreme storm events, based on observed wave data from Crowdy Head. The best fitting statistical model was able to replicate key properties of the observed record. While event clustering was not found to be strong, the model does provide an appropriate input for modelling shoreline response to successive events by defining the time available for beach recovery for a given antecedent beach state (Nichol et al., 2016).

Of most relevance to the current study - Nichol et al. (2016) demonstrates that GPR is a suitable technique for imaging the sediment rock interface at Old Bar Beach in the vicinity of the Urana Bombora. This location aligns with the beach slopes where bedrock has been described as possibly occurring by others (e.g. WorleyParsons, 2013).

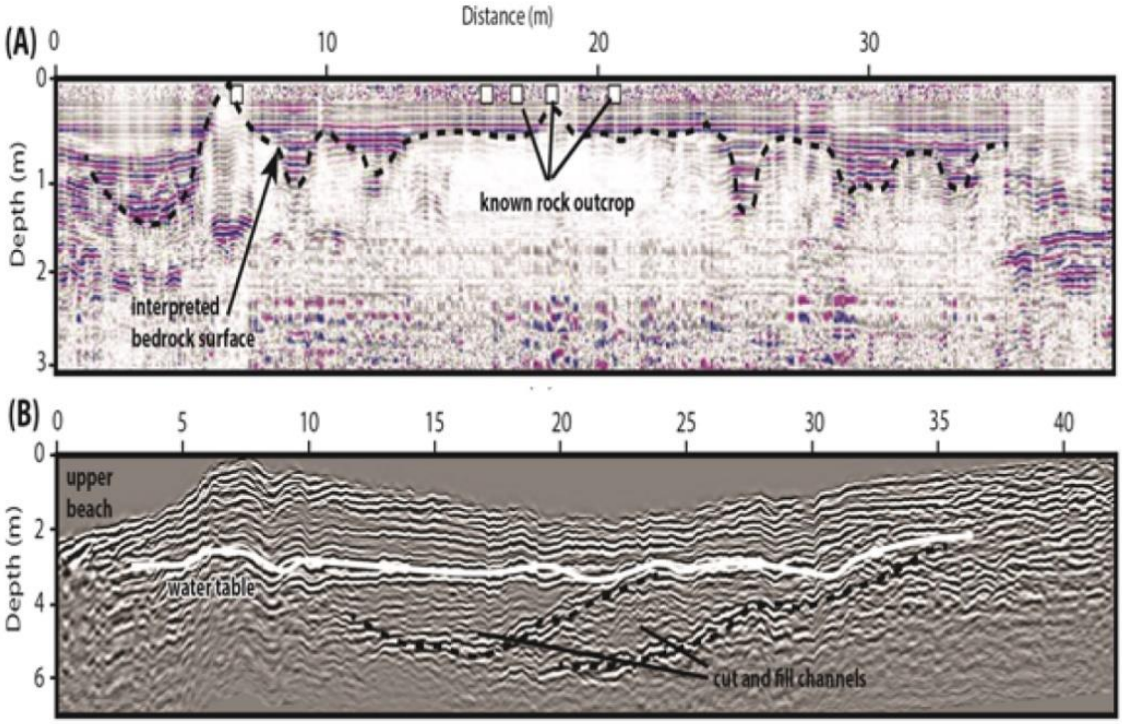


Figure A-8 GPR profiles for Old Bar Beach (250 MHz) showing: (A) shore parallel beach section near Urana Bombora with thin sands (1-2 m) over undulating bedrock subsurface; and (B) cross shore-shore beach/dune section at Farquhar Inlet, showing sands and channel fill (source: Nichol et al., 2016)

A.4.2 ESRI StoryMap: Coastal Erosion, Understanding Cause, Response and Impact [Online] (GA, 2018)

An ESRI StoryMap available online brings together a range of GA and UQ coastal erosion research completed at Old Bar Beach (NSW) and Adelaide metropolitan beaches (SA). The framework presented for understanding coastal erosion impacts from storm clusters is summarised below:

- **Step 1: Understand the context,** through collecting site specific data (topography, geography, geology and geomorphology) guided by a sediment compartment framework.
    - National scale datasets were used to understand the context at Old Bar (sediment compartment mapping, and smartline geomorphology mapping);
    - Field surveys including sediment sampling and GPR surveys were completed to investigate the main landforms of interest, areas of erodible sand and sediment thickness;
    - GPR highlighted the presence of shallow bedrock in the nearshore and upper beach at several locations.
- **Step 2: Investigate drivers for beach erosion** through analysis of observational records (wave buoys) or from wave and wind models, which can be used to model sediment transport along the coast.
    - Storm history and activity with a focus on storm clusters, was analysed to develop a synthetic wave record with statistical characteristics similar to the observed record;

  - Storm events were defined at Old Bar where wave heights (Hs) exceeded the 5th percentile of the total wave record (i.e. wave heights greater than 2.93 m).
- **Step 3: Model beach response** to successive storm events.
  - Beach erosion in response to a range of AEP storm cluster events were modelled, using EVO MOD software that accounts for cross-shore, longshore sediment transport and changes in wave direction and height. Results were mapped for Old Bar (see Figure A-9);
  - Beach change modelling was used to assess longshore variation in beach response to storms;
  - Modelling did not account for the effects of future sea level rise;
  - Other limitations noted included the limitation of incomplete wave records; assumptions within EVO MOD (e.g. dune recovery oversimplification); and SWAN wave modelling uncertainties (e.g. directional spreading).

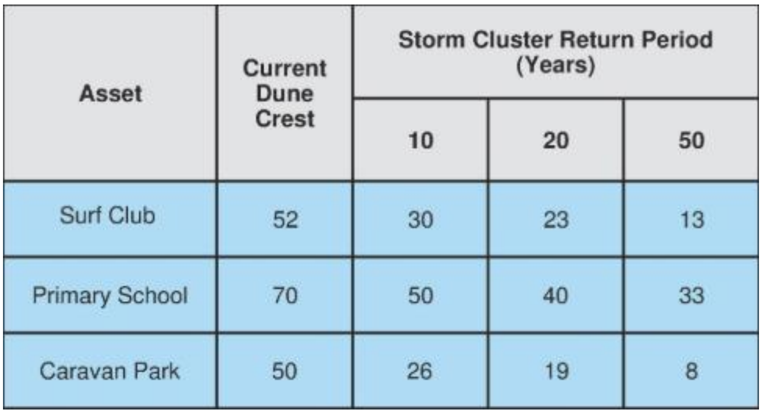
The blue line represents the current location of the dune crest and the other lines define the dune crests following beach erosion events with expected annual exceedance probabilities (AEP) of 10%, 5% and 2% (or equivalently return periods of 10, 20 and 50 years). Where the modelled dune crest is further landward than a building, that building is assumed to be uninhabitable.

The following air photo maps show each building roof colour coded according to proximity to the modelled dune crest position at each return period.

Proximity to the 2% AEP (or the 50 year return period) erosion event dune crest identifies that 26 buildings are exposed, a further 9 buildings are within 10 m of the dune crest and a 280 m section of Pacific Parade is exposed.

Figure A-9 ESRI StoryMap Screen Shot: EvoMod Coastal Erosion Modelling for Old Bar, showing 10%, 5% and 2% AEP Storm Cluster Erosion Events (top) and Modelled Infrastructure Impacts for a 2% AEP Erosion Event (bottom) (source: BNHCRC, 2019)

Table A-5 **Measured distances (metres) between Old Bar infrastructure and dune crests based on beach erosion events with 10%, 5% and 2% AEP (source: BNHCRC, 2019).**



Asset	Current Dune Crest	Storm Cluster Return Period (Years)		
		10	20	50
Surf Club	52	30	23	13
Primary School	70	50	40	33
Caravan Park	50	26	19	8

A.4.3 The Effects of Storm Clustering on Storm Demand and Dune Recession at Old Bar NSW (Gravois et al., 2018)

This paper applies numerical and probabilistic modelling to further investigate the influence of storm clustering on beach erosion and dune recession at Old Bar Beach, using a range of modelling tools (including EVO MOD, SWAN). Storm clustering refers to the individual/discrete storms occurring at close succession, and the impacts of such events are typically additive (i.e. cumulative) in terms of net erosion to a beach.

Storm demand and shoreline position were simulated over a 50 year period for Old Bar Beach, along with modelling morphological response to clustered storm events. Erosion demand volume return periods were compared between clustered and non-clustered storm events, and the total population of individual events. Analysis found that erosion demand from clustered storm events with a 50 year return period is 25% greater than that for individual storm erosion events at Old Bar Beach. This can also be explained as a 50 year ARI (average return interval) storm erosion from a single storm event being equivalent to a return period of 17 years for clustered storm event. Nonetheless, it was found that individual storms can generate the same erosion demand as clustered events, although the likelihood of such individual events occurring is less.

A range of coastal process modelling at Old Bar Beach and surrounds was completed to inform the above analyses, which is insightful to the current investigation. Some key points in this regard are as follows:

- Old Bar region wave climate: typically experiences 20 - 25 storms per year, with a few more in La-Nina year; highest frequency of storm in July (winter); is dominated by southerly waves; and has a 50 year return period storm wave height of 7 m (Figure A-10); easterly swells can have a higher impact on the coast, relative to higher return period events from the south (Figure A-11).
- Sediment budget and transport: sediment flows were modelled in EVO MOD, which adopted a balanced net (neutral) annual sediment budget sediment budget assumptions, contrasting with the net negative sediment budget proposed by MHL (2017). Modelling results indicate that Old

Bar Beach is characterised by average net northward littoral transport of around 40,000 m^3/yr, with much larger north and south gross transport rates indicating wave direction (climate) is important (see Figure A-12)

- Dune movement: Dune position modelling simulated the dune toe position to oscillate through typical range of about 40 metres over 50 years, which is consistent with the expected storm demand from the clustering analysis undertaken. Ongoing recession of 0.5 to 1 metre per year was modelled, consistent with previous studies
- Erosion demand and clustering analysis: Synthetic erosion modelling found that 200 m^3/m was exceeded for 50 year demand scenarios, with individual 50 year storm demand volumes of ~240 m^3/m modelled, and ~300 m^3/m storm demand volumes for combined clustered and non-clustered events (see Figure A-13, left). However, the median storm demand for non-clustered events was of a similar magnitude to that of the clustered events (see Figure A-13, right).

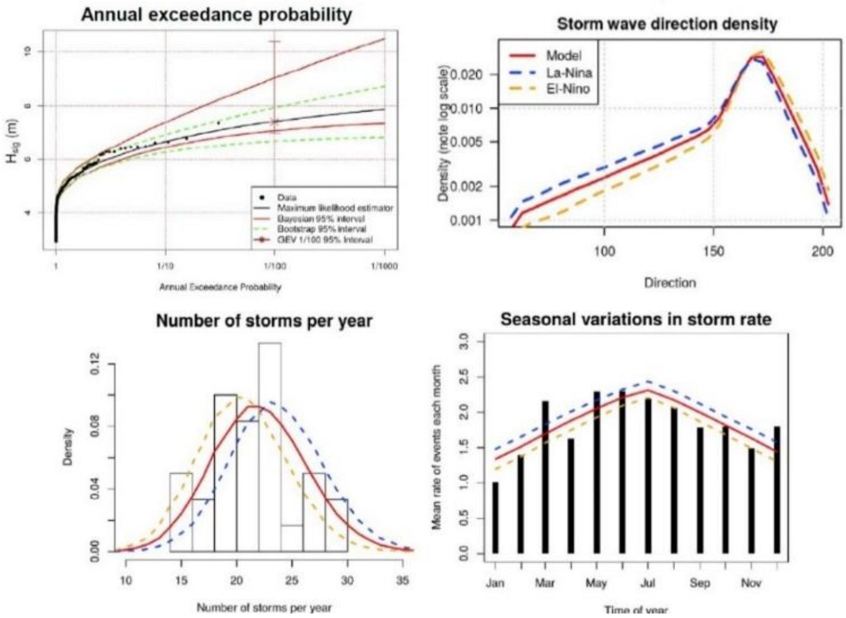


Figure A-10 Old Bar Wave Climate: (far left) Number of storms per year; (middle left) seasonal distribution of storms; (middle right) storm wave direction density; (far right) annual exceedance probability plot (from Davies et al., 2017, in Gravios et al., 2018)

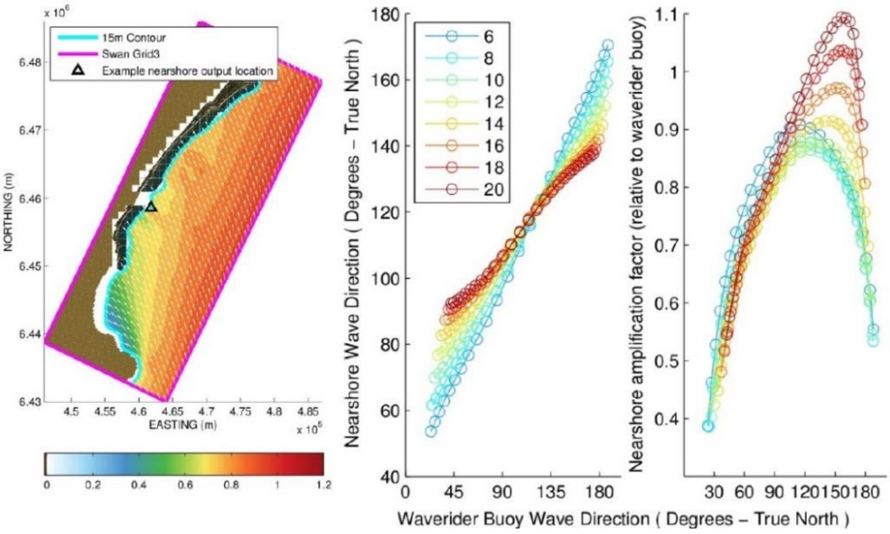


Figure A-11 SWAN wave model: (left) normalised wave height and direction; (middle) nearshore wave angle; and (right) nearshore wave amplification (source: Gravios et al., 2018)

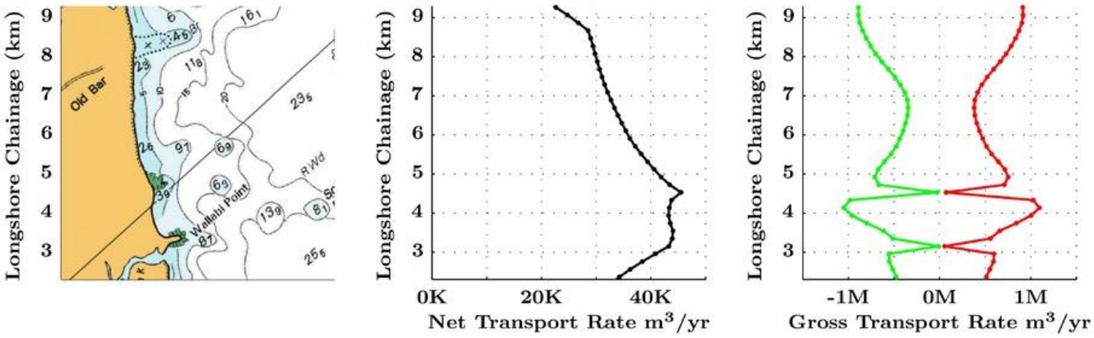


Figure A-12 Simulated Sediment Transport for Old Bar, showing 50 year average net (middle) and gross (right) longshore transport modelled in EVO MOD (source: Gravios et al., 2018)

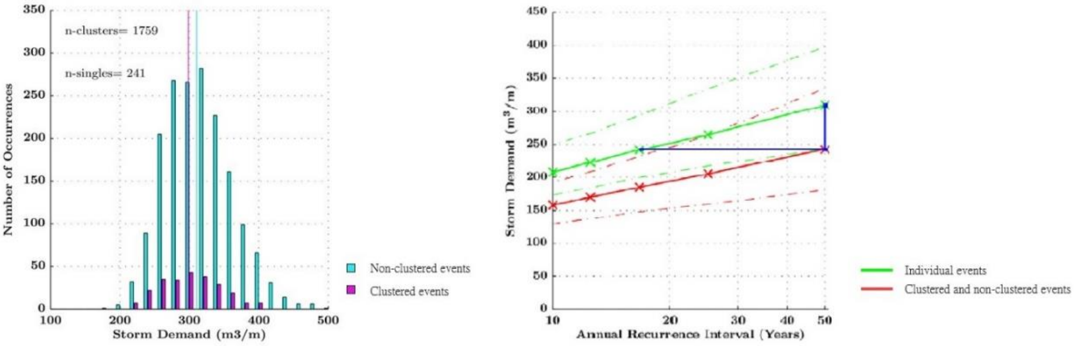


Figure A-13 Synthetic Storm Demand Volumes: (left) Histogram of rank 1 erosion demand volumes; (right) ARI volumes for clustered and non-clustered events compared with individual events, with 90% confidence limits also shown (source: Gravios et al., 2018)

Note: (left) comparable median values for clustered and non-clustered events, but the clustered events are more likely to be larger for any given 50 year realisation; (right) 50 yr ARI induvial event erosion volume equal to ~17 year ARI event for clustered and non-clustered events

Appendix B Geomorphological Site Walkover Investigation

B.1 Introduction

A field geomorphological walk over investigation was completed as one of several field based methods used to investigate the coastal geology of the Old Bar Beach region. The coastal geomorphology walkover investigation aimed to document the range of landforms types, substrate materials and other physical aspects relating to the coastal erosion vulnerability across the Old Bar Beach study area (see \\bmt-ntl-fs01\water\N21005_OldBar_Geotech&Hazards_Study\MapInfo\WS\DRG_001_Locality_Map_GoogleEarth_Landscape.jpg

Figure B-1).

For the purpose of this appendix, the study area spanning from Wallabi Point to Crowdy Head is described as the following five (interconnected) shoreline sectors:

- **Old Bar Beach** spanning from Wallabi Point to Farquhar Inlet,
- **Farquhar Inlet** region,
- **Mitchells Island to Manning Point Beach** coastline,
- **Harrington Inlet**, and
- **Harrington Beach,** spanning Harrington’s Northern Breakwater North to Crowdy Head.

This appendix details the key findings from the geomorphological site walkover investigation.

B.2 Physical setting

B.2.1 Regional geology

The geology of the Manning River region is located within the Hasting Block of the Lachlan Fold Belt. The 250:000 geology sheet for Hastings indicates that the study region is underlain by the Koorainghat Beds (Old Bar region) and the Byabbara Beds both comprising lithic sandstone, siltstone, greywacke, shale and mudstone. These rocks are overlain by coastal, estuarine and alluvial (sand, silt, clay) sediments, which are extensive within the Manning River Estuary floodplain region.

Coastal exposures show the regions bedrock to be upturned (~sloping to vertical bedding), which is reflective of the low grade metamorphism that has influenced the region. Thick and resistant sandstones were observed at Crowdy Head, whereas subvertical interbedded siltstones and sandstones (minor), strongly cleaved and faulted in placed, are exposed at Wallabi Point (Figure B-2).

The regional structure of bedrock geology largely parallels the major fault system trend. This influences the morphology of the major rocky landforms, which have a distinct NW-SE orientation (e.g. Wallabi Point and Saltwater Point, and Urana Bombora).

STUDY AREA

Wallabi Point to Crowdy Head

MANNING SEDIMENT COMPARTMENT

Black Head to Crowdy Head

Image source: Google Earth

Title:

Locality Map, Old Bar Study Region and the Manning Sediment Compartment

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Approx. Scale

Figure:

B-1

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B.2.2 Geomorphological Framework

Manning Sediment Compartment

The Old Bar study area is located within the Manning Coastal Sediment Compartment, which is a secondary level sediment compartment that extends north from Black Head to Crowdy Head. The ‘coastal sediment compartment’ concept provides a framework for dividing the coastline into discrete geographic units that share physical attributes (geology, landforms, sediment flows, nearshore processes) which help to guide decision making.

The Manning Sediment Compartment is characterised by sandstone, siltstone and conglomerate headlands, with both straight and embayed beaches and extensive estuarine plains of Manning River Estuary (CoastAdapt, 2016). The Manning River Estuary has two natural tidal inlets, including Farquhar Inlet in the south which is intermittently closed, and the Harrington Inlet in the north, which is artificially trained and permanently open to the ocean.

The Manning sediment compartment is rated 4 out of 5 in terms of erosion sensitivity, due to significant erosion already occurring at Old Bar Beach and Manning Point Beach (CoastAdapt, 2016). From a sediment budgeting perspective, the Manning sediment compartment receives negligible supply of sediment from the downdrift Tuncurry Sediment Compartment (Roy et al., 1994). In addition, a significant sediment sink has been identified as the cause for the long term recession within the Old Bar region. Although various interpretations are available, this sediment sink has been most recently attributed to anthropogenic influences (including entrance dredging, Harrington Inlet northern breakwater construction; MHL, 2017).

Onshore Quaternary Geology

The Quaternary Geology of the study region is comprised of a range of sediment types which reflect the wave dominated coastal setting and corresponding geomorphic systems for which they have been deposited within. Onshore sediment types and extents have been investigated by PWD (1982) and subsequently mapped in more detail by the NSW Geological Survey (2008).

The coastal beach and dune system spanning Wallabi Point to the Urana Bombora is characterised as a ‘receding barrier’, backed by a narrow bedrock compartment infilled with coastal and estuarine sediments. North of here, the beach backs onto an extensive deltaic complex of coastal, estuarine and alluvial sediments which extents north of Crowdy Head. The Manning River Estuary is a mature barrier estuary. The narrow coastal dune along Mitchells Island to Manning Point is interpreted as a ‘receding barrier’, whereas the Harrington Inlet to Crowdy Head dune barrier is a ‘stable barrier’.

Submerged and Offshore Sediments

Offshore bathymetry surveys and sediment sampling has shown that rocky reefs are a common feature across the inner shelf. Extensive reefs areas occur in the vicinity of the Old Bar Surf Club (Urana Bombora, and beyond) and Wallabi Point. Offshore sediment sampling by SKM (1982) shows the shoreface to be relatively starved of sediment, with no discernible offshore sand body.

River and estuarine channel sediment sampling indicates that marine delta sediments extend some 5 kilometres upstream of the Harrington Entrance, and 2 - 3 kilometres upstream of the Farquhar Inlet (SKM, 1982).

Figure B-2 Bedrock geology exposed in the cliff faces at Wallabi Point (left) and Crowdy Head (right)

Note: Thinly bedded, sub-vertical siltstone dominated sequence at Wallabi Point, contrasts with the thickly bedded, slightly tilted sandstone dominated rock at Crowdy Head

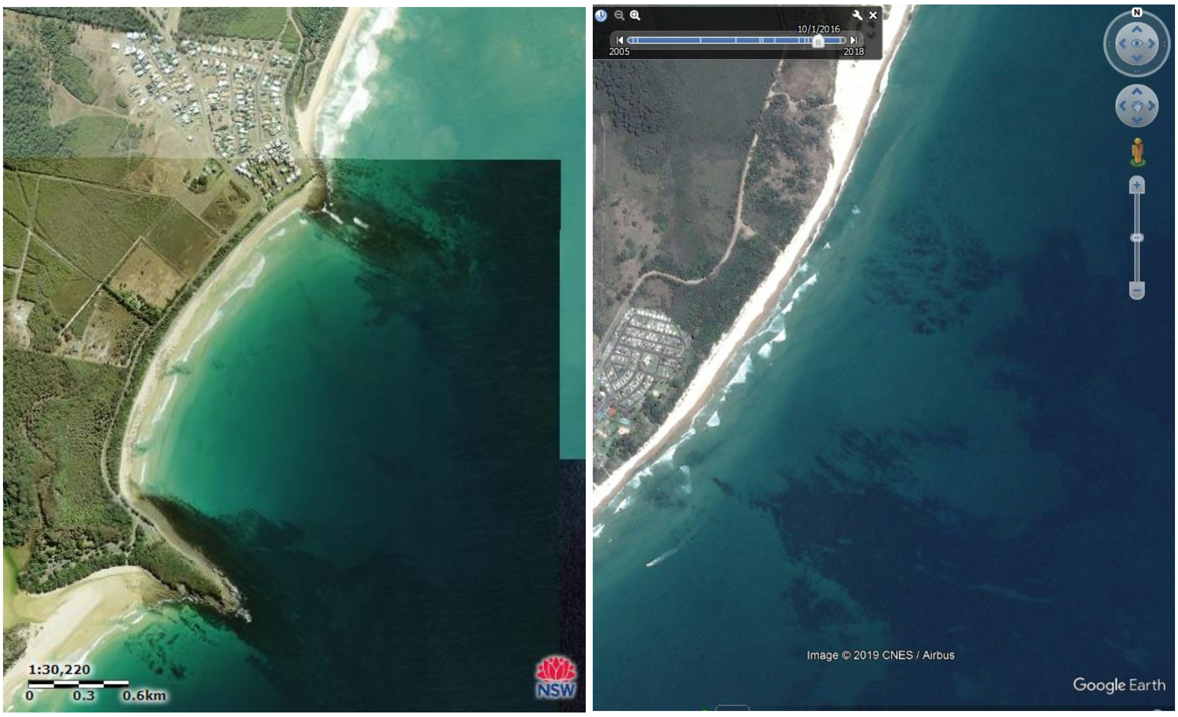


Figure B-3 The regional northwest – southeast fold/fault structure of the bedrock geology is reflected in the orientation of the rocky headland and reef areas at Saltwater Point and Wallabi Point (left; source: NSW SIX Maps) and nearshore reef areas at Old Bar (right; source: Google Earth)

B.3 Manning Sediment Compartment Observations

The below sections provide a field based description of the study area beaches, to provide insight into the geomorphology and erosion sensitivity of the Old Bar to Manning Point study area. Information presented below is primary based on the site walkover investigation completed for this investigation.

B.3.1 Southern Beaches

Geomorphological Framework

The Southern Beaches sector of the Manning Sediment Compartment is described here to span from Black Head to Wallabi Point. This sector is located outside of the study area, but is included here to provide context for the sediment compartment for which Old Bar Beach is located within. The Southern Beaches sector includes the following beaches:

- Black head
- Diamond Bay
- Wallabi Beach

Black Head Beach is the most southern beach within the Manning Sediment Compartment, stretching for 1.6 kilometres between the Black Head (south) and Red Head (north). The east facing beach is backed by a single Holocene-age foredune, with a small narrow creek running out along the southern headland. Pleistocene-age sediments infill the small catchment depression landward of the dune. The beach is fronted by a sandy nearshore profile with areas of submerged rock reef evident in the aerial imagery adjacent to Red and Black Head, and also some 300 metres offshore of the central beach. The beach is home to a small Hallidays Point community situated on the northern slopes of Black Head. A caravan park backs the northern end of the beach (Short, 2007).

Diamond Bay is the sandy beach situated between Red Head (south) and Saltwater Point (north). It stretches for 5.5 kilometres to the south–southwest curving around to trend due south at its southern end. The beach is backed by low foredunes, with the Diamond Beach community situated behind the beach at the southern end (Short, 2007). The northern half of the embayment is largely undeveloped and backed by Darawank Nature Reserve. Khappinghai Creek drains a local bedrock backed catchment that spans between Red Head and Wallabi Point. The creek inlet is positioned adjacent to the Saltwater Point.

Rocky platforms and submerged rocky reef are evident in the aerial imagery adjacent southern and northern headlands. A patch of rocky reef is also observed in the nearshore area off the central section of beach, near to the Diamond Beach resort.

Pleistocene-age sediments (backbarrier clays and indurated sands, or ‘soft rocks’) have been recorded at the base of an erosion escarpment across the central region of the beach (Riedel & Byrne, 1981). This described sequence of sediments is consistent a ‘receding’ coastal barrier type, as described in Roy *et al.* (1994).

Wallabi Beach is a 1.4 kilometre southeast facing beach situated between Saltwater Point (south) and Wallabi Point headland (north). The small sandy beach is beach is backed by a continuous low barrier dune, which is in turn backed by an undeveloped low lying lagoonal infill basin that drains south into Khappinghai Creek. (Short, 2007). Saltwater National park is located behind the southern headland.

Pebbles and cobble deposits are observed along the back of the beach (see Figure B-4).

Figure B-4 Wallabi Beach looking north from Saltwater Point.

B.3.2 Old Bar Beach

Geomorphological Framework

Old Bar Beach is the southern-most stretch of sandy shoreline within the study region, spanning some 4.2 kilometres north of Wallabi Point to Farquhar Inlet. Wallabi Point and Old Bar comprise two residential area that occur within this coastal segment. Wallabi Point is a small coastal settlement located on the small rocky headland of the same name in the far south. Old Bar is a more substantial township located spanning a larger area between Racecourse Creek and Farquhar Inlet. The most southern extent of residential development at Old Bar is located patricianly close to the shoreline and as such is exposed to erosion. Three houses were demolished following severe storm event 2008. A waste water treatment plant is located behind the central region of this beach section, with infiltration ponds located close to the shoreline.

The coastal morphology and processes operating along this shoreline segment is varied, with sediments infilling a minor bedrock embayment between Wallabi Point to Old Bar (SKM, 1982). Key landform features located along this shoreline segment include (from south to north):

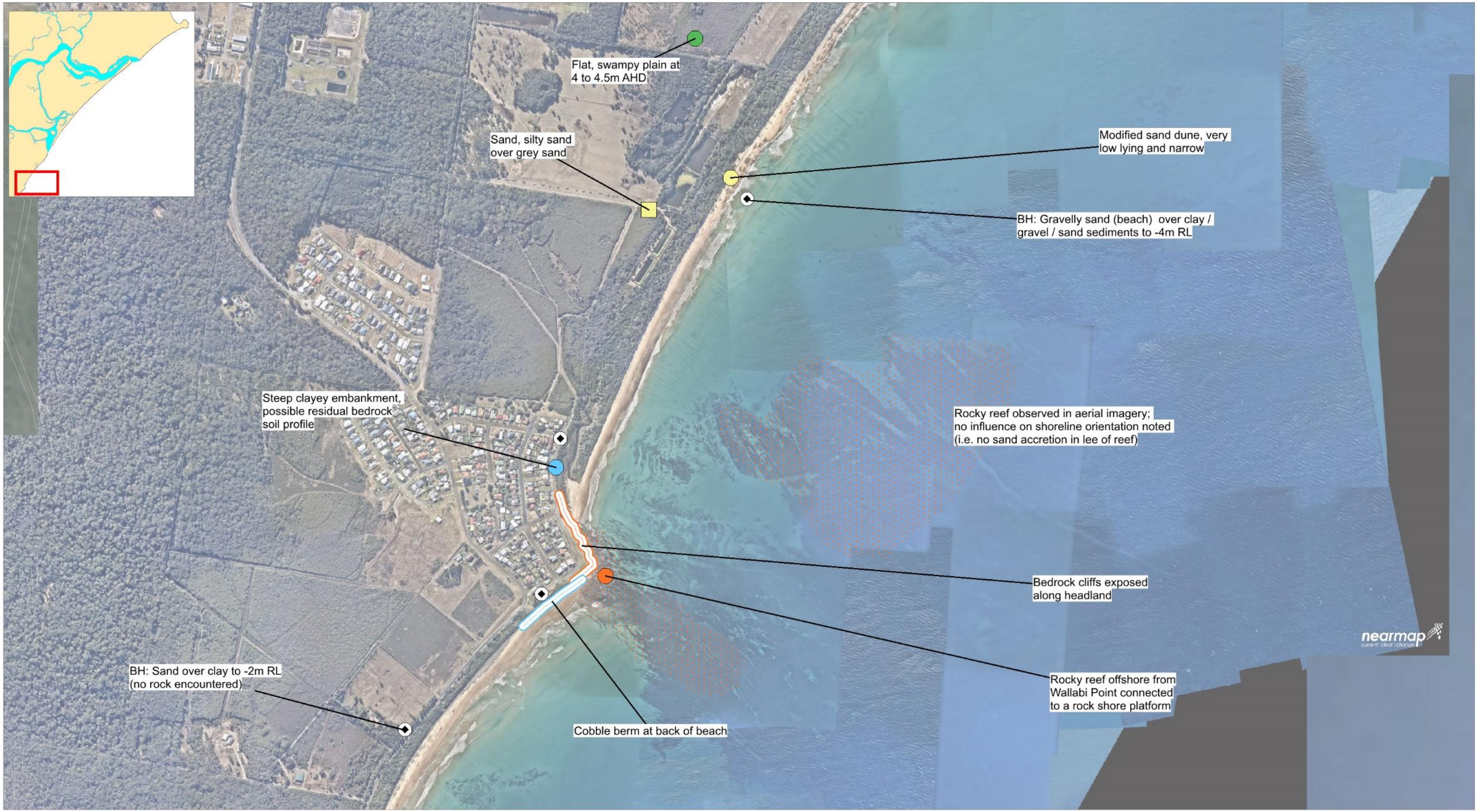
- *Wallabi Point* rocky headland and adjoining rocky shore platforms and offshore reefs, comprised of weathered siltstones bedrock.
- *A narrow sandy beach and dune*, that extends between Wallabi Point and Old Bar township. The dune is backed by coastal and estuarine sediments which drain to the ocean via two small coastal creeks.
- *Racecourse Creek*, which forms a small waterway that traverses foreshore residential area at Old Bar. It has been suggested that the 180 degree change in creek direction near to the Public School is indictive of durable substrate underlying the Public School region (MHL, 2017). Observations made within this study also support this interpretation (see below). A narrow barrier dune fronts the creek entrance. This sandy feature has reportedly become eroded since creek stabilisation works were put in place decades ago.
- *A topographic rise* near to the coast, adjacent to town centre. This geographic feature aligns with *Urana Bombora*, an extensive rocky reef that extends offshore of the Surf Club. Rock outcropping through the narrow strip of dunes was observed in this area, along with small rock quarry located immediately behind the beach. This stretch of beach was particularly narrow at the time of investigation.
- *Tall vegetated dunes* (+10 metres in places) extend from the Caravan Park towards Farquhar Inlet. This region is referred to herein as the Old Bar Beach ‘northern dune area’. The surface morphology indicates the dunes have migrated in a landwards at some point in the past, although they are now well vegetated and stabilised. Clayey substrates were encountered behind the dune at +5 metre elevations, indicating the relic estuarine sediments or else residual soils.
- *Relic coastal barrier sediments*, outcropping as indurated sands and gavels occur as +5 metre vertical cliffs along the southern margin of Farquhar Inlet.

The beach faces primarily southeast and is exposed to a high energy wave climate. The rocky reef extending immediately offshore of the Old Bar township results in reduced wave energy at the shoreline locally due to wave refraction and shoaling across the reef (Short, 2007). A slight foreland (sand accretion) bulge has been reported in the lee of this reef, although no such feature was observed during the field investigation.

Past erosion from tidal flows and channel scour has impacted the stretch of indurated sediments, which demonstrates and cliffed to undercut profile. The indurated sediments are more durable than unconsolidated sands, but can be broken off by hand and thus are much less durable than bedrock.

Site Observations

The site walk over investigation identified local characteristics relating to the coastal substrate types and coastal erosion vulnerability of Old Bar Beach and adjoining foreshore areas. These are mapped in Figure B-5 and Figure B-6. Several key observations are also highlighted in Figure B-7 to Figure B-19 below.



LEGEND

Field observations

●

Data review information

◆ Borehole site

■ Observation / sample (NSW Geological Survey)

Near map images (July 2018)

Title:

Site Walkover Observations Wallabi Point

Figure: **B-5**

Rev: **A**

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

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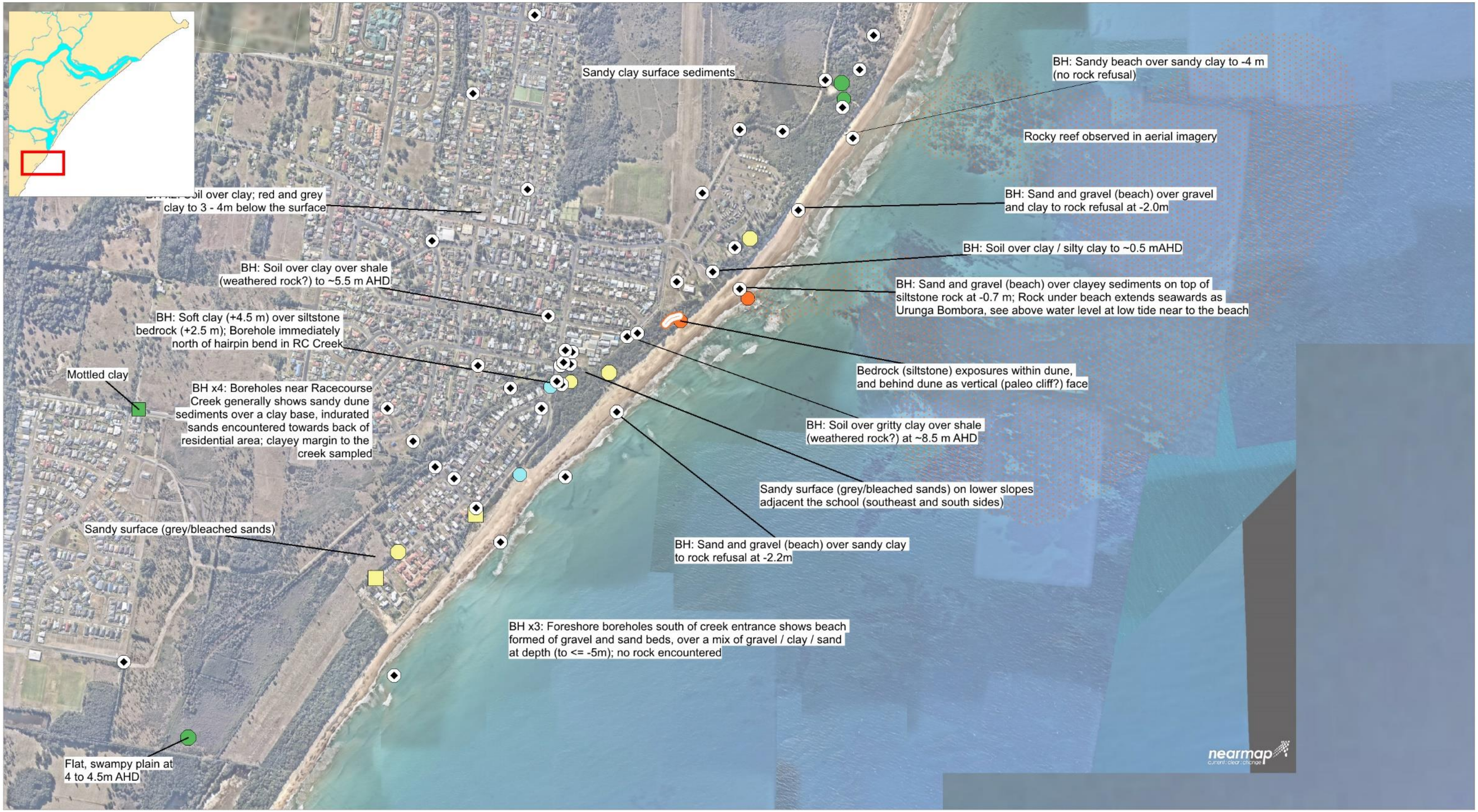

LEGEND

Field observations

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Data review information

◈ Borehole site

■ Observation / sample (NSW Geological Survey)

Near map images (July 2018)

Title:

Site Walkover Observations Old Bar

Figure:

B-6

Rev:

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Figure B-7 Wallabi Point looking south from Wallabi Beach, showing exposed rocky cliffs at the point joined by vegetated slopes, with backing development

Figure B-8 Old Bar Beach looking north from Wallabi Point (foreground) to Urana Bombora (distant background)

Figure B-9 Rocky headland and shore platform at Wallabi Point, in far southern corner of Old Bar Beach

Note: Erosion limiting cliffs shown above are some ~11 metres high

Figure B-10 Very low (4 m AHD) eroded dune profile fronting the Old Bar Sewerage Works (left), with evidence of past disturbance in the eroded sediments (right)

Note: The exposed artificial gravel layer above may represent road base from past sand mining that occurred at this location

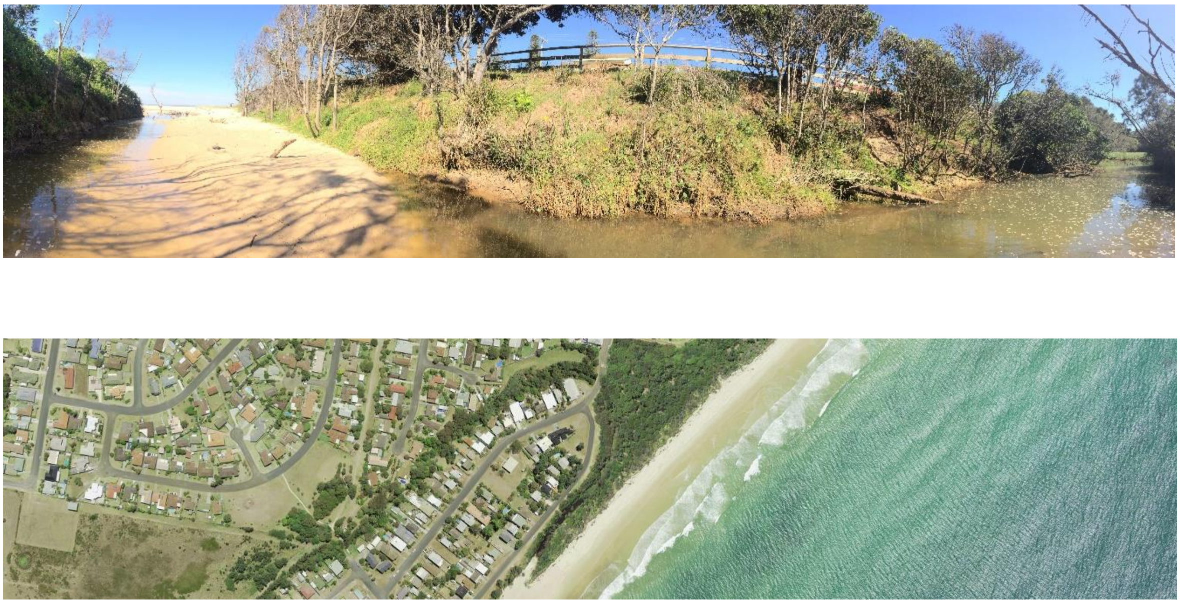

Figure B-11 Panoramic (180 degree) view of Racecource Creek (top), northwest; Aerial image demonstrating why the creek is named such, noting hairpin bend in the middle of the image (bottom)

Note as the sand barrier continues to narrow with shoreline recession, the creek entrance will progressively shift north

Figure B-12 Grey well sorted sands, with abundant organics, comprise relic Pleistocene-age deposits near to the surface adjacent (immediately north) to the bend in Racecourse Creek

Figure B-13 **Recent sand scaping undertaken by Council has moved the beach sands against the prominent erosion scarp (not buried in part) at Old Bar Beach**

Note the high tide (wave runup) water line at the base of the modified dune profile

Figure B-14 **Bedrock exposed within the foredune at Old Bar Beach immediately south of the SLSC.**

Note: The sandy foredune has developed over an area of rocky terrain that is exposed in a gully (above) and nearby rock face (cliff/embankment/quarry?) exposure (below)

Figure B-15 Erosion limiting bedrock exposed behind Old Bar Beach foredune, near to the SLSC

Figure B-16 Urana Bombora at Old Bar beach, formed of Devonian-age siltstone bedrock, outcropping in front of main beach carpark

Note: the Old Bar to Manning Point beach planform undulates from south to north, with a foreland feature developing in the lee of the Urana Bombora. The beach sweeps away in two arcs to either side of the bombora (see below)

Figure B-17 Satellite image of Old Bar Beach, showing the foreland planform relative to the Urana Bombora (nearshore rocky reef seen as dark patchers near the shoreline) (source Google Earth)

Figure B-18 Bedrock samples from the Old Bar reef (right) and rocky slopes/cliffs within partially buried by the Old Bar Beach dune system.

Note: Samples of very hard siltstone, taken from locations shown in Figure B-16 and Figure B-14

Figure B-19 Sandy clay surficial sediments in vegetated terrain behind Old Bar Beach, near to beach access carpark some 300 metres north of the Caravan Park

Note: possibly form Pleistocene age back barrier deposits that formed landward or the relic barrier sands and gravels, exposed adjacent to Farquhar Inlet. Coring needed to determine if bedrock is located at depth

B.3.3 Farquhar Inlet

Geomorphological Framework

Farquhar Inlet is the smaller of two tidal inlets to the Manning River system. It has a high energy, southeast facing entrance region that extends for some 2 kilometres between Old Bar and Mitchells Island. The coastal waterway behaves as an intermittently open and closed lagoon, with the entrance completely closed by a wide and partially vegetated sand berm at this time of the site investigation.

The inlet is connected to the Manning River via the Manning River Channel South and Scotts Channel, which together encompass Oxley Island. Farquhar Inlet and contains a significant volume sediment within the marine delta and entrance berm. Sand shoals become scoured out during significant flood period. The entrance is mechanical opened on a semi-regular basis when an water level trigger is reached, to manage water quality and flooding.

Relic indurated sediments that form Pleistocene shoreline extend along the southern margin of the inlet, which stand as +5 meter tall cliffs in places. The sediments are somewhat durable, but clearly still exposed to channel scour as indicated by the undercut profile observed in places.

The sandy beach berm fronting the inlet had a high gravel content within the lower beach profile, consistent with beach conditions observed elsewhere.

Site Observations

The site walk over investigation identified local characteristics relating to the coastal substrate types and coastal erosion vulnerability in and around Farquhar Inlet. Several key observations are also highlighted in Figure B-21 to Figure B-25 below, with key features mapped in Figure B-21.

Figure B-20 Indurated sand / pebble cliffs adjacent Farquhar Inlet, likely forming Pleistocene beach barrier deposit

LEGEND

Field observations

●

Data review information

◈ Borehole site

■ Observation / sample (NSW Geological Survey)

Near map images (July 2018)

Title:

Site Walkover Observations Farquhar Inlet

Figure: **B-21**

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Figure B-22 Indurated sand shoreline along Farquhar Inlet often forms a cliffed and undercut profile, where the tidal waters abut the relic (Pleistocene-age) sediments

Note: The indurated sands are semi-consolidated and provide some (minor) resistance to erosion

Figure B-23 Contrasting textures from Pleistocene dune sands adjacent Farquhar Inlet, including: unconsolidated grey surface sands (left) and black indurated sands from the exposure base

Note: Sands textures demonstrate a typical weathering profile in a relic coastal deposits

Figure B-24 Farquhar Inlet, looking north from high dunes at Old Bar Beach

Note: Farquhar Inlet was closed during the November 2018 field inspection (see sand berm in distant background)

Figure B-25 Well developed incipient dune, fronting at vegetated dune barrier immediately north of Farquhar Inlet

B.3.4 Mitchell Island / Manning Point Beach (Farquhar Inlet to Manning Point)

Geomorphological Framework

The beach spanning the Mitchells Island and Manning Point shoreline stretches for 9 kilometres between the two tidal entrances to the Manning River system. The high energy southeast facing beach is backed by a narrow dune system that is tall in places. The sandy beach is generally steep and narrow, with gravel sediments common.

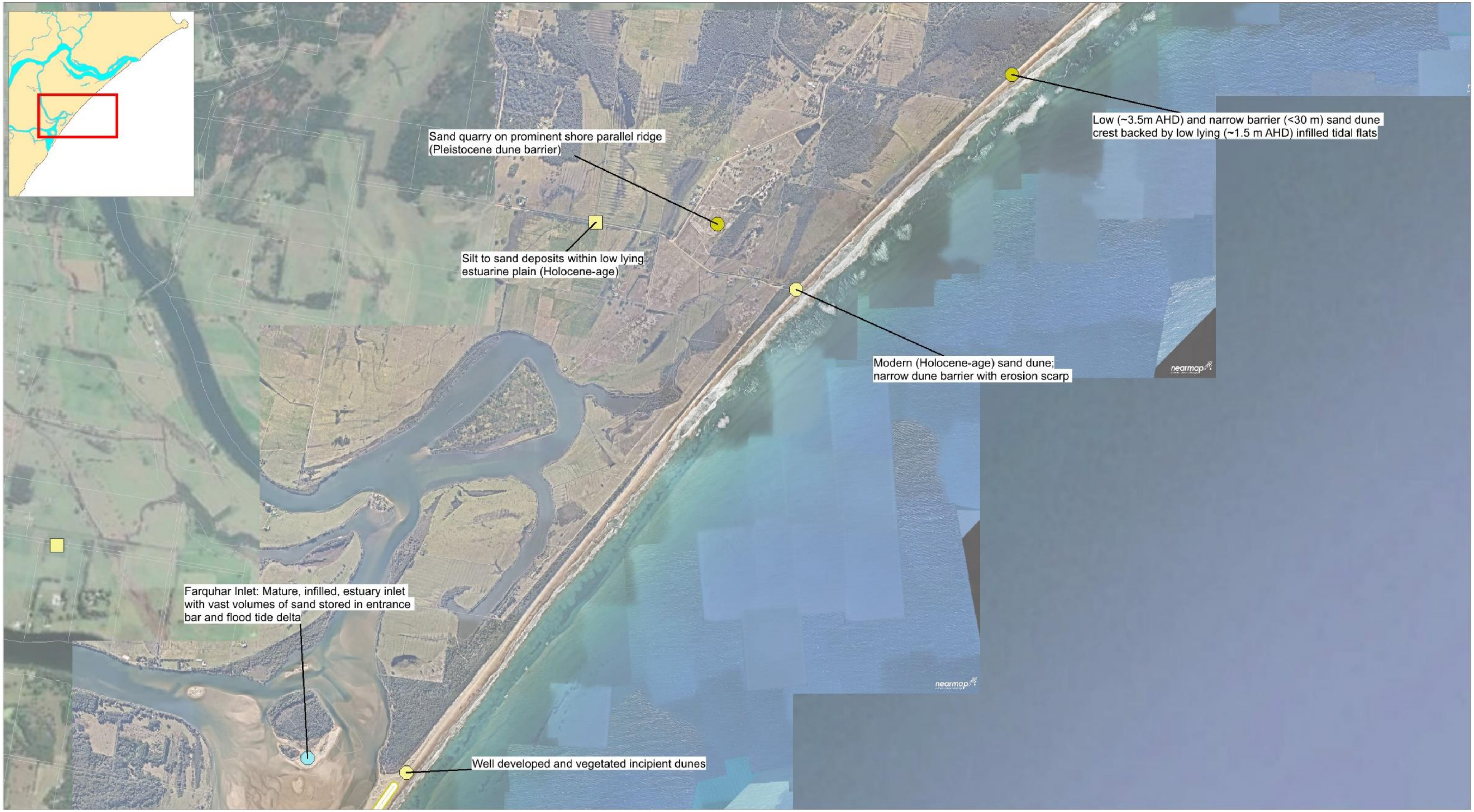
Mitchells Island extends landward from the beach for some 5.5 kilometres and is formed by the bifurcation of the Manning River around at a +30 metres high bedrock outpost. The island is bound by Scotts Creek to the south (joining with Farquhar Inlet) and Manning River to the north (joining with Harrington Inlet).

Manning Point is a riverside township located behind the sand spit that extend north across the Harrington Inlet. Much of the town is located on a low lying estuarine (delta) plain located behind the dunes. Low lying delta areas behind the Mitchells Island comprise a mix of farm land and vegetation.

No erosion resistant or influencing substrates were observed along this stretch of coastline. A tall erosion escarpment observed at Manning Point Beach is indicative of the long term recession documented at this location.

Site Observations

The site walk over investigation identified local characteristics relating to the coastal substrate types and coastal erosion vulnerability of Mitchells Island and Manning Point Beach. These are mapped in Figure B-26 and Figure B-27. Several key observations are also highlighted in Figure B-28 to Figure B-31 below.



LEGEND

Field observations	*Data review information*	
●	◈	Borehole site
	■	Observation / sample (NSW Geological Survey)

Near map images (July 2018)

Title:

Site Walkover Observations Mitchells Island

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LEGEND

Field observations

●

Data review information

◆ Borehole site

■ Observation / sample (NSW Geological Survey)

Near map images (July 2018)

Title:

Site Walkover Observations Manning Point

Figure:

B-27

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Figure B-28 **Sandy beach with numerous pebble / cobbles are a common feature along the Old Bar to Manning Point section of beach**

Note: Gravels originally sourced form Manning River and/or from relic alluvial/coastal deposits that have since become eroded and reworked onto the beach face. Possible for erosion lag deposits forming receding barrier processes, exposing relic Pleistocene age gravelly base layer

Figure B-29 **Tall and continuous erosion escarpment at Manning Point Beach (inset shown below)**

Figure B-30 **Manning Point Beach erosion escarpment is up to 8 metres (AHD, to of scarp) in places**

Figure B-31 Manning River at Manning Point (Main Road) looking northeast, showing the sandy composition of the river foreshore

B.3.5 Harrington Inlet

Geomorphological Framework

Harrington entrance is an artificially opened tidal inlet which is typically some 500 metres wide, but migrates along a ~2.5 kilometre area. This entrance forms the main tidal inlet to the Manning River Estuary system, with Farquhar Inlet forming the other. Manning River is a mature barrier estuary and thus classified as a riverine estuary.

The Harrington entrance has an extensive training wall along its northern bank, which extends seaward of Harrington Beach as a breakwater. The training wall has isolated Harrington Lagoon and Harrington Back Channel, for which the residential suburb of Harrington is located behind. Harrington Waters Estate (marina) is also located along the northern banks of the tidal inlet. An isolated bedrock high point (~20 metres) is located within the township (Pilot Hill Lookout). All surrounding residential areas are positioned on a low lying estuarine plain. However, this land is protected from potential wave erosion propagating into the entrance, and channel scour/migration from the substation training wall.

The entrance channel holds vast volumes of sand in the form of tidal delta deposits, which can be seen as extensive shoals adjacent to the coastline. A low narrow sand spit attached to Manning Point grows northwards across part of the ocean entrance. The estuary mouth is a highly dynamic environment with the sand shoals being regularly reworked (tidal and river flows, channel migration, wave action) and becoming soured out during periods of flood (e.g. 1978, 1990, 2011).

Site Observations

The site walk over investigation identified several local features relating to the geomorphology and coastal process system of Harrington Inlet and adjoining foreshore areas. These are mapped in Figure B-27. Several key observations are also highlighted in Figure B-32 and Figure B-33 below.

Figure B-32 Harrington Training Wall North, Harrington Inlet, looking south from Piolet Hill Lookout

B.3.6 Harrington Beach

Geomorphological Framework

Harrington Beach is both the northern most sandy shoreline within the study region. The beach spans some 5.6 kilometres between the northern Manning River entrance wall at Harrington and Crowdy Head, a round, tall (55 metre high) headland that forms the downdrift limit to the Manning Sediment Compartment. Together with the adjacent Crowdy Bay Beach, Harrington Beach joins with Crowdy Head to form a large tombolo that is backed by a relic estuarine plain, which forms part of Crowdy Head National Park.

Harrington Beach faces southeast and is fully exposed to the dominant wave climate of the region. The beach is backed by a well-established and vegetated dune system. Crowdy Head Road runs along the back of the dune, which in turn is backed by extensive low lying estuarine plains and wetland areas which form part of Crowdy Head National Park.

Figure B-33 Harrington Training Wall North, Harrington Inlet, looking east from Pilot Hill Lookout

Note: Extensive sand shoals and a beach berm are deposited immediately south of the training wall

Crowdy Head is comprised of durable sandstone that forms an erosion limited landform. The sandstone substrate can be seen outcropping along the headland cliffs. This material was quarried for the construction of the Harrington Inlet training wall (Short, 2007). The transition between the erodible sandy landforms (beach and dune) with the bedrock slopes can be readily identified by the clear break in slope in the backbeach area.

Site Observations

The site walk over investigation identified local characteristics relating to the coastal substrate types and coastal erosion vulnerability of Harrington Beach and surrounds. These are mapped in Figure B-34. Several key observations are also highlighted in Figure B-35 and Figure B-36 below.

Crowdy Head: Tall (50m AHD), protruding bedrock headland that forms the northern limit to the Manning Sediment Compartment

Tall and wide dune barrier, with evidence of long term accretion. Possibly Holocene-age dune deposits, welded onto a Pliestocence-age barrier dune deposit

LEGEND

Field observations

●

Data review information

◆ Borehole site

■ Observation / sample (NSW Geological Survey)

Near map images (July 2018)

Title:

Site Walkover Observations
Crowdy Head

Figure:

B-34

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0 250 500m

Approx. Scale

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Figure B-35 Harrington Beach, looking south form Crowdy Head, with a wide beach face and well developed incipient dune

Note: The sandy foreland feature bulging seaward of the generally sweeping shoreline, indicating that nearshore rocky reefs influence wave refection and sediment movement patterns locally

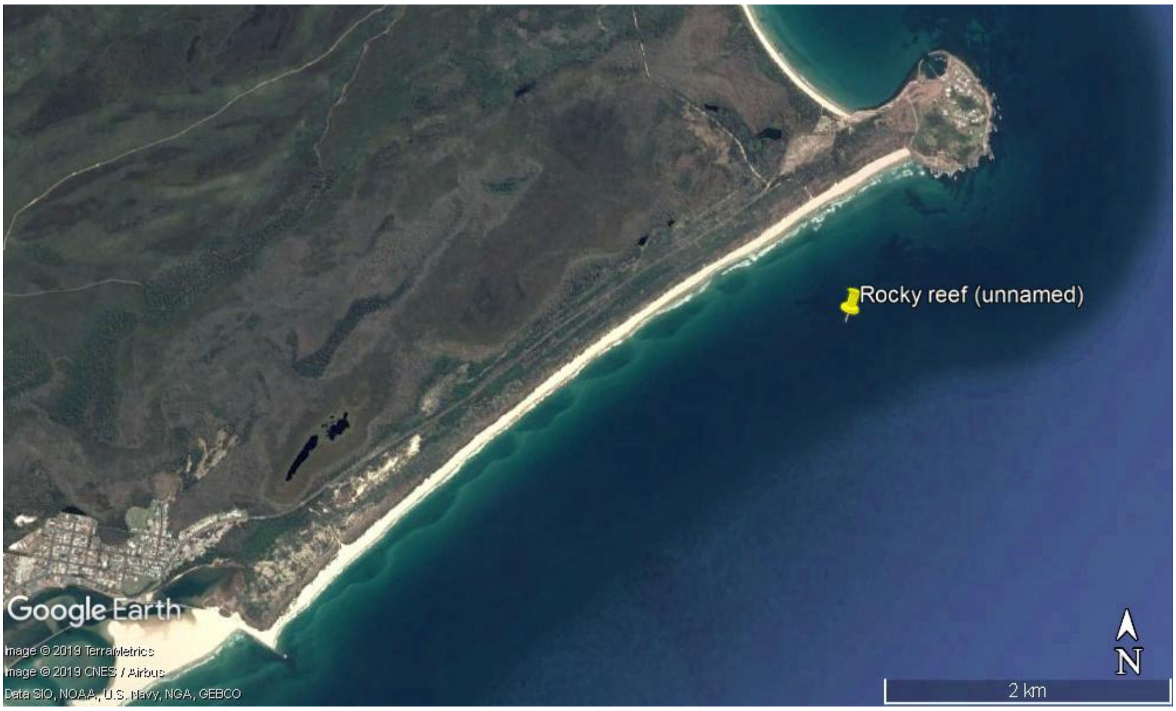

Figure B-36 Satellite image of Harrington Beach (source: Google Earth), showing location of rocky reef that influences wave refraction and sediment flows locally (see Figure B-35)

B.4 References

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Appendix C Ground Penetrating Radar (GPR) Coastal Geology Investigation

C.1 Introduction

A ground penetrating radar (GPR) survey was initiated by Council as one of several field techniques applied to a broader coastal geomorphology investigation of Old Bar Beach and surrounds. The GPR survey targeted priority areas considered potentially suited to geophysical survey, including publicly accessible beach, dune and backbeach areas around Old Bar Beach and Manning Point region.

This appendix documents the GPR Coastal Geology Survey of Old Bar Beach.

C.1.1 Survey Scope and Objectives

The scope of the GPR investigation included the following:

- Undertake a 2-day field GPR survey of Old Bar Beach and Manning Point townships and corresponding coastal zone.
- Process and analyse the GPR survey data, with a focus on interpreting information relating to the geological setting and associated characteristics that will influence coastal erosion hazards within the study region.
- Review the Geoscience Australia (GA) GPR survey data collected from Old Bar Beach in 2015.
- Document the methods, results and outcomes of the investigation in a technical note (this appendix).

The overall goal of the Old Bar Beach field investigation program was to characterise the coastal geological conditions of the target areas, to enable the coastal erosion hazard mapping of the study region to be re-mapped in a geologically meaningful manner.

The specific objective of the Old Bar Beach GPR survey was to investigate the subsurface geological conditions and erosion vulnerability by imaging the subsurface sedimentary system and depth to bedrock, where possible. The geotechnical information obtained from the GPR survey will be synthesised with the existing data sources and complementary field surveys to provide an improved understanding of the stability and erodibility of the shoreline and adjacent backbeach environment, including the dunes.

C.1.2 The Ground Penetrating Radar Method

GPR is a geophysical survey method that uses electromagnetic (radar) pulses to image substrate conditions within the shallow subsurface. The GPR transmitting antenna emits high frequency radar waves into the ground, which become reflected off buried surfaces and objects, and then subsequently recorded by a receiving antenna GPR system. Radar measurements can be used to image both natural features (geological boundaries, sediment, soil layers, water table) and built materials (buried pipes, concrete, seawalls and other infrastructure). The radar reflection information is recorded and displayed as a two-dimension reflection profile of the subsurface (see Figure C-1).

The returned radar data are displayed as a function of distance along the horizontal axis, and two-way time along the vertical axis, i.e. as a vertical cross section of the subsurface. Data processing is typically required to convert the raw GPR data into meaningful information that can be further analysed and interpreted.

All geophysical survey methods have advantages and limitations. GPR is a high-resolution method that collects data relatively quickly and easily. The electrical conductivity of the ground, the GPR antenna (central) frequency (and radiated power) influence the effective depth range of GPR survey. Increases in subsurface electrical conductivity attenuate the radar waves and therefore the penetration depth decreases. Resistive soils, like dry sand dunes, are very suited to GPR, which can achieve up to 15 metres depth of penetration in suitable coastal conditions. Signal penetration is however significantly reduced in conductive clayey soils, like those experienced in estuarine settings for example.

A range of GPR antenna frequencies are available for use, with geological investigation typically applying frequencies between 50 MHz and 500 MHz. A trade-off between resolution and penetration is an important consideration when designing a GPR survey, as higher frequencies provide improved resolution, but do not penetrate as deep as lower frequencies.

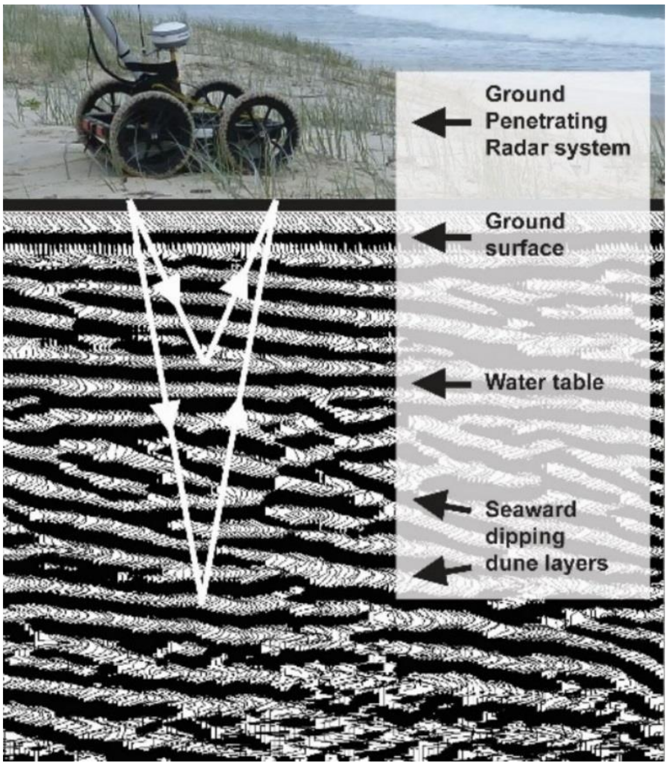


Figure C-1 Ground Penetrating Radar System with an Annotated Reflection Radar Profile

C.2 Methods for GPR Data Collection, Processing and Interpretation

The coastal geology GPR investigation comprised multiple phases, including the field survey for collection of GPR data (see Section C.2.1), processing of raw field data (see Section 0), and the subsequent analysis and interpretation of processed data (see Section C.2.3).

C.2.1 Field Survey

The GPR survey was conducted by BMT at Old Bar Beach, Farquhar Inlet, Mitchells Island and Manning Point Beach over a period of two days (23 to 24 November 2018). GPR data was collected using MALA Ground Explorer HDR system. Profiles were imaged using a combination of 80 MHz and 450 MHz shielded antennas, with many profiles imaged with both antennas. Position and surface elevation information was recorded with an RTK GPS system where GPR data was collected on foot. Several 80 MHz profiles were collected by dragging the antennae behind a 4WD vehicle. In these instances, geographic location was recorded from an internal GPS system and topography information was extracted from a LiDAR based digital elevation model (DEM) for the region.

A previous GPR survey was conducted in 2015 by Geoscience Australia (GA) using a Mala ProEx GPR system with a 250 MHz shielded antennae. Surface elevation information co-acquired with GPS (GA, 2015).

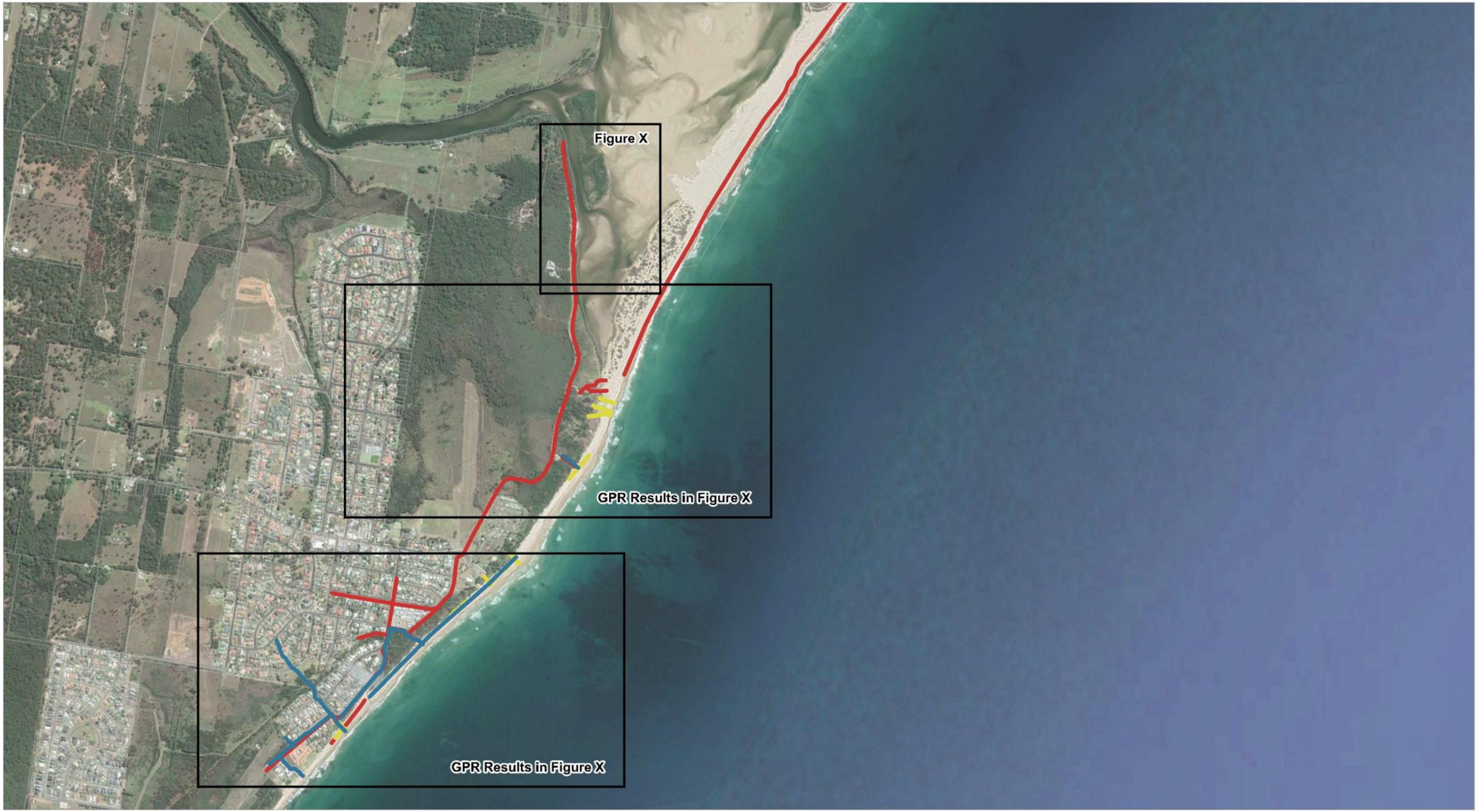
Table C-1 provides a summary of the GPR survey, collected by BMT in 2018. The data acquisition parameters applied to the GPR field survey are summarised in Table C-2. GPR survey coverage by the BMT and GA surveys is mapped in Figure C-2 and Figure C-3.

Table C-1 GPR Survey Summary

Location	Summary	Comment
Old Bar Beach	25 GPR profiles* 80 & 450 MHz antennas	• Variety of subsurface conditions encountered • Favourable GPR conditions experienced across sandy substrates, including in the vicinity of Racecourse Creek, fronting the Primary School and across the 'Northern Dunes' region • High GPR signal attenuation from areas comprising weathered bedrock terrain in the vicinity of the main township, backbarrier (alluvial/estuarine) settings behind Racecourse Creek and along the marine influenced foreshore
Farquhar Inlet	1 GPR profile 80 MHz antenna	• High GPR signal attenuation from the entrance / beach berm survey, due to electrically conductive (saline) conditions being encountered from seawater
Mitchells Island	1 GPR profile 450 MHz antenna	• Suitable GPR subsurface conditions experienced across sand dune and upper beach areas
Manning Point Beach	8 GPR profiles* 450 MHz antenna	• Suitable GPR conditions experienced in the sand dunes area • Electrically conductive conditions leading to poor signal penetrating in the backbarier flats behind the

Location	Summary	Comment
		dunes, where sediments likely comprise estuarine clays

* including duplicate lines



LEGEND

GPR Field Surveys

- 80 MHz (BMT)
- 450 MHz (BMT)
- 250 MHz (GA)

Google Earth satellite imagery

Title:

Ground Penetrating Radar Coastal Geology Survey Old Bar Beach and Farquhar Inlet

N

0 0.5 1km

Approx. Scale

Figure: **C-2**

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GPR Field Surveys

80 MHz (BMT)

450 MHz (BMT)

250 MHz (GA)

Google Earth satellite imagery

Title:

Ground Penetrating Radar Coastal Geology Survey Old Bar Beach and Farquhar Inlet

N

0 0.5 1km

Approx. Scale

Figure: **C-3**

Rev: **A**

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Table C-2 GPR Data Acquisition Parameters

Survey Parameter	450 MHz Antenna	80 MHz Antenna
Antenna Type	Shielded	Shielded
Time Window	160 ns	450 ns
Sample Interval	0.195 ns	0.78 ns
Number of Shot Stacks	~700	~700
Shot Increment	0.017 m	0.078m

C.2.2 GPR Data Processing

GPR field data requires processing to convert the raw GPR records into meaningful information that can be further analysed and interpreted to derive geological insight. The degree of processing required depends largely on the survey objective and scope of the investigation. The Old Bar Beach GPR dataset collected by BMT was initially processed using the GPR software package *ReflexW*. Additional post processing and analysis were also undertaken in GIS (using the MapInfo software package).

GPR data processing undertaken by BMT involved the following processing steps:

- DC removal
- Time zero adjustment
- Temporal signal filtering (band pass filter)
- Spatial ‘ring down’ filtering (background removal), on selected files only
- Display gains (energy decay)
- EM velocity estimation
- Topographic corrections (assuming v = 0.12m/ns), and
- Time-depth conversion (assuming v = 0.12m/ns)

The GPR data collected by GA had already been improved by a sequence of processing steps applied by to this study. As such, no additional GPR processing was undertaken on this datasets.

C.2.3 Data Analysis and Interpretation

The GPR dataset processed by BMT was visualised as 2D cross section profiles using *ReflexW*. Geological interpretation was then conducted on the BMT and GA datasets to identify the buried sedimentary interfaces and bedrock reflections of interest. Such features were digitised as line interpretations.

The 450 MHz profiles provided a higher resolution images but at relatively shallower depths; whereas, the 80 MHz profiles provided a relatively lower resolution images with a greater depth, where the subsurface conditions were suitable.

In some locations, the geological profiles could be clearly mapped, such as where geologically recent (clean) dune sands overlay an older geological surface (sediments or bedrock) at greater depths. In other locations, the subsurface conditions were not clearly imaged due to the clay content (like that of the residual soils across the study area), which caused the GPR signal to become attenuated.

C.3 GPR Survey Results and Interpretation

C.3.1 Old Bar Beach and Farquhar Inlet Region

GPR identified conditions relating to the coastal geology and erosion vulnerability of Old Bar Beach and Farquhar Inlet region. These results are documented in a series of annotated maps and selected GPR profiles (see Table C-3 for figure references).

Key coastal geology findings of the GPR survey of the **Old Bar Beach Racecourse Creek region** are summarised below:

- Various substrate types and their corresponding distributions were identified (Figure C-4), including areas of modern (Holocene-age) beach and dune sands, relic (Pleistocene-age) barrier sediments, and non-sandy or electrically conductive materials (such as weathered bedrock, residual soils and clayey alluvial/estuarine sediments).
- The residential area spanning between the right bank of Racecourse Creek and Old Bar Beach is comprised of older beach and dune deposits, with indurated sediments (~coffee rock) imaged at around 4 to 5 m AHD (Figure C-5, Figure C-6). GPR images the indurated sand layer to overlie a surface that slopes seawards to below sea level. Coring indicates this lower unit to comprise alluvial / estuarine clays.
- Landward of Racecourse Creek, substrates were found to be electrically conductive near to the surface. In this region, the GPR signals became quickly attenuated (i.e. very shallow depth of investigation). Borehole drilling indicates the reserve area behind the creek is formed of alluvial / estuarine clays, whereas the residential area is comprised of highly weathered bedrock material. A change in GPR response at shallow depths was recorded in the vicinity of Rushby Drive. This may identify the landward transition from alluvial / estuarine clays into weathered bedrock terrain (Figure C-4).
- A clear change in substrate material is noted either side of the sharp bend in Racecourse Creek. Sediments are imaged on the inside of the creek bend, whereas electrically conductive substrates occur northward of the bend (Figure C-4). GPR conditions below David Street are consistent with the weathered bedrock substrates encountered in borehole drilling from that region (Appendix D). This confirms the suggestion made in MHL (2017) that Racecourse Creek’s orientation is controlled by bedrock slopes in the vicinity of the Public School.
- Modern sand dune sediments were found to bury the foot slopes from a bedrock bluff in front of the Primary School (Figure C-7). The landward extent and thickness of dune deposits have been resolved in the GPR profile, with clean sub-horizontal layers overlying an electrically conductive (bedrock) substrate slope, which returned no coherent GPR response.

Table C-3 Summary of Results, Old Bar Beach

Location	GPR Profile Summary	Figure
Racecourse Creek Region		
Meridian Resort Region	• Cross shore GPR profiles • 450 MHz (BMT)	See Figure C-5 for GPR profiles Results mapped in Figure C-4
Racecourse Creek Outlet (Rose Street)	• Cross shore GPR profiles • 80 & 450 MHz (BMT)	See Figure C-6 for GPR profiles Results mapped in Figure C-4
Racecourse Creek (Lewis Street, Pacific Parade, David Street)	• Longshore GPR profiles • 80 & 450 MHz (BMT)	Results mapped in Figure C-4
Old Bar Public School	• Cross shore GPR profile • 80 & 450 MHz (BMT)	See Figure C-7 for GPR profiles Results mapped in Figure C-4
Old Bar Beach Township / Surf Club Region		
Old Bar Beach Surf Club	• Cross shore GPR profile • 250 MHz (GA)	See Figure C-8 for GPR profile Results mapped in Figure C-4
Old Bar Beach Caravan Park	• Cross shore GPR profile • 250 MHz (GA)	See Figure C-9 for GPR profile Results mapped in Figure C-4
Northern Dune Region		
Southern Beach Access (off Mudbishops Point Road)	• Cross shore GPR profile • 80 & 450 MHz (BMT)	See Figure C-11 for GPR profiles Results mapped in Figure C-10
Tall Dunes adjacent 4WD Beach Access (off, Mudbishops Point Road)	• Cross shore GPR profile • 80 MHz (BMT)	See Figure C-12for GPR profile Results mapped in Figure C-10
Mudbishops Point Road	• Alongshore GPR profile • 80 MHz (BMT)	See Figure C-13 and Figure C-14 for GPR profiles Results mapped in Figure C-10

A summary of key GPR findings from the **Old Bar Beach Township / Surf Club region** are provided below:

- GPR signal were attenuated near to the surface across the Old Bar township backbeach areas, including along David Street, Smith Street, Ungula Road and Mudbishops Point Road behind the Caravan Park (Figure C-4). Poor signal penetration in this region is consistent with electrically conductive conditions that occur from highly weathered bedrock terrain (+/- residual soils).

- Dune sediments layers can be seen in cross-shore GPR profiles collected by Geoscience Australia, in the vicinity of the Surf Club (Figure C-8) and Caravan Park (Figure C-9). A thin veneer of dune sediments overlies buried substrate that returned no coherent GPR signal. The buried substrate material is interpreted as weathered bedrock slopes, consistent with nearby rock outcrop (old quarry) and adjacent borehole results.
- A relatively wider coastal dune fronts the Caravan Park (although borehole results show the dune sands to transition landward into bedrock terrain).
- Bedrock reflections are recorded below the beach in the Geoscience Australia GPR data adjacent to the Urana Bombora (Figure C-4).

Key GPR findings for the **Old Bar Beach ‘northern dunes’ region** (i.e. north of the Caravan Park), are summarised below:

- GPR profile data along Mudbishops Point Road shows that transition from poor GPR response from weathered bedrock areas (confirmed by borehole data) into a region of relic barrier dune sediments, that extend northwards to parallel Farquhar Inlet (Figure C-10, Figure C-13 and Figure C-14). The relic barrier dunes comprise indurated sediments that return a ‘chaotic’ GPR reflection image. The alongshore extent of Pleistocene barrier sands was well resolved by GPR. The indurated sediments observed outcropping adjacent to Farquhar Inlet provide a good measure for associating the ‘chaotic’ GPR signal with the substrate type.
- A tall barrier dune was imaged by GPR from the southern-most beach accessway, in the ‘northern dunes’ region (Figure C-11). The depth of dune layers imaged by GPR thins in a landward direction. This shows that sandy dune sediments overlie a substrate comprised of electrically conductive materials. Nearby borehole data indicates the buried substrate is weathered bedrock material (although clayey sediments, such as Pleistocene-age estuarine sediments would provide a comparable GPR response). A buried bedrock bluff interpretation is also consistent with the presence of submerged rock reef occurring seaward of this described GPR profile.
- GPR imaged a tall modern (Holocene-age) sand dune to overlie relict (Pleistocene-age) indurated barrier sediments in the vicinity of the 4WD beach accessway (Figure C-12). A relic Farquhar Inlet outlet channel no infilled with sand was imaged below the modern beach in this region.
- The GPR survey found no indication of bedrock near to, or above sea level, adjacent to the Farquhar Inlet.

Seaward dipping dune layers imaged in GA GPR profile

Possible rock reflection below beach in GA profile (position approx), consistent with SKM BH-01 results and BMT field observations

Poor GPR results, consistent with clay rich residual soils and weather bedrock slopes, identified from numerous boreholes across the backbeach slopes

Seaward dipping dune layers overlies substrate that returned poor GPR results, interpreted as buried weathered bedrock slopes. Positioning information (and rock - sediment interface) approximate only in GA data

GPR imaged coastal barrier dune sediments bound by Racecourse Creek, with indurated sands (chaotic GPR reflections) occurring at ~4 - 5 m AHD, consistent with borehole data.

Electrically conductive layer underlies barrier sediments, which dips down in a seaward direction from behind Racecourse Creek, landward of Rose Street.

GPR signal response varies landwards, indicating that sand dune sediments (well defined GPR reflections) overly a buried substrate that rises towards the surface, which likely comprises a weathered bedrock layer (poor reflection response)

Poor GPR response recorded landward of Racecourse Creek, due to electrically conductive (clay rich) substrates near to the surface. Slight change noted near to Rushby Drive. Correlated with borehole conditions, transitioning from alluvial plain sediment into weathered bedrock slopes.

Buried erosion scarp and an infilled paleo-channel imaged at the back of the beach

GPR images mostly older barrier dune sediments, with no indication of bedrock near to, or above sea level.

Sand bag wall also imaged at the back of the beach.

Landward migrating dune sands infill a swale immediately behind the beach, south of the Meridian Resort.

LEGEND

GPR Field Surveys

BMT Survey

GA Survey

Near map images (July 2018)

Title:

Summary of GPR Coastal Geology Results
Old Bar Beach

Figure:

C-4

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Approx. Scale

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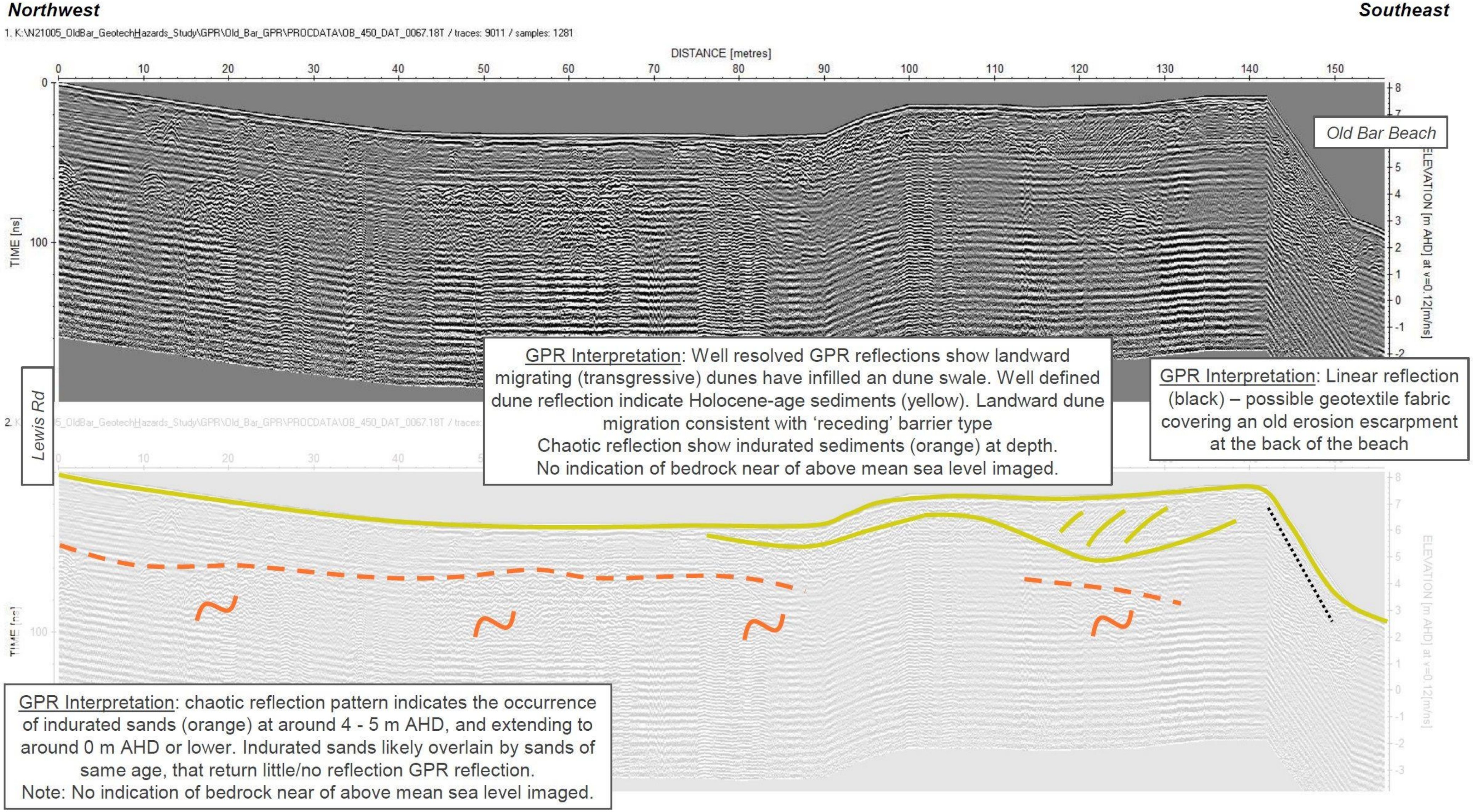


GPR Interpretation: Well resolved GPR reflections show landward migrating (transgressive) dunes have infilled an dune swale. Well defined dune reflection indicate Holocene-age sediments (yellow). Landward dune migration consistent with 'receding' barrier type
Chaotic reflection show indurated sediments (orange) at depth.
No indication of bedrock near of above mean sea level imaged.

GPR Interpretation: Linear reflection (black) – possible geotextile fabric covering an old erosion escarpment at the back of the beach

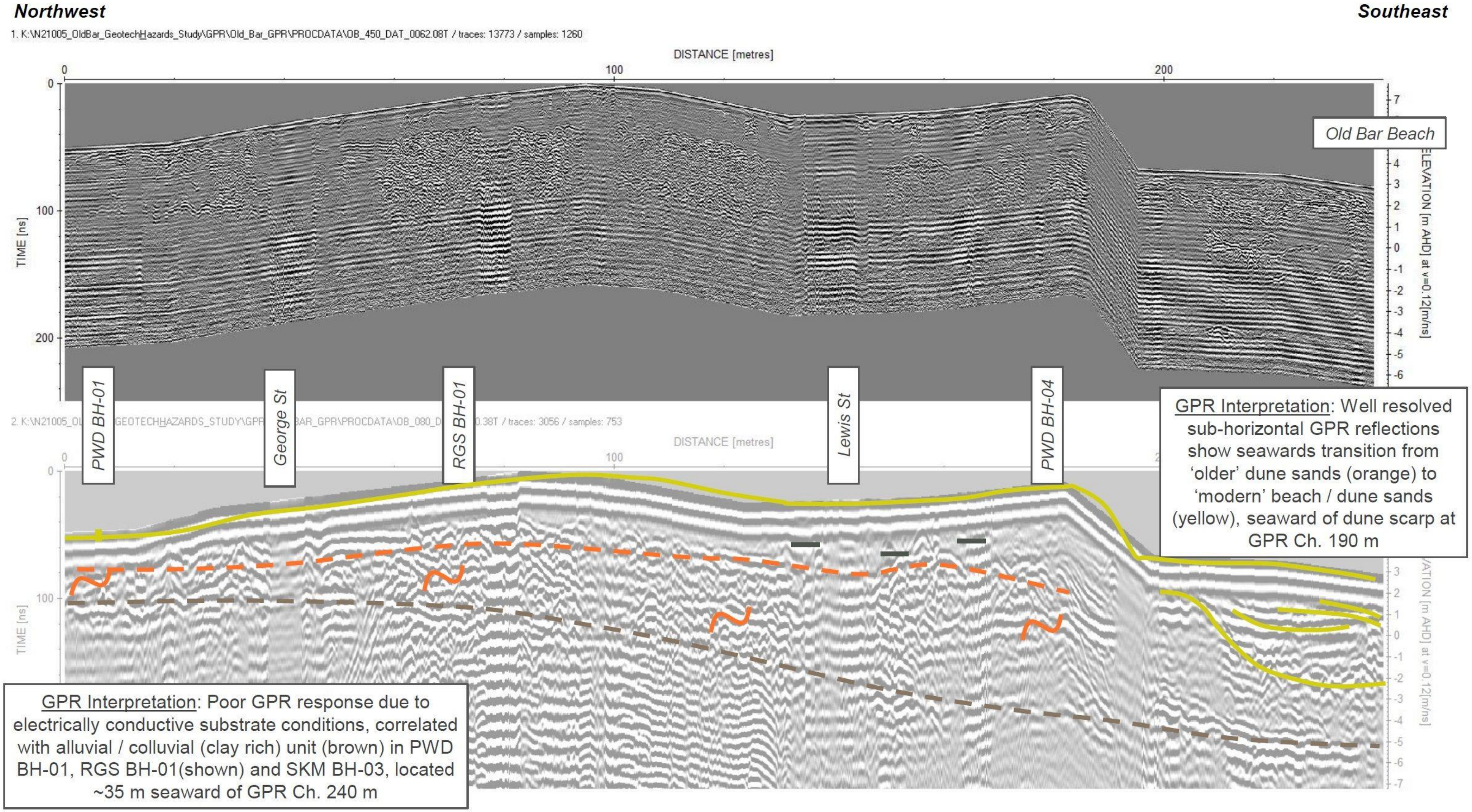
GPR Interpretation: chaotic reflection pattern indicates the occurrence of indurated sands (orange) at around 4 - 5 m AHD, and extending to around 0 m AHD or lower. Indurated sands likely overlain by sands of same age, that return little/no reflection GPR reflection.
Note: No indication of bedrock near of above mean sea level imaged.

Title:

Old Bar Beach, Immediately South of the Meridian Resort
Cross Shore GPR Profile

Top image: Processed 450 MHz GPR profile (DAT 65 and DAT 67, joined)
Bottom Image: GPR line interpretations
Note: the elevations shown above are approximated based on a '1-layer' EM velocity model

Figure:	Rev:
C-5	**A**



GPR Interpretation: Well resolved sub-horizontal GPR reflections show seawards transition from 'older' dune sands (orange) to 'modern' beach / dune sands (yellow), seaward of dune scarp at GPR Ch. 190 m

GPR Interpretation: Poor GPR response due to electrically conductive substrate conditions, correlated with alluvial / colluvial (clay rich) unit (brown) in PWD BH-01, RGS BH-01(shown) and SKM BH-03, located ~35 m seaward of GPR Ch. 240 m

Title:

Old Bar Beach, Rose Street Cross Shore GPR Profile

Figure: C-6

Rev: A

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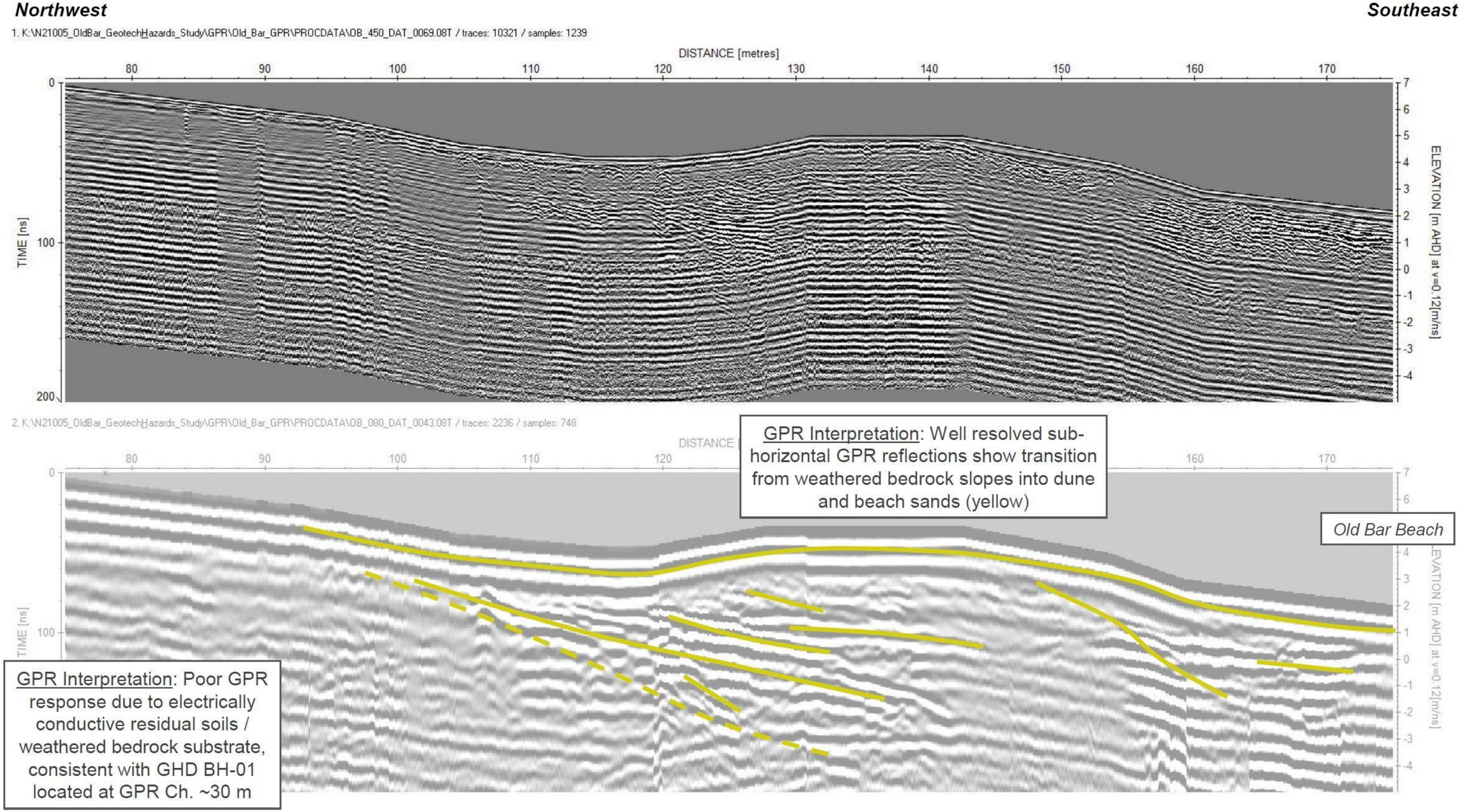
Top image: Processed 450 MHz GPR profile (DAT 62)
Bottom Image: GPR line interpretations over processed 80 MHz GPR profile (DAT 40)
Note: the elevations shown above are approximated based on a '1-layer' EM velocity model



GPR Interpretation: Well resolved sub-horizontal GPR reflections show transition from weathered bedrock slopes into dune and beach sands (yellow)

Old Bar Beach

GPR Interpretation: Poor GPR response due to electrically conductive residual soils / weathered bedrock substrate, consistent with GHD BH-01 located at GPR Ch. ~30 m

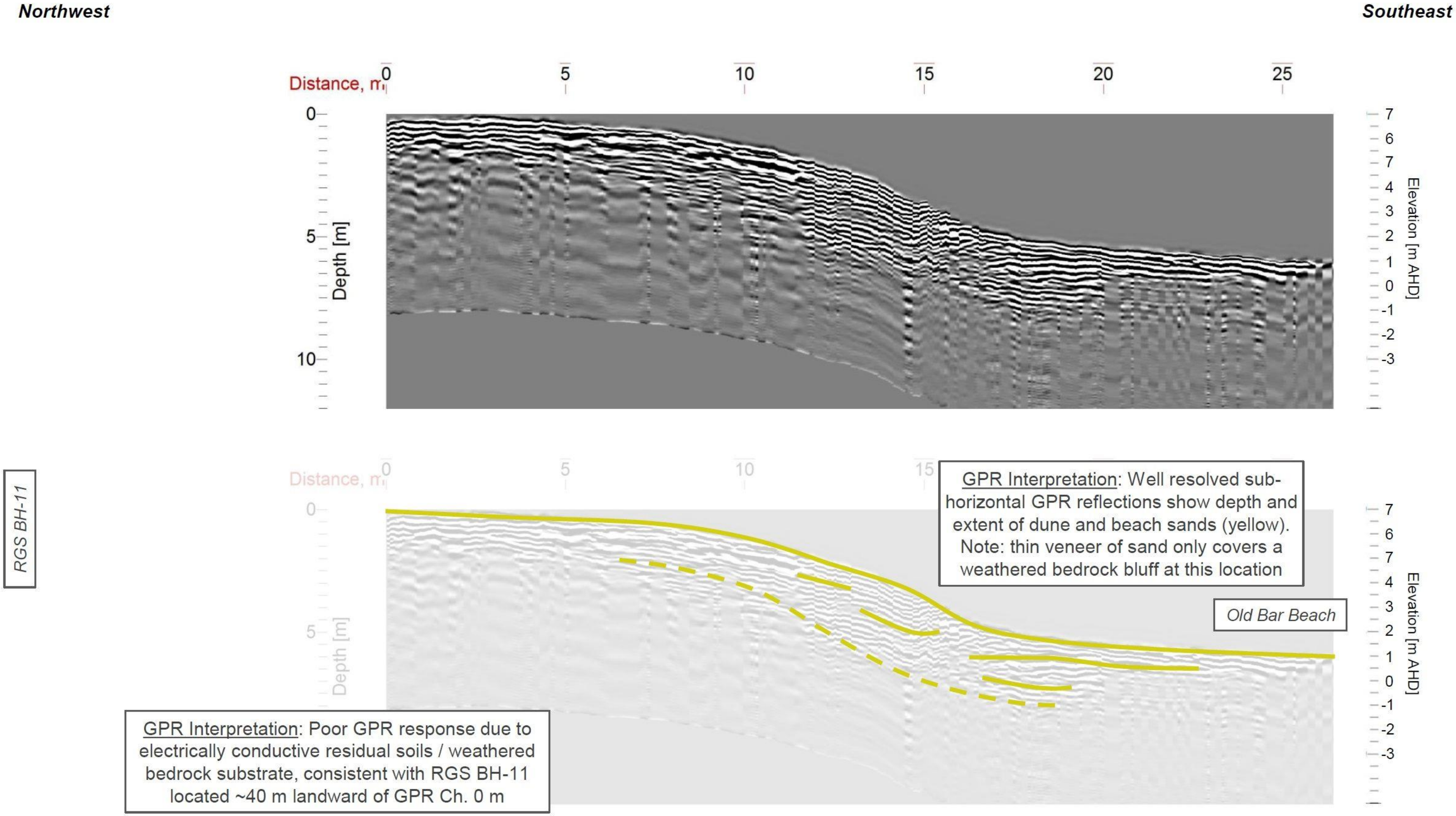
Title:

Old Bar Beach, Public School Region Cross Shore GPR Profile

Figure: **C-7**

Rev: **A**

Top image: Processed 450 MHz GPR profile (DAT 69)
Bottom Image: GPR line interpretations over processed 80 MHz GPR profile (DAT 43)
Note: the elevations shown above are approximated based on a '1-layer' EM velocity model



GPR Interpretation: Well resolved sub-horizontal GPR reflections show depth and extent of dune and beach sands (yellow). Note: thin veneer of sand only covers a weathered bedrock bluff at this location

GPR Interpretation: Poor GPR response due to electrically conductive residual soils / weathered bedrock substrate, consistent with RGS BH-11 located ~40 m landward of GPR Ch. 0 m

Title:

Old Bar Beach - Surf Club Region Cross Shore GPR Profile

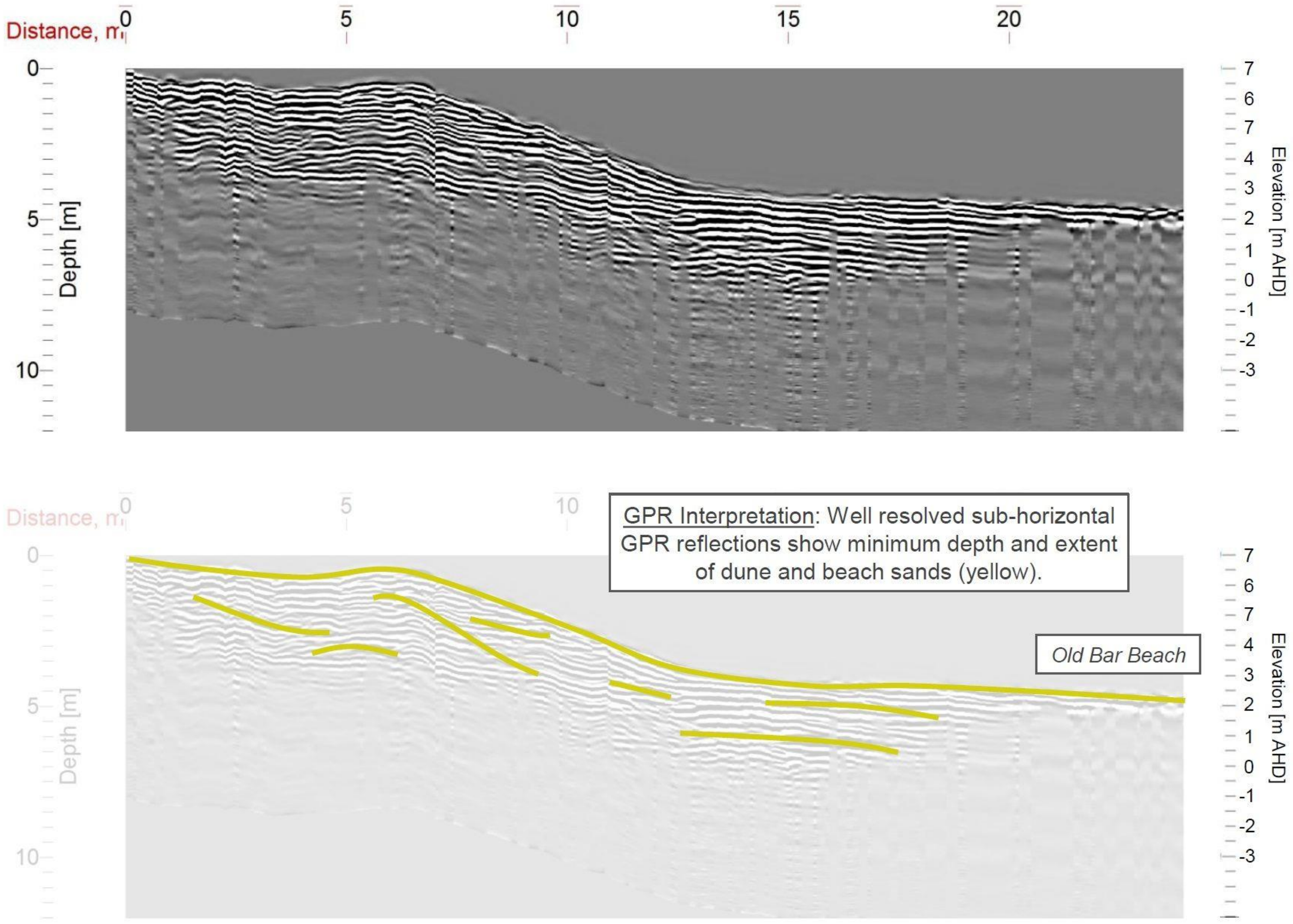
Figure: C-8

Rev: A

Top image: Processed 250 MHz GPR profile (20150303-004200, by Geoscience Australia)
Bottom image: GPR line interpretations
Note: the elevations shown above are approximated based on a '1-layer' EM velocity model

Northwest ***Southeast***

RGS BH-07



GPR Interpretation: Well resolved sub-horizontal GPR reflections show minimum depth and extent of dune and beach sands (yellow).

Note: Weathered bedrock bluff occurs behind dune sediments imaged herein, as indicated by RGS BH-07 located ~20 m landward of GPR Ch. 0 m

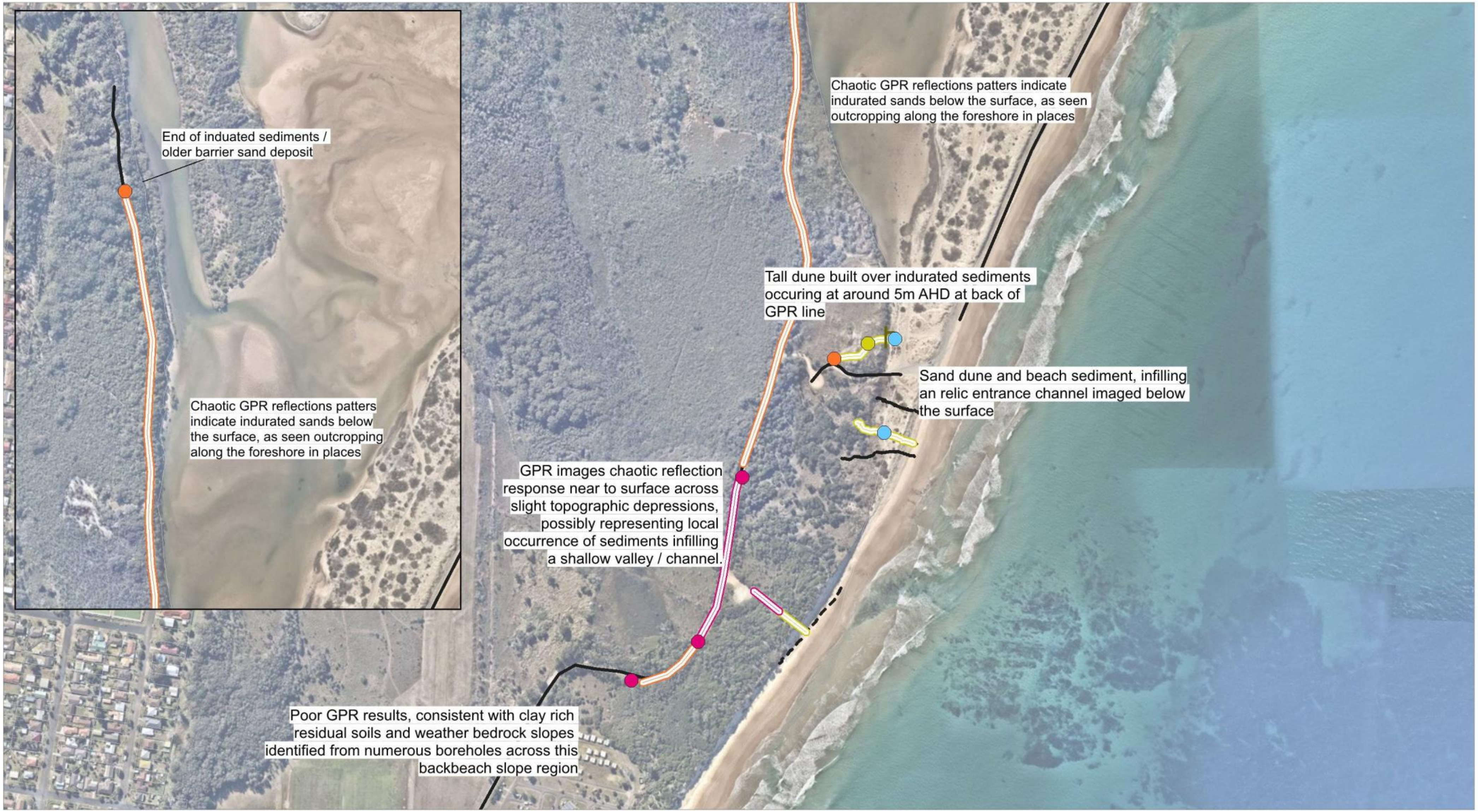
Title:

Old Bar Beach, Caravan Park Region Cross Shore GPR Profile

Figure: **C-9**

Rev: **A**

Top image: Processed 250 MHz GPR profile (20150303-010716, by Geoscience Australia)
Bottom image: GPR line interpretations
Note: the elevations shown above are approximated based on a '1-layer' EM velocity model



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GPR Field Surveys

— BMT Survey

- - - GA Survey

Near map images (July 2018)

Title:

Summary of GPR Coastal Geology Results Northern Dune Region (main) and Farquhar Inlet (inset)

Figure: **C-10**

Rev: **A**

N

0 1.25 2.5km

Approx. Scale

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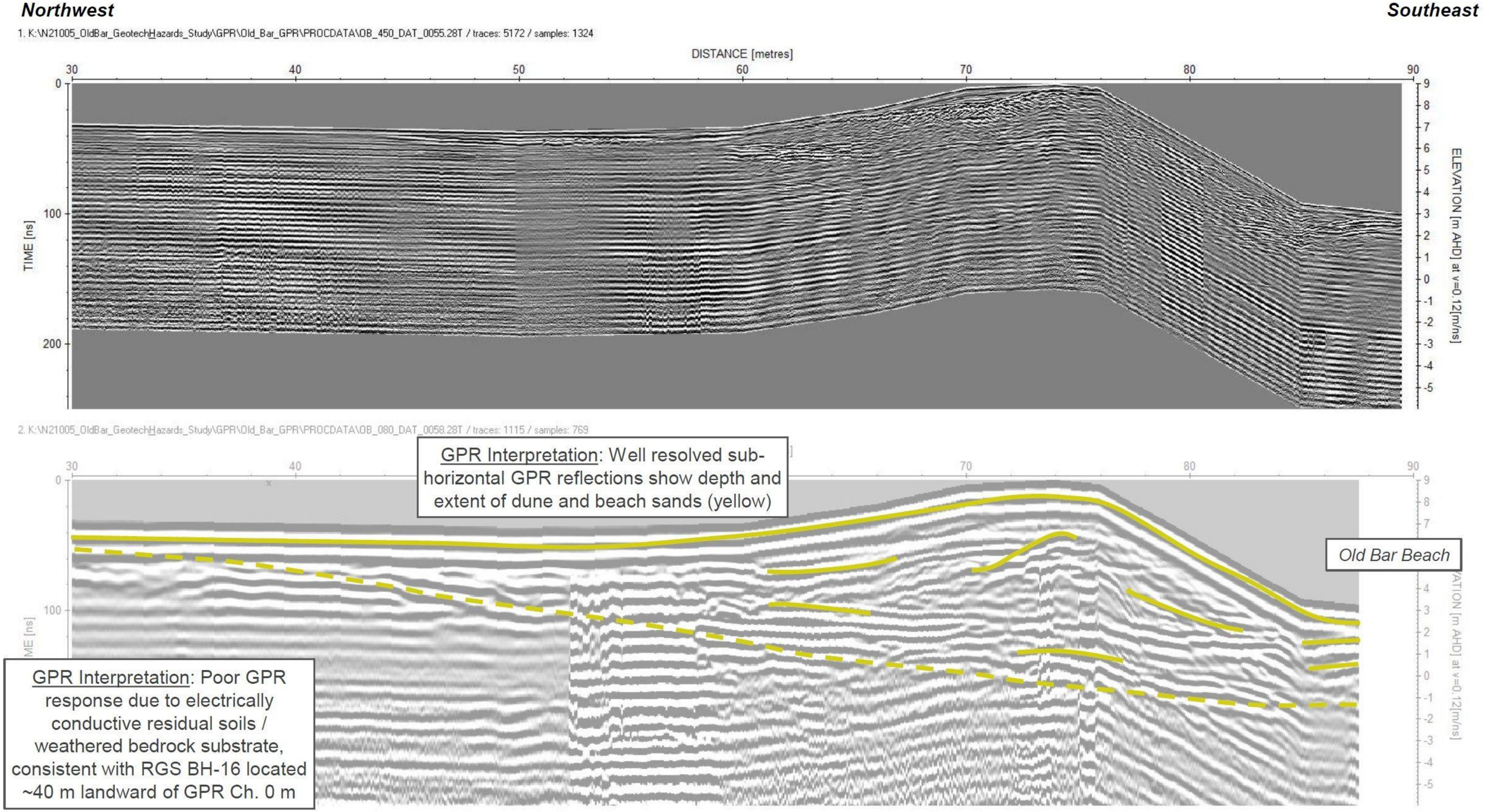


GPR Interpretation: Well resolved sub-horizontal GPR reflections show depth and extent of dune and beach sands (yellow)

GPR Interpretation: Poor GPR response due to electrically conductive residual soils / weathered bedrock substrate, consistent with RGS BH-16 located ~40 m landward of GPR Ch. 0 m

Title:

Northern Dune Region of Old Bar Beach Cross Shore GPR Profile

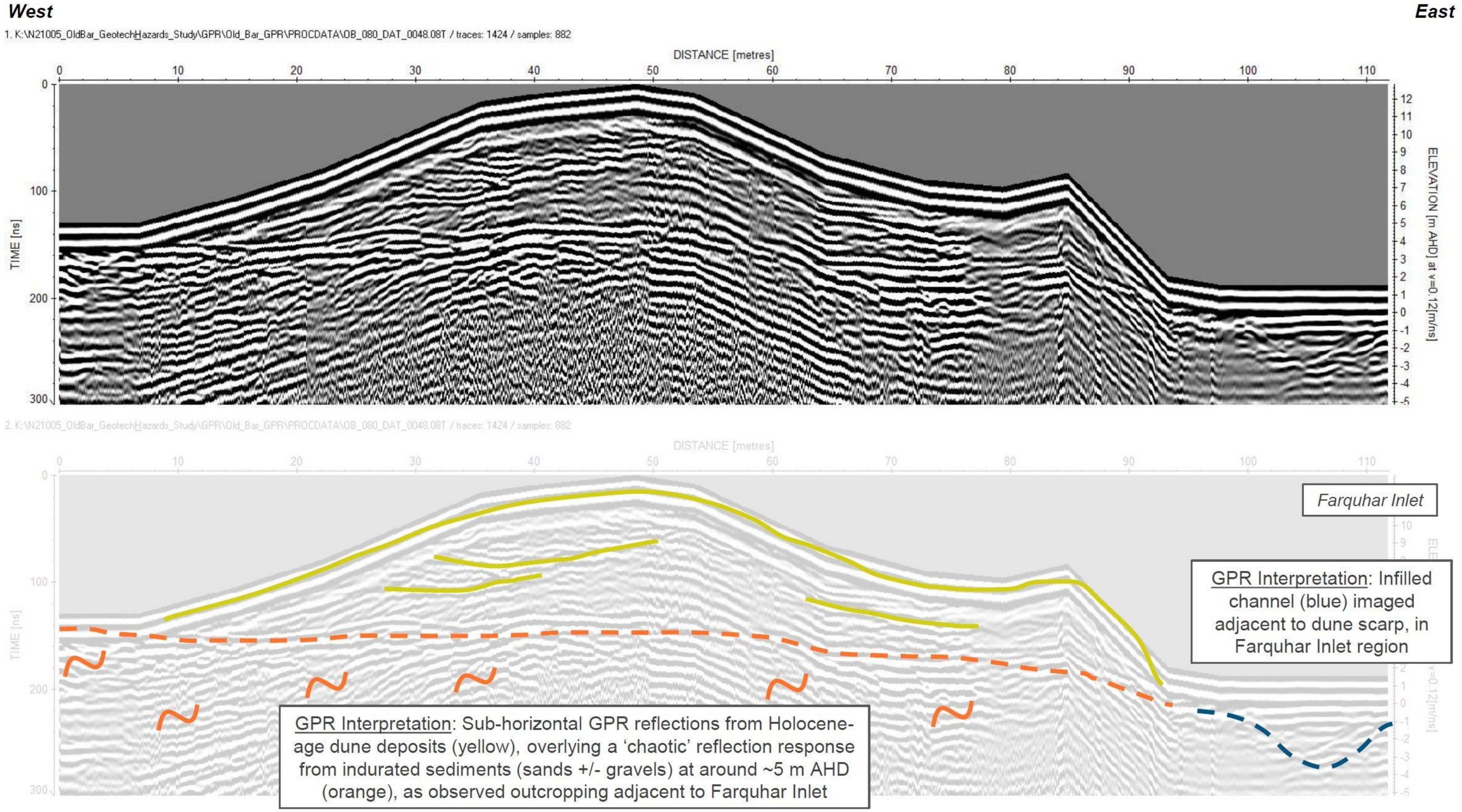
Figure:

C-11

Rev:

A

Top image: Processed 450 MHz GPR profile (DAT 55)
Bottom Image: GPR line interpretations over processed 80 MHz GPR profile (DAT 58)
Note: the elevations shown above are approximated based on a '1-layer' EM velocity model



GPR Interpretation: Infilled channel (blue) imaged adjacent to dune scarp, in Farquhar Inlet region

GPR Interpretation: Sub-horizontal GPR reflections from Holocene-age dune deposits (yellow), overlying a 'chaotic' reflection response from indurated sediments (sands +/- gravels) at around ~5 m AHD (orange), as observed outcropping adjacent to Farquhar Inlet

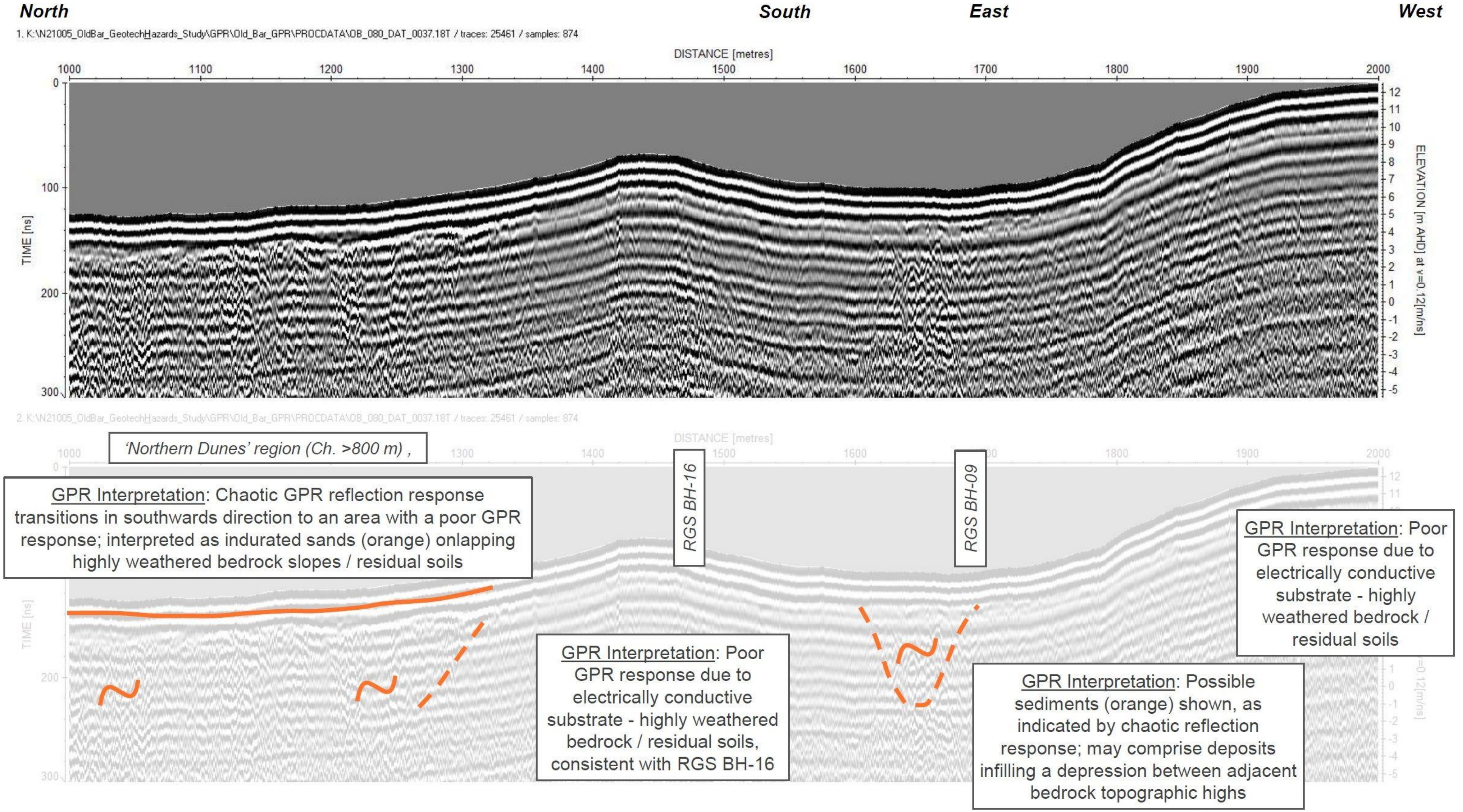
Title:

Old Bar Northern Dunes Region, Adjacent 4WD Beach Access Cross Shore GPR Profile

Figure: **C-12**

Rev: **A**

Top image: Processed 80 MHz GPR profile (DAT 48)
Bottom image: GPR line interpretations
Note: the elevations shown above are approximated based on a '1-layer' EM velocity model



GPR Interpretation: Chaotic GPR reflection response transitions in southwards direction to an area with a poor GPR response; interpreted as indurated sands (orange) onlapping highly weathered bedrock slopes / residual soils

GPR Interpretation: Poor GPR response due to electrically conductive substrate - highly weathered bedrock / residual soils, consistent with RGS BH-16

GPR Interpretation: Possible sediments (orange) shown, as indicated by chaotic reflection response; may comprise deposits infilling a depression between adjacent bedrock topographic highs

GPR Interpretation: Poor GPR response due to electrically conductive substrate - highly weathered bedrock / residual soils

Title:

Old Bar Beach, Mudbishops Point Road (Ch. 1000 – 2000 m) Alongshore GPR Profile

Figure:

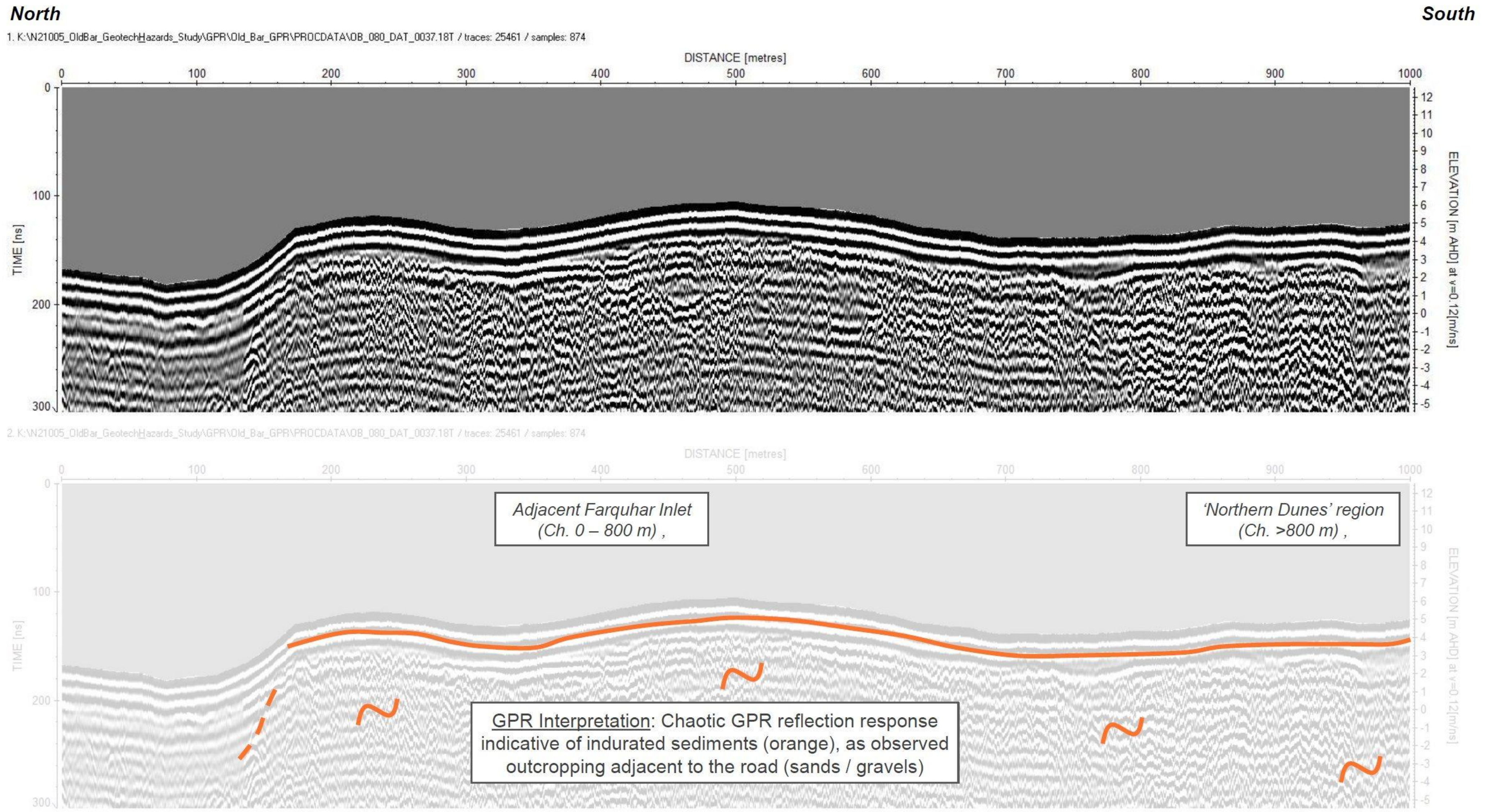
C-13

Rev:

A

Top image: Processed 80 MHz GPR profile (DAT 37)
Bottom image: GPR line interpretations
Note: the elevations shown above are approximated based on a '1-layer' EM velocity model

BMT



Adjacent Farquhar Inlet (Ch. 0 – 800 m) ,

'Northern Dunes' region (Ch. >800 m) ,

<u>GPR Interpretation</u>: Chaotic GPR reflection response indicative of indurated sediments (orange), as observed outcropping adjacent to the road (sands / gravels)

Title:

Old Bar Beach, Mudbishops Point Road (Ch. 0 – 1000 m)
Alongshore GPR Profile

Figure: **C-14**

Rev: **A**

Top image: Processed 80 MHz GPR profile (DAT 37)
Bottom image: GPR line interpretations
Note: the elevations shown above are approximated based on a '1-layer' EM velocity model

C.3.2 Mitchells Island and Manning Point Beach

GPR identified the coastal geology and erosion vulnerability characteristics of Mitchells Island and Manning Point Beach region. These results are documented in a series of GPR profiles and an accompanying summary map (see Table C-4 for figure references).

In summary, key coastal geology findings of the GPR survey of **Mitchells Island** and **Manning Point Beach** include:

- The dune barrier imaged by GPR at Beach Road, Mitchells Island, shows the beach and dune areas to be formed or erodible sands only (Figure C-15), with no indication of bedrock present in the GPR image.
- Similarly, for Manning Point Beach, the GPR profiles across the coastal barrier show that beach and dune substrates are formed of erodible sediments to below sea level. This is determined from the clearly imaged layering, which is indicative of young (Holocene-age) sands (Figure C-15 and Figure C-16).

Table C-4 Summary of Results, Mitchells Island and Manning Point Beach

Location	GPR Profile Summary	Results
Mitchells Island		
Mitchells Island at Beach Road	• Cross shore GPR profile • 450 MHz (BMT)	Results mapped in Figure C-15
Manning Point Beach		
Main Beach Access (Main Road)	• Cross shore GPR profile • 450 MHz (BMT)	See Figure C-16 for GPR profile Results mapped in Figure C-15
Middle Beach Access at Bowling Club	• Cross shore GPR profile • 450 MHz (BMT)	Results mapped in Figure C-15
Southern Beach Access at Caravan Park	• Cross shore GPR profile • 450 MHz (BMT)	Results mapped in Figure C-15

LEGEND

GPR Field Surveys

BMT Survey

GA Survey

Near map images (July 2018)

Title:

Summary of GPR Coastal Geology Results Mitchells Island (inset) and Manning Point (main)

N

0 1.25 2.5km
Approx. Scale

Figure: **C-15**

Rev: **A**

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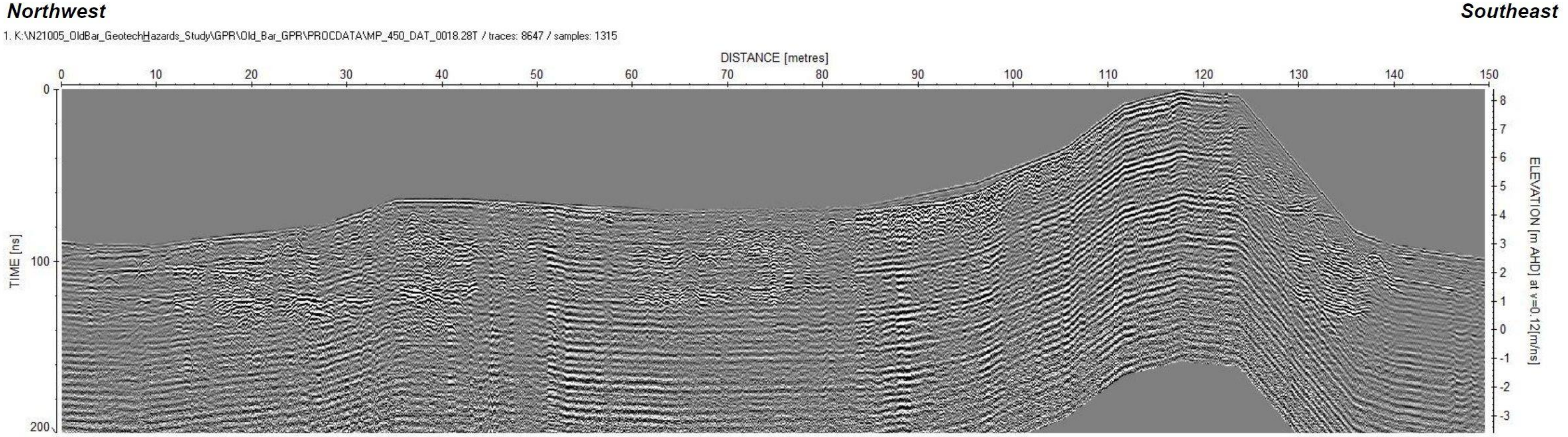
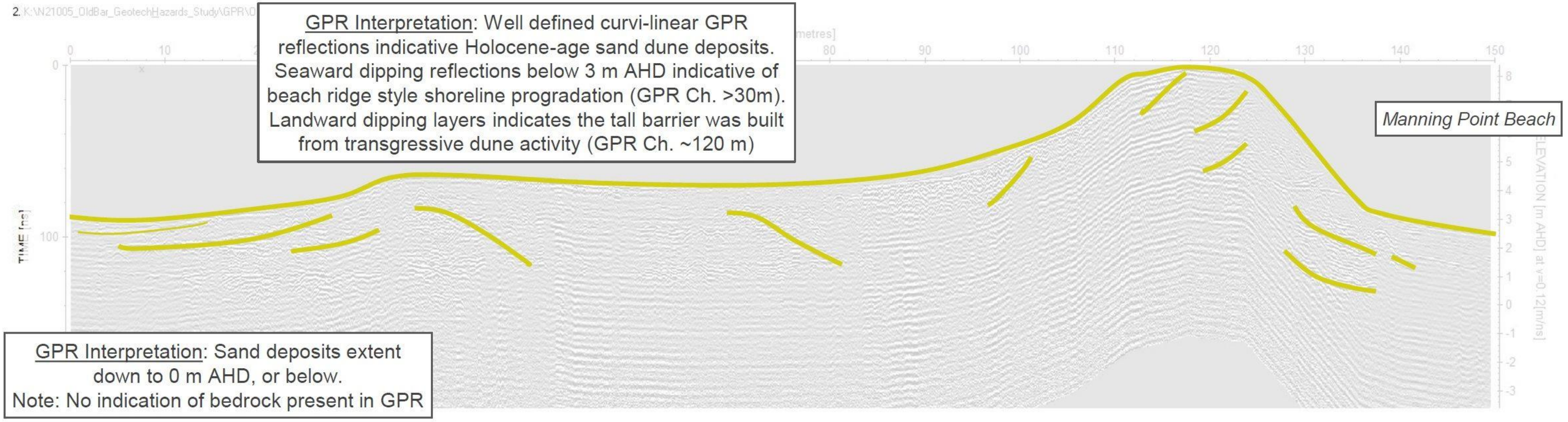




GPR Interpretation: Well defined curvi-linear GPR reflections indicative Holocene-age sand dune deposits. Seaward dipping reflections below 3 m AHD indicative of beach ridge style shoreline progradation (GPR Ch. >30m). Landward dipping layers indicates the tall barrier was built from transgressive dune activity (GPR Ch. ~120 m)

GPR Interpretation: Sand deposits extent down to 0 m AHD, or below.
Note: No indication of bedrock present in GPR

Title:

Manning Point, Main Beach Access Cross Shore GPR Profile

Figure: **C-16**

Rev: **A**

Top image: Processed 450 MHz GPR profile (DAT 18)
Bottom Image: GPR line interpretations
Note: the elevations shown above are approximated based on a '1-layer' EM velocity model

C.4 Discussion and Conclusion

C.4.1 Survey Appraisal

The GPR survey successfully imaged the coastal geology at Old Bar Beach and Manning Point Beach. Various substrate types and their corresponding distributions were identified. This includes areas of modern beach and dune sands, relic barrier sediments, and areas of electrically conductive substrates, including clayey alluvial / estuarine sediments (e.g. landward of Racecourse Creek) and weathered bedrock slopes (e.g. in the vicinity of the Urana Bombora).

The bedrock – sediment interface was clearly identified within several cross shore GPR profiles where sand overlay rock, including at the Public School and in the Old Bar ‘northern dunes’ area. This geological feature is interpreted as bedrock bluff whereby weathered rocky profile that slopes seaward has been concealed by coastal sediments, such as transgressive dune sands. Clear bedrock reflections were not returned from the buried rocky slopes, due to the typically weathered profile consisting of electrically conductive materials. Nonetheless, a clear transition from dune layers well defined in GPR images into subsurface areas regions where the GPR signal becomes abruptly attenuated identifies change in geological substrate. Such subsurface areas with attenuated GPR signal near to the surface have been identified as bedrock, where complementary geotechnical and/or geomorphological information support this interpretation. Such data include nearby borehole information, distinct change in surface landform profile (i.e. break in slope), and other contextual data (e.g. nearby rocky outcrops).

Bedrock areas across the Old Bar region are formed of a highly weathered material that is often overlain by residual soils. A limitation of the GPR method is that it cannot resolve the geotechnical nature of the weathered bedrock profile. This limitation was recognised in the survey design stage and has been effectively accounted for through the parallel borehole investigation. The borehole campaign was designed to characterise both geographic extent of bedrock and determine the geotechnical characteristics of the soil / rock profile.

Indeed, the three pronged (GPR, borehole, field walkover) approach adopted for this study has enabled the coastal geology to be characterised for the onshore regions. GPR added great value to the broader study by imaging subsurface areas that could not be accessed by truck mounted drill rig, and enable complementing of various data sources to derive geological insight. GPR has also added significant confidence in the geomorphological substrate mapping presented in the main report body. The rapid nature of GPR data collection also meant that much greater areas could be covered by geophysical survey within the project scope, relative to other geophysical methods.

C.4.2 Coastal Geomorphology and Erosion Vulnerability

Results from the GPR investigation at **Old Bar Beach** shows that the **Racecourse Creek** coastal region typically comprises a range of erodible substrates, including alluvial / estuarine sediments, relic dune deposits including indurated sands and a narrow fringe of modern dune and beach sediments. Bedrock slopes are located no closer than ~300 metres landward of the present day shoreline in the Racecourse Creek region.

However, immediately north of the creek bedrock terrain is located much closer to the shoreline with the relic bedrock bluff protruding to its most seaward position adjacent to the Urana Bombora. The Public School is located on bedrock and fronted by approximately 60 metre wide sand dune area. The sand dune width progressively narrows northwards of here, and reaches its narrowest width in the vicinity of the **Surf Club**. Cross shore GPR profiles show that the modern dune sediments mantle the relic coastal bluff in this region, with a seaward sloping rocky substrate joining high ground between the Public School and Mudbishops Point Road southern beach carpark. Along the foreshore of this region, GPR survey by Geoscience Australia reported imaged bedrock at shallow depths below the beach (Nichol et al., 2016); which is consistent with borehole data presented in SKM (1982). These data sources indicate that the bedrock bluff extends seaward below the beach to join with the nearby submerged rocky reef (Urana Bombora). The GPR results, combined with the field observation and geomorphic interpretation will enable the sand – rock interface to be mapped with reasonable confidence. However, consideration is required in relation to the erodibility of the weathered bedrock material – noting that deep residual soils are common across the bluff.

The GPR survey found that the **northern dune** area comprises a mix of erodible coastal sediments along the coastal fringe. Relic indurated sediments were consistently imaged at around 5 m AHD as seen outcropping next to Farquhar Inlet. Foreshore areas with higher relief were shown to comprise modern (unconsolidated) transgressive dune (e.g. adjacent the 4WD beach access carpark). A relic outlet channel to Farquhar Inlet was imaged below the beach in this vicinity. The infilled channel aligns with the outcropping indurated sand/gravel cliffs observed further upstream. This relationship indicates that relic Pleistocene-age coastal deposits have a (possibly marginal) controlling effect on the channel breakout/migration location. While still clearly erodible, this indurated sediment deposit appears to be more durable than the adjoining unconsolidated beach and dune sands.

The GPR survey across the **Mitchells Island** and **Manning Point** foreshore found comparable coastal geological conditions. The well-defined dune layers indicate the coastal barrier deposits are formed of unconsolidated beach and dune sands which are highly susceptible to erosion when exposed to wave action, for example. No bedrock or other resistant substrates were observed near to, or above sea level. in the targeted profiles collected north of Farquhar Inlet.

C.4.3 Summary and Conclusion

In summary, this Old Bar GPR investigation completed an extensive geophysical field survey across all readily accessible coastal areas, including Old Bar (priority location), Mitchells Island and Manning Point. A sequence of processing steps was applied to the GPR data, to enable expert interpretation of the coastal geological conditions. A range of complementary datasets were analysed as part of this investigation, including GPR data collected by Geoscience Australia and other geotechnical information available (e.g. boreholes).

A sequence of erodible sediment approximately 300 meters wide was found to underlie the residential land at Racecourse Creek. Durable substrate associated with a buried bedrock bluff was imaged near to the shore across the Surf Club region. The sediment – bedrock interface identified in several GPR profiles indicates the bluff protrudes to its most seaward point adjacent to the Urana Bombora, with the fronting sand dunes deposits varying in width along this foreshore region.

Indurated sediments were found to parallel the Farquhar Inlet foreshore, along with modern dune deposits behind the open coastline.

The Mitchells Island and Manning Point GPR survey indicates the open coastline is formed of a barrier dune built from erodible beach and dune sands. No resistant or semi-durable material was identified in the GPR data from this region.

In conclusion, the GPR survey successfully identified a range of geological substrates with variable geotechnical properties, with respect to coastal erosion resistance. The bedrock bluff identified close to the shoreline between the Public School and north of the Caravan Park indicates that existing erosion hazard estimates are overly conservative for this region. The varied coastal geological conditions described herein should be incorporated into future erosion hazard assessment. In such assessments, it will be important to also consider how the highly weathered bedrock substrate may respond to coastal processes (e.g. wave action) and sea level rise, when updating erosion hazard estimates for Old Bar Beach.

C.5 Disclaimer

BMT guarantees the GPR survey has been completed in a professional manner, using high performance equipment in accordance with best industry practice.

However, due to the inherent limitations of GPR technology and the interpretive nature of the results we cannot guarantee 100% accuracy of the interpretations provided in this report.

For this reason, BMT does not accept any responsibility or liability for losses or damages of any kind, resulting from misinterpreted or misrepresented subsurface conditions / features presented within this report. Further, BMT does not accept any responsibility or liability for losses or damages of any kind resulting from decisions or actions based on information provided within this report.

Please also note that the geological interpretations provided in this report do not substitute for drilling, sampling and *in situ* testing that may be required for site specific geotechnical investigations (including those required to inform civil design or support residential development applications, for example).

C.6 References

Bristow, C.S. and Jol, H.M. (2003) *Ground Penetrating Radar in Sediments*. Geological Society, London, Special Publication 211.

Hashimoto, T. and Troedson, A (2008). Coffs Harbour 1:100,000 and 1:25,000, Coastal Quaternary Geology Map Series. Geological Survey of New South Wales, Maitland.

Appendix D Coastal Geotechnical Borehole Investigation

D.1 Introduction

A borehole investigation was completed as one of several field based methods used to investigate the coastal geology of the Old Bar Beach region. Borehole drilling and the production of geotechnical logs were conducted by Regional Geotechnical Solutions (RGS) at locations nominated by BMT. The survey spanned the Old Bar township and foreshore regions, plus the Wallabi Point residential area. The RGS (2019) data was analysed with a range of existing borehole information compiled for this study from past investigations (PWD, 1981; SKM, 1982; GHD, 2017).

The RGS borehole logs and associated technical report is presented in Appendix E. Borehole logs from three previous subsurface investigations by PWD (1981), SKM (1982) and GHD (2017) are reproduced in Appendix F.

D.1.1 Investigation scope and objectives

The scope of this borehole investigation included the following:

- Compile and analyse existing borehole records within the study site.
- Design and undertake a borehole survey to investigate the sediment types, depth to bedrock and substrate strength at targeted locations.
- Characterise the geological profiles and geotechnical conditions of the study area, based on the available information.

BMT engaged RGS to undertake a targeted borehole survey, with the objectives to document the geological substrates and profiles that comprise the Old Bar Beach coastal zone (e.g. sediment types, depth to bedrock), and determine their corresponding geotechnical characteristics (e.g. rock strength).

Borehole locations were identified by BMT based on the following:

- Priority locations (e.g. high risk residential areas);
- Areas of suspected bedrock terrain that has been modelled as comprising sandy substrates in prior hazard assessments;
- Requirement for GPR depth to bedrock calibration and interpretation confirmation;
- Locations where some uncertainty remained with respect to the subsurface conditions, following on from the literature review, field walkover assessment and GPR survey undertaken in parallel (see Appendix B, Appendix C); and
- Site access and suitability.

D.1.2 Field work

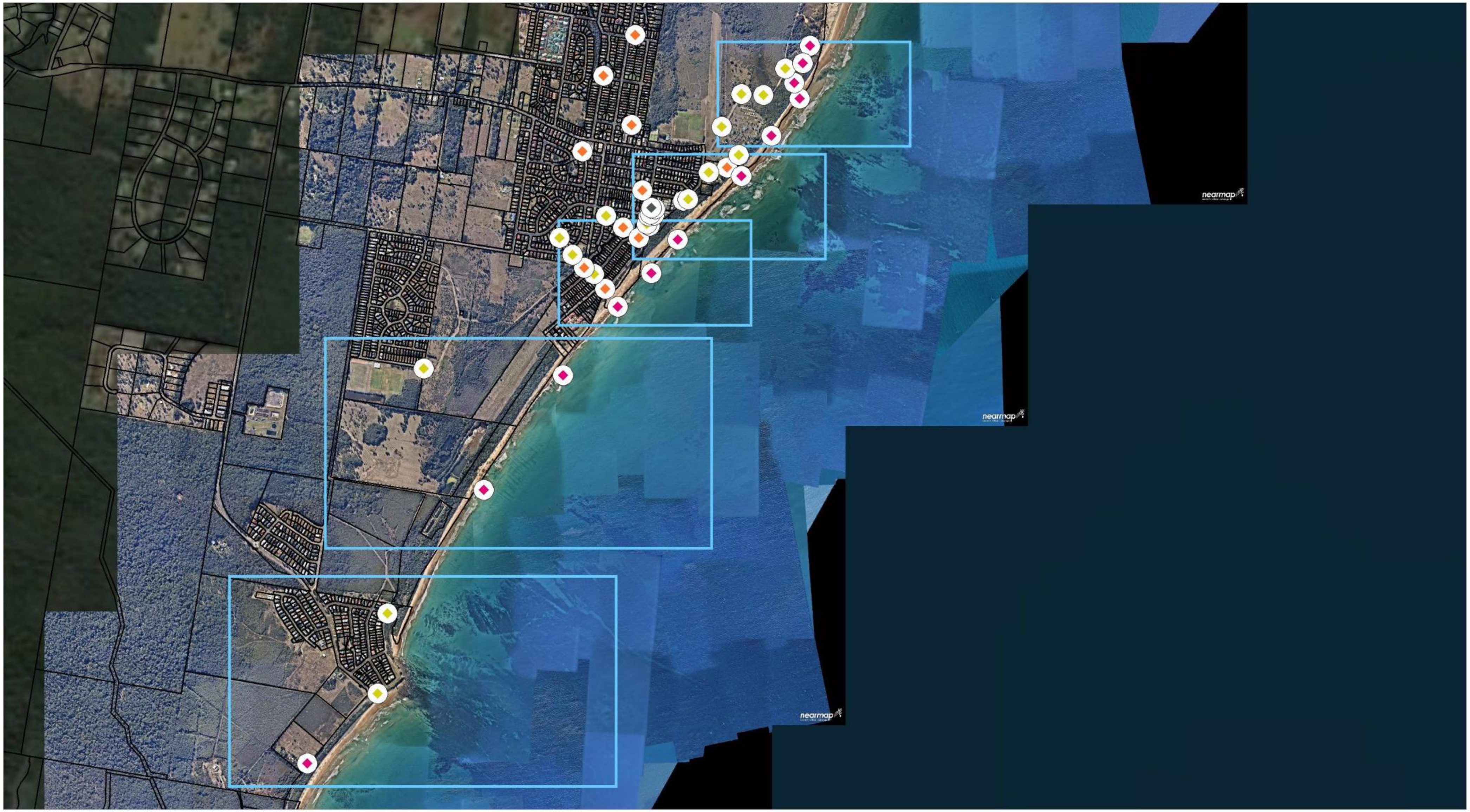
Borehole drilling was undertaken by RGS at locations shown in Figure D-2, which also maps borehole sites from prior investigations that have been complied and analysed by BMT within this appendix.

The February 2019 survey involved drilling and geotechnical logging of boreholes with a truck mounted drill rig (see Figure D-1) by RGS. Standard penetrometer tests were carried out at 1.5 m intervals to assess undrained shear strength of cohesive soils and density of granular soils.

Figure D-1 Borehole Drilling by RGS at Wallabi Point

D.1.3 Existing Information

Prior to the current investigation, borehole drilling had been conducted across the Old Bar region in three prior investigations, relating to (i) stormwater planning and design (PWD,1981); (ii) coastal geomorphology and erosion (SKM, 1982); and (iii) the upgrade of the Old Bar Public School (GHD, 2017). The historical (1980's) borehole data was collected prior to the development of current geotechnical engineering standards. As such, the geological data within the PWD (1981) and SKM (1982) are not a rigorous as that documented in the GHD (2017) and RGS (2019) borehole logs. Nonetheless, the 1980's records provide a very useful complementary dataset to the current investigation, which shows the variability in substrate conditions within the Old Bar Beach region.



LEGEND

Borehole campaign

◆ PWD (1981)
◆ SKM (1982)
◆ GHD (2017)
◆ RGS (2019)

Near map images (July 2018)

Title:

Borehole Summary Map
Old Bar Beach Study Region

Figure: **D-2**

Rev: **A**

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D.2 Borehole Compilation

The four borehole campaigns summarised and synthesised herein were conducted across a range of geological settings. Borehole data were collected from both areas comprising backbeach bedrock terrain and within geologically recent sedimentary settings. The bedrock geology of the region mapped as comprising Devonian-age Kooringhat beds that are typically made up of sandstones, greywackes, laminate, tuff and shale (GSNSW, 1970; 1987). The contemporary sedimentary environments ranged from Holocene-age to Pleistocene-age coastal barrier and estuarine plain settings (SKM, 1982; GSNSW, 2008), across beach, dune and backbarrier areas.

Borehole locations and corresponding information sources are summarised in Table D-1. The **location and surface level information** (and accuracy) provided for each dataset was variable, as discussed below:

- **RGS (2019)** documented 16 boreholes for a targeted coastal hazard subsurface investigation across Old Bar and Wallabi Point. Borehole locations were documented with MGA co-ordinates and surface RLs were provided in metres AHD. Location data were collected with a handheld GPS device (accuracy +/- 5m). BMT provided surface RLs by extracting elevation information from the 2012 LiDAR digital elevation model (DEM) in GIS.
- **GHD (2018)** documented 4 boreholes for a geotechnical investigation at Old Bar Public School. Borehole locations and levels were apparently determined from a survey plan. The borehole location records provided within a report table are incorrect (co-ordinates for Port Macquarie region), however a small scale (detailed) site plan of the Old Bar Public School is provided which shows the borehole locations. BMT used the site plan map to determine the borehole co-ordinates and corresponding surface elevation in GIS (i.e. borehole map was georeferenced to determine location data and the elevation information was then extracted from the 2012 LiDAR DEM).
- **SKM (1982)** documented 13 boreholes as part of a coastal geomorphology and erosion investigation from the beach and dune areas along Old Bar Beach and at Wallabi Beach. The borehole locations were mapped on a large scale (regional) map only, with no co-ordinate information provided. The course scale borehole map was georeferenced in GIS to provide approximate co-ordinate information that is provided herein (Table D-1). The surface RL information was documented/estimated relative to an ISWL datum (~ 0.85 metres below AHD). Based on the GIS mapping of boreholes from the backbeach (northern dune) area, we consider that an AHD datum better approximates the surface RLs from the SKM dataset (note the 1980's surface RL information provided for the foreshore (beach) boreholes was much higher than that experienced under current conditions due to the progressive recession shoreline recession that has been experienced over preceding decades).
- **PWD (1981)** documented 12 boreholes for a sewerage investigation, including 11 boreholes from the Old Bar township region. Borehole locations were mapped across a detailed site plan, but no geographic co-ordinates or surface elevation information was provided. The site plan map was georeferenced in GIS to determine the mapped borehole locations and their corresponding surface elevations, which were derived from the 2012 LiDAR DEM.

The **substrate descriptions** documented within each report were also variable. RGS (2019) and GHD (2017) provided detailed descriptions of the substrate profiles, which were presented in Engineering Logs. The SKM (1982) and PWD (1981) information sources provide only relatively simple records of substrate types encountered. BMT has synthesised and interpreted these various information sources to provide a consistent description of substrates encountered in all four borehole campaigns. These results are presented in Table D-2 to Table D-5 and summarised in Figure D-3 to Figure D-7.

Table D-1 Summary of Old Bar Beach Borehole Data from Various Sources

BH #	Borehole ID	Information Source	Geographic Region[1]	Easting (m MGA)	Northing (m MGA)	Estimated Accuracy (m)
1	SKM BH-13	SKM (1982)	WB	459,080	6,459,400	+/- 25
2	RGS BH-14	RGS (2019)	WP	459,480	6,459,795	+/- 5
3	RGS BH-10	RGS (2019)	WP	459,535	6,460,250	+/- 5
4	SKM BH-10	SKM (1982)	FS	460,080	6,460,950	+/- 25
5	SKM BH-04	SKM (1982)	FS	460,530	6,461,600	+/- 25
6	SKM BH-03	SKM (1982)	FS	460,840	6,461,990	+/- 25
7	SKM BH-11	SKM (1982)	FS	461,030	6,462,180	+/- 25
8	SKM BH-02	SKM (1982)	FS	461,180	6,462,370	+/- 25
9	SKM BH-01	SKM (1982)	FS	461,540	6,462,730	+/- 25
10	SKM BH-09	SKM (1982)	FS	461,710	6,462,960	+/- 25
11	SKM BH-08	SKM (1982)	FS	461,870	6,463,170	+/- 25
12	RGS BH-15	RGS (2019)	RC	459,740	6,461,640	+/- 5
13	PWD BH-04	PWD (1981)	RC	460,770	6,462,090	+/- 20
14	RGS BH-01	RGS (2019)	RC	460,705	6,462,175	+/- 5
15	PWD BH-01	PWD (1981)	RC	460,650	6,462,210	+/- 20
16	RGS BH-02	RGS (2019)	RC	460,585	6,462,285	+/- 5
17	RGS BH-03	RGS (2019)	RC	460,510	6,462,380	+/- 5
18	PWD BH-05	PWD (1981)	RC	460,960	6,462,380	+/- 20
19	PWD BH-06	PWD (1981)	RC	460,870	6,462,440	+/- 20
20	RGS BH-12	RGS (2019)	RC	460,775	6,462,505	+/- 5
21	SKM BH-12	SKM (1982)	RC	461,020	6,462,450	+/- 25
22	RGS BH-04	RGS (2019)	RC	461,005	6,462,460	+/- 5
23	RGS BH-05	RGS (2019)	BS	461,015	6,462,505	+/- 5
24	GHD BH-01	GHD (2017)	BS	461,045	6,462,510	+/- 5
25	GHD BH-02	GHD (2017)	BS	461,025	6,462,515	+/- 5
26	GHD BH-04	GHD (2017)	BS	461,050	6,462,545	+/- 5

BH #	Borehole ID	Information Source	Geographic Region[1]	Easting (m MGA)	Northing (m MGA)	Estimated Accuracy (m)
27	GHD BH-03	GHD (2017)	BS	461,030	6,462,550	+/- 5
28	PWD BH-07	PWD (1981)	BS	460,980	6,462,650	+/- 20
29	PWD BH-09	PWD (1981)	BS	460,640	6,462,870	+/- 20
30	PWD BH-08	PWD (1981)	BS	461,210	6,462,590	+/- 20
31	RGS BH-06	RGS (2019)	BS	461,240	6,462,600	+/- 5
32	RGS BH-11	RGS (2019)	BS	461,355	6,462,750	+/- 5
33	PWD BH-11	PWD (1981)	BS	460,920	6,463,020	+/- 20
34	PWD BH-03	PWD (1981)	BS	460,760	6,463,300	+/- 20
35	PWD BH-02	PWD (1981)	BS	461,460	6,462,780	+/- 20
36	RGS BH-07	RGS (2019)	BS	461,525	6,462,850	+/- 5
37	RGS BH-13	RGS (2019)	BS	461,430	6,463,010	+/- 5
38	PWD BH-10	PWD (1981)	BS	460,940	6,463,530	+/- 20
39	RGS BH-08	RGS (2019)	BS	461,540	6,463,195	+/- 5
40	RGS BH-09	RGS (2019)	BS	461,665	6,463,190	+/- 5
41	SKM BH-07	SKM (1982)	ND	461,840	6,463,260	+/- 25
42	RGS BH-16	RGS (2019)	ND	461,790	6,463,340	+/- 5
43	SKM BH-05	SKM (1982)	ND	461,930	6,463,470	+/- 25
44	SKM BH-06	SKM (1982)	ND	461,890	6,463,370	+/- 25

[1] (WB) Wallabi Beach, (WP) Wallabi Point, (FS) Old Bar Beach – foreshore; (RC) Old Bar Beach – Racecourse Creek region; Old Bar Beach - backshore slopes / town; (ND) Old Bar Beach – northern dune region.

Table D-2 Wallabi Beach, Wallabi Point and Old Bar Beach Foreshore

Unit	RGS Unit	Substrate Type	Borehole ID	SKM BH-13	RGS BH-14	RGS BH-10	SKM BH-10	SKM BH-04	SKM BH-03	SKM BH-11	SKM BH-02	SKM BH-01	SKM BH-09	SKM BH-08
			Surface RL (mAHD)	*3*	*5.9*	*6.6*	*2*	*2*	*2*	*2*	*2*	*2*	*2*	*2*
			Geographic Region[1]	*WB*	*WP*	*WP*	*FS*	*FS*	*FS*	*FS*	*FS*	*FS*	*FS*	*FS*
			Material Description	**Depth (m) to base of material**										
1	1	Top soil / fill	**Topsoil:** Sandy Silt, low plasticity, grey and brown, root affected.	-	-	0.2	-	-	-	-	-	-	-	-
2	2		**Fill:** Comprising either silty sandy gravel, clay or sand.	-	0.5	-	-	-	-	-	-	-	-	-
3	3	Coast / estuarine / fluvial sediments	**Aeolian / Marine Sand**: fine to medium grained, grey, medium dense to very dense.	2	2	-	0.5	0.5	5	0.5	0.5	0.5	0.5	0.5
5	N/A		**Beach Sediments:** mixed or interbedded SAND and GRAVEL	-	-	-	6	4.5	7.5	6.5	1.7	1.3	2	6
6	N/A		**Alluvial / Estuarine Sediments:** mixed or interbedded SAND, GAVEL and/or CLAY (either sandy clay, clayey sand or clay and gravel), clays often stiff with medium to high plasticity	-	-	-	-	-	-	-	4.1	2.6	2.5	-
7	4		**Indurated Sand:** (as above)	5	-	-	-	7	-	-	-		-	-
8	5	Natural soils	**Alluvial / Colluvial Clay:** High plasticity, grey / brown, very stiff	-	-	-	-	-	-	-	-	-	-	-
9	6		**Residual Soil:** Silty CLAY and Sandy CLAY, medium plasticity, pale grey to grey with yellow, orange and brown mottle, very stiff to hard	-	-	4	-	-	-	-	-	-	-	-
10	7	Weathered Rock	**Extremely Weathered Metasandstone / Metasiltstone:** Fine to medium grained, pale grey/brown, estimated very low strength.	-	-	-	-	-	-	-	-	-	-	-
11	8		**Extremely to Highly Weathered Metasandstone / Metasiltstone:** Fine to medium grained, pale grey/brown, estimated very low to low strength.	-	-	7.55	-	-	-	-	4.2	2.7	4	-
12	9		**Highly to Slightly Weathered Metasandstone / Metasiltstone:** Fine to medium grained, pale grey/brown, estimated low to high strength	-	3.2	-	-	-	-	-	-	-	-	-

[1] (WB) Wallabi Beach, (WP) Wallabi Point, (FS) Old Bar Beach – foreshore; (RC) Old Bar Beach – Racecourse Creek region; Old Bar Beach - backshore slopes / town; (ND) Old Bar Beach – northern dune region.

* Nominal 0.5 metre depths provided for SKM (1982) borehole where surface sediments without any depth information was described.

Table D-3 Old Bar Beach – Racecourse Creek Region

Unit	RGS Unit	Substrate Type	Borehole ID	RGS BH-15	PWD BH-04	RGS BH-01	PWD BH-01	RGS BH-02	RGS BH-03	PWD BH-05	PWD BH-06	RGS BH-12	SKM BH-12	RGS BH-04
			Surface RL (mAHD)	*5.1*	*6*	*7.2*	*5*	*5.9*	*8.9*	*4.5*	*4.5*	*5.7*	*5.5*	*5*
			Geographic Region[1]	*RC*	*RC*	*RC*	*RC*	*RC*	*RC*	*RC*	*RC*	*RC*	*RC*	*RC*
			Material Description	**Depth (m) to base of material**										
1	1	Top soil / fill	**Topsoil:** Sandy Silt, low plasticity, grey and brown, root affected.	-	-	-	-	0.4	0.2	-	0.2	0.25	-	-
2	2		**Fill:** Comprising either silty sandy gravel, clay or sand.	1.6	-	-	-	1.1	0.7	-	-	-	-	1.7
3	3	Coast / estuarine / fluvial sediments	**Aeolian / Marine Sand**: fine to medium grained, grey, medium dense to very dense.	-	1	2.7	0.5	-	-	3	-	-	-	-
5	N/A		**Beach Sediments:** mixed or interbedded SAND and GRAVEL	-	-	-	-	-	-	-	-	-	-	
6	N/A		**Alluvial / Estuarine Sediments:** mixed or interbedded SAND, GAVEL and/or CLAY (either sandy clay, clayey sand or clay and gravel), clays often stiff with medium to high plasticity	-	-	-	1.3	-	-	-	-	-	-	
7	4		**Indurated Sand:** fine to medium grained, dark brown, very dense.	-	3.5	4.7	3	-	-	4.5	3.5	-	1	
8	5	Natural soils	**Alluvial / Colluvial Clay:** High plasticity, grey / brown, very stiff	7	4.5	6	-	1.7	-	-	-	-	-	-
9	6		**Residual Soil:** Silty CLAY and Sandy CLAY, medium plasticity, pale grey to grey with yellow, orange and brown mottle, very stiff to hard	-	-	8.3	6	4.8	3.5	-	4.5	1.3	1.8	2.4
10	7	Weathered Rock	**Extremely Weathered Metasandstone / Metasiltstone:** Fine to medium grained, pale grey/brown, estimated very low strength.	-	-	9.45	-	-	6	-	-	-	-	-
11	8		**Extremely to Highly Weathered Metasandstone / Metasiltstone:** Fine to medium grained, pale grey/brown, estimated very low to low strength.	-	-	-	-	8	8.9	-	-	2	3	2.8
12	9		**Highly to Slightly Weathered Metasandstone / Metasiltstone:** Fine to medium grained, pale grey/brown, estimated low to high strength	-	-	-	-	-	-	-	-	2.5	-	-

[1] (WB) Wallabi Beach, (WP) Wallabi Point, (FS) Old Bar Beach – foreshore; (RC) Old Bar Beach – Racecourse Creek region; Old Bar Beach - backshore slopes / town; (ND) Old Bar Beach – northern dune region.

* Nominal 0.5 metre depths provided for SKM (1982) borehole where surface sediments without any depth information was described.

Table D-4 Old Bar Beach – Backshore Slope / Township Region

Unit	RGS Unit	Substrate Type	Borehole ID	RGS BH-05	GHD BH-01	GHD BH-02	GHD BH-04	GHD BH-03	PWD BH-07	PWD BH-09	PWD BH-08	RGS BH-06	RGS BH-11	PWD BH-11
			Surface RL (mAHD)	*6.7*	*8.1*	*8.3*	*8.4*	*8.5*	*10*	*12*	*12.5*	*13.1*	*10.6*	*13*
			Geographic Region[1]	*BS*	*BS*	*BS*	*BS*	*BS*	*BS*	*BS*	*BS*	*BS*	*BS*	*BS*
			Material Description	**Depth (m) to base of material**										
1	1	Top soil / fill	**Topsoil:** Sandy Silt, low plasticity, grey and brown, root affected.	0.9	-	-	-	0.4	0.4	0.2	0.3		0.1	0.2
2	2		**Fill:** Comprising either silty sandy gravel, clay or sand.	-	1.1	1.6	0.6	0.8	-	-	-	-	-	-
3	3	Coast / estuarine / fluvial sediments	**Aeolian / Marine Sand**: fine to medium grained, grey, medium dense to very dense.	-	-	-	-	-	-	-	-	0.8	-	-
4	N/A		**Beach Sediments:** mixed or interbedded SAND and GRAVEL	-	-	-	-	-	-	-	-	-	-	-
5	N/A		**Alluvial / Estuarine Sediments:** mixed or interbedded SAND, GAVEL and/or CLAY (either sandy clay, clayey sand or clay and gravel), clays often stiff with medium to high plasticity	-	-	-	-	-	-	-	-	-	-	-
6	4		**Indurated Sand:** (as above)	-	-	-	-	-	1.2	-	1	-	-	-
7	5	Natural soils	**Alluvial / Colluvial Clay:** High plasticity, grey / brown, very stiff	-	1.4	1.9	-	-	-	-	-	-	0.6	-
8	6		**Residual Soil:** Silty CLAY and Sandy CLAY, medium plasticity, pale grey to grey with yellow, orange and brown mottle, very stiff to hard	3	2.2	3.4	3.4	3.5	2.8	3	3	2.2	6.5	4.5
9	7	Weathered Rock	**Extremely Weathered Metasandstone / Metasiltstone:** Fine to medium grained, pale grey/brown, estimated very low strength.	4.2	2.5	3.52	5.2	5.2	4.5	-	3.75	-	12.4	-
10	8		**Extremely to Highly Weathered Metasandstone / Metasiltstone:** Fine to medium grained, pale grey/brown, estimated very low to low strength.	4.5	6	-	6	6	-	-	-	-	-	-
11	9		**Highly to Slightly Weathered Metasandstone / Metasiltstone:** Fine to medium grained, pale grey/brown, estimated low to high strength	-	-	-	-	-	-	-	-	3.5	-	-

[1] (WB) Wallabi Beach, (WP) Wallabi Point, (FS) Old Bar Beach – foreshore; (RC) Old Bar Beach – Racecourse Creek region; Old Bar Beach - backshore slopes / town; (ND) Old Bar Beach – northern dune region.

* Nominal 0.5 metre depths provided for SKM (1982) borehole where surface sediments without any depth information was described.

Table D-5 Old Bar Beach – Backshore Slope / Township Region

Unit	**RGS Unit**	**Substrate Type**	**Borehole ID**	**PWD BH-03**	**PWD BH-02**	**RGS BH-07**	**RGS BH-13**	**PWD BH-10**	**RGS BH-08**	**RGS BH-09**	**SKM BH-07**	**RGS BH-16**	**SKM BH-05**	**SKM BH-06**
			Surface RL (mAHD)	*6.5*	*6.5*	*8.4*	*12.7*	*7.5*	*8.8*	*6.5*	*6*	*8.5*	*6.1*	*5*
			Geographic Region[1]	*BS*	*BS*	*BS*	*BS*	*BS*	*BS*	*BS*	*ND*	*ND*	*ND*	*ND*
			Material Description	**Depth (m) to base of material**										
1	1	Top soil / fill	**Topsoil:** Sandy Silt, low plasticity, grey and brown, root affected.	0.3	0.3	-	0.2	0.2	0.3	0.2	-	0.2	-	-
2	2		**Fill:** Comprising either silty sandy gravel, clay or sand.	-	-	-	-	-	-	-	-	-	-	-
3	3	Coast / estuarine / fluvial sediments	**Aeolian / Marine Sand**: fine to medium grained, grey, medium dense to very dense.	-	-	0.9	-	-	-	-	3.5	-	1.6	-
4	N/A		**Beach Sediments:** mixed or interbedded SAND and GRAVEL	-	-	-	-	-	-	-	4.5	-	-	4.6
5	N/A		**Alluvial / Estuarine Sediments:** SAND, GAVEL and/or CLAY, often mixed or interbedded (either sandy clay, clayey sand or clay and gravel), with clays usually stiff and medium to high plasticity	-	-	-	-	-	-	-	-	-	2.3	-
6	4		**Indurated Sand:** fine to medium grained, dark brown, very dense.	-	-	-	-	-	-	-	-	-	-	-
7	5	Natural soils	**Alluvial / Colluvial Clay:** High plasticity, grey / brown, very stiff	-	-	1.5	0.4	-	1	1.1	-	-	-	-
8	6		**Residual Soil:** Silty CLAY and Sandy CLAY, medium plasticity, pale grey to grey with yellow, orange and brown mottle, very stiff to hard	4	2.5	6.2	6.5	4.5	3	2.8	-	3.4	-	-
9	7	Weathered Rock	**Extremely Weathered Metasandstone / Metasiltstone:** Fine to medium grained, pale grey/brown, estimated very low strength.	6	6	-	7	-	4	-	-	4.5	-	-
10	8		**Extremely to Highly Weathered Metasandstone / Metasiltstone:** Fine to medium grained, pale grey/brown, estimated very low to low strength.	-	-	7	-	-	4.3	4.5	-	8.45	-	-
11	9		**Highly to Slightly Weathered Metasandstone / Metasiltstone:** Fine to medium grained, pale grey/brown, estimated low to high strength	-	-	-	-	-	-	-	-	-	-	-

[1] (WB) Wallabi Beach, (WP) Wallabi Point, (FS) Old Bar Beach – foreshore; (RC) Old Bar Beach – Racecourse Creek region; Old Bar Beach - backshore slopes / town; (ND) Old Bar Beach – northern dune region.

* Nominal 0.5 metre depths provided for SKM (1982) borehole where surface sediments without any depth information was described.

Unit	Borehole ID	SKM BH-13	RGS BH-14	RGS BH-10
	Surface RL (m)	3	5.9	6.6
	Material Description	*Depth (m) to base of material*		
1	**Topsoil:** Sandy silt, low plasticity, grey and brown, root affected.	-	-	0.2
2	**Fill:** Comprising either silty sandy gravel, clay or sand.	-	0.5	-
3	**Aeolian / Marine Sand**: Fine to medium grained, grey, medium dense to very dense.	2.5	2	-
4	**Beach Sediments**: Mixed or interbedded sand and gravel	-	-	-
5	**Estuarine Sediments:** Sand, gravel and/or clay; often mixed or interbedded; clays usually stiff and medium to high plasticity	5	-	-
6	**Indurated Sand:** Fine to medium grained, dark brown, very dense	-	-	-
7	**Alluvial / Colluvial Clay:** High plasticity, grey/brown, very stiff		-	-
8	**Residual Soil:** Silty clay and sand clay, medium plasticity, pale grey to grey with yellow, orange and brown mottle, very stiff to hard	-	-	4
9	**Extremely Weathered Metasandstone / Metasiltstone:** Fine to medium grained, pale grey/brown, estimated very low strength.	-	-	-
10	**Extremely to Highly Weathered Metasandstone / Metasiltstone:** Fine to medium grained, pale grey/brown, estimated very low to low strength.	-	-	7.55
11	**Highly to Slightly Weathered Metasandstone / Metasiltstone:** Fine to medium grained, pale grey/brown, estimated low to high strength	-	3.2	-

LEGEND

Borehole campaign

◆	PWD (1981)
◆	SKM (1982)
◆	GHD (2017)
◆	RGS (2019)

Near map images (July 2018)
LiDAR (2012) hillshade overlay

Title:

Borehole Results and Sythesis Wallabi Point Region

Figure: **D-3**

Rev: **A**

N

0 125 250m
Approx. Scale

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Unit	Borehole ID	SKM BH-10	SKM BH-04	RGS BH-15
	Surface RL (m)	2	2	5.1
	Material Description	*Depth (m) to base of material*		
1	**Topsoil:** Sandy silt, low plasticity, grey and brown, root affected.	-	-	-
2	**Fill:** Comprising either silty sandy gravel, clay or sand.	-	-	1.6
3	**Aeolian / Marine Sand**: Fine to medium grained, grey, medium dense to very dense.	0.5	-	-
4	**Beach Sediments**: Mixed or interbedded sand and gravel	-	0.5	-
5	**Estuarine Sediments:** Sand, gravel and/or clay; often mixed or interbedded; clays usually stiff and medium to high plasticity	6	7	-
6	**Indurated Sand:** Fine to medium grained, dark brown, very dense	-	-	-
7	**Alluvial / Colluvial Clay:** High plasticity, grey/brown, very stiff	-		7
8	**Residual Soil:** Silty clay and sand clay, medium plasticity, pale grey to grey with yellow, orange and brown mottle, very stiff to hard	-	-	-
9	**Extremely Weathered Metasandstone / Metasiltstone:** Fine to medium grained, pale grey/brown, estimated very low strength.	-	-	-
10	**Extremely to Highly Weathered Metasandstone / Metasiltstone:** Fine to medium grained, pale grey/brown, estimated very low to low strength.	-	-	-
11	**Highly to Slightly Weathered Metasandstone / Metasiltstone:** Fine to medium grained, pale grey/brown, estimated low to high strength	-	-	-

LEGEND

Borehole campaign

- ◆ PWD (1981)
- ◆ SKM (1982)
- ◆ GHD (2017)
- ◆ RGS (2019)

Near map images (July 2018)
LiDAR (2012) hillshade overlay

Title:

Borehole Results and Sythesis
Old Bar Beach - WWTW Exfiltration Ponds Region

N

0 125 250m
Approx. Scale

Figure: **D-4**

Rev: **A**

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Unit	Borehole ID	SKM BH-03	SKM BH-11	SKM BH-02	RGS BH-15	RGS BH-01	PWD BH-01	RGS BH-02	RGS BH-03	PWD BH-05	PWD BH-06	SKM BH-12	RGS BH-04
	Surface RL (m)	2	2	2	5.1	7.2	5	5.9	8.9	4.5	4.5	5.5	5
	Region	FS	FS	FS	RC	RC	RC	RC	RC	RC	RC	RC	RC
	Material Description	*Depth (m) to base of material*											
1	**Topsoil:** Sandy silt, low plasticity, grey and brown, root affected.	-	-	-	-	-	-	0.4	0.2	-	0.2	-	-
2	**Fill:** Comprising either silty sandy gravel, clay or sand.	-	-	-	1.6	-	-	1.1	0.7	-	-	-	1.7
3	**Aeolian / Marine Sand**: Fine to medium grained, grey, medium dense to very dense.	-	0.5	0.5	-	2.7	0.5	-	-	3	-	-	-
4	**Beach Sediments**: Mixed or interbedded sand and gravel	5	2	1.7	-	-	-	-	-	-	-	-	-
5	**Estuarine Sediments:** Sand, gravel and/or clay; often mixed or interbedded; clays usually stiff and medium to high plasticity	7.5	6.5	4.1	-	-	-	-	-	-	3.5	-	-
6	**Indurated Sand:** Fine to medium grained, dark brown, very dense	-	-	-	-	4.7	1.3	-	-	-	-	-	-
7	**Alluvial / Colluvial Clay:** High plasticity, grey/brown, very stiff	-	-	-	7	6	3	1.7	-	4.5	-	1	-
8	**Residual Soil:** Silty clay and sand clay, medium plasticity, pale grey to grey with yellow, orange and brown mottle, very stiff to hard	-	-	-	-	8.3	6	4.8	3.5	-	4.5	1.8	2.4
9	**Extremely Weathered Metasandstone / Metasiltstone:** Fine to medium grained, pale grey/brown, estimated very low strength.	-	-	-	-	9.45	-	-	6	-	-	-	-
10	**Extremely to Highly Weathered Metasandstone / Metasiltstone:** Fine to medium grained, pale grey/brown, estimated very low to low strength.	-	-	4.2	-	-	-	8	8.9	-	-	3	2.8
11	**Highly to Slightly Weathered Metasandstone / Metasiltstone:** Fine to medium grained, pale grey/brown, estimated low to high strength	-	-	-	-	-	-	-	-	-	-	-	-

LEGEND

Borehole campaign

- ◆ PWD (1981)
- ◆ SKM (1982)
- ◆ GHD (2017)
- ◆ RGS (2019)

Near map images (July 2018)
LiDAR (2012) hillshade overlay

Title:

Borehole Results and Sythesis
Old Bar Beach - Racecourse Creek Region

Figure:
D-5

Rev:
A

N

0 75 150m
Approx. Scale

BMT
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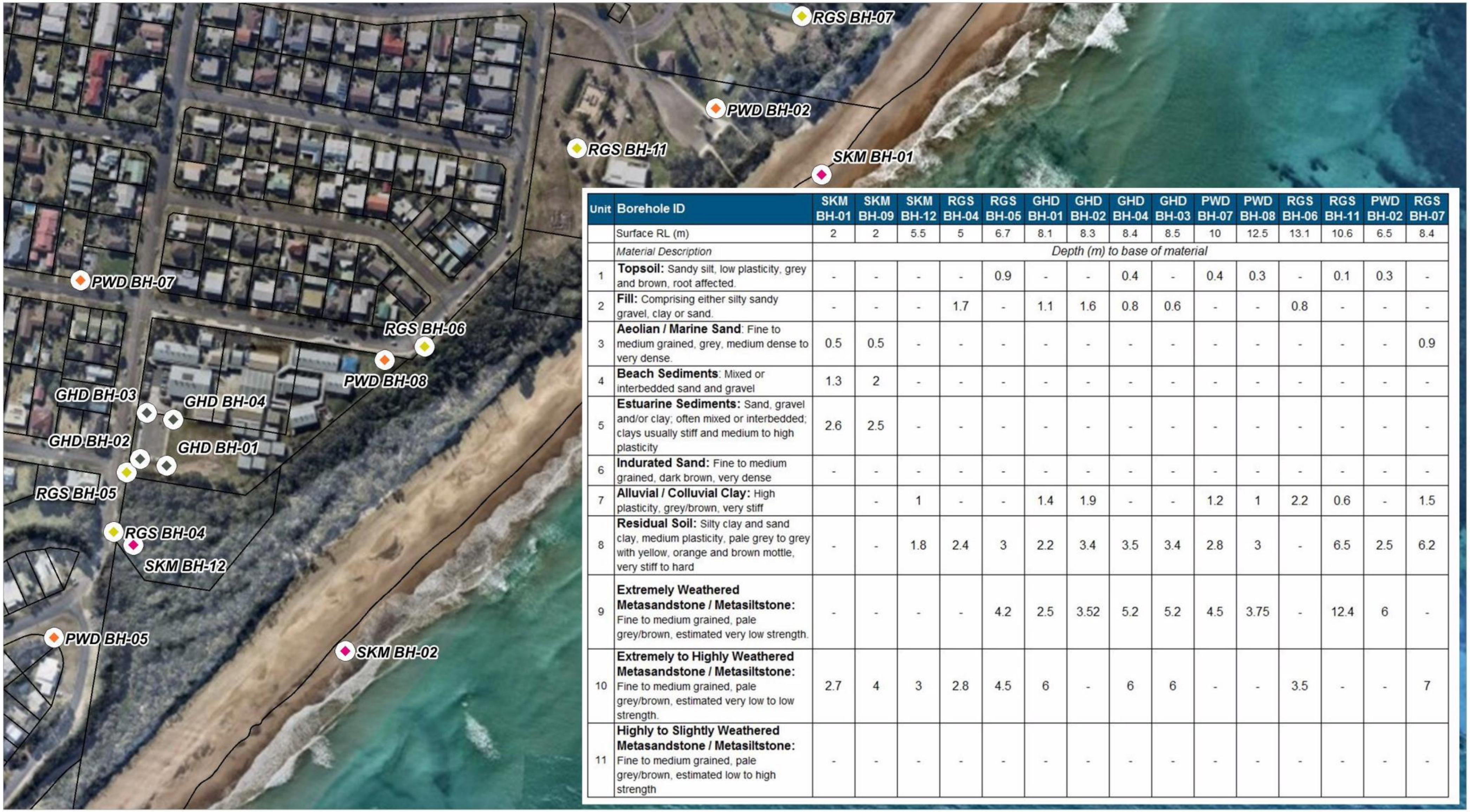

Unit	Borehole ID	SKM BH-01	SKM BH-09	SKM BH-12	RGS BH-04	RGS BH-05	GHD BH-01	GHD BH-02	GHD BH-04	GHD BH-03	PWD BH-07	PWD BH-08	RGS BH-06	RGS BH-11	PWD BH-02	RGS BH-07
	Surface RL (m)	2	2	5.5	5	6.7	8.1	8.3	8.4	8.5	10	12.5	13.1	10.6	6.5	8.4
	Material Description	*Depth (m) to base of material*														
1	**Topsoil:** Sandy silt, low plasticity, grey and brown, root affected.	-	-	-	-	0.9	-	-	0.4	-	0.4	0.3	-	0.1	0.3	-
2	**Fill:** Comprising either silty sandy gravel, clay or sand.	-	-	-	1.7	-	1.1	1.6	0.8	0.6	-	-	0.8	-	-	-
3	**Aeolian / Marine Sand**: Fine to medium grained, grey, medium dense to very dense.	0.5	0.5	-	-	-	-	-	-	-	-	-	-	-	-	0.9
4	**Beach Sediments**: Mixed or interbedded sand and gravel	1.3	2	-	-	-	-	-	-	-	-	-	-	-	-	-
5	**Estuarine Sediments:** Sand, gravel and/or clay; often mixed or interbedded; clays usually stiff and medium to high plasticity	2.6	2.5	-	-	-	-	-	-	-	-	-	-	-	-	-
6	**Indurated Sand:** Fine to medium grained, dark brown, very dense	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
7	**Alluvial / Colluvial Clay:** High plasticity, grey/brown, very stiff		-	1	-	-	1.4	1.9	-	-	1.2	1	2.2	0.6	-	1.5
8	**Residual Soil:** Silty clay and sand clay, medium plasticity, pale grey to grey with yellow, orange and brown mottle, very stiff to hard	-	-	1.8	2.4	3	2.2	3.4	3.5	3.4	2.8	3	-	6.5	2.5	6.2
9	**Extremely Weathered Metasandstone / Metasiltstone:** Fine to medium grained, pale grey/brown, estimated very low strength.	-	-	-	-	4.2	2.5	3.52	5.2	5.2	4.5	3.75	-	12.4	6	-
10	**Extremely to Highly Weathered Metasandstone / Metasiltstone:** Fine to medium grained, pale grey/brown, estimated very low to low strength.	2.7	4	3	2.8	4.5	6	-	6	6	-	-	3.5	-	-	7
11	**Highly to Slightly Weathered Metasandstone / Metasiltstone:** Fine to medium grained, pale grey/brown, estimated low to high strength	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

LEGEND

Borehole campaign

🔶	PWD (1981)
🔶	SKM (1982)
🔶	GHD (2017)
🔶	RGS (2019)

Near map images (July 2018)
LiDAR (2012) hillshade overlay

Title:

Borehole Results and Sythesis
Old Bar Beach - Township Slopes

Figure: **D-6**

Rev: **A**

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Approx. Scale

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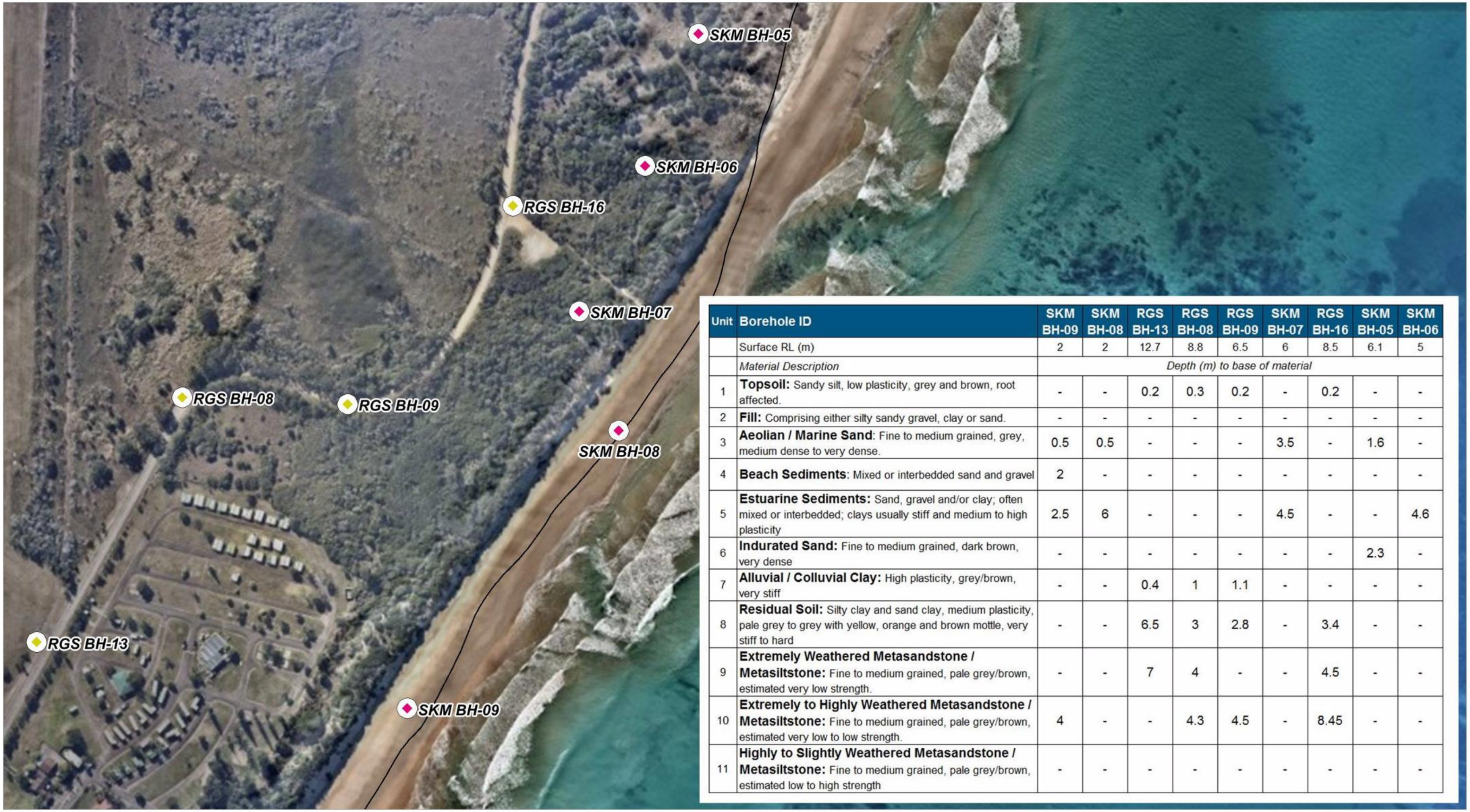

Unit	Borehole ID	SKM BH-09	SKM BH-08	RGS BH-13	RGS BH-08	RGS BH-09	SKM BH-07	RGS BH-16	SKM BH-05	SKM BH-06
	Surface RL (m)	2	2	12.7	8.8	6.5	6	8.5	6.1	5
	Material Description	*Depth (m) to base of material*								
1	**Topsoil:** Sandy silt, low plasticity, grey and brown, root affected.	-	-	0.2	0.3	0.2	-	0.2	-	-
2	**Fill:** Comprising either silty sandy gravel, clay or sand.	-	-	-	-	-	-	-	-	-
3	**Aeolian / Marine Sand**: Fine to medium grained, grey, medium dense to very dense.	0.5	0.5	-	-	-	3.5	-	1.6	-
4	**Beach Sediments**: Mixed or interbedded sand and gravel	2	-	-	-	-	-	-	-	-
5	**Estuarine Sediments:** Sand, gravel and/or clay; often mixed or interbedded; clays usually stiff and medium to high plasticity	2.5	6	-	-	-	4.5	-	-	4.6
6	**Indurated Sand:** Fine to medium grained, dark brown, very dense	-	-	-	-	-	-	-	2.3	-
7	**Alluvial / Colluvial Clay:** High plasticity, grey/brown, very stiff	-	-	0.4	1	1.1	-	-	-	-
8	**Residual Soil:** Silty clay and sand clay, medium plasticity, pale grey to grey with yellow, orange and brown mottle, very stiff to hard	-	-	6.5	3	2.8	-	3.4	-	-
9	**Extremely Weathered Metasandstone / Metasiltstone:** Fine to medium grained, pale grey/brown, estimated very low strength.	-	-	7	4	-	-	4.5	-	-
10	**Extremely to Highly Weathered Metasandstone / Metasiltstone:** Fine to medium grained, pale grey/brown, estimated very low to low strength.	4	-	-	4.3	4.5	-	8.45	-	-
11	**Highly to Slightly Weathered Metasandstone / Metasiltstone:** Fine to medium grained, pale grey/brown, estimated low to high strength	-	-	-	-	-	-	-	-	-

LEGEND

Borehole campaign

- ◆ PWD (1981)
- ◆ SKM (1982)
- ◆ GHD (2017)
- ◆ RGS (2019)

Near map images (July 2018)
LiDAR (2012) hillshade overlay

Title:

Borehole Results and Sythesis
Old Bar Beach - Northern Dunes Region

N

0 75 150m
Approx. Scale

Figure: **D-7**

Rev: **A**

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D.3 Geotechnical Conditions

The borehole records from the Old Bar region has identified a range of substrate conditions and strengths across the study site. Many of the recorded substrates can be observed on the ground surface (beach, dunes) or exposed as outcrops (Wallabi Point, Farquhar Inlet). The below sections document the geotechnical conditions and substrate strengths. A discussion on how the varied geological materials may be considered in the context of erosion hazard assessment is also provided herein.

D.3.1 Substrate Conditions

The geological conditions identified within the borehole surveys have been synthesised to comprise 11 substrate types. These are described below:

- **Unit 1 - Topsoil:** Sandy silt, low plasticity, grey and brown, root affected; corresponds to RGS unit 1 (Appendix E).
- **Unit 2 - Fill:** Comprising either silty sand, gravel, clay or sand; corresponds to RGS unit 2 (Appendix E).
- **Unit 3 - Aeolian / Marine Sand:** fine to medium grained, grey, medium dense to very dense; corresponds to RGS unit 3 (Appendix E).
- **Unit 4 - Beach Sediments:** mixed or interbedded SAND and GRAVEL; identified in the SKM foreshore boreholes and corresponds with the active beach face sediments observed in the field.
- **Unit 5 - Estuarine Sediments:** SAND, GAVEL and/or CLAY, often mixed or interbedded (either sandy clay, clayey sand or clay and gravel), with clays usually stiff and medium to high plasticity; identified in the PWD and SKM boreholes from the foreshore, coastal barrier and estuarine plain settings; often found underlying Unit 3 and/or Unit 4.
- **Unit 6 - Indurated Sand:** Fine to medium grained, dark brown, very dense, cemented in places; corresponds to RGS unit 4 (Appendix E).
- **Unit 7 - Alluvial / Colluvial Clay:** High plasticity, grey/brown, very stiff; corresponds to RGS unit 5 (Appendix E).
- **Unit 8 - Residual Soil:** Silty CLAY and Sandy CLAY, medium plasticity, pale grey to grey with yellow, orange and brown mottle, very stiff to hard. This unit corresponds to RGS unit 6 (Appendix E).
- **Unit 9 - Extremely Weathered Metasandstone / Metasiltstone:** Fine to medium grained, pale grey/brown, estimated very low strength; corresponds to RGS unit 7 (Appendix E).
- **Unit 10 - Extremely to Highly Weathered Metasandstone / Metasiltstone:** Fine to medium grained, pale grey/brown, estimated very low to low strength; corresponds to RGS unit 8 (Appendix E).
- **Unit 11 - Highly to Slightly Weathered Metasandstone / Metasiltstone:** Fine to medium grained, pale grey/brown, estimated low to high strength; corresponds with RGS unit 9 (Appendix E).

D.3.2 Substrate strength

For the purpose of assessing coastal erosion risks over planning timeframes (~100 years), the substrate strength of geological materials encountered at Old Bar can be classified as:

- **Erodible substrate** – which includes a variety of unconsolidated sediments that can be readily eroded by wave action and transported elsewhere by coastal processes. Aeolian, beach, marine, estuarine and alluvial/colluvial sediments (Units 3, 4, 5 and 7) encountered within the Old Bar borehole surveys are considered to form erodible substrates.
- **Partially resistant (semi erodible) substrate** – which encompass a wide variety of materials types and strengths that can be eroded by wave action over planning timeframes, but the erosion potential of such materials is relatively less than say unconsolidated sands (i.e. erodible substrates). Indurated sand (Unit 6), residual soil (Unit 8) and extremely weathered rock (Unit 9) are considered to form partially erosion resistant substrates (see Figure D-8, Figure D-9)
- Sediments may transition from erodible substrates into partially resistant substrates due to processes that occur over geological timescales, including induration (i.e. precipitation of mineral or organic cements) to form Pleistocene-age coastal sand and gravel deposits) or sediment compaction to form semi-lithified (Tertiary-age, or Pleistocene-age) sediments.
- The relative resistance to wave erosion processes vary between substrate types captured within this classification type, with extremely weathered rock having a higher strength and greater resistance to erosion than indurated sands, for example.
- Cliff and rocky platform exposures at Wallabi Point demonstrate the degrees of bedrock weathering recorded in the Old Bar borehole investigation, with extremely weathered rock eroding at a faster rate than highly weathered rock (see Figure D-10 to Figure D-13).
- **Erosion resistant substrate** – which comprise hard bedrock landforms that are considered to either provide a landward limit to erosion potential (e.g. tall cliffs, sloping bluff), or reduce erosion potential through wave dissipation processes (e.g. rocky reefs or shore platforms).
- Highly weathered to slightly weathered rock materials encountered within the Old Bar borehole are considered to form erosion resistant substrates, based on the rocky geomorphology observed at Crowdy Head, Old Bar Beach and Wallabi Point. Borehole Unit 9 and Unit 8 are considered to form erosion resistant substrates for the purpose of erosion hazard estimates (see Figure D-12 to Figure D-14).
- Wallabi Point cliffs exposures can be characterised as a bedrock landform comprising highly weathered, low strength, interbedded siltstones and sandstones. Photogrammetry records of changes to the bedrock cliff profile through time show that little to no cliff face recession occurred since 1965 (~0.03m/year), as demonstrated in Figure D-15. The negligible change in cliff profile recorded at this location supports the classification adopted herein, that highly weathered, low strength rocks within the Old Bar region can be considered to form erosion resistant material for the purpose of erosion hazard assessment.

Figure D-8 Indurated sands and gavel exposures at Farquhar Inlet

Figure D-9 Substrate exposure at Wallabi Point headland, showing a residual bedrock soil (top left) that grades into an extremely weathered (bottom left) and highly weathered (top right) bedrock

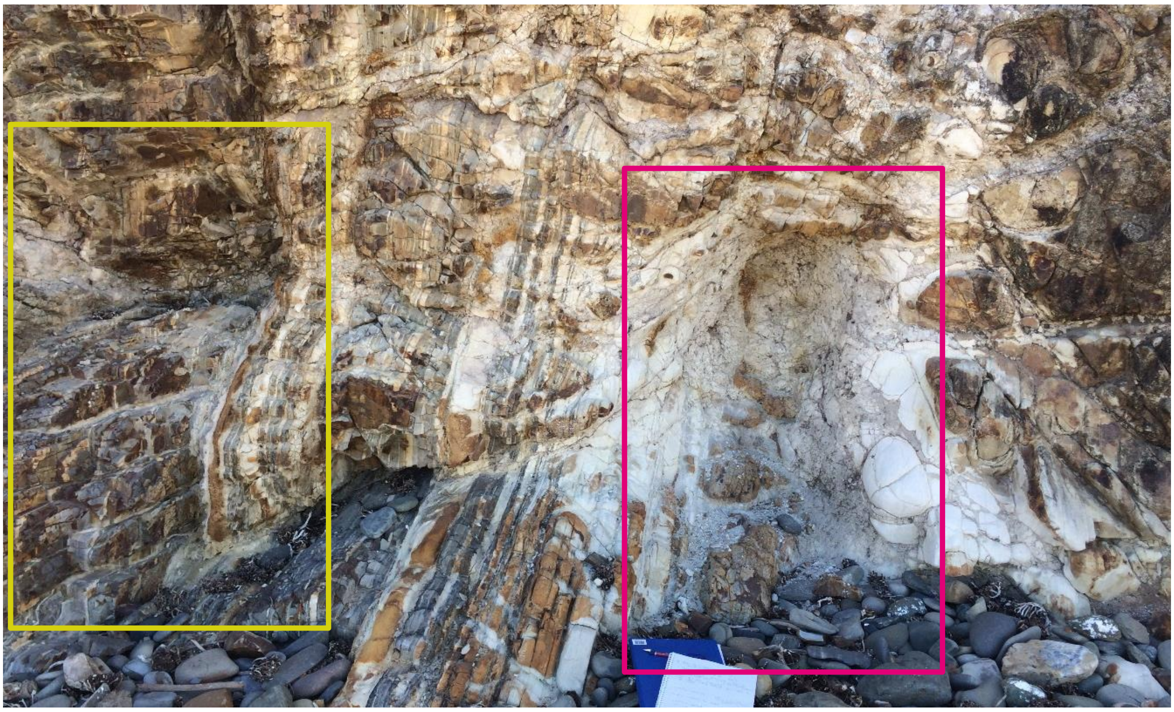


Figure D-10 Wallabi Point cliff exposure of sub-vertical dipping siltstones and sandstones, showing varied weathered conditions of the bedrock exposures

Note: Weathering profiles highlighted above (left - highly weathered bedrock; right- extremely weathered bedrock), with detailed inset photos below

Figure D-11 'Extremely weathered' siltstone exposure, Wallabi Point

Note: Very low strength rock with structures; demonstrates some resistance to wave action

Figure D-12 'Highly Weathered' Siltstone Exposure, Wallabi Point

Note: Low strength rock with structures, demonstrating resistance to wave action over planning timeframes

Figure D-13 Erosion resistant rocky shore platform at Wallabi Point (joined to the cliff face shown in Figure D-10), which forms an erosion influencing bedrock landform.

Note: Moderately to slightly weathered rock exposures, forming medium to high strength material

Figure D-14 Crowdy Head cliff exposure of showing slightly weathered, high strength sandstone that forms an erosion limiting bedrock landform

D.4 Summary and Conclusion

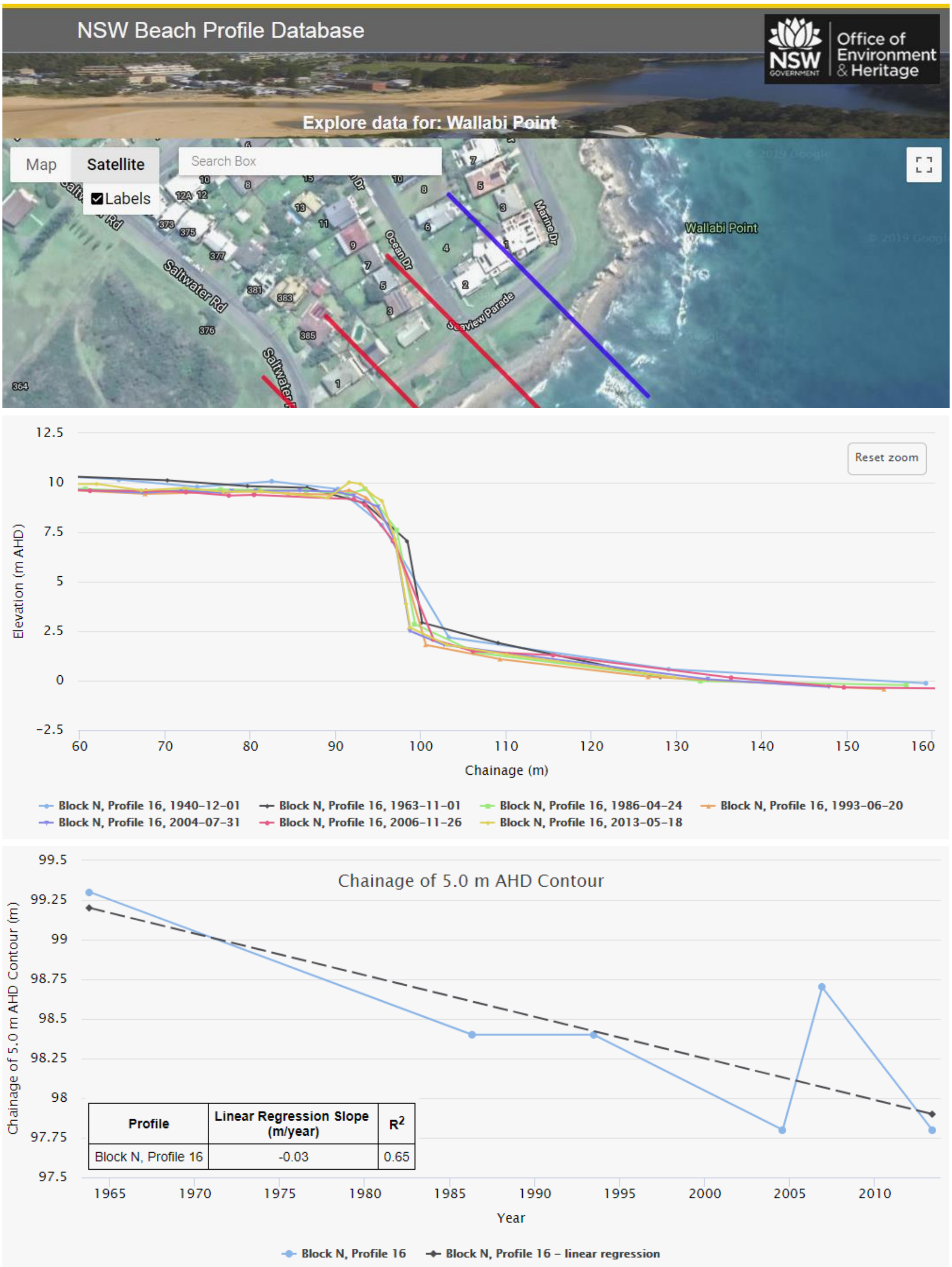
The Appendix presents the results of a geotechnical investigation that syntheses borehole records for the Old Bar Beach region from four different sources. The borehole datasets have been summarised in a consistent format, with substrate types and strengths correlated between data sources and conditions observed in the field.

A total of 11 geological units are recorded, including natural soils, coastal/estuarine/alluvial sediments and bedrock substrates with varying degrees of weathering. Coastal erosion substrate strength classifications have been provided for each geological unit, in the context of erosion risk over planning timeframes. This information will help guide a reassessment of erosion and recession hazards, which that better reflects the geological variability of the coastline.

As a key outcome, this investigation provides a:

- **borehole database** that compiles the available geotechnical records using the geological descriptions (units) described in this appendix; and
- **borehole summary map series** (and accompanying GIS), which shows the geographic locations and synthesised attributes from the four borehole campaigns undertaken since the 1980's.

The information documented within this appendix will be useful for analysing the geophysical (GPR) survey with the known coastal geological conditions (e.g. depth to bedrock) and guide the interpretation of geological factors (geological profiles, landform distributions and their corresponding substrate strengths) that may influence erosion hazards across the Old Bar study region.



Profile	Linear Regression Slope (m/year)	R^2
Block N, Profile 16	-0.03	0.65

Figure D-15 Photogrammetry Data from Wallabi Point Headland Cliff (source: NSW Beach Profile Database)

Note: Photogrammetry profile records of Wallabi Point shows negligible cliff face erosion of the highly weathered siltstone / sandstone cliff over historical timeframes

Appendix E Old Bar Beach Geotechnical Borehole Investigation, RGS (2019)

REGIONAL
GEOTECHNICAL
SOLUTIONS

Manning-Great Lakes
Port Macquarie
Coffs Harbour

RGS31505.1 (Rev 0)

5 March 2019

BMT Pty Ltd
126 Belford Street
BROADMEADOW NSW 2292

Attention: Paul Donaldson

Dear Paul

RE: Mid North Coast Council Coastal Hazard Assessment – Old Bar and Wallabi Point

1. INTRODUCTION

Regional Geotechnical Solutions Pty Ltd (RGS) has undertaken geotechnical investigations at two locations including:

- Old Bar and
- Wallabi Point Headland

The purpose of the geotechnical assessment was to provide information on subsurface conditions for the reassessment and refinement of the current Coastal Processes and Hazards Study.

The work included the drilling of boreholes at nominated locations to target depths of RL0 to RL-2m or prior refusal on bedrock.

The work was carried out for BMT Pty Ltd (BMT) who are undertaking the coastal hazards assessment for the Mid North Coast Council.

2 FIELD WORK

Field work was undertaken in February 2019, and involved:

- The drilling and logging of sixteen boreholes with a truck mounted drill rig at locations nominated by BMT;

Standard penetration tests were carried out at approximately 1.5m intervals to assess the undrained shear strength of cohesive soils and the density of granular soils.

The locations nominated by BMT WBM included:

- Old Bar Foreshore – 7 boreholes;
- Old Bar – General Town Area – 7 boreholes;
- Wallabi Point Foreshore Area – 2 boreholes

The subsurface profiles encountered are presented on the Engineering Logs provided in the attachments. The fieldwork was undertaken by an Associate Engineering Geologist from RGS. The approximate borehole locations are shown on the attached figures.

3 SUBSURFACE CONDITIONS

The 1:250,000 geology sheet of Hastings indicates that all sites are underlain by the Koorainghat Beds and the Kiwarrak Beds comprising lithic sandstone, greywacke, slate and mudstone overlain in parts by Quaternary deposits comprising sand, silt and clay are located nearby to each site.

The subsurface profiles encountered during the investigation is summarised in below Table 1 and Table 2.

Table 1: Summary of Subsurface Conditions – Old Bar

Unit	Material Description	Depth to Base of Material (m)													
		BH101	BH102	BH103	BH104	BH105	BH106	BH107	BH108	BH109	BH211	BH212	BH213	BH215	BH216
1	**Topsoil:** Sandy Silt, low plasticity, grey and brown, root affected.	--	0.4	0.2	--	0.9	--	--	0.3	0.2	0.1	0.25	0.2	--	0.2
2	**Fill:** Comprising either silty sandy gravel, clay or sand.		1.1	0.7	1.7	--	0.8	--	--	--	--	--	--	1.6	--
3	**Aeolian Sand:** fine to medium grained, grey, medium dense to very dense.	2.7	--	--	--	--	--	0.9	--	--	--	--	--	--	--
4	**Alluvial Indurated Sand:** fine to medium grained, dark brown, very dense.	4.7	--	--	--	--	--	--	--	--	--	--	--	--	--
5	**Alluvial / Colluvial Clay:** High plasticity, grey / brown, very stiff	6.0	1.7	--	--	--	2.2	1.5	1.0	1.1	0.6	--	0.4	>7.0	--
6	**Residual Soil:** Silty CLAY and Sandy CLAY, medium plasticity, pale grey to grey with yellow, orange and brown mottle, very stiff to hard	8.3	4.8	3.5	2.4	3.0	--	6.2	3.0	2.8	6.5	1.3	6.5	--	3.4
7	**Extremely Weathered Metasandstone / Metasiltstone:** Fine to medium grained, pale grey/brown, estimated very low strength.	>9.45	--	6.0	--	4.2	--	--	4.0	--	>12.4	--	7.0	--	4.5
8	**Extremely to Highly Weathered Metasandstone / Metasiltstone:** Fine to medium grained, pale grey/brown, estimated very low to low strength.	--	>8.0	>8.9	>2.8	>4.5	>3.5	>7.0	>4.3	>4.5	--	2.0	--	--	>8.45
9	**Highly to Slightly Weathered Metasandstone / Metasiltstone:** Fine to medium grained, pale grey/brown, estimated low to high strength	--	--	--	--	--	--	--	--	--	--	>2.5	--	--	--

Note: -- Indicates not encountered

Table 2: Summary of Subsurface Conditions – Wallabi Point

Unit	Material Description	Depth to Base of Material (m)	
		BH110	BH214
1	**Topsoil:** Sandy Silt, low plasticity, grey and brown, root affected.	0.2	--
2	**Fill:** Comprising either silty sandy gravel, clay or sand.	--	0.5
3	**Aeolian Sand:** fine to medium grained, grey, medium dense to very dense.	--	2.0
4	**Alluvial Indurated Sand:** fine to medium grained, dark brown, very dense.	--	--
5	**Alluvial / Colluvial Clay:** High plasticity, grey / brown, very stiff	--	--
6	**Residual Soil:** Silty CLAY and Sandy CLAY, medium plasticity, pale grey to grey with yellow, orgnge and brown mottle, very stiff to hard	4.0	--
7	**Extremely Weathered Metasandstone / Metasiltstone:** Fine to medium grained, pale grey/brown, estimated very low strength.	--	--
8	**Extremely to Highly Weathered Metasandstone / Metasiltstone:** Fine to medium grained, pale grey/brown, estimated very low to low strength.	>7.55	--
9	**Highly to Slightly Weathered Metasandstone / Metasiltstone:** Fine to medium grained, pale grey/brown, estimated low to high strength	--	>3.2

Note: -- Indicates not encountered

4 LIMITATIONS

The subsurface information collected is specific to investigation locations only and is intended to provide an indication of conditions beneath the site. It is unlikely the information is indicative of the full range of conditions which may be encountered in the area of investigation. If conditions other than those described in this report are encountered, further advice should be sought without delay.

We trust this report meets your requirements. If you have any questions regarding this project please contact the undersigned.

For and on behalf of

Regional Geotechnical Solutions Pty Ltd

Matt Rowbotham

Associate Engineering Geologist

REGIONAL GEOTECHNICAL SOLUTIONS

Client:	BMT Pty Ltd	Job No.	RGS31505.1
Project:	Mid Coast Council Coastal Hazard Assessment - Old Bar and Wallabi Point	Drawn By:	MR
		Date:	25.2.19
Title:	Borehole Location Plan	Drawing No.	**Figure 1**

REGIONAL GEOTECHNICAL SOLUTIONS	Client:	BMT Pty Ltd	Job No.	RGS31505.1
	Project:	Mid Coast Council Coastal Hazard Assessment - Old Bar and Wallabi Point	Drawn By:	MR
			Date:	25.2.19
	Title:	Borehole Location Plan	Drawing No.	**Figure 2**

REGIONAL GEOTECHNICAL SOLUTIONS	**Client:**	BMT Pty Ltd	Job No.	RGS31505.1
	Project:	Mid Coast Council	Drawn By:	MR
		Coastal Hazard Assessment - Old Bar and Wallabi Point	Date:	25.2.19
	Title:	Borehole Location Plan	Drawing No.	**Figure 3**

REGIONAL GEOTECHNICAL SOLUTIONS

Client:	BMT Pty Ltd	Job No.	RGS31505.1
Project:	Mid Coast Council	Drawn By:	MR
	Coastal Hazard Assessment - Old Bar and Wallabi Point	Date:	25.2.19
Title:	Borehole Location Plan	Drawing No.	**Figure 4**

REGIONAL GEOTECHNICAL SOLUTIONS

ENGINEERING LOG - BOREHOLE

BOREHOLE NO: BH101

CLIENT:	BMT PTY LIMITED	**PAGE:**	1 of 2
PROJECT NAME:	Midcoast Council	**JOB NO:**	RGS31505.1
SITE LOCATION:	Coastal Hazard Assessment	**LOGGED BY:**	MR
TEST LOCATION:	See figure 1	**DATE:**	14/2/19

DRILL TYPE: MD200
BOREHOLE DIAMETER: 100 mm **INCLINATION:** 90°
EASTING:
NORTHING:
SURFACE RL: 7.2 m
DATUM: AHD

METHOD	WATER	SAMPLES	RL (m)	DEPTH (m)	CLASSIFICATION SYMBOL	MATERIAL DESCRIPTION: Soil type, plasticity/particle characteristics,colour,minor components	MOISTURE CONDITION	CONSISTENCY DENSITY	Test Type	Result	Structure and additional observations
AD/TC BIT			7.0	0.00	SP	**SAND:** Fine to medium grained, grey, becoming pale grey	D				ALLUVIAL
	▶	3.00m SPT 20 for 70mm		2.70m	SM	**Silty SAND:** Fine to medium grained, dark brown, (weakly cemented). Possibly becoming Silty SAND, weakly cemented	W D	VD			Coffee Rock
	▽	4.50m SPT 15R		4.70m	CL	**CLAY:** High plasticity, grey	M > W_P	VSt			ALLUVIAL
		6.00m									

RL scale: 7.0, 6.0, 5.0, 4.0, 3.0, 2.0
Depth scale: 1.0, 2.0, 3.0, 4.0, 5.0

LEGEND:

Water
- ▽ Water Level (Date and time shown)
- ▶ Water Inflow
- ◀ Water Outflow

Strata Changes
- — — Gradational or transitional strata
- —— Definitive or distict strata change

Notes, Samples and Tests

U_{50}	50mm Diameter tube sample
CBR	Bulk sample for CBR testing
E	Environmental sample
ASS	Acid Sulfate Soil Sample
B	Bulk Sample

Field Tests

PID	Photoionisation detector reading (ppm)
DCP(x-y)	Dynamic penetrometer test (test depth interval shown)
HP	Hand Penetrometer test (UCS kPa)

Consistency		**UCS (kPa)**
VS	Very Soft	<25
S	Soft	25 - 50
F	Firm	50 - 100
St	Stiff	100 - 200
VSt	Very Stiff	200 - 400
H	Hard	>400
Fb	Friable	

Moisture Condition

D	Dry
M	Moist
W	Wet
W_p	Plastic Limit
W_L	Liquid Limit

Density

V	Very Loose	Density Index <15%
L	Loose	Density Index 15 - 35%
MD	Medium Dense	Density Index 35 - 65%
D	Dense	Density Index 65 - 85%
VD	Very Dense	Density Index 85 - 100%

REGIONAL GEOTECHNICAL SOLUTIONS

ENGINEERING LOG - BOREHOLE

BOREHOLE NO: **BH101**

CLIENT:	BMT PTY LIMITED	**PAGE:**	2 of 2
PROJECT NAME:	Midcoast Council	**JOB NO:**	RGS31505.1
SITE LOCATION:	Coastal Hazard Assessment	**LOGGED BY:**	MR
TEST LOCATION:	See figure 1	**DATE:**	14/2/19

DRILL TYPE: MD200
BOREHOLE DIAMETER: 100 mm **INCLINATION:** 90°
EASTING:
NORTHING:
SURFACE RL: 7.2 m
DATUM: AHD

Drilling and Sampling					Material description and profile information					Field Test		
METHOD	WATER	SAMPLES	RL (m)	DEPTH (m)	GRAPHIC LOG	CLASSIFICATION SYMBOL	MATERIAL DESCRIPTION: Soil type, plasticity/particle characteristics,colour,minor components	MOISTURE CONDITION	CONSISTENCY DENSITY	Test Type	Result	Structure and additional observations
AD/TC BIT		SPT 4,7,14 N=21 6.45m	1.0 0.0 -1.0	7.0 8.0	▨	CL	**CLAY:** High plasticity, grey *(continued)* Becoming pale grey	M > W_P	VSt			RESIDUAL SOIL
		9.00m SPT 11,10,13 N=23	-2.0	9.0			8.30m **Extremely Weathered METASANDSTONE:** Medium to coarse grained, pale grey, pale green, estimated Sandy CLAY zones 9.45m					EXTREMELY WEATHERED METASANDSTONE
		9.45m	-3.0 -4.0	10.0 11.0			Hole Terminated at 9.45 m					

LEGEND:

Water

▼ Water Level (Date and time shown)

► Water Inflow

◄ Water Outflow

Strata Changes

— — Gradational or transitional strata

—— Definitive or distict strata change

Notes, Samples and Tests

U_{50}	50mm Diameter tube sample
CBR	Bulk sample for CBR testing
E	Environmental sample
ASS	Acid Sulfate Soil Sample
B	Bulk Sample

Field Tests

PID	Photoionisation detector reading (ppm)
DCP(x-y)	Dynamic penetrometer test (test depth interval shown)
HP	Hand Penetrometer test (UCS kPa)

Consistency		**UCS (kPa)**
VS	Very Soft	<25
S	Soft	25 - 50
F	Firm	50 - 100
St	Stiff	100 - 200
VSt	Very Stiff	200 - 400
H	Hard	>400
Fb	Friable	

Moisture Condition

D	Dry
M	Moist
W	Wet
W_p	Plastic Limit
W_L	Liquid Limit

Density

V	Very Loose	Density Index <15%
L	Loose	Density Index 15 - 35%
MD	Medium Dense	Density Index 35 - 65%
D	Dense	Density Index 65 - 85%
VD	Very Dense	Density Index 85 - 100%

ENGINEERING LOG - BOREHOLE

REGIONAL GEOTECHNICAL SOLUTIONS

CLIENT:	BMT PTY LIMITED	**BOREHOLE NO:**	**BH102**
PROJECT NAME:	Midcoast Council	**PAGE:**	1 of 2
SITE LOCATION:	Coastal Hazard Assessment	**JOB NO:**	RGS31505.1
TEST LOCATION:	See figure 1	**LOGGED BY:**	MR
		DATE:	14/2/19

DRILL TYPE: MD200
BOREHOLE DIAMETER: 100 mm **INCLINATION:** 90°
EASTING:
NORTHING:
SURFACE RL: 5.9 m
DATUM: AHD

Drilling and Sampling					Material description and profile information					Field Test		
METHOD	WATER	SAMPLES	RL (m)	DEPTH (m)	GRAPHIC LOG	CLASSIFICATION SYMBOL	MATERIAL DESCRIPTION: Soil type, plasticity/particle characteristics,colour,minor components	MOISTURE CONDITION	CONSISTENCY DENSITY	Test Type	Result	Structure and additional observations
AD/TC BIT				0.40m	▩		**FILL:** SILT, low plasticity, dark brown, root affected, some Gravel	D	H			FILL
			5.0	1.0 1.10m	▨	CH	**CLAY:** Medium to high plasticity, dark brown, some Gravel	D	H			
		1.50m		1.70m	▨		**Sandy CLAY:** High plasticity, dark brown	M > W$_P$	St			ALLUVIAL
		SPT 4,4,3 N=7 1.95m	4.0 3.0 2.0	2.0 3.0 4.0 4.00m	▨	CH	**CLAY:** High plasticity, grey/pale grey with orange mottle	M > W$_P$	St			RESIDUAL SOIL
		4.50m SPT 9,13,21 N=34 4.95m		4.80m	▨	SC	**Becoming Sandy CLAY:** With zones of extremely weathered Metasandstone	M < W$_P$	VSt / H			HP = 550-600kPa
		6.00m	1.0 0.0	5.0 6.00m	⁘		**Highly Weathered METASANDSTONE:** Medium to coarse grained, pale grey with orange/brown iron oxide staining, estimated low strength					HIGHLY WEATHERED METASANDSTONE

LEGEND:

Water

▼	Water Level (Date and time shown)
▶—	Water Inflow
—◀	Water Outflow

Strata Changes

— — —	Gradational or transitional strata
———	Definitive or distict strata change

Notes, Samples and Tests

U_{50}	50mm Diameter tube sample
CBR	Bulk sample for CBR testing
E	Environmental sample
ASS	Acid Sulfate Soil Sample
B	Bulk Sample

Field Tests

PID	Photoionisation detector reading (ppm)
DCP(x-y)	Dynamic penetrometer test (test depth interval shown)
HP	Hand Penetrometer test (UCS kPa)

Consistency		**UCS (kPa)**
VS	Very Soft	<25
S	Soft	25 - 50
F	Firm	50 - 100
St	Stiff	100 - 200
VSt	Very Stiff	200 - 400
H	Hard	>400
Fb	Friable	

Moisture Condition

D	Dry
M	Moist
W	Wet
W$_p$	Plastic Limit
W$_L$	Liquid Limit

Density

V	Very Loose	Density Index <15%
L	Loose	Density Index 15 - 35%
MD	Medium Dense	Density Index 35 - 65%
D	Dense	Density Index 65 - 85%
VD	Very Dense	Density Index 85 - 100%

REGIONAL GEOTECHNICAL SOLUTIONS

ENGINEERING LOG - BOREHOLE

CLIENT:	BMT PTY LIMITED	**BOREHOLE NO:**	**BH102**
PROJECT NAME:	Midcoast Council	**PAGE:**	2 of 2
SITE LOCATION:	Coastal Hazard Assessment	**JOB NO:**	RGS31505.1
TEST LOCATION:	See figure 1	**LOGGED BY:**	MR
		DATE:	14/2/19

DRILL TYPE: MD200
BOREHOLE DIAMETER: 100 mm **INCLINATION:** 90°
EASTING:
NORTHING:
SURFACE RL: 5.9 m
DATUM: AHD

Drilling and Sampling					Material description and profile information					Field Test		
METHOD	WATER	SAMPLES	RL (m)	DEPTH (m)	GRAPHIC LOG	CLASSIFICATION SYMBOL	MATERIAL DESCRIPTION: Soil type, plasticity/particle characteristics,colour,minor components	MOISTURE CONDITION	CONSISTENCY DENSITY	Test Type	Result	Structure and additional observations
AD/TC BIT		SPT 34,10R N >50 6.30m					**Becoming Moderately Weathered Low strength METASANDSTONE:** Highly fractured					MODERATELY WEATHERED METASANDSTONE
			-1.0	7.0			Becoming medium strength, dark brown/dark grey, some Clay seams throughout					
		7.50m SPT 30,10R N >50 7.80m	-2.0	8.0			8.00m					
							Hole Terminated at 8.00 m					
			-3.0	9.0								
			-4.0	10.0								
			-5.0	11.0								
			-6.0									

LEGEND:

Water

- Water Level (Date and time shown)
- ▶— Water Inflow
- —◀ Water Outflow

Strata Changes

- — — Gradational or transitional strata
- —— Definitive or distict strata change

Notes, Samples and Tests

U_{50}	50mm Diameter tube sample
CBR	Bulk sample for CBR testing
E	Environmental sample
ASS	Acid Sulfate Soil Sample
B	Bulk Sample

Field Tests

PID	Photoionisation detector reading (ppm)
DCP(x-y)	Dynamic penetrometer test (test depth interval shown)
HP	Hand Penetrometer test (UCS kPa)

Consistency		UCS (kPa)
VS	Very Soft	<25
S	Soft	25 - 50
F	Firm	50 - 100
St	Stiff	100 - 200
VSt	Very Stiff	200 - 400
H	Hard	>400
Fb	Friable	

Moisture Condition	
D	Dry
M	Moist
W	Wet
W_p	Plastic Limit
W_L	Liquid Limit

Density		
V	Very Loose	Density Index <15%
L	Loose	Density Index 15 - 35%
MD	Medium Dense	Density Index 35 - 65%
D	Dense	Density Index 65 - 85%
VD	Very Dense	Density Index 85 - 100%

REGIONAL GEOTECHNICAL SOLUTIONS

ENGINEERING LOG - BOREHOLE

BOREHOLE NO: BH103

CLIENT:	BMT PTY LIMITED	**PAGE:**	1 of 2
PROJECT NAME:	Midcoast Council	**JOB NO:**	RGS31505.1
SITE LOCATION:	Coastal Hazard Assessment	**LOGGED BY:**	MR
TEST LOCATION:	See figure 1	**DATE:**	14/2/19

DRILL TYPE: MD200
BOREHOLE DIAMETER: 100 mm **INCLINATION:** 90°
EASTING:
NORTHING:
SURFACE RL: 8.9 m
DATUM: AHD

Drilling and Sampling					Material description and profile information					Field Test		
METHOD	WATER	SAMPLES	RL (m)	DEPTH (m)	GRAPHIC LOG	CLASSIFICATION SYMBOL	MATERIAL DESCRIPTION: Soil type, plasticity/particle characteristics,colour,minor components	MOISTURE CONDITION	CONSISTENCY DENSITY	Test Type	Result	Structure and additional observations
AD/TC BIT	Not Encountered					ML	**Sandy SILT:** Dark brown	M				TOPSOIL
				0.20m		GW	**FILL:** Silty Sandy GRAVEL	M	MD			FILL
				0.70m		CH	**CLAY:** High plasticity, grey and dark brown/dark red mottle	M > W_P	VSt			RESIDUAL SOIL
			8.0	1.0						HP	200	
		1.50m SPT 2,3,4 N=7 1.95m	7.0	2.0								
				2.10m		CH	**Becoming CLAY:** High plasticity, grey with dark red/brown mottle, some extremely weathered zones throughout					
		3.00m SPT 8,11,20 N=31 3.45m	6.0	3.0								
				3.50m			**Extremely Weathered METASILTSTONE/METASANDSTONE:** Fine to medium grained, grey					EXTREMELY WEATHERED METASILTSTONE/METASANDSTON
			5.0	4.0								
		4.50m SPT 10,12,20 N=32 4.95m	4.0	5.0								
	▶ Not Encountered						Seepage inflow					
		6.00m	3.0	6.00m								

LEGEND:

Water

- ▼ Water Level (Date and time shown)
- ▶— Water Inflow
- —◀ Water Outflow

Strata Changes

- — — Gradational or transitional strata
- —— Definitive or distict strata change

Notes, Samples and Tests

U_{50}	50mm Diameter tube sample
CBR	Bulk sample for CBR testing
E	Environmental sample
ASS	Acid Sulfate Soil Sample
B	Bulk Sample

Field Tests

PID	Photoionisation detector reading (ppm)
DCP(x-y)	Dynamic penetrometer test (test depth interval shown)
HP	Hand Penetrometer test (UCS kPa)

Consistency		**UCS (kPa)**
VS	Very Soft	<25
S	Soft	25 - 50
F	Firm	50 - 100
St	Stiff	100 - 200
VSt	Very Stiff	200 - 400
H	Hard	>400
Fb	Friable	

Moisture Condition	
D	Dry
M	Moist
W	Wet
W_p	Plastic Limit
W_L	Liquid Limit

Density		
V	Very Loose	Density Index <15%
L	Loose	Density Index 15 - 35%
MD	Medium Dense	Density Index 35 - 65%
D	Dense	Density Index 65 - 85%
VD	Very Dense	Density Index 85 - 100%

REGIONAL GEOTECHNICAL SOLUTIONS

ENGINEERING LOG - BOREHOLE

CLIENT:	BMT PTY LIMITED	**BOREHOLE NO:**	**BH103**
PROJECT NAME:	Midcoast Council	**PAGE:**	2 of 2
SITE LOCATION:	Coastal Hazard Assessment	**JOB NO:**	RGS31505.1
TEST LOCATION:	See figure 1	**LOGGED BY:**	MR
		DATE:	14/2/19

DRILL TYPE: MD200
BOREHOLE DIAMETER: 100 mm **INCLINATION:** 90°
EASTING:
NORTHING:
SURFACE RL: 8.9 m
DATUM: AHD

Drilling and Sampling					Material description and profile information					Field Test		
METHOD	WATER	SAMPLES	RL (m)	DEPTH (m)	GRAPHIC LOG	CLASSIFICATION SYMBOL	MATERIAL DESCRIPTION: Soil type, plasticity/particle characteristics,colour,minor components	MOISTURE CONDITION	CONSISTENCY DENSITY	Test Type	Result	Structure and additional observations
AD/TC BIT		SPT 25,30 N= >50 6.30m 7.50m SPT 25,30 N= >50 7.80m	2.0 1.0 0.0	7.0 8.0			**Highly Weathered METASANDSTONE:** Medium to coarse grained, pale grey, estimated low strength Some low to medium strength zones throughout	M > W_P	VSt			HIGHLY WEATHERED METASANDSTONE
			-1.0 -2.0 -3.0	9.0 10.0 11.0		8.90m	Hole Terminated at 8.90 m On Medium to High Strength Sandstone					

LEGEND:

Water

▼	Water Level (Date and time shown)
▶—	Water Inflow
—◀	Water Outflow

Strata Changes

— — -	Gradational or transitional strata
———	Definitive or distict strata change

Notes, Samples and Tests

U_{50}	50mm Diameter tube sample
CBR	Bulk sample for CBR testing
E	Environmental sample
ASS	Acid Sulfate Soil Sample
B	Bulk Sample

Field Tests

PID	Photoionisation detector reading (ppm)
DCP(x-y)	Dynamic penetrometer test (test depth interval shown)
HP	Hand Penetrometer test (UCS kPa)

Consistency		**UCS (kPa)**
VS	Very Soft	<25
S	Soft	25 - 50
F	Firm	50 - 100
St	Stiff	100 - 200
VSt	Very Stiff	200 - 400
H	Hard	>400
Fb	Friable	

Moisture Condition	
D	Dry
M	Moist
W	Wet
W_p	Plastic Limit
W_L	Liquid Limit

Density		
V	Very Loose	Density Index <15%
L	Loose	Density Index 15 - 35%
MD	Medium Dense	Density Index 35 - 65%
D	Dense	Density Index 65 - 85%
VD	Very Dense	Density Index 85 - 100%

ENGINEERING LOG - BOREHOLE

BOREHOLE NO: **BH104**

CLIENT:	BMT PTY LIMITED	**PAGE:**	1 of 1
PROJECT NAME:	Midcoast Council	**JOB NO:**	RGS31505.1
SITE LOCATION:	Coastal Hazard Assessment	**LOGGED BY:**	MR
TEST LOCATION:	See figure 1	**DATE:**	14/2/19

DRILL TYPE:	MD200			**EASTING:**		**SURFACE RL:**	5.0 m
BOREHOLE DIAMETER:	100 mm	**INCLINATION:**	90°	**NORTHING:**		**DATUM:**	AHD

Drilling and Sampling					Material description and profile information					Field Test		
METHOD	WATER	SAMPLES	RL (m)	DEPTH (m)	GRAPHIC LOG	CLASSIFICATION SYMBOL	MATERIAL DESCRIPTION: Soil type, plasticity/particle characteristics,colour,minor components	MOISTURE CONDITION	CONSISTENCY DENSITY	Test Type	Result	Structure and additional observations
AD/TC BIT					▩	GW	**FILL:** Silty Sandy GRAVEL, medium to coarse grained, brown	M	VD			FILL
			4.0	1.0	⁘	SW	0.90m **SAND:** Fine to medium grained, dark brown	M				FILL
	▶	1.70m SPT 7,7,11 N=18 2.15m	3.0	2.0	▨	CL	1.70m **Sandy CLAY:** Medium plasticity, pale grey and pale yellow, some remnant rock structure	M < W_p	VSt	HP	350	RESIDUAL SOIL
		2.70m SPT 30 for 100mm N=R			⁘		2.40m **Highly Weathered METASANDSTONE:** Fine to medium grained, pale grey with yellow and orange/brown iron oxide stained, estimated low to medium strength					
			2.0	3.0			2.80m Hole Terminated at 2.80 m TC Bit Refusal					
			1.0	4.0								
			0.0	5.0								

LEGEND:

Water

▼	Water Level (Date and time shown)
▶—	Water Inflow
—◀	Water Outflow

Strata Changes

— — —	Gradational or transitional strata
———	Definitive or distict strata change

Notes, Samples and Tests

U_{50}	50mm Diameter tube sample
CBR	Bulk sample for CBR testing
E	Environmental sample
ASS	Acid Sulfate Soil Sample
B	Bulk Sample

Field Tests

PID	Photoionisation detector reading (ppm)
DCP(x-y)	Dynamic penetrometer test (test depth interval shown)
HP	Hand Penetrometer test (UCS kPa)

Consistency		**UCS (kPa)**
VS	Very Soft	<25
S	Soft	25 - 50
F	Firm	50 - 100
St	Stiff	100 - 200
VSt	Very Stiff	200 - 400
H	Hard	>400
Fb	Friable	

Moisture Condition

D	Dry
M	Moist
W	Wet
W_p	Plastic Limit
W_L	Liquid Limit

Density

V	Very Loose	Density Index <15%
L	Loose	Density Index 15 - 35%
MD	Medium Dense	Density Index 35 - 65%
D	Dense	Density Index 65 - 85%
VD	Very Dense	Density Index 85 - 100%

REGIONAL GEOTECHNICAL SOLUTIONS

ENGINEERING LOG - BOREHOLE

CLIENT:	BMT PTY LIMITED	**BOREHOLE NO:**	**BH105**
PROJECT NAME:	Midcoast Council	**PAGE:**	1 of 1
SITE LOCATION:	Coastal Hazard Assessment	**JOB NO:**	RGS31505.1
TEST LOCATION:	See figure 1	**LOGGED BY:**	MR
		DATE:	14/2/19

DRILL TYPE:	MD200	**EASTING:**		**SURFACE RL:**	6.7 m
BOREHOLE DIAMETER:	100 mm **INCLINATION:** 90°	**NORTHING:**		**DATUM:**	AHD

Drilling and Sampling					Material description and profile information				Field Test		
METHOD	WATER	SAMPLES	RL (m)	DEPTH (m)	CLASSIFICATION SYMBOL	MATERIAL DESCRIPTION: Soil type, plasticity/particle characteristics,colour,minor components	MOISTURE CONDITION	CONSISTENCY DENSITY	Test Type	Result	Structure and additional observations
AD/TC BIT	Not Encountered			0.00–0.25m	ML	**Sandy SILT:** Low plasticity, root affected, brown					TOPSOIL
			6.0	0.25m–0.90m	ML	**Sandy SILT:** Low plasticity, dark brown	M				SLOPEWASH
		1.50m SPT 3,3,4 N=7 1.95m	5.0	0.90m–2.20m (1.0, 2.0)	CH	**CLAY:** High plasticity, grey and pale red mottle	M > W_P	VSt	HP	210	RESIDUAL SOIL
			4.0	2.20m–3.00m	SC	**Sandy CLAY:** Medium plasticity, pale grey, some remnant Rock structure zones of metasiltstone throughout					
		3.00m SPT 30 for 100mm	3.0	3.00m–4.20m (3.0, 4.0)		**Extremely to Highly Weathered METASILTSTONE:** Pale grey, estimated very low strength					EXTREMELY TO HIGHLY WEATHERED METASILTSTONE
				4.20m–4.50m		**Becoming Highly Weathered METASILTSTONE:** Estimated low to medium strength					HIGHLY WEATHERED METASILTSTONE
			2.0 1.0	4.50m (5.0)		Hole Terminated at 4.50 m					

LEGEND:

Water

- Water Level (Date and time shown)
- Water Inflow
- Water Outflow

Strata Changes

- Gradational or transitional strata
- Definitive or distict strata change

Notes, Samples and Tests

U_{50}	50mm Diameter tube sample
CBR	Bulk sample for CBR testing
E	Environmental sample
ASS	Acid Sulfate Soil Sample
B	Bulk Sample

Field Tests

PID	Photoionisation detector reading (ppm)
DCP(x-y)	Dynamic penetrometer test (test depth interval shown)
HP	Hand Penetrometer test (UCS kPa)

Consistency		**UCS (kPa)**
VS	Very Soft	<25
S	Soft	25 - 50
F	Firm	50 - 100
St	Stiff	100 - 200
VSt	Very Stiff	200 - 400
H	Hard	>400
Fb	Friable	

Moisture Condition

D	Dry
M	Moist
W	Wet
W_p	Plastic Limit
W_L	Liquid Limit

Density

V	Very Loose	Density Index <15%
L	Loose	Density Index 15 - 35%
MD	Medium Dense	Density Index 35 - 65%
D	Dense	Density Index 65 - 85%
VD	Very Dense	Density Index 85 - 100%

REGIONAL
GEOTECHNICAL
SOLUTIONS

ENGINEERING LOG - BOREHOLE

BOREHOLE NO: **BH106**

CLIENT:	BMT PTY LIMITED	**PAGE:**	1 of 1
PROJECT NAME:	Midcoast Council	**JOB NO:**	RGS31505.1
SITE LOCATION:	Coastal Hazard Assessment	**LOGGED BY:**	MR
TEST LOCATION:	See figure 1	**DATE:**	15/2/19

DRILL TYPE:	MD200			**EASTING:**		**SURFACE RL:**	13.1 m
BOREHOLE DIAMETER:	100 mm	**INCLINATION:**	90°	**NORTHING:**		**DATUM:**	AHD

Drilling and Sampling					Material description and profile information					Field Test		
METHOD	WATER	SAMPLES	RL (m)	DEPTH (m)	GRAPHIC LOG	CLASSIFICATION SYMBOL	MATERIAL DESCRIPTION: Soil type, plasticity/particle characteristics,colour,minor components	MOISTURE CONDITION	CONSISTENCY DENSITY	Test Type	Result	Structure and additional observations
AD/TC BIT	Not Encountered		13.0		▩	CL	**FILL:** Silty CLAY, medium plasticity, dark brown	$M < W_P$	H			FILL
		1.50m SPT 5,7,7 N=14 1.95m	12.0 11.0	0.80m 1.0 2.0	▨	CH	**CLAY:** High plasticity, pale grey/brown, some charcoal traces	$M < W_P$	VSt	HP	400	COLLUVIUM
		3.00m SPT 23,30 R N >50 3.30m	10.0	2.20m 3.0	⁙		**Highly Weathered METASANDSTONE:** Medium to coarse grained, pale grey and brown, estimated medium strength					HIGHLY WEATHERED METASILTSTONE
				3.50m			Some medium to high zones					
			9.0 8.0	4.0 5.0			Hole Terminated at 3.50 m Due to TC Bit Refusal					

LEGEND:

Water

▼	Water Level (Date and time shown)
►—	Water Inflow
—◄	Water Outflow

Strata Changes

— — —	Gradational or transitional strata
———	Definitive or distict strata change

Notes, Samples and Tests

U_{50}	50mm Diameter tube sample
CBR	Bulk sample for CBR testing
E	Environmental sample
ASS	Acid Sulfate Soil Sample
B	Bulk Sample

Field Tests

PID	Photoionisation detector reading (ppm)
DCP(x-y)	Dynamic penetrometer test (test depth interval shown)
HP	Hand Penetrometer test (UCS kPa)

Consistency		**UCS (kPa)**
VS	Very Soft	<25
S	Soft	25 - 50
F	Firm	50 - 100
St	Stiff	100 - 200
VSt	Very Stiff	200 - 400
H	Hard	>400
Fb	Friable	

Moisture Condition

D	Dry
M	Moist
W	Wet
W_p	Plastic Limit
W_L	Liquid Limit

Density

V	Very Loose	Density Index <15%
L	Loose	Density Index 15 - 35%
MD	Medium Dense	Density Index 35 - 65%
D	Dense	Density Index 65 - 85%
VD	Very Dense	Density Index 85 - 100%

REGIONAL GEOTECHNICAL SOLUTIONS

ENGINEERING LOG - BOREHOLE

BOREHOLE NO: **BH107**

CLIENT: BMT PTY LIMITED
PROJECT NAME: Midcoast Council
SITE LOCATION: Coastal Hazard Assessment
TEST LOCATION: See figure 1

PAGE: 1 of 2
JOB NO: RGS31505.1
LOGGED BY: MR
DATE: 14/2/19

DRILL TYPE: MD200
BOREHOLE DIAMETER: 100 mm
INCLINATION: 90°
EASTING:
NORTHING:
SURFACE RL: 8.4 m
DATUM: AHD

Drilling and Sampling					Material description and profile information					Field Test		
METHOD	WATER	SAMPLES	RL (m)	DEPTH (m)	GRAPHIC LOG	CLASSIFICATION SYMBOL	MATERIAL DESCRIPTION: Soil type, plasticity/particle characteristics,colour,minor components	MOISTURE CONDITION	CONSISTENCY DENSITY	Test Type	Result	Structure and additional observations
AD/TC BIT	Not Encountered	0.50m SPT 2,2,3 N=5 0.95m	8.0			SP	**SAND:** Medium to coarse grained, pale grey red	D	MD			AEOLIAN
			7.0	1.0 (0.90m)		CH	**CLAY:** High plasticity, dark brown	M > W_P	VSt	HP	250	COLLUVIAL
		1.50m SPT 4,5,6 N=11 1.95m	6.0	2.0 (1.50m)		CH	**CLAY:** High plasticity, pale grey with orange/brown and pale red mottle	M > W_P	VSt	HP	350	RESIDUAL SOIL
		3.00m SPT 9,11,12 N=23 3.45m 4.50m SPT 7,11,16 N=27 4.95m	5.0 4.0 3.0	3.0 (3.00m) 4.0 5.0		SC	**Clayey SAND:** Medium to coarse grained, pale grey, remnant Rock structure	M < W_P	H			HP = >600kPa
	Not Encountered											

LEGEND:

Water

- Water Level (Date and time shown)
- ▶ Water Inflow
- ◀ Water Outflow

Strata Changes

- — — Gradational or transitional strata
- —— Definitive or distict strata change

Notes, Samples and Tests

U_{50}	50mm Diameter tube sample
CBR	Bulk sample for CBR testing
E	Environmental sample
ASS	Acid Sulfate Soil Sample
B	Bulk Sample

Field Tests

PID	Photoionisation detector reading (ppm)
DCP(x-y)	Dynamic penetrometer test (test depth interval shown)
HP	Hand Penetrometer test (UCS kPa)

Consistency		UCS (kPa)
VS	Very Soft	<25
S	Soft	25 - 50
F	Firm	50 - 100
St	Stiff	100 - 200
VSt	Very Stiff	200 - 400
H	Hard	>400
Fb	Friable	

Moisture Condition	
D	Dry
M	Moist
W	Wet
W_p	Plastic Limit
W_L	Liquid Limit

Density		
V	Very Loose	Density Index <15%
L	Loose	Density Index 15 - 35%
MD	Medium Dense	Density Index 35 - 65%
D	Dense	Density Index 65 - 85%
VD	Very Dense	Density Index 85 - 100%

REGIONAL GEOTECHNICAL SOLUTIONS

ENGINEERING LOG - BOREHOLE

BOREHOLE NO: **BH107**
PAGE: 2 of 2
JOB NO: RGS31505.1
LOGGED BY: MR
DATE: 14/2/19

CLIENT: BMT PTY LIMITED
PROJECT NAME: Midcoast Council
SITE LOCATION: Coastal Hazard Assessment
TEST LOCATION: See figure 1

DRILL TYPE: MD200
BOREHOLE DIAMETER: 100 mm
INCLINATION: 90°
EASTING:
NORTHING:
SURFACE RL: 8.4 m
DATUM: AHD

Drilling and Sampling					Material description and profile information					Field Test		
METHOD	WATER	SAMPLES	RL (m)	DEPTH (m)	GRAPHIC LOG	CLASSIFICATION SYMBOL	MATERIAL DESCRIPTION: Soil type, plasticity/particle characteristics,colour,minor components	MOISTURE CONDITION	CONSISTENCY DENSITY	Test Type	Result	Structure and additional observations
AD/TC BIT						SC		M < W_P	H			RESIDUAL SOIL
		6.37m SPT 25,30,30 N=60 6.82m	2.0	7.0			6.20m **Extremely to Highly Weathered SANDSTONE:** Medium to coarse grained, estimated low strength 7.00m					EXTREMELY TO HIGHLY SANDSTONE
			1.0 0.0 -1.0 -2.0 -3.0	8.0 9.0 10.0 11.0			Hole Terminated at 7.00 m					

LEGEND:

Water

▼ Water Level (Date and time shown)
▶— Water Inflow
—◀ Water Outflow

Strata Changes

— — Gradational or transitional strata
—— Definitive or distict strata change

Notes, Samples and Tests

U_{50}	50mm Diameter tube sample
CBR	Bulk sample for CBR testing
E	Environmental sample
ASS	Acid Sulfate Soil Sample
B	Bulk Sample

Field Tests

PID	Photoionisation detector reading (ppm)
DCP(x-y)	Dynamic penetrometer test (test depth interval shown)
HP	Hand Penetrometer test (UCS kPa)

Consistency		UCS (kPa)
VS	Very Soft	<25
S	Soft	25 - 50
F	Firm	50 - 100
St	Stiff	100 - 200
VSt	Very Stiff	200 - 400
H	Hard	>400
Fb	Friable	

Moisture Condition	
D	Dry
M	Moist
W	Wet
W_p	Plastic Limit
W_L	Liquid Limit

Density		
V	Very Loose	Density Index <15%
L	Loose	Density Index 15 - 35%
MD	Medium Dense	Density Index 35 - 65%
D	Dense	Density Index 65 - 85%
VD	Very Dense	Density Index 85 - 100%

REGIONAL GEOTECHNICAL SOLUTIONS

ENGINEERING LOG - BOREHOLE

BOREHOLE NO: **BH108**

CLIENT: BMT PTY LIMITED
PROJECT NAME: Midcoast Council
SITE LOCATION: Coastal Hazard Assessment
TEST LOCATION: See figure 1

PAGE: 1 of 1
JOB NO: RGS31505.1
LOGGED BY: MR
DATE: 14/2/19

DRILL TYPE: MD200
BOREHOLE DIAMETER: 100 mm
INCLINATION: 90°
EASTING:
NORTHING:
SURFACE RL: 8.8 m
DATUM: AHD

Drilling and Sampling					Material description and profile information					Field Test		
METHOD	WATER	SAMPLES	RL (m)	DEPTH (m)	GRAPHIC LOG	CLASSIFICATION SYMBOL	MATERIAL DESCRIPTION: Soil type, plasticity/particle characteristics,colour,minor components	MOISTURE CONDITION	CONSISTENCY DENSITY	Test Type	Result	Structure and additional observations
AD/TC BIT	Not Encountered				0.30m		**FILL:** Silty Sandy GRAVEL, medium to coarse grained, brown and grey	D	VD			FILL
		0.50m SPT 5,6,7 N=13 0.95m	8.0		1.00m	CH	**CLAY:** High plasticity, brown and orange/red mottle	M < W_P	H	HP	500	COLLUVIUM
		1.50m SPT 5,5,5 N=10 1.95m	7.0 6.0	1.0 2.0	3.00m	CH	**CLAY:** High plasticity, pale grey and orange/pale red mottle	M < W_P	VSt	HP	350	RESIDUAL SOIL
		3.00m SPT 33, R N=R 3.15m	5.0	3.0	4.00m		**Extremely Weathered SANDSTONE:** Medium to coarse grained, pale grey, estimated very low strength	D				EXTREMELY WEATHERED SANDSTONE
				4.0	4.30m		**Becoming Highly Weathered SANDSTONE:** Estimated low to medium strength					HIGHLY WEATHERED SANDSTONE
			4.0 3.0	5.0			Hole Terminated at 4.30 m Refusal on Highly Weathered Sandstone estimated low to very low strength					

LEGEND:

Water

- Water Level (Date and time shown)
- ▶— Water Inflow
- —◀ Water Outflow

Strata Changes

- — — Gradational or transitional strata
- —— Definitive or distict strata change

Notes, Samples and Tests

U_{50}	50mm Diameter tube sample
CBR	Bulk sample for CBR testing
E	Environmental sample
ASS	Acid Sulfate Soil Sample
B	Bulk Sample

Field Tests

PID	Photoionisation detector reading (ppm)
DCP(x-y)	Dynamic penetrometer test (test depth interval shown)
HP	Hand Penetrometer test (UCS kPa)

Consistency		**UCS (kPa)**
VS	Very Soft	<25
S	Soft	25 - 50
F	Firm	50 - 100
St	Stiff	100 - 200
VSt	Very Stiff	200 - 400
H	Hard	>400
Fb	Friable	

Moisture Condition

D	Dry
M	Moist
W	Wet
W_p	Plastic Limit
W_L	Liquid Limit

Density

V	Very Loose	Density Index <15%
L	Loose	Density Index 15 - 35%
MD	Medium Dense	Density Index 35 - 65%
D	Dense	Density Index 65 - 85%
VD	Very Dense	Density Index 85 - 100%

ENGINEERING LOG - BOREHOLE

REGIONAL GEOTECHNICAL SOLUTIONS

CLIENT:	BMT PTY LIMITED	**BOREHOLE NO:**	**BH109**
PROJECT NAME:	Midcoast Council	**PAGE:**	1 of 1
SITE LOCATION:	Coastal Hazard Assessment	**JOB NO:**	RGS31505.1
TEST LOCATION:	See figure 1	**LOGGED BY:**	MR
		DATE:	14/2/19

DRILL TYPE:	MD200		**EASTING:**	**SURFACE RL:**	6.5 m
BOREHOLE DIAMETER:	100 mm	**INCLINATION:** 90°	**NORTHING:**	**DATUM:**	AHD

Drilling and Sampling					Material description and profile information					Field Test		
METHOD	WATER	SAMPLES	RL (m)	DEPTH (m)	GRAPHIC LOG	CLASSIFICATION SYMBOL	MATERIAL DESCRIPTION: Soil type, plasticity/particle characteristics,colour,minor components	MOISTURE CONDITION	CONSISTENCY DENSITY	Test Type	Result	Structure and additional observations
AD/TC BIT	Not Encountered				⁚	SM	**Silty SAND:** Medium to coarse grained, brown	M				TOPSOIL
		0.50m SPT 10,16,20 N=36 0.95m	6.0	0.20m 1.0	▨	CL	**Silty CLAY:** Medium plasticity, dark brown	M < W_P	H			COLLUVIUM / SLOPEWASH HP = >600kPa
		1.20m SPT 6,6,6 N=12 1.65m	5.0 4.0	1.10m 2.0	▨	CH	**CLAY:** High plasticity, pale brown/pale grey	M > W_P	VSt	HP	350	RESIDUAL SOIL
		3.00m SPT 10,20,35 N=55 3.45m	3.0 2.0	2.80m 3.0 4.0	⁚		**Highly Weathered SANDSTONE:** Medium to coarse grained, pale grey with orange/brown iron oxide staining, estimated low strength					HIGHLY WEATHERED SANDSTONE
			1.0	4.50m 5.0			Hole Terminated at 4.50 m TC Bit Refusal					

LEGEND:

Water

▼	Water Level (Date and time shown)
▶—	Water Inflow
—◀	Water Outflow

Strata Changes

— —	Gradational or transitional strata
——	Definitive or distict strata change

Notes, Samples and Tests

U_{50}	50mm Diameter tube sample
CBR	Bulk sample for CBR testing
E	Environmental sample
ASS	Acid Sulfate Soil Sample
B	Bulk Sample

Field Tests

PID	Photoionisation detector reading (ppm)
DCP(x-y)	Dynamic penetrometer test (test depth interval shown)
HP	Hand Penetrometer test (UCS kPa)

Consistency		**UCS (kPa)**
VS	Very Soft	<25
S	Soft	25 - 50
F	Firm	50 - 100
St	Stiff	100 - 200
VSt	Very Stiff	200 - 400
H	Hard	>400
Fb	Friable	

Moisture Condition

D	Dry
M	Moist
W	Wet
W_p	Plastic Limit
W_L	Liquid Limit

Density

V	Very Loose	Density Index <15%
L	Loose	Density Index 15 - 35%
MD	Medium Dense	Density Index 35 - 65%
D	Dense	Density Index 65 - 85%
VD	Very Dense	Density Index 85 - 100%

REGIONAL GEOTECHNICAL SOLUTIONS

ENGINEERING LOG - BOREHOLE

CLIENT:	BMT PTY LIMITED	**BOREHOLE NO:**	**BH110**
PROJECT NAME:	Midcoast Council	**PAGE:**	1 of 2
SITE LOCATION:	Coastal Hazard Assessment	**JOB NO:**	RGS31505.1
TEST LOCATION:	See figure 1	**LOGGED BY:**	MR
		DATE:	15/2/19

DRILL TYPE:	MD200	**EASTING:**		**SURFACE RL:**	6.6 m
BOREHOLE DIAMETER:	100 mm **INCLINATION:** 90°	**NORTHING:**		**DATUM:**	AHD

Drilling and Sampling					Material description and profile information				Field Test		
METHOD	WATER	SAMPLES	RL (m)	DEPTH (m)	CLASSIFICATION SYMBOL	MATERIAL DESCRIPTION: Soil type, plasticity/particle characteristics,colour,minor components	MOISTURE CONDITION	CONSISTENCY DENSITY	Test Type	Result	Structure and additional observations
AD/TC BIT	Not Encountered			0.00 - 0.20m	ML	**Sandy SILT:** Low plasticity dark red		H			TOPSOIL
			6.0	0.20m	CH	**CLAY:** High plasticity, pale grey and orange/brown mottle	M > W_p	VSt	HP	400	RESIDUAL SOIL
				1.0							
		1.50m SPT 5,8,8 N=16 1.95m	5.0			With pale yellow mottle					
				2.0							
		3.00m SPT 5,7,12 N=19 3.45m	4.0	3.0							
			3.0			Some zones of extremely to highly weathered metasiltstone throughout					
				4.00m		**Extremely to Highly Weathered METASANDSTONE:** Medium to coarse grained, orange/brown red, with pale grey, estimated very low strength					EXTREMELY TO HIGHLY WEATHERED METASANDSTONE
		4.50m SPT 40, R N = >50 4.65m	2.0								
				5.0							
	Not Encountered	6.00m	1.0	6.00m							

LEGEND:

Water

- ▼ Water Level (Date and time shown)
- ▶— Water Inflow
- —◀ Water Outflow

Strata Changes

- — — Gradational or transitional strata
- —— Definitive or distict strata change

Notes, Samples and Tests

U_{50}	50mm Diameter tube sample
CBR	Bulk sample for CBR testing
E	Environmental sample
ASS	Acid Sulfate Soil Sample
B	Bulk Sample

Field Tests

PID	Photoionisation detector reading (ppm)
DCP(x-y)	Dynamic penetrometer test (test depth interval shown)
HP	Hand Penetrometer test (UCS kPa)

Consistency		**UCS (kPa)**
VS	Very Soft	<25
S	Soft	25 - 50
F	Firm	50 - 100
St	Stiff	100 - 200
VSt	Very Stiff	200 - 400
H	Hard	>400
Fb	Friable	

Moisture Condition

D	Dry
M	Moist
W	Wet
W_p	Plastic Limit
W_L	Liquid Limit

Density

V	Very Loose	Density Index <15%
L	Loose	Density Index 15 - 35%
MD	Medium Dense	Density Index 35 - 65%
D	Dense	Density Index 65 - 85%
VD	Very Dense	Density Index 85 - 100%

REGIONAL GEOTECHNICAL SOLUTIONS

ENGINEERING LOG - BOREHOLE

BOREHOLE NO: **BH110**

CLIENT:	BMT PTY LIMITED	**PAGE:**	2 of 2
PROJECT NAME:	Midcoast Council	**JOB NO:**	RGS31505.1
SITE LOCATION:	Coastal Hazard Assessment	**LOGGED BY:**	MR
TEST LOCATION:	See figure 1	**DATE:**	15/2/19

DRILL TYPE: MD200
BOREHOLE DIAMETER: 100 mm **INCLINATION:** 90°
EASTING:
NORTHING:
SURFACE RL: 6.6 m
DATUM: AHD

Drilling and Sampling					Material description and profile information					Field Test		
METHOD	WATER	SAMPLES	RL (m)	DEPTH (m)	GRAPHIC LOG	CLASSIFICATION SYMBOL	MATERIAL DESCRIPTION: Soil type, plasticity/particle characteristics,colour,minor components	MOISTURE CONDITION	CONSISTENCY DENSITY	Test Type	Result	Structure and additional observations
AD/TC BIT		SPT 45, R N = >50 6.15m					**Becoming Highly Weathered METASILTSTONE:** Very low to low strength, grey/dark grey and brown highly fractured	$M > W_P$	VSt			HIGHLY WEATHERED METASILTSTONE
			0.0									
				7.0			Becoming pale grey/dark grey in colour					
		7.50m SPT 20 for 50mm	-1.0				7.55m					
							Hole Terminated at 7.55 m					
				8.0								
			-2.0									
				9.0								
			-3.0									
				10.0								
			-4.0									
				11.0								
			-5.0									

LEGEND:

Water

- Water Level (Date and time shown)
- ▶— Water Inflow
- —◀ Water Outflow

Strata Changes

- — — Gradational or transitional strata
- —— Definitive or distict strata change

Notes, Samples and Tests

U_{50}	50mm Diameter tube sample
CBR	Bulk sample for CBR testing
E	Environmental sample
ASS	Acid Sulfate Soil Sample
B	Bulk Sample

Field Tests

PID	Photoionisation detector reading (ppm)
DCP(x-y)	Dynamic penetrometer test (test depth interval shown)
HP	Hand Penetrometer test (UCS kPa)

Consistency		**UCS (kPa)**
VS	Very Soft	<25
S	Soft	25 - 50
F	Firm	50 - 100
St	Stiff	100 - 200
VSt	Very Stiff	200 - 400
H	Hard	>400
Fb	Friable	

Moisture Condition	
D	Dry
M	Moist
W	Wet
W_p	Plastic Limit
W_L	Liquid Limit

Density		
V	Very Loose	Density Index <15%
L	Loose	Density Index 15 - 35%
MD	Medium Dense	Density Index 35 - 65%
D	Dense	Density Index 65 - 85%
VD	Very Dense	Density Index 85 - 100%

REGIONAL GEOTECHNICAL SOLUTIONS

ENGINEERING LOG - BOREHOLE

BOREHOLE NO: **BH211**

CLIENT:	BMT PTY LIMITED	**PAGE:**	1 of 3
PROJECT NAME:	Midcoast Council	**JOB NO:**	RGS31505.1
SITE LOCATION:	Coastal Hazard Assessment	**LOGGED BY:**	MR
TEST LOCATION:	See figure 1	**DATE:**	14/2/19

DRILL TYPE:	MD200	**EASTING:**		**SURFACE RL:**	10.6 m
BOREHOLE DIAMETER:	100 mm **INCLINATION:** 90°	**NORTHING:**		**DATUM:**	AHD

Drilling and Sampling					Material description and profile information					Field Test		
METHOD	WATER	SAMPLES	RL (m)	DEPTH (m)	GRAPHIC LOG	CLASSIFICATION SYMBOL	MATERIAL DESCRIPTION: Soil type, plasticity/particle characteristics,colour,minor components	MOISTURE CONDITION	CONSISTENCY DENSITY	Test Type	Result	Structure and additional observations
AD/TC BIT				0.10m		ML	**Sandy SILT:** Low plasticity	$M < W_P$	H			TOPSOIL
						CL	**Silty CLAY:** Medium plasticity, dark brown			HP	600	SLOPEWASH
			10.0	0.60m		CH	**CLAY:** High plasticity, pale grey with pale red mottle	$M > W_P$	St			RESIDUAL SOIL
				1.0						HP	200	
		1.50m SPT 5,4,6 N=10 1.95m	9.0									
				2.0								
			8.0				Some weathered rock throughout					
				3.0				$M < W_P$	H	HP	500	
			7.0									
				4.0								RESIDUAL SOIL
		4.50m SPT 7,10,16 N=26 4.95m	6.0				With some iron stained zones of extremely weathered metasiltstone throughout					HP = >600kPa
				5.0								
		6.00m	5.0									

LEGEND:

Water

- ▼ Water Level (Date and time shown)
- ▶ Water Inflow
- ◀ Water Outflow

Strata Changes

- – – – Gradational or transitional strata
- —— Definitive or distict strata change

Notes, Samples and Tests

U_{50}	50mm Diameter tube sample
CBR	Bulk sample for CBR testing
E	Environmental sample
ASS	Acid Sulfate Soil Sample
B	Bulk Sample

Field Tests

PID	Photoionisation detector reading (ppm)
DCP(x-y)	Dynamic penetrometer test (test depth interval shown)
HP	Hand Penetrometer test (UCS kPa)

Consistency		**UCS (kPa)**
VS	Very Soft	<25
S	Soft	25 - 50
F	Firm	50 - 100
St	Stiff	100 - 200
VSt	Very Stiff	200 - 400
H	Hard	>400
Fb	Friable	

Moisture Condition	
D	Dry
M	Moist
W	Wet
W_p	Plastic Limit
W_L	Liquid Limit

Density		
V	Very Loose	Density Index <15%
L	Loose	Density Index 15 - 35%
MD	Medium Dense	Density Index 35 - 65%
D	Dense	Density Index 65 - 85%
VD	Very Dense	Density Index 85 - 100%

ENGINEERING LOG - BOREHOLE

REGIONAL GEOTECHNICAL SOLUTIONS

CLIENT:	BMT PTY LIMITED	**BOREHOLE NO:**	**BH211**
PROJECT NAME:	Midcoast Council	**PAGE:**	2 of 3
SITE LOCATION:	Coastal Hazard Assessment	**JOB NO:**	RGS31505.1
TEST LOCATION:	See figure 1	**LOGGED BY:**	MR
		DATE:	14/2/19

DRILL TYPE:	MD200	**EASTING:**		**SURFACE RL:**	10.6 m
BOREHOLE DIAMETER:	100 mm	**NORTHING:**		**DATUM:**	AHD
INCLINATION:	90°				

Drilling and Sampling					Material description and profile information					Field Test		Structure and additional observations
METHOD	WATER	SAMPLES	RL (m)	DEPTH (m)	GRAPHIC LOG	CLASSIFICATION SYMBOL	MATERIAL DESCRIPTION: Soil type, plasticity/particle characteristics,colour,minor components	MOISTURE CONDITION	CONSISTENCY DENSITY	Test Type	Result	
AD/TC BIT		SPT 11,13,13 N=26			▨	CH	**CLAY:** High plasticity, pale grey with pale red mottle *(continued)*	M < W_P	H			RESIDUAL SOIL
		6.45m	4.0	6.50m			**Becoming Extremely to Highly Weathered METASANDSTONE:** Fine to medium grained, pale grey, yellow/brown, estimated very low strength					EXTREMELY TO HIGHLY WEATHERED METASANDSTONE
				7.0								
	▶						Inflow					
			3.0									
				8.0								
			2.0									
		9.00m		9.0								Soil type properties
		SPT 11,17,26 N=43										
		9.45m	1.0									
				10.0								
			0.0									
				11.0								
			-1.0									
		12.00m										

LEGEND:

Water

▼	Water Level (Date and time shown)
▶—	Water Inflow
—◀	Water Outflow

Strata Changes

— — —	Gradational or transitional strata
———	Definitive or distict strata change

Notes, Samples and Tests

U_{50}	50mm Diameter tube sample
CBR	Bulk sample for CBR testing
E	Environmental sample
ASS	Acid Sulfate Soil Sample
B	Bulk Sample

Field Tests

PID	Photoionisation detector reading (ppm)
DCP(x-y)	Dynamic penetrometer test (test depth interval shown)
HP	Hand Penetrometer test (UCS kPa)

Consistency		**UCS (kPa)**
VS	Very Soft	<25
S	Soft	25 - 50
F	Firm	50 - 100
St	Stiff	100 - 200
VSt	Very Stiff	200 - 400
H	Hard	>400
Fb	Friable	

Moisture Condition	
D	Dry
M	Moist
W	Wet
W_p	Plastic Limit
W_L	Liquid Limit

Density		
V	Very Loose	Density Index <15%
L	Loose	Density Index 15 - 35%
MD	Medium Dense	Density Index 35 - 65%
D	Dense	Density Index 65 - 85%
VD	Very Dense	Density Index 85 - 100%

ENGINEERING LOG - BOREHOLE

REGIONAL GEOTECHNICAL SOLUTIONS

CLIENT:	BMT PTY LIMITED	**BOREHOLE NO:**	**BH211**
PROJECT NAME:	Midcoast Council	**PAGE:**	3 of 3
SITE LOCATION:	Coastal Hazard Assessment	**JOB NO:**	RGS31505.1
TEST LOCATION:	See figure 1	**LOGGED BY:**	MR
		DATE:	14/2/19

DRILL TYPE:	MD200			**EASTING:**		**SURFACE RL:**	10.6 m
BOREHOLE DIAMETER:	100 mm	**INCLINATION:**	90°	**NORTHING:**		**DATUM:**	AHD

Drilling and Sampling					Material description and profile information					Field Test		
METHOD	WATER	SAMPLES	RL (m)	DEPTH (m)	GRAPHIC LOG	CLASSIFICATION SYMBOL	MATERIAL DESCRIPTION: Soil type, plasticity/particle characteristics,colour,minor components	MOISTURE CONDITION	CONSISTENCY DENSITY	Test Type	Result	Structure and additional observations
AD/TC BIT		SPT 16,25,26 N=51				12.45m	**Becoming Extremely to Highly Weathered METASANDSTONE:** Fine to medium grained, pale grey, yellow/brown, estimated very low strength *(continued)*	M < W_P	H			EXTREMELY TO HIGHLY WEATHERED METASANDSTONE
		12.45m	-2.0				Hole Terminated at 12.45 m					
				13.0								
			-3.0									
				14.0								
			-4.0									
				15.0								
			-5.0									
				16.0								
			-6.0									
				17.0								
			-7.0									

LEGEND:

Water

▼	Water Level (Date and time shown)
▶—	Water Inflow
—◀	Water Outflow

Strata Changes

— — -	Gradational or transitional strata
——	Definitive or distict strata change

Notes, Samples and Tests

U_{50}	50mm Diameter tube sample
CBR	Bulk sample for CBR testing
E	Environmental sample
ASS	Acid Sulfate Soil Sample
B	Bulk Sample

Field Tests

PID	Photoionisation detector reading (ppm)
DCP(x-y)	Dynamic penetrometer test (test depth interval shown)
HP	Hand Penetrometer test (UCS kPa)

Consistency		**UCS (kPa)**
VS	Very Soft	<25
S	Soft	25 - 50
F	Firm	50 - 100
St	Stiff	100 - 200
VSt	Very Stiff	200 - 400
H	Hard	>400
Fb	Friable	

Moisture Condition

D	Dry
M	Moist
W	Wet
W_p	Plastic Limit
W_L	Liquid Limit

Density		
V	Very Loose	Density Index <15%
L	Loose	Density Index 15 - 35%
MD	Medium Dense	Density Index 35 - 65%
D	Dense	Density Index 65 - 85%
VD	Very Dense	Density Index 85 - 100%

ENGINEERING LOG - BOREHOLE

REGIONAL GEOTECHNICAL SOLUTIONS

CLIENT:	BMT PTY LIMITED	**BOREHOLE NO:**	**BH212**
PROJECT NAME:	Midcoast Council	**PAGE:**	1 of 1
SITE LOCATION:	Coastal Hazard Assessment	**JOB NO:**	RGS31505.1
TEST LOCATION:	See figure 1	**LOGGED BY:**	MR
		DATE:	14/2/19

DRILL TYPE: MD200
BOREHOLE DIAMETER: 100 mm **INCLINATION:** 90°
EASTING:
NORTHING:
SURFACE RL: 5.7 m
DATUM: AHD

Drilling and Sampling					Material description and profile information					Field Test		
METHOD	WATER	SAMPLES	RL (m)	DEPTH (m)	GRAPHIC LOG	CLASSIFICATION SYMBOL	MATERIAL DESCRIPTION: Soil type, plasticity/particle characteristics,colour,minor components	MOISTURE CONDITION	CONSISTENCY DENSITY	Test Type	Result	Structure and additional observations
AD/TC BIT	Not Encountered					ML	**Sandy SILT:** Low plasticity, dark brown					TOPSOIL
				0.25m		CH	**CLAY:** High plasticity, pale grey	M < W_P	VSt / H	HP	400	RESIDUAL SOIL
			5.0	1.0								
		1.30m SPT 25,R N= >50		1.30m			**Highly Weathered METASILTSTONE:** Fine to medium grained, pale grey, estimated, highly fractured					HIGHLY WEATHERED METASILTSTONE
			4.0	2.0								
				2.00m			**Highly to Moderately Weathered METASILTSTONE:** Fine grained, pale grey, estimated medium strength, highly fractured					
				2.20m			**Becoming Slightly Weathered METASILTSTONE:** Fine to medium grained, estimated high strength, highly fractured					
				2.50m			Hole Terminated at 2.50 m Due to TC Bit Refusal					
			3.0	3.0								
			2.0	4.0								
			1.0	5.0								
			0.0									

LEGEND:

Water

- Water Level (Date and time shown)
- ▶— Water Inflow
- —◀ Water Outflow

Strata Changes

- — — Gradational or transitional strata
- ——— Definitive or distict strata change

Notes, Samples and Tests

U_{50}	50mm Diameter tube sample
CBR	Bulk sample for CBR testing
E	Environmental sample
ASS	Acid Sulfate Soil Sample
B	Bulk Sample

Field Tests

PID	Photoionisation detector reading (ppm)
DCP(x-y)	Dynamic penetrometer test (test depth interval shown)
HP	Hand Penetrometer test (UCS kPa)

Consistency		**UCS (kPa)**
VS	Very Soft	<25
S	Soft	25 - 50
F	Firm	50 - 100
St	Stiff	100 - 200
VSt	Very Stiff	200 - 400
H	Hard	>400
Fb	Friable	

Moisture Condition

D	Dry
M	Moist
W	Wet
W_p	Plastic Limit
W_L	Liquid Limit

Density		
V	Very Loose	Density Index <15%
L	Loose	Density Index 15 - 35%
MD	Medium Dense	Density Index 35 - 65%
D	Dense	Density Index 65 - 85%
VD	Very Dense	Density Index 85 - 100%

REGIONAL GEOTECHNICAL SOLUTIONS

ENGINEERING LOG - BOREHOLE

CLIENT:	BMT PTY LIMITED	**BOREHOLE NO:**	**BH213**
PROJECT NAME:	Midcoast Council	**PAGE:**	1 of 2
SITE LOCATION:	Coastal Hazard Assessment	**JOB NO:**	RGS31505.1
TEST LOCATION:	See figure 1	**LOGGED BY:**	MR
		DATE:	14/2/19

DRILL TYPE:	MD200	**EASTING:**		**SURFACE RL:**	12.7 m
BOREHOLE DIAMETER:	100 mm **INCLINATION:** 90°	**NORTHING:**		**DATUM:**	AHD

Drilling and Sampling					Material description and profile information					Field Test		
METHOD	WATER	SAMPLES	RL (m)	DEPTH (m)	GRAPHIC LOG	CLASSIFICATION SYMBOL	MATERIAL DESCRIPTION: Soil type, plasticity/particle characteristics,colour,minor components	MOISTURE CONDITION	CONSISTENCY DENSITY	Test Type	Result	Structure and additional observations
AD/TC BIT	Not Encountered					GW	**FILL:** Silty Sandy GRAVEL, brown/grey	D	VD			FILL
				0.20m		CL	**Silty CLAY:** Medium plasticity brown	D	H			COLLUVIUM
		0.40m SPT 6,8,12 N=20 0.85m	12.0	0.40m		CH	**CLAY:** High plasticity, pale red/pale brown	M < W$_P$	H			RESIDUAL SOIL
				1.0								HP = >600kPa
		1.50m SPT 10,12,13 N=25 1.95m	11.0									
				2.0			Becoming pale grey and pale red mottle					
			10.0									
		3.00m SPT 10,14,18 N=32 3.45m		3.0			Becoming pale grey with trace of pale red mottle					
			9.0	4.0								
		4.50m SPT 10,11,20 N=31 4.95m	8.0	4.50m		CH	**CLAY:** High to medium plasticity, pale grey with orange/brown, pale grey and yellow mottle, some remnant Rock structure					
				5.0								HP = >600kPa
	Not Encountered		7.0									

LEGEND:

Water

▼ Water Level (Date and time shown)

► Water Inflow

◄ Water Outflow

Strata Changes

– – – Gradational or transitional strata

——— Definitive or distict strata change

Notes, Samples and Tests

U$_{50}$	50mm Diameter tube sample
CBR	Bulk sample for CBR testing
E	Environmental sample
ASS	Acid Sulfate Soil Sample
B	Bulk Sample

Field Tests

PID	Photoionisation detector reading (ppm)
DCP(x-y)	Dynamic penetrometer test (test depth interval shown)
HP	Hand Penetrometer test (UCS kPa)

Consistency		**UCS (kPa)**
VS	Very Soft	<25
S	Soft	25 - 50
F	Firm	50 - 100
St	Stiff	100 - 200
VSt	Very Stiff	200 - 400
H	Hard	>400
Fb	Friable	

Moisture Condition	
D	Dry
M	Moist
W	Wet
W$_p$	Plastic Limit
W$_L$	Liquid Limit

Density		
V	Very Loose	Density Index <15%
L	Loose	Density Index 15 - 35%
MD	Medium Dense	Density Index 35 - 65%
D	Dense	Density Index 65 - 85%
VD	Very Dense	Density Index 85 - 100%

ENGINEERING LOG - BOREHOLE

REGIONAL GEOTECHNICAL SOLUTIONS

CLIENT:	BMT PTY LIMITED	**BOREHOLE NO:**	**BH213**
PROJECT NAME:	Midcoast Council	**PAGE:**	2 of 2
SITE LOCATION:	Coastal Hazard Assessment	**JOB NO:**	RGS31505.1
TEST LOCATION:	See figure 1	**LOGGED BY:**	MR
		DATE:	14/2/19

DRILL TYPE:	MD200	**EASTING:**		**SURFACE RL:**	12.7 m
BOREHOLE DIAMETER:	100 mm	**INCLINATION:** 90°	**NORTHING:**	**DATUM:**	AHD

Drilling and Sampling					Material description and profile information					Field Test		
METHOD	WATER	SAMPLES	RL (m)	DEPTH (m)	GRAPHIC LOG	CLASSIFICATION SYMBOL	MATERIAL DESCRIPTION: Soil type, plasticity/particle characteristics,colour,minor components	MOISTURE CONDITION	CONSISTENCY DENSITY	Test Type	Result	Structure and additional observations
AD/TC BIT					▨	CH	**CLAY:** High to medium plasticity, pale grey with orange/brown, pale grey and yellow mottle, some remnant Rock structure *(continued)*	$M < W_P$	H			RESIDUAL SOIL
			6.0	7.0	⁙		6.50m **Extremely to Highly Weathered SANDSTONE:** Medium to coarse grained, estimated low strength					EXTREMELY TO HIGHLY WEATHERED SANDSTONE
							7.00m Hole Terminated at 7.00 m					
			5.0	8.0								
			4.0	9.0								
			3.0	10.0								
			2.0	11.0								
			1.0									

LEGEND:

Water

▼	Water Level (Date and time shown)
▶—	Water Inflow
—◀	Water Outflow

Strata Changes

— — —	Gradational or transitional strata
———	Definitive or distict strata change

Notes, Samples and Tests

U_{50}	50mm Diameter tube sample
CBR	Bulk sample for CBR testing
E	Environmental sample
ASS	Acid Sulfate Soil Sample
B	Bulk Sample

Field Tests

PID	Photoionisation detector reading (ppm)
DCP(x-y)	Dynamic penetrometer test (test depth interval shown)
HP	Hand Penetrometer test (UCS kPa)

Consistency		**UCS (kPa)**
VS	Very Soft	<25
S	Soft	25 - 50
F	Firm	50 - 100
St	Stiff	100 - 200
VSt	Very Stiff	200 - 400
H	Hard	>400
Fb	Friable	

Moisture Condition

D	Dry
M	Moist
W	Wet
W_p	Plastic Limit
W_L	Liquid Limit

Density		
V	Very Loose	Density Index <15%
L	Loose	Density Index 15 - 35%
MD	Medium Dense	Density Index 35 - 65%
D	Dense	Density Index 65 - 85%
VD	Very Dense	Density Index 85 - 100%

REGIONAL GEOTECHNICAL SOLUTIONS

ENGINEERING LOG - BOREHOLE

BOREHOLE NO: **BH214**

CLIENT: BMT PTY LIMITED
PROJECT NAME: Midcoast Council
SITE LOCATION: Coastal Hazard Assessment
TEST LOCATION: See figure 1

PAGE: 1 of 1
JOB NO: RGS31505.1
LOGGED BY: MR
DATE: 14/2/19

DRILL TYPE: MD200
BOREHOLE DIAMETER: 100 mm
INCLINATION: 90°
EASTING:
NORTHING:
SURFACE RL: 5.6 m
DATUM: AHD

Drilling and Sampling					Material description and profile information					Field Test		
METHOD	WATER	SAMPLES	RL (m)	DEPTH (m)	GRAPHIC LOG	CLASSIFICATION SYMBOL	MATERIAL DESCRIPTION: Soil type, plasticity/particle characteristics,colour,minor components	MOISTURE CONDITION	CONSISTENCY DENSITY	Test Type	Result	Structure and additional observations
AD/TC BIT	Not Encountered					GW	**FILL:** Silty Sandy GRAVEL, fine to medium grained, grey 0.50m	D	VD			FILL: UNSEALED PAVEMENT
			5.0 4.0	1.0 2.0		SP	**SAND:** Fine to medium grained, brown Becoming pale yellow 2.00m					AEOLIAN
						SM	**Becoming Silty SAND:** with some Gravel, fine to medium grained, angular shape 2.60m					
		3.00m SPT 18, R N = >50	3.0	3.0			**Slightly Weathered METASILTSTONE:** Dark grey and brown, estimated high strength 3.20m					SLIGHTLY WEATHERED METASILTSTONE
			2.0 1.0 0.0	4.0 5.0			Hole Terminated at 3.20 m TC Bit Refusal					

LEGEND:

Water

▼	Water Level (Date and time shown)
▶	Water Inflow
◀	Water Outflow

Strata Changes

— —	Gradational or transitional strata
——	Definitive or distict strata change

Notes, Samples and Tests

U_{50}	50mm Diameter tube sample
CBR	Bulk sample for CBR testing
E	Environmental sample
ASS	Acid Sulfate Soil Sample
B	Bulk Sample

Field Tests

PID	Photoionisation detector reading (ppm)
DCP(x-y)	Dynamic penetrometer test (test depth interval shown)
HP	Hand Penetrometer test (UCS kPa)

Consistency		UCS (kPa)
VS	Very Soft	<25
S	Soft	25 - 50
F	Firm	50 - 100
St	Stiff	100 - 200
VSt	Very Stiff	200 - 400
H	Hard	>400
Fb	Friable	

Moisture Condition

D	Dry
M	Moist
W	Wet
W_p	Plastic Limit
W_L	Liquid Limit

Density

V	Very Loose	Density Index <15%
L	Loose	Density Index 15 - 35%
MD	Medium Dense	Density Index 35 - 65%
D	Dense	Density Index 65 - 85%
VD	Very Dense	Density Index 85 - 100%

REGIONAL GEOTECHNICAL SOLUTIONS

ENGINEERING LOG - BOREHOLE

BOREHOLE NO: **BH215**

CLIENT:	BMT PTY LIMITED	**PAGE:**	1 of 2
PROJECT NAME:	Midcoast Council	**JOB NO:**	RGS31505.1
SITE LOCATION:	Coastal Hazard Assessment	**LOGGED BY:**	MR
TEST LOCATION:	See figure 1	**DATE:**	15/2/19

DRILL TYPE:	MD200		**EASTING:**	**SURFACE RL:**	5.1 m
BOREHOLE DIAMETER:	100 mm	**INCLINATION:** 90°	**NORTHING:**	**DATUM:**	AHD

Drilling and Sampling					Material description and profile information					Field Test		
METHOD	WATER	SAMPLES	RL (m)	DEPTH (m)	GRAPHIC LOG	CLASSIFICATION SYMBOL	MATERIAL DESCRIPTION: Soil type, plasticity/particle characteristics,colour,minor components	MOISTURE CONDITION	CONSISTENCY DENSITY	Test Type	Result	Structure and additional observations
AD/TC BIT	Not Encountered		5.0		▨	GW	**FILL:** Silty Sandy GRAVEL, fine to medium grained, dark grey	D	VD			FILL
				0.50m	▨	CH	**FILL:** CLAY, high plasticity, pale grey and pale red	M < W_P	VSt			FILL
				1.0						HP	400	
			4.0									
		1.60m SPT 3,4,5 N=9		1.60m	▧	CH	**Silty CLAY:** High plasticity, dark grey, some organics	M > W_P	VSt			ALLUVIUM
				2.0						HP	280	
		2.05m	3.0									
				2.50m	▧	CH	**CLAY:** High plasticity, pale grey and orange, some fissures	M > W_P	VSt			
		3.00m SPT 2,3,4 N=7		3.0						HP	200	
			2.0									
		3.45m										
				4.0								
			1.0									
		4.50m SPT 5,5,7 N=12										
				5.0								
		4.95m	0.0									
	Not Encountered											

LEGEND:

Water

▼	Water Level (Date and time shown)
►—	Water Inflow
—◄	Water Outflow

Strata Changes

— — —	Gradational or transitional strata
———	Definitive or distict strata change

Notes, Samples and Tests

U_{50}	50mm Diameter tube sample
CBR	Bulk sample for CBR testing
E	Environmental sample
ASS	Acid Sulfate Soil Sample
B	Bulk Sample

Field Tests

PID	Photoionisation detector reading (ppm)
DCP(x-y)	Dynamic penetrometer test (test depth interval shown)
HP	Hand Penetrometer test (UCS kPa)

Consistency		**UCS (kPa)**
VS	Very Soft	<25
S	Soft	25 - 50
F	Firm	50 - 100
St	Stiff	100 - 200
VSt	Very Stiff	200 - 400
H	Hard	>400
Fb	Friable	

Moisture Condition

D	Dry
M	Moist
W	Wet
W_p	Plastic Limit
W_L	Liquid Limit

Density		
V	Very Loose	Density Index <15%
L	Loose	Density Index 15 - 35%
MD	Medium Dense	Density Index 35 - 65%
D	Dense	Density Index 65 - 85%
VD	Very Dense	Density Index 85 - 100%

REGIONAL GEOTECHNICAL SOLUTIONS

ENGINEERING LOG - BOREHOLE

BOREHOLE NO: **BH215**

CLIENT:	BMT PTY LIMITED	**PAGE:**	2 of 2
PROJECT NAME:	Midcoast Council	**JOB NO:**	RGS31505.1
SITE LOCATION:	Coastal Hazard Assessment	**LOGGED BY:**	MR
TEST LOCATION:	See figure 1	**DATE:**	15/2/19

DRILL TYPE: MD200
BOREHOLE DIAMETER: 100 mm **INCLINATION:** 90°
EASTING:
NORTHING:
SURFACE RL: 5.1 m
DATUM: AHD

Drilling and Sampling					Material description and profile information					Field Test		
METHOD	WATER	SAMPLES	RL (m)	DEPTH (m)	GRAPHIC LOG	CLASSIFICATION SYMBOL	MATERIAL DESCRIPTION: Soil type, plasticity/particle characteristics,colour,minor components	MOISTURE CONDITION	CONSISTENCY DENSITY	Test Type	Result	Structure and additional observations
AD/TC BIT		6.50m SPT 9,12,13 N=25 6.95m	-1.0	7.0	▨	CH	**CLAY:** High plasticity, pale grey and orange, some fissures *(continued)* 7.00m	M > w_P	VSt			ALLUVIUM
			-2.0 -3.0 -4.0 -5.0 -6.0	8.0 9.0 10.0 11.0			Hole Terminated at 7.00 m					

LEGEND:

Water

- ▼ Water Level (Date and time shown)
- ► Water Inflow
- ◄ Water Outflow

Strata Changes

- – – – Gradational or transitional strata
- ——— Definitive or distict strata change

Notes, Samples and Tests

U_{50}	50mm Diameter tube sample
CBR	Bulk sample for CBR testing
E	Environmental sample
ASS	Acid Sulfate Soil Sample
B	Bulk Sample

Field Tests

PID	Photoionisation detector reading (ppm)
DCP(x-y)	Dynamic penetrometer test (test depth interval shown)
HP	Hand Penetrometer test (UCS kPa)

Consistency		**UCS (kPa)**
VS	Very Soft	<25
S	Soft	25 - 50
F	Firm	50 - 100
St	Stiff	100 - 200
VSt	Very Stiff	200 - 400
H	Hard	>400
Fb	Friable	

Moisture Condition

D	Dry
M	Moist
W	Wet
W_p	Plastic Limit
W_L	Liquid Limit

Density

V	Very Loose	Density Index <15%
L	Loose	Density Index 15 - 35%
MD	Medium Dense	Density Index 35 - 65%
D	Dense	Density Index 65 - 85%
VD	Very Dense	Density Index 85 - 100%

ENGINEERING LOG - BOREHOLE

REGIONAL GEOTECHNICAL SOLUTIONS

BOREHOLE NO: BH216

CLIENT:	BMT PTY LIMITED	**PAGE:**	1 of 2
PROJECT NAME:	Midcoast Council	**JOB NO:**	RGS31505.1
SITE LOCATION:	Coastal Hazard Assessment	**LOGGED BY:**	MR
TEST LOCATION:	UTM 565	**DATE:**	15/2/19

DRILL TYPE: MD200 **EASTING:** 461796 m **SURFACE RL:** 8.0 m

BOREHOLE DIAMETER: 100 mm **INCLINATION:** 90° **NORTHING:** 646334 m **DATUM:** AHD

Drilling and Sampling					Material description and profile information					Field Test		Structure and additional observations
METHOD	WATER	SAMPLES	RL (m)	DEPTH (m)	GRAPHIC LOG	CLASSIFICATION SYMBOL	MATERIAL DESCRIPTION: Soil type, plasticity/particle characteristics,colour,minor components	MOISTURE CONDITION	CONSISTENCY DENSITY	Test Type	Result	
AD/TC BIT	Not Encountered						**FILL:** Sandy Silty GRAVEL, dark brown, dark grey					FILL
				0.20m		CH	**CLAY:** High plasticity, pale grey with yellow/brown mottle					RESIDUAL SOIL
			7.0	1.0								
		1.50m SPT 4,10,9 N=19 1.95m								HP	350	
			6.0	2.0								
		3.00m SPT 6,11,28 N=39 3.45m	5.0	3.0								HP = >600kPa
				3.40m			**Extremely Weathered METASILTSTONE:** Pale grey, estimated low strength					
			4.0	4.0								
		4.50m SPT 20 for 50mm 4.65m		4.50m			**Becoming Extremely to Highly Weathered METASILTSTONE:** Estimated very low to low strength					
	Not Encountered		3.0	5.0								

LEGEND:

Water

- ▼ Water Level (Date and time shown)
- ► Water Inflow
- ◄ Water Outflow

Strata Changes

- — — Gradational or transitional strata
- —— Definitive or distict strata change

Notes, Samples and Tests

U_{50}	50mm Diameter tube sample
CBR	Bulk sample for CBR testing
E	Environmental sample
ASS	Acid Sulfate Soil Sample
B	Bulk Sample

Field Tests

PID	Photoionisation detector reading (ppm)
DCP(x-y)	Dynamic penetrometer test (test depth interval shown)
HP	Hand Penetrometer test (UCS kPa)

Consistency		UCS (kPa)
VS	Very Soft	<25
S	Soft	25 - 50
F	Firm	50 - 100
St	Stiff	100 - 200
VSt	Very Stiff	200 - 400
H	Hard	>400
Fb	Friable	

Moisture Condition	
D	Dry
M	Moist
W	Wet
W_p	Plastic Limit
W_L	Liquid Limit

Density		
V	Very Loose	Density Index <15%
L	Loose	Density Index 15 - 35%
MD	Medium Dense	Density Index 35 - 65%
D	Dense	Density Index 65 - 85%
VD	Very Dense	Density Index 85 - 100%

REGIONAL GEOTECHNICAL SOLUTIONS

ENGINEERING LOG - BOREHOLE

CLIENT:	BMT PTY LIMITED	**BOREHOLE NO:**	**BH216**
PROJECT NAME:	Midcoast Council	**PAGE:**	2 of 2
SITE LOCATION:	Coastal Hazard Assessment	**JOB NO:**	RGS31505.1
TEST LOCATION:	UTM 565	**LOGGED BY:**	MR
		DATE:	15/2/19

DRILL TYPE: MD200
EASTING: 461796 m
SURFACE RL: 8.0 m
BOREHOLE DIAMETER: 100 mm
INCLINATION: 90°
NORTHING: 646334 m
DATUM: AHD

Drilling and Sampling					Material description and profile information					Field Test		
METHOD	WATER	SAMPLES	RL (m)	DEPTH (m)	GRAPHIC LOG	CLASSIFICATION SYMBOL	MATERIAL DESCRIPTION: Soil type, plasticity/particle characteristics,colour,minor components	MOISTURE CONDITION	CONSISTENCY DENSITY	Test Type	Result	Structure and additional observations
AD/TC BIT							**Becoming Extremely to Highly Weathered METASILTSTONE:** Estimated very low to low strength *(continued)*					RESIDUAL SOIL
			1.0	7.0								
							Becoming very low strength					
		8.00m SPT 11,17,25 N=42	0.0	8.0								
						8.45m						
		8.45m					Hole Terminated at 8.45 m					
			-1.0	9.0								
			-2.0	10.0								
			-3.0	11.0								

LEGEND:

Water

▼	Water Level (Date and time shown)
►	Water Inflow
◄	Water Outflow

Strata Changes

— —	Gradational or transitional strata
——	Definitive or distict strata change

Notes, Samples and Tests

U_{50}	50mm Diameter tube sample
CBR	Bulk sample for CBR testing
E	Environmental sample
ASS	Acid Sulfate Soil Sample
B	Bulk Sample

Field Tests

PID	Photoionisation detector reading (ppm)
DCP(x-y)	Dynamic penetrometer test (test depth interval shown)
HP	Hand Penetrometer test (UCS kPa)

Consistency		**UCS (kPa)**
VS	Very Soft	<25
S	Soft	25 - 50
F	Firm	50 - 100
St	Stiff	100 - 200
VSt	Very Stiff	200 - 400
H	Hard	>400
Fb	Friable	

Moisture Condition	
D	Dry
M	Moist
W	Wet
W_p	Plastic Limit
W_L	Liquid Limit

Density		
V	Very Loose	Density Index <15%
L	Loose	Density Index 15 - 35%
MD	Medium Dense	Density Index 35 - 65%
D	Dense	Density Index 65 - 85%
VD	Very Dense	Density Index 85 - 100%

Appendix F Existing Borehole Records

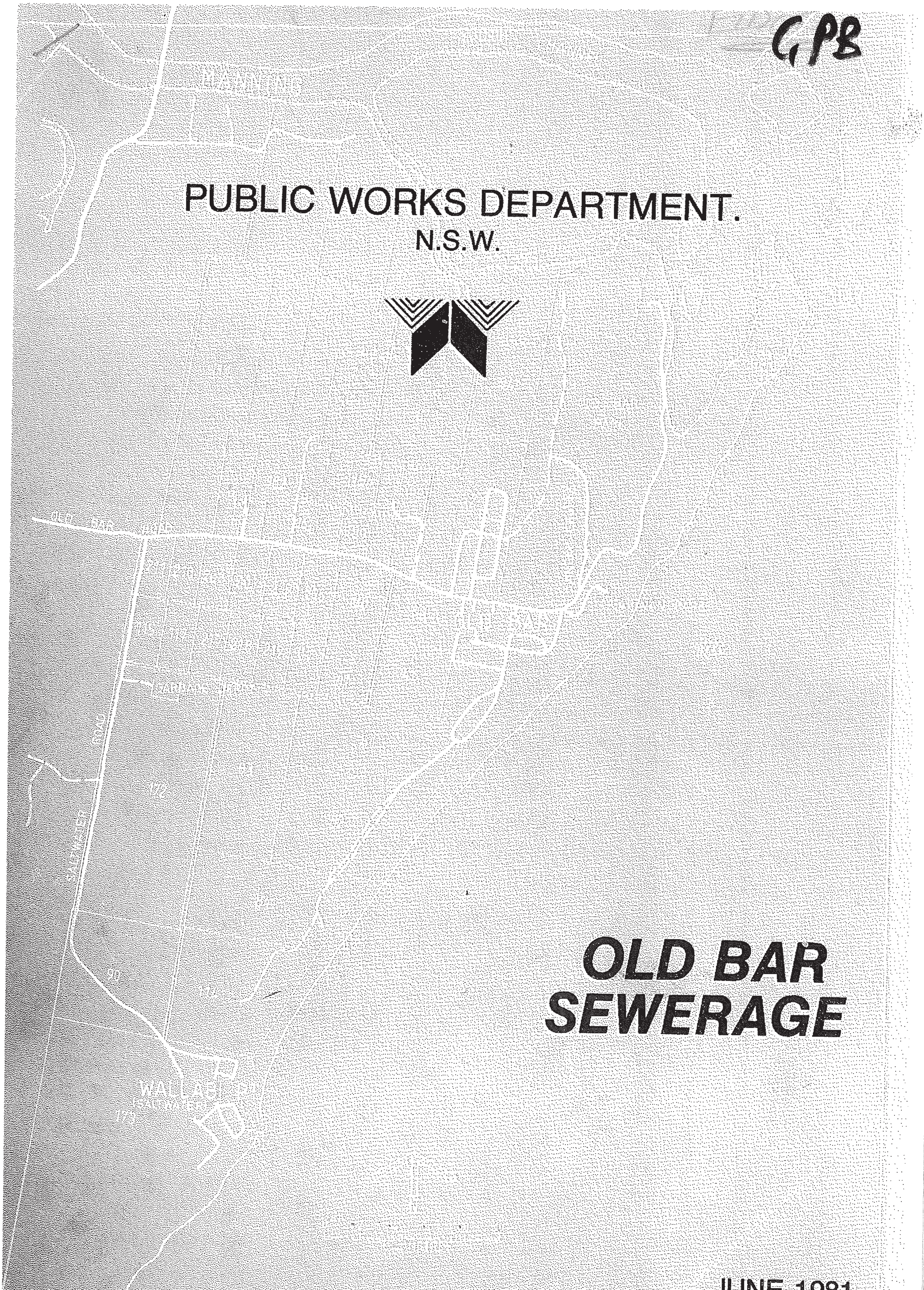
This appendix reproduces the borehole records from the Old Bar Beach study region completed from three geotechnical investigations completed prior to this study are reproduced within this appendix. These records include:

- Old Bar Sewerage Investigation (PWD, 1981; Section F.1)
- Old Bar Coastal Erosion Study (SKM,1982; Section F.2)
- Northern NSW Schools Geotechnical Assessment: Old Bar Public School (GHD, 2017; Section F.3)

F.1 Old Bar Sewerage Investigation (PWD, 1981)

GPB

PUBLIC WORKS DEPARTMENT.
N.S.W.



OLD BAR SEWERAGE

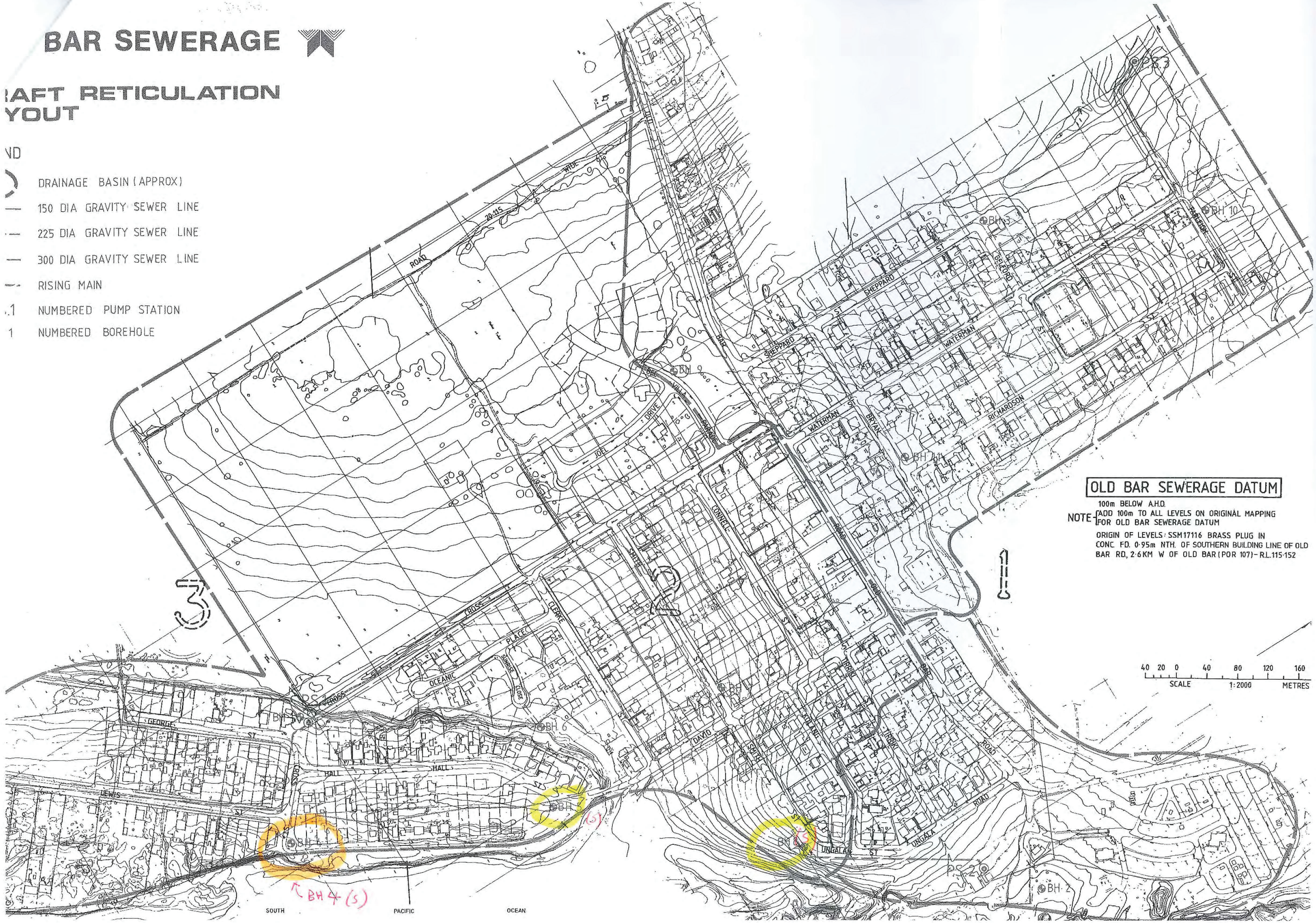
JUNE 1981.

BAR SEWERAGE

AFT RETICULATION
YOUT

ND

DRAINAGE BASIN (APPROX)
150 DIA GRAVITY SEWER LINE
225 DIA GRAVITY SEWER LINE
300 DIA GRAVITY SEWER LINE
RISING MAIN
.1 NUMBERED PUMP STATION
1 NUMBERED BOREHOLE



APPENDIX A
BOREHOLE INFORMATION

The following bores were taken during July 1980 using 3½" Gemco Auger at positions shown on the appended drawings. Information obtained forms the basis for scheme costing.

Bore Hole No.	Depth	Colour	Description	Remarks
B.H. 1	Surface		Grassy block near creek	
	0.5	Black	Sand	Dry easy
	1.3	Black	Indurated sand	Wet easy
	3.0	Grey	Clay	Damp soft
	6.0	Red & Grey	Clay	Firm dry
		T.W.L. 0.50 m		
B.H. 2	Surface	On eastern end of Park beside white fence		
	0.3	Black	Top soil	Soft
	1.0	Red & Grey	Clay	Firm dry
	2.5	Mustard	Silty clay	Wet soft
	6.0	Red & Grey	Clay	Firm dry
		T.W.L. 2.40 m		
B.H. 3	Surface	Corner of Belford and Sheppard St., near swamp		
	0.5	Black	Loamy soil	Damp soft
	1.3	Red	Clay	Dry firm
	4.0	Mustard	Clay	Wet soft
	6.0	Red	Clay	Hard firm
RL ↓		T.W.L. 0.50 m		
B.H. 4	Surface (RL6)		Sandy footpath Ch 900/130m	Dry
5.0	1.0	Black	Sand	Dry
2.5	3.5	Grey	Clay S. end P. Parade	Soft wet
1.5	4.5	Black	Indurated sand	Soft wet
RL ↓		T.W.L. 3.50 m		
B.H. 5	Surface ← say (RL6)		Sandy block Ch1200/100m	Dry
5.5	0.5	Black	Sand N. end	Dry
3.0	3.0	Grey	Coarse sand Pac. Parade	Wet soft
1.5	4.5	Grey	Clay	Firm dry
		T.W.L. 2.50 m		

Bore Hole No.	Depth	Colour	Description	Remarks
B.H. 6	Surface		Dry grassy block near creek	Dry
	0.2	Black	Top soil	Dry easy
	1.5	Red & grey	Clay	Dry easy
	3.5	Grey	Clay	Firm dry
	4.5	Yellow & grey	Clay	Damp soft
		T.W.L. 3.5 m		
B.H. 7	Surface		Grassy footpath	Dry
	0.4	Black	Top soil	Soft
	1.2	Grey	Clay	Soft
	2.8	Yellow & Grey	Clay	Soft
RL	4.5	Grey	Shale	Firm dry
B.H. 8 ↓	Surface	← est RL7	Grassy footpath	Dry
6.7	0.3	Brown	Gritty top soil	Dry
6.0	1.0	Brown	Gritty clay	Dry
4.0	3.0	Red & Grey	Gritty	Dry firm
3.25	3.75	Grey	Shale School near cnr Smith + Ungala St	Dry firm
2.5	4.5	Yellow & Grey	Clay	Dry firm
B.H. 9	Surface		Grassy block	Dry
	0.2	Black	Top soil	Dry soft
	3.0	Red & Grey	Clay	Firm dry
B.H. 10	Surface		Grassy footpath	Dry
	0.2	Black	Top soil	Dry soft
	4.5	Red & Grey	Clay	Firm dry
B.H. 11	Surface		Dry grassy block	
	0.3	Black	Top soil	Dry Soft
	4.5	Red & Grey	Clay	Firm dry
		<u>SALTWATER</u>		
B.H. 12	Surface		15 m behind sand dunes	
	0.5	Black	Sand	Damp
	4.5	Red & Grey	Gritty clay	Firm dry
			Firm to drill	

F.2 Old Bar Coastal Erosion Study (SKM,1982)

Note that borehole records for SKM BH-05, SKM BH-06 and SKM BH-07 have been documented in different formats from the 1982 and 1981 report versions. As such, both report records are re-produced below.

For boreholes SKM BH-05 to BH-07, the 1982 report documents RL levels from the base of the field substrate record, and no surface RL level is provided. For the same three boreholes, the 1981 report documents the depth (m) to the base of the substrate record. Combined, these two report versions have enabled the surface RL level to be determined – as synthesised in Appendix E.

DEPARTMENT OF PUBLIC WORKS, NSW

OLD BAR COASTAL EROSION STUDY

AUGUST 1982

SINCLAIR KNIGHT AND PARTNERS
PTY. LTD
CONSULTING ENGINEERS

FIGURE 14

OFFSHORE SEDIMENT DISTRIBUTION
WALLABI POINT — MITCHELLS ISLAND

APPENDIX B.3

TABLE B.3 - FIELD NOTES FROM BEACH AUGERING SITES

Note: Depths are given in metres relative to ISLW and locations are shown on **Figure 14.**

BH-1 Old Bar beach, opposite Surf Life Saving Club, mid-tide

+2.0 surface, fawn, fine-medium sand
+0.7 gravel and sand
+0.3 clay, low plasticity, some fine sand
-0.7 gravely clay on top of siltstone, rock refusal to auger bit

---

BH-2 Old Bar beach, 500 metres south of BH-1

+2.0 surface, fawn fine-medium sand
+0.3 gravel and sand
-2.2 sandy clay, light grey, low plasticity rock refusal

BH-3 Old Bar beach, 1 000 metres south of BH-1

+2.0 surface gravel layers and fine-medium sand
-3.0 bands of heavy gravel and sand over clay
-5.5 sandy clay, medium plasticity, fine-coarse sand, refusal

---

BH-4 Old Bar beach, 1 500 metres south of BH-1

+2.0 gravel beds on surface of fine-medium sand
-2.5 bands of heavy gravel with soft clay lenses
-5.0 firm dry clay, high plasticity, trace of fine sand, refusal

---

BH-5 Sand dune north of Old Bar

+4.5 sand 0.1-0.3 millimetres, concentrations of humic material

+3.8 dark cemented sands, high organic material content, refusal

---

continued

Appendix B.3 (continued)

BH-6 Sand dune north of Old Bar

+0.5 sandy clay, medium plasticity, light grey, refusal

BH-7 Sand Dunes north of Old Bar

+2.5 sand became yellowy orange in colour, traces of clay

+1.5 sandy clay, low plasticity, silstone pebbles, refusal

BH-8 Old Bar beach, 500 metres north of BH-1

+2.0 surface fawn fine-medium sand
0.0 firm green/grey sandy clay, medium plasticity
-4.0 sandy clay, green, grey and orange mottled clay, high plasticity, very stiff, some shell fragments, refusal

BH-9 Old Bar beach 250 metres north of BH-1

+2.0 surface, fawn fine-medium sand
0.0 gravel and sand
-0.5 gravel and firm green/grey clay
-2.0 siltstone rock, refusal

BH-10 Old Bar beach 2.3 kilometres south of BH-1

+2.0 surface, gravel over sand
-1.0 clay and gravel layer firm but with thin layers of softer clay and less gravel
-4.0 firm very stiff grey sandy clay, refusal

BH-11 Old Bar beach 750 metres south of BH-1

-2.0 surface, fawn fine-medium sand
0.0 thin gravel layers with coarse sand
-3.0 soft sandy clay
-4.5 firm dry clay, high plasticity, traces of fine sand, refusal

continued

APPENDIX B.3 (continued)

BH-12	Inland, north of bend in Racecourse Creek
	+4.5 orange and grey soft damp clay +3.7 red and orange damp clay +2.5 siltstone rock, refusal
BH-13	Midway along Saltwater beach, in low area on back face of dunes
	+3.0 surface browny grey medium-fine sand +0.5 bright burnt orange sand -1.0 dark grey clay, very high plasticity -2.0 refusal in clay

GPB

DEPARTMENT OF PUBLIC WORKS, NSW

DRAFT REPORT

OLD BAR COASTAL EROSION STUDY

NOVEMBER 1981

SINCLAIR KNIGHT & PARTNERS PTY. LTD. CONSULTING ENGINEERS

APPENDIX B.3

TABLE B.3 - FIELD NOTES FROM BEACH AUGERING SITES

Note: Depths are given in metres relative to ISLW and locations are shown on **Figure 14.**

BH-1 Old Bar beach, opposite Surf Life Saving Club, mid-tide

+2.0	surface, fawn, fine-medium sand
+0.7	gravel and sand
+0.3	clay, low plasticity, some fine sand
-0.7	gravely clay on top of siltstone, rock refusal to auger bit

---

BH-2 Old Bar beach, 500 metres south of BH-1

+2.0	surface, fawn fine-medium sand
+0.3	gravel and sand
-2.2	sandy clay, light grey, low plasticity rock refusal

BH-3 Old Bar beach, 1 000 metres south of BH-1

+2.0	surface gravel layers and fine-medium sand
-3.0	bands of heavy gravel and sand over clay
-5.5	sandy clay, medium plasticity, fine-coarse sand, refusal

---

BH-4 Old Bar beach, 1 500 metres south of BH-1

+2.0	gravel beds on surface of fine-medium sand
-2.5	bands of heavy gravel with soft clay lenses
-5.0	firm dry clay, high plasticity, trace of fine sand, refusal

BH-5 Sand dune north of Old Bar

1.6 metres below ground surface - sand 0.1-0.3 millimetres, concentrations of humic material

2.2 metres below ground surface - dark cemented sands, high organic material content, refusal

---

continued

BH-6 Sand dune north of Old Bar

4.5 metres below ground surface - sandy clay, medium plasticity, light grey, refusal

---

BH-7 Sand Dunes north of Old Bar

3.5 metres below ground surface, sand became yellowy orange in colour, traces of clay

4.5 metres below ground surface, sandy clay, low plasticity, siltstone pebbles, refusal

---

BH-8 Old Bar beach, 500 metres north of BH-1

+2.0 surface fawn fine-medium sand
0.0 firm green/grey sandy clay, medium plasticity
-4.0 sandy clay, green, grey and orange mottled clay, high plasticity, very stiff, some shell fragments, refusal

---

BH-9 Old Bar beach 250 metres north of BH-1

+2.0 surface, fawn fine-medium sand
0.0 gravel and sand
-0.5 gravel and firm green/grey clay
-2.0 siltstone rock, refusal

BH-10 Old Bar beach 2.3 kilometres south of BH-1

+2.0 surface gravel over sand
-1.0 clay and gravel layer firm but with thin layers of softer clay and less gravel
-4.0 firm very stiff grey sandy clay, refusal

BH-11 Old Bar beach 750 metres south of BH-1

+ ? → -2.0 surface fawn fine-medium sand
0.0 thin gravel layers with coarse sand
-3.0 soft sandy clay
-4.5 firm dry clay, high plasticity, traces of fine sand, refusal

---

continued

BH-12 Inland, north of bend in Racecourse Creek

1.0 metres below surface - orange and grey soft damp clay
1.7 metres below surface - red and orange damp clay
2.9 metres below surface - siltstone rock, refusal *

BH-13 Midway along Saltwater beach, in low area on back face of dunes

+3.0 surface browny grey medium-fine sand
+0.5 bright burnt orange sand
-1.0 dark grey clay, very high plasticity
-2.0 refusal in clay

F.3 Northern NSW Schools Geotechnical Assessment: Old Bar Public School (GHD, 2017)

Note while the GHD (2017) Old Bar Public School geotechnical investigation was made available by the NSW Department of Education for review and use in this study, although it is not a public document. Permission was also granted to reproduce the four borehole logs and corresponding location map (D. Wheeler, personal communication, May 2019), as provided below.

BOREHOLE LOG SHEET

Client : Bligh Tanner Pty. Ltd.
Project : Northern NSW Schools Geotechnical Investigation
Location : Old Bar Public School, NSW

HOLE No. OBBH01

SHEET 1 OF 2

Position :	*See site plan*	**Surface RL:** TBA AHD	**Angle from Horiz. :** 90°		**Processed :** SBO
Rig Type :	MPD R180	**Mounting:** Ute	**Contractor :** Port Stephens Drilling	**Driller :** Peter Stewart	**Checked :** TGN
Date Started :	19/6/2017	**Date Completed :** 19/6/2017		**Logged by :** MJJ	**Date:** 10/7/17

Note: * indicates signatures on original issue of log or last revision of log.

DRILLING					MATERIAL					
SCALE (m)	Drilling Method	Hole Support \ Casing	Water	Samples & Tests	Depth / (RL) metres	USC Symbol	**Description** SOIL TYPE, colour, structure, minor components (origin), and ROCK TYPE, colour, grain size, structure, weathering, strength	Moisture Condition	Consistency / Density Index	**Comments/ Observations**
	Solid Flight Auger + V-Bit	Nil		D		CI-CH	CLAY, dark grey, brown and orange, medium to high plasticity (MC<PL), trace fine to medium grained sand, trace fine to medium, angular to sub-rounded gravel (fill).	M	-	CS=Contam Sample ASS= ASS Sample CS, 0.1-0.3m ASS, 0.2-0.4m
1				D	0.60	CI-CH	CLAY, mottled dark grey, brown and orange, medium to high plasticity (MC<PL), trace fine to medium grained sand (fill).	M	-	ASS, 0.7-0.9m CS, 1.0-1.45m
				SPT 3/4/5 N=9	1.10	CI-CH	CLAY/SILT, dark grey black, medium to high plasticity (MC<PL), slight organic smell, with Fe staining in parts (alluvium).	SM-M	VSt	1.1-1.4m, PP=230-240kPa ASS, 1.1-1.4m
			▽ 3pm (19/6/17)	D	1.40	CH	CLAY, mottled pale brown, grey and red, high plasticity (MC<PL), trace fine to medium grained sand (residual).	SM	St-VSt	ASS, 1.6-1.7m
				D	1.70	CI-CH	CLAY, pale grey and pale orange, medium to high plasticity (MC<PL), with fine to medium grained sand (residual).	SM	St-VSt	
2				D	1.90	CL-CI	Sandy CLAY, pale grey and pale orange, low to medium plasticity (MC≈PL), trace fine to medium grained sand (residual).	SM	VSt-H	
				D	2.20	SC	Clayey SAND, pale grey and pale orange, fine to medium grained sand (extremely weathered sandstone).	D-SM	D	2.2m, increase drilling resistance
				SPT 23/25 for 110mm (HB) N=ref	2.50	-	SANDSTONE, pale grey stained orange in parts, fine to medium grained, with Fe laminations, highly weathered, estimate very low rock strength, with bands of extremely weathered sandstone (clayey sand).	-	-	2.8m, V-Bit refusal
3	Solid Flight Auger + TC-Bit			D						
							From 3.2m, with 100mm thick harder bands.			
							From 3.3m, very low to low strength.			3.3m, increase drilling resistance
							From 3.5m, pale orange.			
4										
							From 4.2m, off-white pale grey.			
5										

See standard sheets for details of abbreviations & basis of descriptions

GHD GEOTECHNICS
Level 3, GHD Tower, 24 Honeysuckle Drive, Newcastle 2300 Australia
T: 61 2 4979 9999 F: 61 2 4979 9988 E: ntlmail@ghd.com
CONSULTING GEOTECHNICAL ENGINEERS AND GEOLOGISTS

Job No.
22-19010

GEO BOREHOLE 2219010 PUBLICSCHOOLS 3.GPJ GHD GEO TEMPLATE.GDT 13/7/17

Client : Bligh Tanner Pty. Ltd.
Project : Northern NSW Schools Geotechnical Investigation
Location : Old Bar Public School, NSW

HOLE No. OBBH01

SHEET 2 OF 2

Position : *See site plan* **Surface RL:** TBA AHD **Angle from Horiz. :** 90° **Processed :** SBO
Rig Type : MPD R180 **Mounting:** Ute **Contractor :** Port Stephens Drilling **Driller :** Peter Stewart **Checked :** TGN
Date Started : 19/6/2017 **Date Completed :** 19/6/2017 **Logged by :** MJJ **Date:** 10/7/17

Note: * indicates signatures on original issue of log or last revision of log

DRILLING					MATERIAL						
SCALE (m)	Drilling Method	Hole Support \ Casing	Water	Samples & Tests	Depth / (RL) metres	Graphic Log	USC Symbol	**Description** SOIL TYPE, colour, structure, minor components (origin), and ROCK TYPE, colour, grain size, structure, weathering, strength	Moisture Condition	Consistency / Density Index	**Comments/ Observations**
	Solid Flight Auger + TCBit	Nil			6.00		-	SANDSTONE, as previous. From 5.0m, pale orange to orange.	-	-	
6								End of borehole at 6 metres. Target Depth.			
7											
8											
9											
10											

See standard sheets for details of abbreviations & basis of descriptions

GHD GEOTECHNICS
Level 3, GHD Tower, 24 Honeysuckle Drive, Newcastle 2300 Australia
T: 61 2 4979 9999 F: 61 2 4979 9988 E: ntlmail@ghd.com
CONSULTING GEOTECHNICAL ENGINEERS AND GEOLOGISTS

Job No. 22-19010

BOREHOLE LOG SHEET

Client : Bligh Tanner Pty. Ltd.
Project : Northern NSW Schools Geotechnical Investigation
Location : Old Bar Public School, NSW

HOLE No. OBBH02

SHEET 1 **OF** 1

Position : *See site plan*
Surface RL: TBA AHD
Angle from Horiz. : 90°
Processed : SBO
Rig Type : MPD R180
Mounting: Ute
Contractor : Port Stephens Drilling
Driller : Peter Stewart
Checked : TGN
Date Started : 19/6/2017
Date Completed : 19/6/2017
Logged by : MJJ
Date: 10/7/17

Note: * indicates signatures on original issue of log or last revision of log.

DRILLING					MATERIAL						
SCALE (m)	Drilling Method	Hole Support \ Casing	Water	Samples & Tests	Depth / (RL) metres	Graphic Log	USC Symbol	Description SOIL TYPE, colour, structure, minor components (origin), and ROCK TYPE, colour, grain size, structure, weathering, strength	Moisture Condition	Consistency / Density Index	Comments/ Observations
	Solid Flight Auger + TC-Bit	Nil					-	CONCRETE, pale grey with medium angular black aggregate (fill).	-	-	CS=Contam Sample ASS= ASS Sample
1			▽ 12pm (19/6/17) ▼	D	0.13		-	Sandy GRAVEL, dark grey brown, fine to coarse, angular to sub-angular gravel, medium to coarse grained sand, with fines (fill).	SM-M	-	CS, 0.13-0.3m ASS, 0.13-0.4m At 0.4m, appears well compacted CS, 1.0-1.3m DUP3 CS, 1.5-1.6m
				D	1.60		CH	CLAY/SILT, dark grey black, high plasticity (MC> PL), slight organic smell, relic rootlets (alluvium).	M-VM	F-St	1.6m, decrease drilling resistance ASS, 1.6-1.7m
2	Solid Flight Auger + V-Bit			SPT 2/4/5 N=9	1.90		CH	CLAY, grey mottled red and tan, high plasticity (MC<PL), (resdiual). From 2.8m, pale grey minor tan and red mottling.	M	VSt	2.0-2.45m, PP=280kPa CS, 2.0-2.45m
3				D D	3.00		CI	Sandy CLAY, pale grey and orange, medium plasticity (MC ≈ PL), fine to medium grained sand (residual).	SM	VSt-H	At 3.0m, increase drilling resistance At 3.3m, near V-Bit refusal
					3.40		SC	Clayey SAND, pale grey, fine to medium grained sand (extremely weathered sandstone).	D-SM	D	
4 5				SPT 20 for 130mm (HB) N=ref	3.52			End of borehole at 3.52 metres. V-Bit Refusal.			At 3.5m, V-Bit refusal, rig jacking up

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Level 3, GHD Tower, 24 Honeysuckle Drive, Newcastle 2300 Australia
T: 61 2 4979 9999 F: 61 2 4979 9988 E: ntlmail@ghd.com
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Job No.
22-19010

BOREHOLE LOG SHEET

Client : Bligh Tanner Pty. Ltd.
Project : Northern NSW Schools Geotechnical Investigation
Location : Old Bar Public School, NSW

HOLE No. OBBH03

SHEET 1 OF 2

Position : *See site plan*
Surface RL: TBA AHD
Angle from Horiz. : 90°
Processed : SBO
Rig Type : MPD R180
Mounting: Ute
Contractor : Port Stephens Drilling
Driller : Peter Stewart
Checked : TGN
Date Started : 19/6/2017
Date Completed : 19/6/2017
Logged by : MJJ
Date: 10/7/17

Note: * indicates signatures on original issue of log or last revision of log

SCALE (m)	Drilling Method	Hole Support \ Casing	Water	Samples & Tests	Depth / (RL) metres	Graphic Log	USC Symbol	Description SOIL TYPE, colour, structure, minor components (origin), and ROCK TYPE, colour, grain size, structure, weathering, strength	Moisture Condition	Consistency / Density Index	Comments/ Observations
	[illegible] mm Ø				0.13	▩	-	CONCRETE, pale grey with medium, angular black aggregate (fill).	-	-	CS=Contam Sample ASS= ASS Sample
	[illegible]			D	0.60	▩	-	Sandy GRAVEL, dark grey brown, fine to coarse angular to sub-angular gravel, medium to coarse grained sand, with fines (fill).	SM-M	-	CS, 0.13-0.3m ASS, 0.2-0.4m At 0.4m, appears well compacted
				D		▨	CH	CLAY, tan mottled red, high plasticity (MC<PL), with trace iron staining (residual).	M	St	ASS, 0.7-0.9m
1			▽ (19/6/17)	SPT 2/3/4 N=7		▨		At 1.2m, mottled grey and red.		St-VSt	1.0-1.2m, PP=230-240kPa CS, 1.0-1.4m ASS, 1.0-1.4m 1.2-1.4m, PP=280-310kPa
						▨		From 1.6m, grey mottled red.			
2				D	2.40	▨					
	Solid Flight Auger + V-Bit	Nil		SPT 2/2/4 N=6		▨	CI	CLAY, grey off white, with minor mottling of tan, medium plasticity (MC~PL), with dark orange red iron staining, trace ironstone clusters (residual).	M	VSt	2.5-2.95m, PP=330-350kPa CS, 2.5-2.95m
3				D	3.40	▨					
				D D		▨	CI	CLAY, beige, minor yellow staining in parts, medium plasticity (MC<PL), with patches of iron staining (extremely weathered siltstone).	M	VSt-H	At 3.4m, increase drilling resistance At 3.8m, increase drilling resistance
4				SPT 7/8/9 N=17		▨			SM	H	4.0-4.35m, PP=380-410kPa
5				D							

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GHD GEOTECHNICS
Level 3, GHD Tower, 24 Honeysuckle Drive, Newcastle 2300 Australia
T: 61 2 4979 9999 F: 61 2 4979 9988 E: ntlmail@ghd.com
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BOREHOLE LOG SHEET

Client : Bligh Tanner Pty. Ltd.
Project : Northern NSW Schools Geotechnical Investigation
Location : Old Bar Public School, NSW

HOLE No. OBBH03

SHEET 2 OF 2

Position : *See site plan*
Surface RL: TBA AHD
Angle from Horiz. : 90°
Processed : SBO
Rig Type : MPD R180
Mounting: Ute
Contractor : Port Stephers Drilling
Driller : Peter Stewart
Checked : TGN
Date Started : 19/6/2017
Date Completed : 19/6/2017
Logged by : MJJ
Date: 10/7/17

Note: * indicates signatures on original issue of log or last revision of log

DRILLING					MATERIAL						
SCALE (m)	Drilling Method	Hole Support \ Casing	Water	Samples & Tests	Depth / (RL) metres	Graphic Log	USC Symbol	Description SOIL TYPE, colour, structure, minor components (origin), and ROCK TYPE, colour, grain size, structure, weathering, strength	Moisture Condition	Consistency / Density Index	Comments/ Observations
	Solid Flight Auger + V-Bit	Nil					CI	CLAY (extremely weathered siltstone), as previous.	SM	H	
				D SPT 8/10/13 N=23	5.20		-	SILTSTONE, off white, with dark grey irregular swirls and laminations, minor iron staining, extremely to highly weathered, soil strength (hard) to very low strength.	-	-	5.5m, PP=+600kPa
6					6.00			End of borehole at 6 metres. Limit of Investigation.			
7											
8											
9											
10											

BOREHOLE LOG SHEET

Client : Bligh Tanner Pty. Ltd.
Project : Northern NSW Schools Geotechnical Investigation
Location : Old Bar Public School, NSW

HOLE No. OBBH04

SHEET 1 OF 2

Position : *See site plan*
Surface RL: TBA AHD
Angle from Horiz. : 90°
Processed : SBO
Rig Type : MPD R180
Mounting: Ute
Contractor : Port Stephens Drilling
Driller : Peter Stewart
Checked : TGN
Date Started : 19/6/2017
Date Completed : 19/6/2017
Logged by : MJJ
Date: 10/7/17

Note: * indicates signatures on original issue of log or last revision of log

DRILLING					MATERIAL						
SCALE (m)	Drilling Method	Hole Support \ Casing	Water	Samples & Tests	Depth / (RL) metres	Graphic Log	USC Symbol	**Description** SOIL TYPE, colour, structure, minor components (origin), and ROCK TYPE, colour, grain size, structure, weathering, strength	Moisture Condition	Consistency / Density Index	**Comments/ Observations**
	Solid Flight Auger + V-Bit	Nil		D			CH	CLAY, dark grey, high plasticity (MC ≈ PL), trace sand, trace fine gravel (topsoil).	M	-	CS=Contam Sample ASS= ASS Sample CS, 0.1-0.3m ASS, 0.1-0.3m
				D	0.40		CH	CLAY, dark grey and black minor dark tan mottling, high plasticity (MC ≈ PL) (fill).	M		ASS, 0.5-0.7m
				D	0.80		CH	CLAY, tan mottled red, high plasticity (MC<PL), with some iron staining (residual?).	M	St	ASS, 0.8-0.9m
1											1.0-1.4m, PP=180-200kPa
			▽ (19/6/17) ▼	SPT 2/2/2 N=4							
				D				From 1.6m, grey mottled red.			ASS, 1.6-1.8m
										St-VSt	At 1.8m, increase drilling resistance
2				D							
					2.50		CI	CLAY, grey off white, with-minor mottling of tan, medium plasticity (MC ≈ PL), orange red iron staining, trace ironstone clusters (residual).	M	VSt	2.5-2.95m, PP=320-340kPa CS, 2.5-2.95m ASS, 2.5-2.95m
				SPT 6/15/19 N=34							
3				D							
					3.50		CI	CLAY, beige, minor yellow staining in parts, medium plasticity (MC<PL), with patches of iron staining (residual).	SM	VSt-H	
				D							
4											4.0-4.45m, PP=420kPa
				SPT 8/15/14 N=29							
											At 4.5m, increase drilling resistance
5				D							

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BOREHOLE LOG SHEET

Client : Bligh Tanner Pty. Ltd.
Project : Northern NSW Schools Geotechnical Investigation
Location : Old Bar Public School, NSW

HOLE No. OBBH04

SHEET 2 OF 2

Position : *See site plan*
Surface RL: TBA AHD
Angle from Horiz. : 90°
Processed : SBO
Rig Type : MPD R180
Mounting: Ute
Contractor : Port Stephens Drilling
Driller : Peter Stewart
Checked : TGN
Date Started : 19/6/2017
Date Completed : 19/6/2017
Logged by : MJJ
Date: 10/7/17

Note: * indicates signatures on original issue of log or last revision of log

DRILLING					MATERIAL						
SCALE (m)	Drilling Method	Hole Support \ Casing	Water	Samples & Tests	Depth / (RL) metres	Graphic Log	USC Symbol	Description SOIL TYPE, colour, structure, minor components (origin), and ROCK TYPE, colour, grain size, structure, weathering, strength	Moisture Condition	Consistency / Density Index	Comments/ Observations
	Solid Flight Auger + V-Bit	Nil			5.20	▨	CI	CLAY, as previous.	SM	VSt-H	
				D SPT 11/14/12 N=26	6.00	▦	-	SILTSTONE, off-white, with dark grey irregular swirls, minor iron staining, extremely to highly weathered extremely to very low strength.	-	-	At 5.2m, increase drilling resistance 5.5-5.8m, PP=530-550kPa before crumbling
6								End of borehole at 6 metres. Limit of Investigation.			
7											
8											
9											
10											

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T: 61 2 4979 9999 F: 61 2 4979 9988 E: ntlmail@ghd.com
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Job No.
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Bligh Tanner Pty Ltd
Northern NSW Schools Geotechnical Assessment
Borehole Location Plan – Old Bar Public School

scale | As Shown
date | July 2017

job no | 22-19010
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Figure 1

BMT has a proven record in addressing today's engineering and environmental issues.

Our dedication to developing innovative approaches and solutions enhances our ability to meet our client's most challenging needs.

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● BMT in Environment ● Other BMT offices

Brisbane
Level 8, 200 Creek Street
Brisbane Queensland 4000
PO Box 203 Spring Hill Queensland 4004
Australia
Tel +61 7 3831 6744
Fax +61 7 3832 3627
Email brisbane@bmtglobal.com

Melbourne
Level 5, 99 King Street
Melbourne Victoria 3000
Australia
Tel +61 3 8620 6100
Fax +61 3 8620 6105
Email melbourne@bmtglobal.com

Newcastle
126 Belford Street
Broadmeadow New South Wales 2292
PO Box 266 Broadmeadow
New South Wales 2292
Australia
Tel +61 2 4940 8882
Fax +61 2 4940 8887
Email newcastle@bmtglobal.com

Adelaide
5 Hackney Road
Hackney Adelaide South Australia 5069
Australia
Tel +61 8 8614 3400
Email info@bmtdt.com.au

Northern Rivers
Suite 5
20 Byron Street
Bangalow New South Wales 2479
Australia
Tel +61 2 6687 0466
Fax +61 2 6687 0422
Email northernrivers@bmtglobal.com

Sydney
Suite G2, 13-15 Smail Street
Ultimo Sydney New South Wales 2007
Australia
Tel +61 2 8960 7755
Fax +61 2 8960 7745
Email sydney@bmtglobal.com

Perth
Level 4
20 Parkland Road
Osborne Park Western Australia 6017
PO Box 2305 Churchlands Western Australia 6018
Australia
Tel +61 8 6163 4900
Email wa@bmtglobal.com

London
Zig Zag Building, 70 Victoria Street
Westminster
London, SW1E 6SQ
UK
Tel +44 (0) 20 8090 1566
Email london@bmtglobal.com

Leeds
Platform
New Station Street
Leeds, LS1 4JB
UK
Tel: +44 (0) 113 328 2366
Email environment.env@bmtglobal.com

Aberdeen
11 Bon Accord Crescent
Aberdeen, AB11 6DE
UK
Tel: +44 (0) 1224 414 200
Email aberdeen@bmtglobal.com

Asia Pacific
Indonesia Office
Perkantoran Hijau Arkadia
Tower C, P Floor
Jl: T.B. Simatupang Kav.88
Jakarta, 12520
Indonesia
Tel: +62 21 782 7639
Email asiapacific@bmtglobal.com

Alexandria
4401 Ford Avenue, Suite 1000
Alexandria, VA 22302
USA
Tel: +1 703 920 7070
Email inquiries@dandp.com

www.bmt.org