REPORT

Newcastle Southern Beaches CMP

Coastal Processes Review Report

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Table of Contents

Royal HaskoningDHV

Table of Tables

Royal HaskoningDHV

Table of Figures

Royal HaskoningDHV

Royal HaskoningDHV

Royal HaskoningDHV

Appendices

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Executive Summary

The Coastal Zone Management Plan – Part A, Newcastle Southern Beaches (BMT WBM, 2018) was based on coastal processes understanding and hazards assessment based on data up to 2009. New data has since become available and there have been legislative changes in the form of the *Coastal Management Act 2016* and the *State Environment Planning Policy (Coastal Management) 2018* and the supporting guidance document, the Coastal Management Manual. In accordance with the new legislative requirements, City of Newcastle (CN) engaged RHDHV to update the coastal processes and hazard assessment to inform the development of a Coastal Management Program for Newcastle Southern beaches from the Hunter River south to (and including) Burwood Beach.

In line with the new legislative requirements the previous deterministic hazard assessment was updated using a probabilistic Monte Carlo analysis to quantify the risk of beach erosion and recession due to sea level rise. This assessment looked at two scenarios to inform CN decisions regarding coastal management and asset maintenance:

1. All existing seawalls are maintained
2. No seawalls

The probabilistic hazard lines represent the annual exceedance probability (AEP) of the landward edge of the Zone of Reduced Foundation Capacity (ZRFC) for the specified planning years. The 1% AEP is comparable to the 100-year annual recurrence interval (ARI) event for the presented years.

The results of the first scenario indicated that if existing seawalls are maintained and upgraded to appropriate levels of protection, the main area at risk is the unprotected frontage at Bar Beach between The Cliff and Cooks Hill SLSC. The new probabilistic hazard analysis indicated that the timing of the hazard threat is approximately 10 years earlier than previously shown in the CZMP (BMT WBM, 2018).

The updated mapping of the hazard lines in this area (refer **Figure 60**) show Memorial Drive roadway has a 1% probability, of being within the Zone of Reduced Foundation capacity (ZRFC) if a design storm event were to occur in the immediate future. It is therefore evident that significant action is needed within the short term to manage these assets.

The probabilistic hazard line mapping of the ‘no seawall’ scenario indicated that if a seawall did not exist there are a significant number of residences, roadways and other infrastructure and assets immediately threatened by coastal hazards. These include:

- The Surfhouse building;
- Bathers Way from Merewether to Bar Beach;
- Merewether, Cooks Hill and Newcastle and Nobbys SLS Clubs and associated buildings (with Dixon Park at risk by 2030),
- all of the beach promenades, kiosks and furniture,
- Merewether and Newcastle Ocean Baths; and
- residential properties on John Parade and The Esplanade.

An updated coastal inundation and wave runup assessment was also undertaken highlighting the areas of highest risk as:

- The Esplanade between Newcastle and Nobbys Beaches;

- the lower promenades at Newcastle Beach, Bar Beach (including the Cooks Hill SLSC) and Merewether; and
- the ocean baths at Newcastle and Merewether.

In addition to updating the hazard lines and inundation mapping, analysis was undertaken to review the understanding of coastal processes within the study area. This knowledge will form the basis of the feasibility assessment for coastal management options undertaken in later stages of the CMP preparation.

The coastal processes review, and update involved new data and new technology such as the use of satellite bathymetry data from 2015 to 2021 to observe offshore sediment movement. This analysis showed that the beaches are very dynamic with complex sediment transport pathways including a net northerly sediment transport, seasonal sediment movement to/from offshore bars and bypassing of rocky headland or reef features.

Graphic schematics of the coastal processes understanding were developed for each beach. All of the beaches showed relative stability in terms of long-term erosion with onshore/ offshore movement resulting in no net losses. Nobbys Beach is the only exception whereby the beach continues to prograde due to sand supply from the south and the effective longshore barrier created by the Hunter River breakwater. The major contributor to predicted shoreline recession on all of the Newcastle southern beaches is sea level rise.

In agreement with previous studies, the updated coastal processes understanding indicates that complete sediment removal from upper beaches with cliffs or seawalls would occur more frequently as sea level rises and wave action occurs at a higher position on the beach. Timeframes for some areas to be comprised of exposed rock revetment or seawall without a sandy beach seaward of the structures were previously 2100, or even 2050. The recent analysis suggested this may occur earlier than previously considered likely based on the probabilistic hazard assessment.

Rock platforms beneath the dry beach and the seabed feature on all of the beaches and influence water movement and limit seabed lowering. Further investigation of extent of rock features within the beach and dunes is recommended to better understand their likely effect on future erosion and recession. This is particularly pertinent between The Cliff and Cooks Hill SLSC where there are currently no coastal protection structures and numerous assets are at risk in the short term.

1 Introduction

1.1 Study Objectives

City of Newcastle (CN) are preparing the Southern Beaches Coastal Management Program (CMP), to set the long-term strategy for coordinated management of the Newcastle coastline between Nobbys Head and Burwood Lagoon. The CMP is being prepared under the NSW Government's Coastal Management Framework, which includes the *Coastal Management Act 2016*.

The current study forms a CMP Stage 2 technical investigation to revise the previous coastal hazard assessment for Newcastle Beaches undertaken by consultants BMT WBM in 2000 and reassessed in 2014 (BMT WBM (2014)).

The main objective of this assessment is to review and update the coastal processes understanding and the coastal erosion and inundation hazard by including; new data (post 2009), updated sea level rise predictions and the latest best-practice probabilistic hazard assessment methodology. The updated information is to inform the development of long-term management actions to address the hazards identified.

1.2 Study Area

The study area includes the sandy beaches located between the Hunter River and the CN Local Government Area (LGA) southern boundary and include Nobbys Beach, Newcastle Beach, Bar Beach, Dixon Park, Merewether and Burwood Beach (refer **Figure 1**).

The coastline is typically characterised by sandy pocket beach embayments between rocky headlands or cliffs. The shoreline generally faces southeast which is the most energetic and predominant regional wave direction. Accordingly, this section of coast is considered very exposed.

Burwood Beach at the southern end of the study area fronts Glenrock State Recreation Area and is undeveloped with the exception of the Wastewater Treatment works located at the northern end behind the frontal dune. A pipeline extends from these works to an offshore discharge point. Glenrock Lagoon sits near the southern end of the beach and intermittently outlets through the dunes after significant rainfall. A small cliff area near the middle of the beach is fronted by a narrow stretch of sand.

The next embayment to the north encapsulates three “beaches”; Merewether, Dixon Park and Bar Beach, which are delineated, not by significant coastal features crossing the subaerial beach face, but rather three separate Surf Life Saving Club (SLSC) jurisdictions. Although, between Dixon Park and Bar Beach, “the Cliff” is a prominent geological feature backing the subaerial beach.

The foreshore land between Dixon Park and Merewether was developed with housing along John Parade, evident in the early 1950s (**Figure 2**). To mitigate against storm erosion and the associated threat to private property and infrastructure, a rock armour revetment was constructed along the toe of the erosion scarp following the 1974 storms (**Figure 3**). The existing revetment has been buried since it was constructed with a vegetated dune and only occasional exposure of the rock armour in the lower slope of the structure occurs following storm events (**Figure 4)**.

Figure 1: Study Area

Figure 2: The foreshore land along the southern section of the Merewether/Dixon Park frontage was developed in the early 1950s with housing visible along John Parade

Figure 3: John Parade Merewether and Dixon Park following the May/June 1974 storms.

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Figure 4: Pogos rock platform and exposed lower slope rock armour in John Parade revetment following storms in 2021.

The coastline north from Bar Beach to Newcastle Beach is characterised by rock cliffs up to 70m in height and rock platforms below. Susan Gilmore Beach is a thin lens of sand overlying rock platforms near the southern end of this area.

Newcastle Beach is a small pocket beach between rock headland features. It is underlain by bedrock features which are exposed in significant storm events (such as in 1974). Promenades and development are situated at the back of the beach where sand dunes would originally have been. The Newcastle Ocean Baths are built into the rock platform to the north of Newcastle Beach.

The shoreline between the Newcastle Ocean Baths and Nobbys Beach comprises Shortland Esplanade roadway, a seawall and narrow beaches overlying rock platforms. The promenade and roadway are relatively low lying and subject to wave overtopping and inundation.

Nobbys Beach extends from Fort Scratchley Headland to Nobbys Head. This beach has formed since the construction of the southern breakwater at the back of the beach in the mid 1800's, which connected the mainland to Nobbys Island at the time. Sand has since accreted on this beach, trapped by the barrier to northerly sediment transport created by the southern breakwater. There are existing seawalls along the southern portion of the beach.

1.3 Scope of this Report

This report outlines the revised assessment and understanding of coastal processes for the whole study area between Burwood Beach and Nobbys Beach, as follows:

- Background (**Section 2**)
- Photogrammetric analysis (**Section 3**)
- Analysis of satellite derived bathymetry data (**Section 4**)
- Inundation assessment (**Section 5**)
- Probabilistic hazard assessment (**Section 6**)
- A review of the coastal processes understanding in the study area (**Section 7**)

All reference to Reduced Level (RL) in this report is given in metres above Australian Height Datum (AHD). AHD is a local datum which is approximately equal to current Mean Sea Level at the coastline of mainland Australia.

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2 Background

2.1 Previous hazard assessments

A coastal hazard assessment for Newcastle Beaches was undertaken by consultants BMT WBM in 2000 and a reassessment in 2014. The coastal hazard assessment was undertaken using a deterministic approach. In a deterministic approach, each parameter that is an input to calculation of the hazard, e.g. design storm demand, SLR projection, etc. is assigned a single value. The single value is typically a conservative estimate for the parameter.

The 2014 study mapped coastal hazards using this deterministic risk based approach that defines the likely extent of the hazards for 2014, 2050 and 2100 planning periods. However, the likelihoods for the erosion hazard were qualitatively derived by combining estimated storm demand and long-term recession values. The storm erosion extent was adopted as the most eroded profile in the photogrammetry data while long term recession was determined using a simplified numerical modelling approach and analysis of photogrammetry data.

BMT WBM identified and reported the following key findings in the 2014 hazard assessment:

- in terms of long-term recession trends, most of the beaches were considered to be stable (though no quantified recession rates were provided);
- while long term accretion had been evident at Nobbys Beach, the rate of accretion had slowed, and was expected to stabilise without sea level rise;
- it was expected that complete sediment removal from upper beaches with cliffs or seawalls would occur more frequently as sea level rises and wave action occurs at a higher position on the beach. Some areas were considered likely to be comprised of exposed rock revetment or seawall without a sandy beach seaward of the structures by 2100, or even 2050;
- back beach areas at Burwood Beach and The Cliff to the Cooks Hill SLSC (CHSLSC) at Bar Beach are comprised of dunal sands, and therefore can retreat landward. However, at Bar Beach, this would necessitate; the relocation of the roadway and Skate Park, and the sacrifice of sections of Empire Park.
- lower promenades at Newcastle, Merewether and Bar Beach, the Dixon Park boat ramp and Merewether and Newcastle Ocean Baths and Shortland Esplanade experience overtopping, and this was expected to increase in frequency and volume into the future, impacting on the condition and use of the structures and assets.
- wind blow sand drift occurred mainly; up the ramps at Bar Beach (south of the CHSLSC) and Dixon Park, and from Nobbys Beach over into Horseshoe Beach and the Hunter River.

The hazard lines previously produced by BMT WBM (2014) provided risk likelihood categories as follows; almost certain, likely, unlikely and rare. However, these categories were not quantified with estimates of probability of occurrence. BMT WBM made judgements regarding the likely timing of seawall failures and incorporated this aspect into the hazard lines (BMT WBM (2014).

The 2014 LGA-wide hazard assessment was undertaken according to the Guidelines for Preparing Coastal Zone Management Plans by Office Environment Heritage (OEH) (OEH, 2013). These guidelines have been superseded by the *Coastal Management Act 2016* and the Coastal Management Manual (DPIE, 2018), which provides guidance for preparing and implementing CMP's under the NSW Management Framework.

Accordingly, the hazard assessment requires an update for the following reasons:

- the new Coastal Management Manual (OEH, 2019);
- industry leading practice hazard modelling now applies a probabilistic approach, to account for uncertainty and also feed into economic analysis. In the probabilistic approach, each input parameter varies randomly according to an appropriate probability distribution function and are combined to form a discrete sample. This is then repeated in a process known as Monte Carlo simulation in which a very large number (>100,000's) of sample are synthesised. All outputs of the Monte Carlo simulation are collected to develop a probability curve for the shoreline position at the end of a particular adopted planning period. In the probabilistic approach applied by RHDHV, the Monte Carlo simulation involves one million values of a parameter for each year of the planning period.
- new data available including high quality 2020 and 2018 topography data as baseline;
- updated sea level rise projections; and
- consideration of built coastal protection structures.

The upgrades to the previous hazard assessment are described in **Section 6.**

2.2 Geotechnical Conditions

The shoreline is characterised by sandy pocket beaches between rocky headlands and cliffs, with rock reef frequently exposed in the nearshore zone. Sandy dunes are limited to a short section between Merewether and Dixon Park and the central portion of Bar Beach.

The shoreline typically faces southeast (i.e. is oriented south-west to northeast), and is fully exposed to the dominant southeast wave climate. The cliffed and rocky nature of the shoreline has resulted in narrow beach embayments with thin sand reserves overlying shallow rocky reefs and bedrock.

A desk top review of geotechnical data was undertaken to investigate the following:

- rock platforms or non-erodible material buried below the beach sand or seabed; and
- rock or non-erodible material buried at the back of the beach, focussing particularly on the Bar Beach frontage between The Cliff and the SLSC, (where there are no coastal protection structures), and Dixon Park, (where there was some uncertainty regarding the presence of a coastal protection structure).

Both of these factors would potentially affect the coastal erosion hazard assessment. This review included examination of material from the following sources:

- Quaternary bedrock geology dataset, Department of Primary Industries, Mineral Resources, Geological Survey of New South Wales
- aerial photography (including Google Earth and Nearmap).
- post storm photography including 1974 and 2015;
- archaeological studies; and
- RCA report (provided by CN), Geotechnical Risk Assessment, Proposed Upgrade to Bathers Way Ocean Street, Merewether to Kilgour Avenue, Bar Beach (RCA, 2014)

Findings of these reviews are outlined in the sections below.

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2.2.1 Rock below beach sand or seabed

The review findings indicated that many of the subaerial beaches are underlain by rock platforms which are exposed intermittently (refer **Figure 5** and **Figure 6**). The extent and level of these rock platforms is not currently well documented. These natural rock formations have afforded the beaches protection from erosion as evidenced in some of the significant storm events when the beaches were striped back to rock (refer **Figure 7** to **Figure 11** progressing south from Bar Beach to Merewether Beach).

Figure 5: Nearmap image showing significant nearshore and offshore rock platforms/ reefs at Burwood (top image) and Merewether/ Dixon/Bar Beach and Susan Gilmore Beach (bottom image) (15-06-2018).

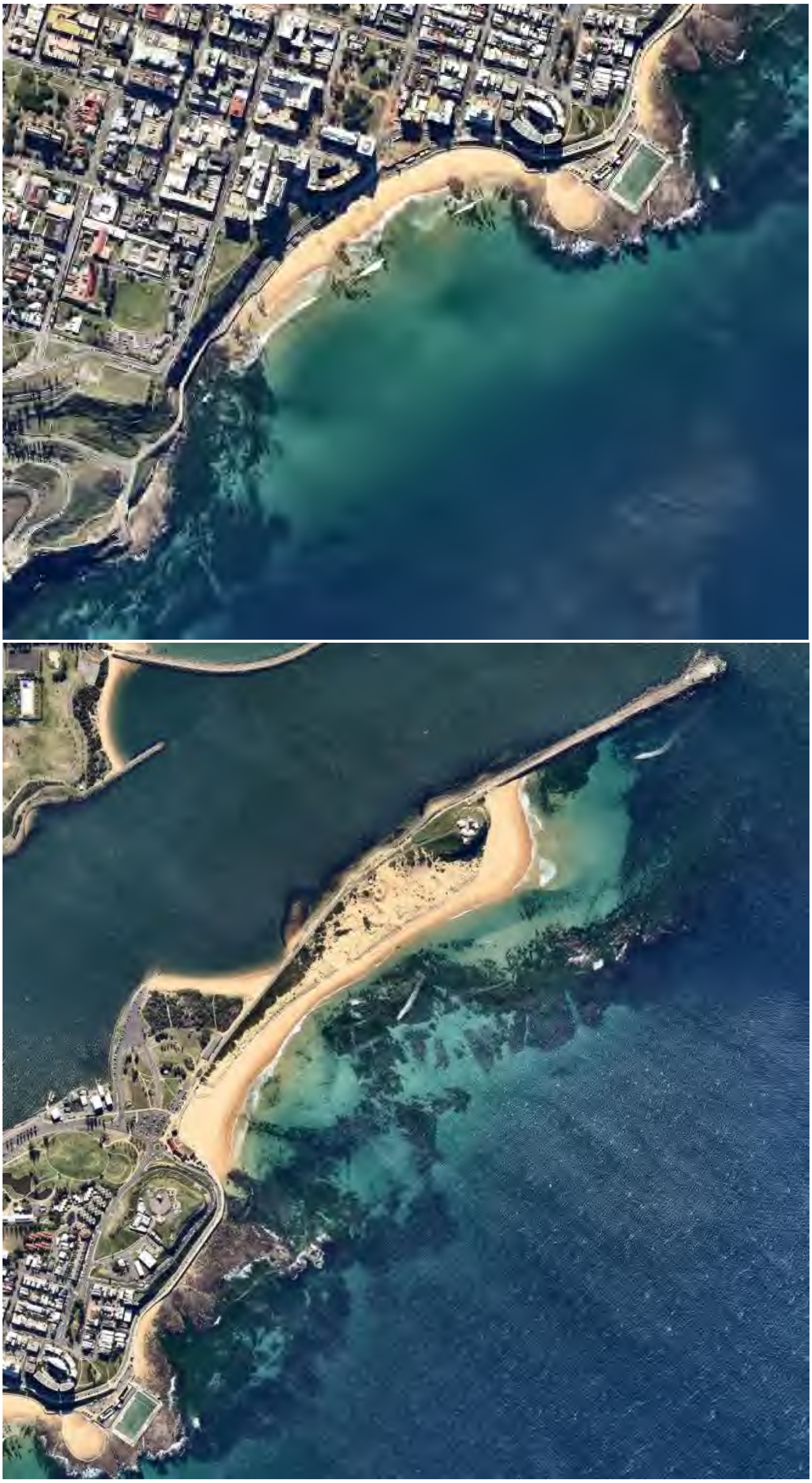

Figure 6: Nearmap image showing significant nearshore and offshore rock platforms/reefs at Newcastle (top image) and Nobbys Beaches (bottom image) (15-06-2018).

Figure 7: Bar Beach following 1974 storms showing underlying rock and rock platforms (Newcastle Herald).

Figure 8: Bar Beach following 1974 storms showing underlying rock and rock platforms (Newcastle Herald).

Figure 9: Near Map image, March 2013, showing significant rock underlying beach at The Cliff at the southern end of Bar Beach.

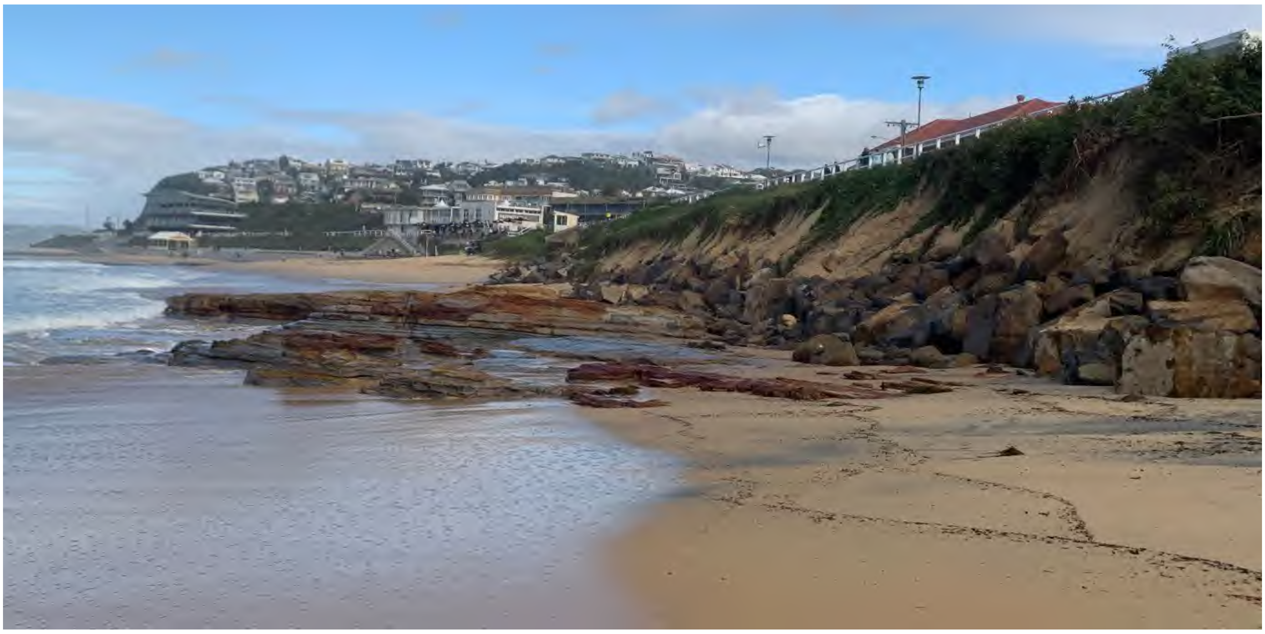

Figure 10: Rock platforms exposed at John Pde Merewether Beach following 2020 storms (provided by Tim Ryan).

Figure 11: Rocks and rock platforms at Merewether beach following 1974 storms, prior to construction of John Pde revetment (provided by Tim Ryan/Kim Brent)

2.2.2 Rock at the back of the beach

The geotechnical data review indicated that the Dixon Park Beach frontage typically comprises unconsolidated sand material and may have legacy coal refuse (refer **Figure 12** to **Figure 15**). No data pertaining to the presence of rock or non-erodible areas buried at the back of the beach was found and there remains uncertainty around the geotechnical composition of this area. The likelihood of rock or non-erodible areas buried at the back of the beach at Bar Beach (south of the SLSC) also remains uncertain as this was not found to be well documented.

It is recommended that further investigations be undertaken to define the geotechnical strata in these locations.

Figure 12: An overlay of a 1903 plan of Dixon Park on top of a more recent aerial photograph showing the sites use as a refuse coal dump and the area containing railway sidings from the coal mining era. Note that the scale might not be accurate. The 1850s house occupied by W. Davidson is believed to be represented on the 1903 plan as shown by the green arrow. The railway siding track has been identified on the overlay by an orange line. Overlay by Vetta (source: (AMAC, 2014)

Figure 13: A c1930 photograph facing south and showing Merewether Beach (green) and Dixon Park (red) with extensive rock platforms exposed on the beach. Newcastle City Council Cultural Collections, Junter Photobank (ref no. 16300198) Source: (AMAC, 2014)

Figure 14: Part of a 1850 plan overlay (green) onto a more recent aerial photograph, showing sand hills within the Dixon Park area. Note that the scale may not be accurate, and the image is to be used for indicative purposes only. Overlay by Strickland (Newcastle Regional Library). The red outline was the study area for these previous investigations. (Source: AMAC, (2014))

Figure 15: A c1950 photograph showing Merewether Beach and Dixon Park Surf Club (green arrow) and significant rock exposed at the base of The Cliff area. University of Newcastle Cultural Collections (access through Hunter Photobank) (Source: AMAC, (2014))

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2.3 Coastal Protection Structures

There are a number of man-made coastal protection structures along the study area frontage varying in construction, age, condition and setback or alignment. These include:

- the Newcastle Harbour (Hunter River) Entrance Breakwaters;
- rock revetments between Merewether and Dixon Park (along John Parade) and Nobbys SLSC and Nobbys headland
- vertical seawalls extending from Nobbys Beach around to the southern end of Newcastle Beach;
- vertical seawalls at the northern end of Bar Beach;
- vertical seawalls and concrete bleacher style seawalls at the southern end of Merewether; and
- vertical structure beneath Cooks Hill Surf Club (which is currently acting as a seawall but was unlikely to have been constructed as a coastal protection structure).

There are currently varying degrees of documentation available about the design and condition of each of the structures. It is recommended that these data gaps be further investigated and recorded to enable effective maintenance, management and budgeting of future upgrade works to be planned to ensure the ongoing effectiveness of these protection structures. The presence of coastal protection structures is provided on the coastal erosion hazard mapping (refer **Figure 57** to **Figure 65**).

The main areas without some form of coastal protection structure (or natural rock cliff protection) are Bar Beach between The Cliff and Cooks Hill SLSC and Burwood Beach.

There was some uncertainty as to whether there was a coastal protection structure at Dixon Park Beach (or how far north the rock revetment along John Pde extended). RHDHV undertook some further review of available information to address this uncertainty. The data review indicated that there is likely to be a rock revetment structure continuing from the revetment visible along John Parade, northwards up the southern end of The Cliff (approximately in line with the northern edge of the Dixon Park SLSC building). The data review and findings are further detailed in **Appendix E**.

3 Photogrammetric Analysis

3.1 Introduction

Photogrammetric data analysis involves use of a stereoscope to measure the elevation of points on an aerial photograph along a horizontal chainage line (profile). This information can then be used to determine comparative changes in beach volume and beach profiles over time. The photographs present 'snap-shots' that describes the beach state at a particular time. The effectiveness of the analysis is therefore highly dependent on the available data.

Since the previous photogrammetric analysis was undertaken (BMT WBM,2014), there has been additional aerial photography taken in 2011, 2018, 2020 (2 dates) and 2021 which have been included in the updated analysis.

The updated photogrammetric assessment was undertaken for the entire study area, including the DPIE photogrammetric profile locations in Blocks 1, 2, 5, 6, 7, 8 and 9, as indicated in **Figure 16**. The objective of this assessment is to produce revised coastal erosion hazard mapping based on the current industry leading practice (probabilistic) method. The coastal erosion hazard mapping will provide CN with information regarding potential coastal management implications that would be associated with the adoption of the probabilistic results for local planning purposes.

The photogrammetry data, updated with the most contemporary information, was analysed in detail to:

- indicate rates of shoreline change;
- review storm demand volumes previously adopted and update where appropriate; and
- identify the presence/location of hard substrate limiting erosion.

Based on the improved understanding of coastal hazards as a result of the analysis, appropriate representative input parameters were adopted for the probabilistic assessment as outlined in **Section 6**.

Figure 16: DPIE Photogrammetry block and profile locations.

3.2 Photogrammetry Dates

The adopted analysis period included photogrammetry data collected between 1954 and 2021. The photogrammetry dates available are outlined in **Table 1**.

Table 1: Dates of photogrammetry used in analysis

Photogrammetry dates
22-7-1954
16-10-1974
01-12-1996
14-09-2001
3-12-2011
24-8-2018
18-6-2020
22-7-2020
13-4-2021

3.3 Shoreline Change Assessment

Rates of shoreline change were obtained from the NSW Beach Profile Database. For each of the profiles, the rate of change of the RL 4m contour position was derived by linear regression; i.e. by determining the line of best fit (least squares error) in each case[1]. Occasionally, reduced levels between 2.5 and 3m were used if it was assessed by RHDHV there was a man-made change or influence above this height. The rate of change of the RL 2m AHD was also determined to observe the movement patterns closer to the waterline.

Shoreline change of the 4m AHD contour was assessed over the following periods to gain a balanced view of long-term trends and any changes since previous studies:

- 1954-2021 – the longest available dataset;
- 1996-2021 - to observe more contemporary behaviour noting that 1996 was a particularly beach full beach profile resulting in skewed results with higher apparent recession rates, compounded by the period ending in a La Nina phase;
- 2001-2021- again, a contemporary period, but with a more average starting profile reducing the skew towards apparent recessionary trends (though recognising that this period ends within a La Nina phase).

From this assessment a minimum, maximum and mode (or best estimate) value were determined for each block as summarised in **Table 2.** This assessment of long term shoreline change indicated that most of the beaches were relatively stable, and that Nobbys beach has prograded. This long term progradation is largely due to the barrier to further northerly sediment transport created by the southern breakwater at the Hunter River entrance.

[1] *This does not imply that there were uniform rates of positional change between dates of photography.*

The results of the assessment for the longest data set (1954-2021) are provided graphically in **Appendix A.**

Table 2: Shoreline change values

Beach	Rate of Positional Change (m/year)								
	Burwood	Merewether Sth	John Pde/ Dixon/Bar	Newcastle Sth	Newcastle Nth	Cowrie Hole	Nobbys Sth	Nobbys Central	Nobbys Nth
Block	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Min.	-0.3	-0.2	-0.5	-0.5	-0.5	-0.05	-0.1	0.4	0.2
Mode (best estimate)	-0.1	0.0	0.0	0.0	0.0	0	0.7	1	0.5
Max.	0.4	0.12	0.4	0.3	0.2	0.05	1.4	1.4	1.3

Note: -ve values indicate recession (or landward movement) and +ve values indicate progradation (or seaward movement).

It should be noted that the values presented herein were not adjusted to account for any Sea Level Rise (SLR) recession that may have occurred during the analysis period.

To gain a broader view of the historic shoreline movement along this coast, 2m and 4m AHD contour positions were plotted for each profile for all available dates. The 2m and 4m AHD contour positions are shown in **Figure 17** to **Figure 20** for Burwood, Merewether/Dixon/Bar Beach and Newcastle Nobbys beaches, respectively. From these plots it is evident that the shoreline positions have fluctuated onshore and offshore and shoreline alignments have oscillated within a rotational envelope from north to south. This is consistent with the long-term stability that has been reported in previous studies. Nobbys Beach in contrast, can be seen to move progressively seaward, indicative of a long-term trend of progradation (refer **Figure 20**).

Volume change assessment was also undertaken to review storm demand volumes as outlined in **Section 3.4.**

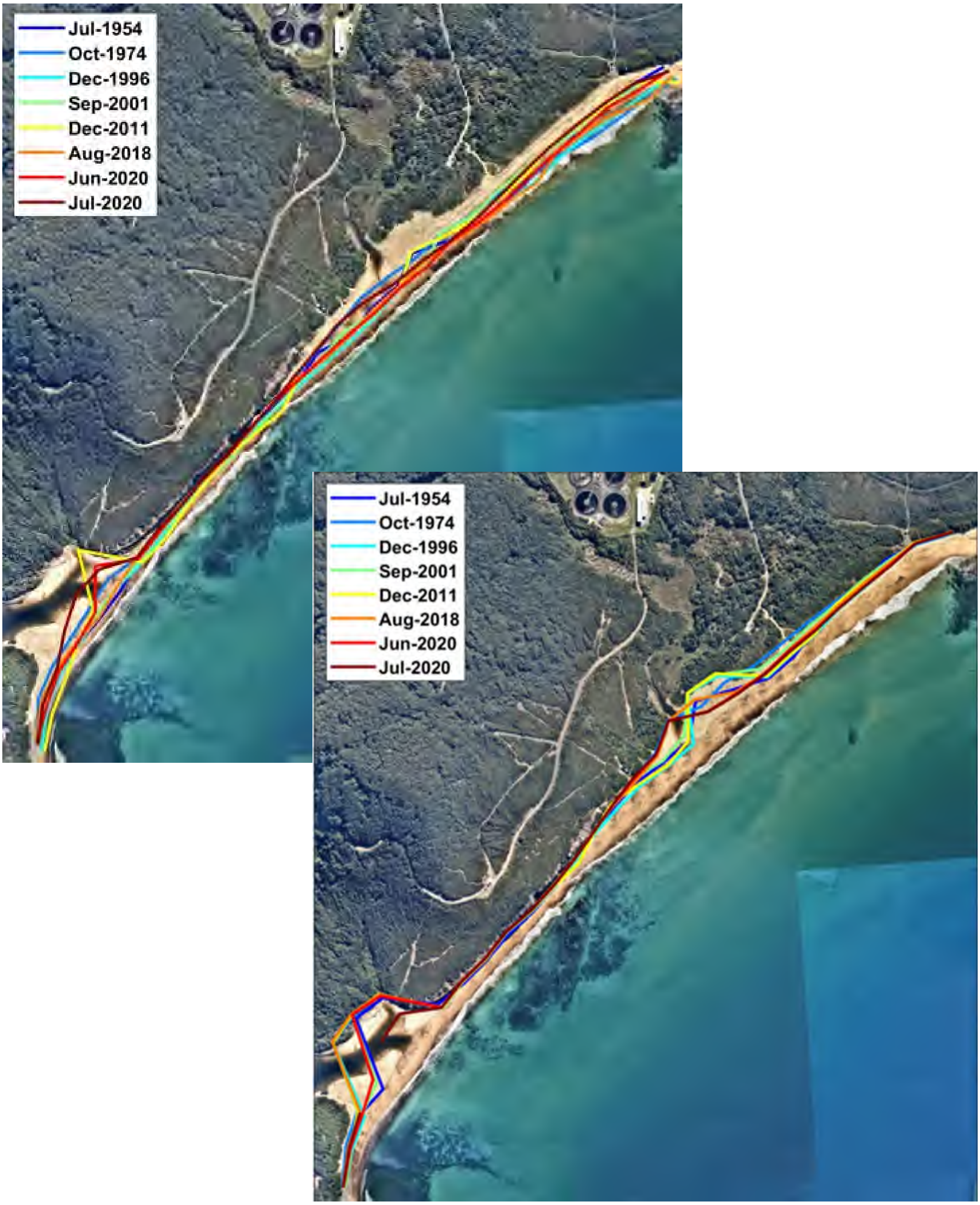

Figure 17: Position of 2m and 4m AHD contours (top and bottom photos respectively) for Burwood Beach.

Figure 18: Position of 2m and 4m AHD contours (top and bottom photos respectively) for Merewether to Bar Beach.

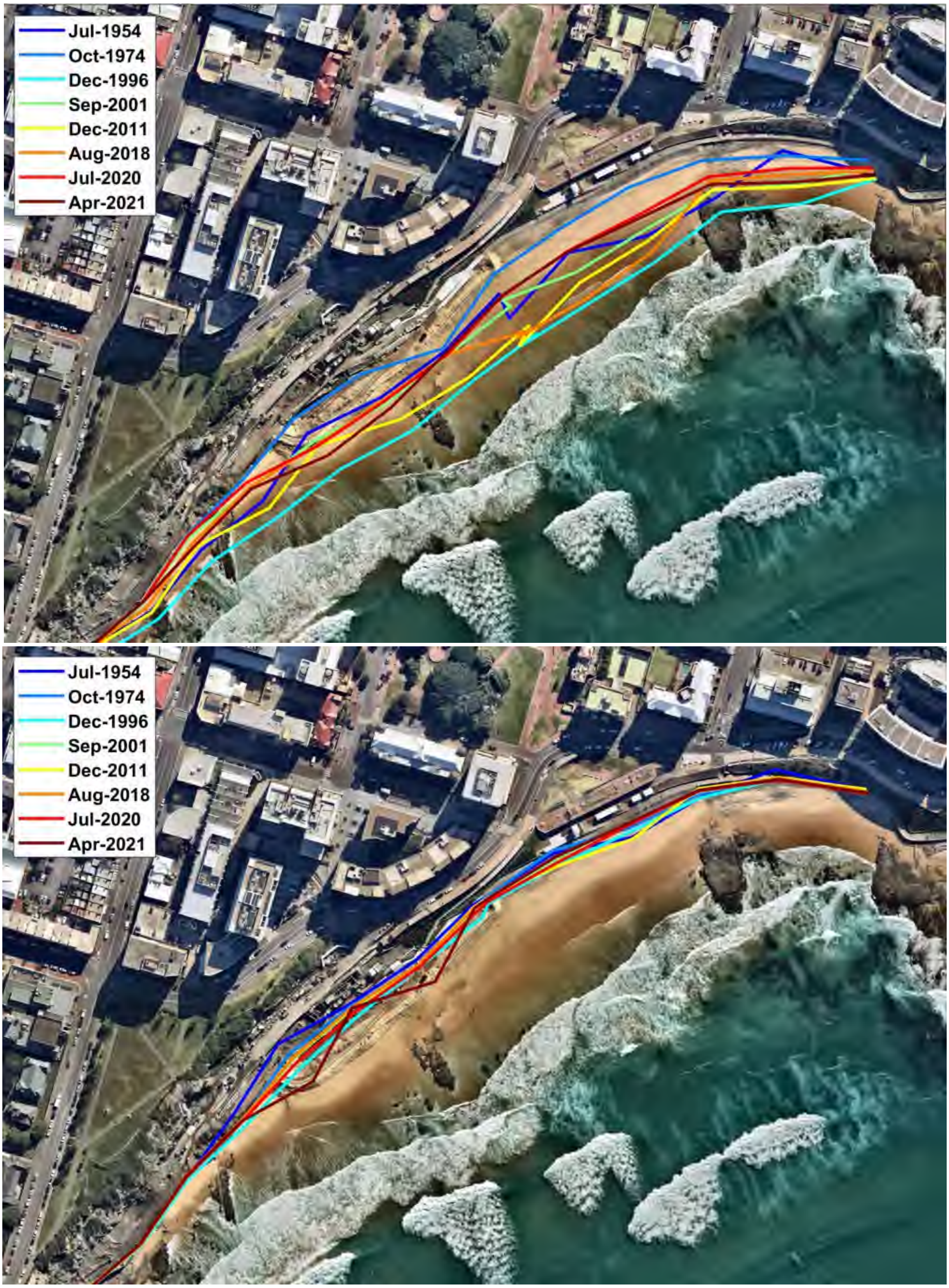

Figure 19: Position of 2m and 4m AHD contours (top and bottom photos respectively) for Newcastle Beach

Figure 20: Position of 2m and 4m AHD contours (top and bottom photos respectively) for Nobbys Beach

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3.4 Volume Change Assessment

The rate of volume change above 0m AHD (in m^3/m/year) was assessed for the study area using the photogrammetric data (truncated at the landward end at man-made structures or extent of active dunes). The results of this assessment are provided graphically, for the longest data set (1954-2021), in **Appendix A.** The block average volume changes over the 1954-2021 period are summarised in **Table 3** below.

Table 3: Block averaged volume change above 0m AHD between 1954 and 2021.

Location	Block	Net volume change (m3/m/year)
Burwood Beach	1	-1
Merewether (sth)	2	2
Dixon Park/ Bar Beach	3	8
Newcastle Beach south	4	2
Newcastle Beach north	5	3
Cowrie Hole	6	0
Nobbys Beach south	7	60
Nobbys Beach central	8	33
Nobbys Beach nth	9	26

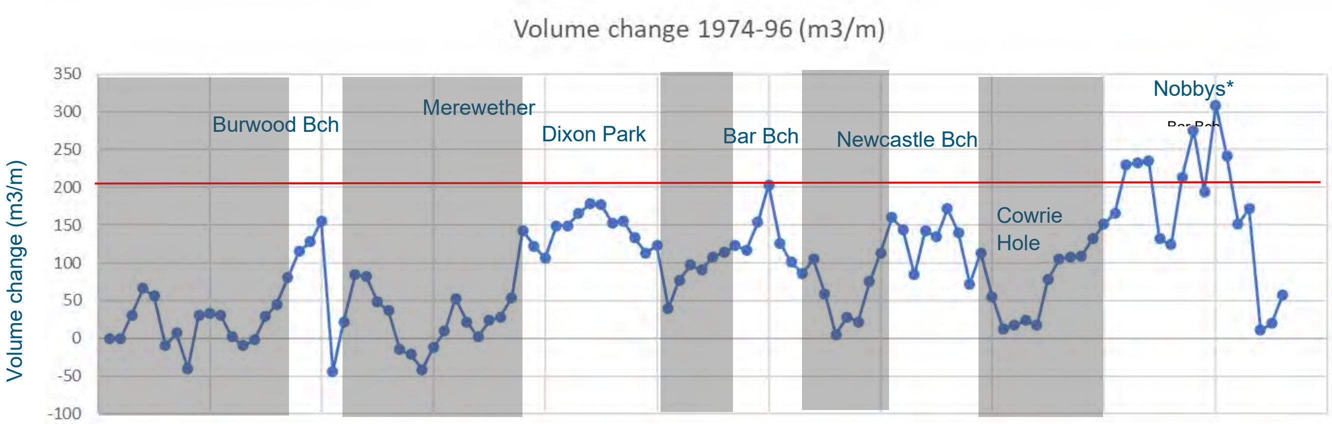
This data is consistent with the shoreline movement change assessment indicating relative stability of most of the beaches and progradation at Nobbys Beach.

3.4.1 Storm Demand

BMT WBM (2000) assessed historical observations of short-term erosion at the beaches to the south of the Hunter River due to the major storm events and adopted a storm erosion demand value of 200m^3/m for all of the beaches (or the available sand reserves to underlying rock or seawalls whichever is greater).

The approach adopted in a later study, BMT WBM (2014), to defining the extents of combined potential beach erosion was to consider the most eroded beach and dune position given in the photogrammetric data, rather than attempt to define the erosive capacity of one 'design' storm. Photogrammetric data included 1954, 1974, 1996, 2001 and 2007 (derived from LiDAR data). The resulting values were assessed by BMT WBM to be in good agreement with BMT WBM (2000), adopting a storm erosion potential of 200 m^3/m or to the limit of bedrock or seawalls, whichever occurs first.

RHDHV have analysed the updated photogrammetry data to review the assessment of design storm demand values for the beaches. Ideally this would involve a calculation of volume change above 0m AHD from a profile taken just prior to a severe storm relative to the post storm profile. In this case, such data was not available. An assessment of storm erosion associated with the May/June 1974 storm events was therefore undertaken through comparison of the 1974 and 1996 beach volume data. Whilst the 1996 profiles are some decades later, they are the next data in the photogrammetry and also represent a relatively average "beach full" scenario considered reasonable for use in storm demand volume calculations. This also considers the reported limited long-term recession/progradation prevalent at the beaches in question, except for Nobbys Beach. Results are presented in **Figure 21** and support the adoption of a 200 m^3/m design storm demand value.



* volume change (1974-96) at Nobbys beach is not indicative of potential storm demand due to underlying long term progradation.

Figure 21: Volume change 1974-96 (m^3/m) from photogrammetry (where positive values indicate erosion); adopted storm demand value and areas of rock limiting storm demand sand supply (shaded in grey).

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4 Satellite Bathymetry Analysis

4.1 Introduction

Satellite-Derived Bathymetry (SDB) is a recently developed method of surveying shallow waters (typically less than 10m depth, but deeper where water clarity allows). SDB algorithms developed since the 1990s are used to convert the information collected by the satellite sensor into bathymetric data. The derived bathymetry information from satellite images collected over time can be a useful for understanding coastal processes, seasonal patterns in seabed condition and long term trends in sand movement.

Imagery from the Sentinel 2 satellite has been downloaded and processed to derive (where possible) bi-annual bathymetric datasets within the Newcastle Southern Beaches Coastal Management Plan (CMP) area (the ‘study area’) between the years 2015 to 2021. This report details the approach taken and the limitations of the study.

4.2 Data and Methodology

4.2.1 Imagery

In order to derive accurate bathymetry from satellite remote sensing products, suitable imagery which are captured in the right metocean conditions are required. In particular, the images need to be free from cloud cover and the wind and wave conditions need to be relatively calm so that the sea surface is not distorted by waves which result in varying surface reflectance. Further, the amount of suspended sediment in the water column needs to be low to avoid false shoaling. For an open ocean exposed location such as Newcastle, this limits the number of suitable images, which has meant that it has not been possible to select two images for all years considered (with no suitable imagery available for summer 2018). Satellite data for the dates detailed in **Table 4** were downloaded from the Copernicus Open Access Hub (https://scihub.copernicus.eu/dhus/#/home).

Table 4: Details of Sentinel 2 satellite imagery used for this analysis.

Number	Date Time (UTC)
1	18th December 2015 23:59
2	5th July 2016 23:52
3	2nd December 2016 23:52
4	1st May 2017 23:52
5	22nd December 2017 23:52
6	6th May 2018 23:52
7	3rd August 2018 00:02[2]
8	4th August 2018 23:52[3]
9	25th May 2019 00:05
10	27th December 2019 23:55
11	14th June 2020 23:56
12	26th December 2020 23:55
13	30th April 2021 23:44

[2] This image has been considered to help identify the uncertainty in the derived bathymetric datasets.
[3] This image was used for calibration.

4.2.2 Atmospheric Corrections

For consistency across all images, the Level-1C (top of the atmosphere) products were downloaded (Level-2A imagery corrected for atmospheric effects are only available post December 2018) and were processed to Level-2A using the ACOLITE processor developed by the Royal Belgian Institute of Natural Sciences (RBINS) (Vanhellemont and Ruddick, 2016). The ACOLITE processor was developed to correct imagery for atmospheric effects specifically over water and has been widely used in Satellite Derived Bathymetry studies (for example Cabellero and Stumpf (2019) and Cabellero and Stumpf (2020)) and was found to perform well in an assessment of different atmospheric correction methods (Ilori et al., 2019).

4.2.3 Satellite Derived Bathymetry Model

The bathymetry was derived using the ratio model of log-transformed bands as developed by Stumpf *et al.*, (2003). The ratio model makes use of the reflectance of the blue (490 nm), green (560 nm) and red (664 nm) bands for each satellite image corrected for atmospheric effects, with the log transform accounting for the exponential decrease in light with depth.

Following the method of Cabellero and Stumpf (2020), the ratio of blue (λ_i) to either green or red (λ_j) bands was used to produce the Satellite Derived Bathymetry (SDB). The SDB derived from the green band (SDBgreen) performs better in deeper areas, while the SDB derived from the red band (SDBred) performs better in shallow water. Between the shallow and deeper waters a merging of data from SDBred and SDBgreen was performed. For this study, SDBred was applied in water depths of less than 2.7 m below the surface, SDBgreen was applied in depths of more than 5.2 m below the surface and a combination of SDBred and SDBgreen was applied in depths between 2.7 m and 5.2 m.

The SDB was calibrated against a subset of data from a 5 m Digital Elevation Model (DEM) based on a marine Lidar survey from 2018 collected between 26th July 2018 and 22nd September 2018 (see **Figure 22**). The subset included a small number of points at a range of depths to ensure a robust fit against the SDBgreen and SDBred bands could be achieved. The use of a subset was found to improve the overall data fit and provides a semi-independent dataset for verification of the SDB across a wider domain. SDBgreen was recalibrated for each image to help reduce uncertainty in the derived SDB (since changes in the bathymetry in deeper waters are expected to be small in relation to the uncertainty in the SDB), while SDBred was calculated based on the fit derived from the August 2018 image. Corrections to the fit were made to account for the varying tidal water level at the time of image capture. Measured water level data from the Newcastle Port tide gauge, provided by the Port Authority of New South Wales, were used to determine the water level at the time of each image.

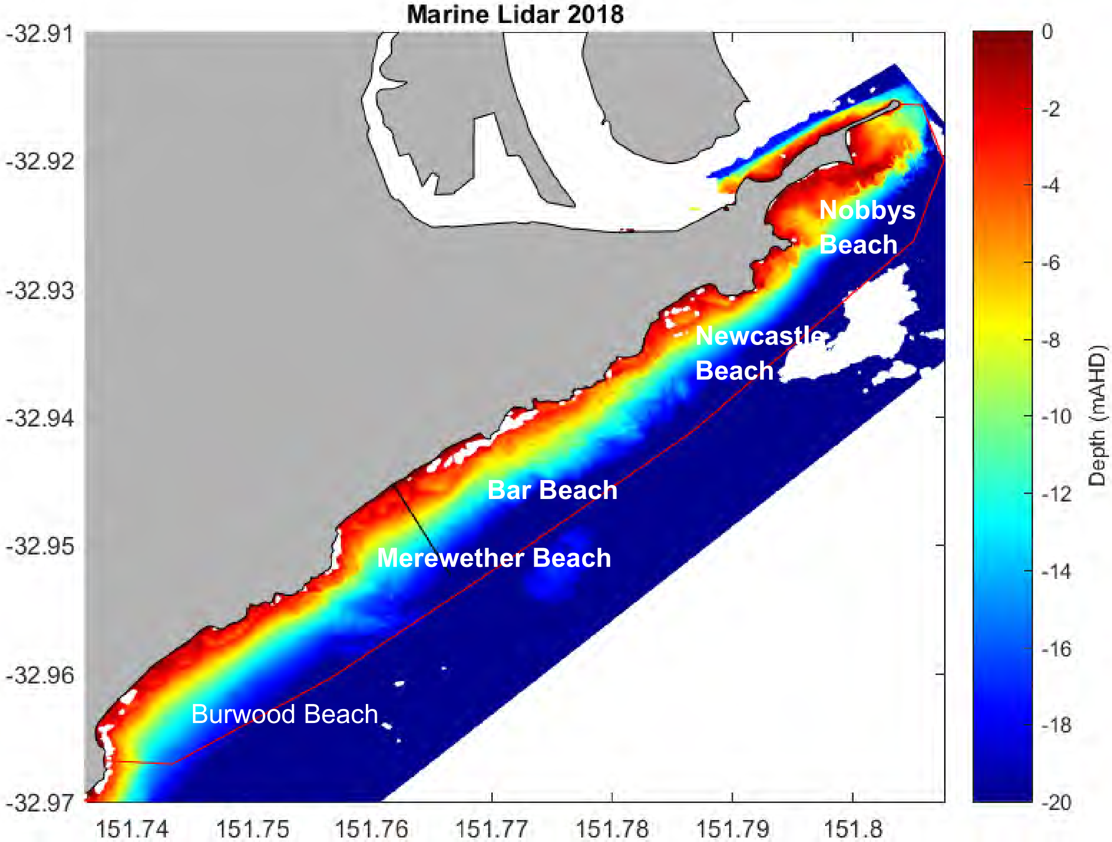

Figure 22. Marine Lidar survey data 2018. Black line shows where data subset was extracted for calibrating the SDBred and SDBgreen fits.

Comparisons of the SDB for the image captured on the 4th of August 2018 and the 2018 marine Lidar data indicate a correlation (r^2) of 0.89, a median absolute error (MedAE) of 0.48 m over depths of 0 to 6 m AHD and a MedAE of 0.75 m over depths of 0 to 15 m. For verification purposes and to provide further insight into the likely accuracy of the SDB, comparisons of the SDB for the image captured on the 3rd of August 2018 against the marine Lidar survey data were also made. The fit was found to be broadly comparable, but with slightly increased error to that for the 4th August 2018, with a correlation of 0.86, a MedAE of 0.62 m over depths of 0 to 6 m and a MedAE of 0.90 m over depths of 0 to 15 m.

Bathymetric contours from the 2018 marine Lidar and the SDB from two images from the 3rd August 2018 and the 4th of August 2018 (the latter image having been used to derive the fit to apply to obtain SDBred) are compared in **Figure 23**. The comparison generally shows a good agreement between bathymetric contours from all three data sources (especially in light of the different timings of the marine Lidar survey and satellite imagery) for depths of less than 10 m AHD but with increasing noise and uncertainty beyond a depth of 10 m AHD. As a result, the depths from the SDB have been cut off at 10 m.

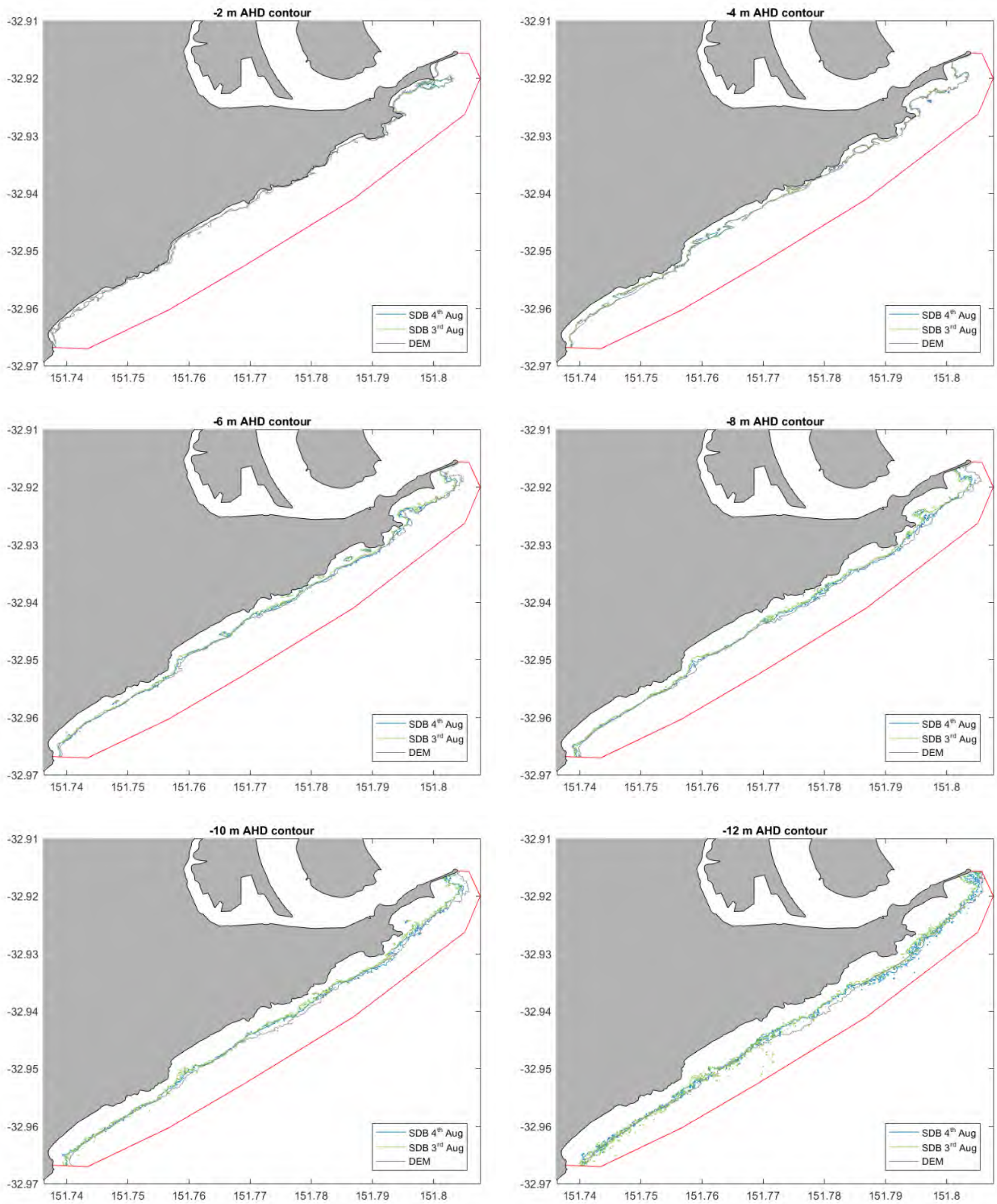

Figure 23. *Comparison of SDB and marine Lidar depth contours.*

4.3 Results

SDB data have been provided in matlab format along with this report. For reference, truecolour satellite images and corresponding SDB data are shown for each date of suitable imagery in **Appendix C**. The data files include gridded SDB at 10 m resolution for each of the available bi-annual images and cross-shore profiles at the locations of the NSW photogrammetry beach profiles. Along coastline sections without profiles (i.e. in gaps between photogrammetry blocks) profiles have been defined at 50 m spacing perpendicular to the seabed contours. In total, data along 157 profiles have been extracted from the gridded data (starting at P1 at the north-eastern end to P157 at the southwestern end). Coordinates of the start and end points for each profile have also been provided. The locations of the profiles are also shown in **Appendix C**.

4.3.1 Seasonal Changes

To assess the seasonal patterns along this stretch of coastline, the survey data were averaged across all available years into a summer (imagery captured in December) and winter (imagery captured between May and August) bathymetry. A difference plot between Winter and Summer averages is shown below in **Figure 24**. Along the sandy beaches, a seaward migration of the sandbar is evident in winter. This shows the natural cross-shore adjustment of the beach in response to increased wave energy in the winter. Calmer summer conditions tend to result in lower energy beach states (e.g. reflective and low tide-terrace) with welded or welding sandbars (Wright and Short, 1984). Conversely, high energy states tend to prevail in winter leading to high energy beach states (e.g. rhythmic bar beach) with offshore sandbars.

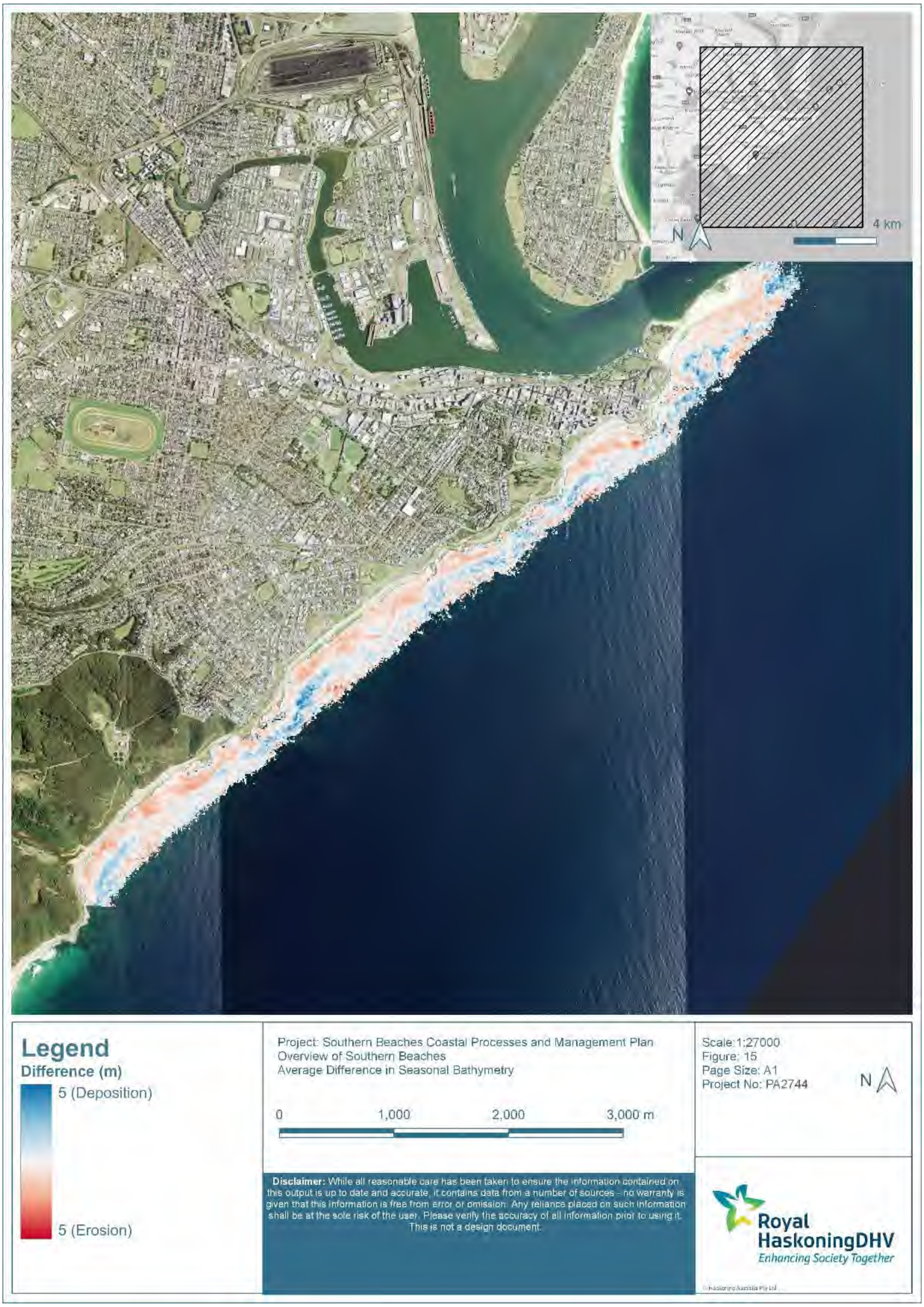

Figure 24: A plot showing the elevation difference of the average summer bathymetry subtracted from the average winter bathymetry. Blue values represent areas where the winter bathymetry is higher than the summer bathymetry.

There is some evidence of increased build-up against the breakwater wall at Nobby's Head in the winter months, indicating both cross-shore transport of sand from Nobby's Beach itself, but also alongshore transport of sand from South to North accumulating against the wall in the more energetic and southerly winter wave climate. There is also evidence to indicate a seasonal tendency for the bypassing of the rocky headlands and points which delineate the embayed beaches along this coastline. In the winter bathymetry measurements deposition can be seen in the lee of these features and at the southern ends of each of the embayed beaches. This winter deposition can be seen in **Figure 25**, for a profile at the southern end of Mereweather Beach (just north of the ocean pool) offshore of the rocky section of shoreline that extends from the Northern end of Burwood beach.

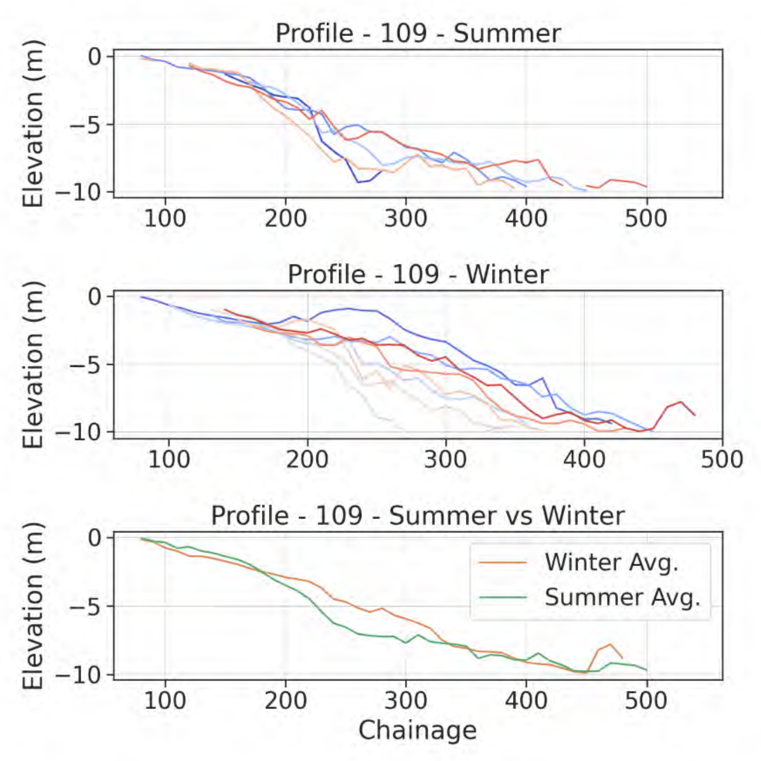

Figure 25: Profile data at Profile 109, adjacent to Ridge Street at the southern end of Merewether Beach. The top two panels show profiles from summer and winter respectively with profile line colour indicating date, grading from blue for 2015 to red for 2021. The bottom panel shows the average profiles in summer and winter months.

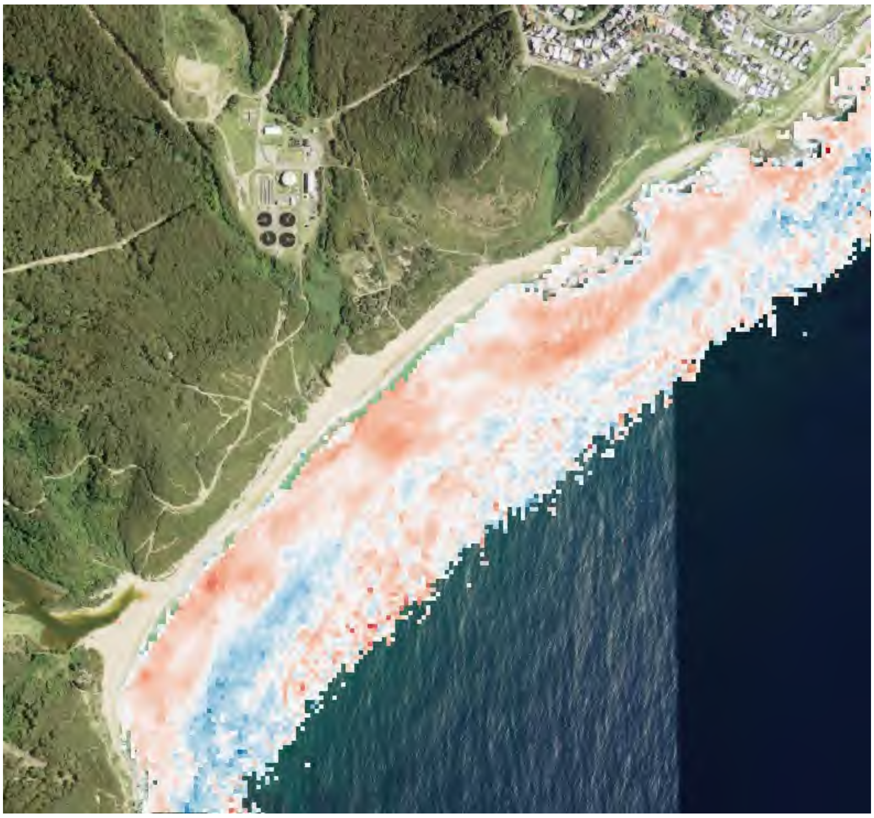

Figure 26: Detailed view of Burwood Beach showing the elevation difference of the average summer bathymetry subtracted from the average winter bathymetry. Blue values represent areas where the winter bathymetry is higher than the summer bathymetry.

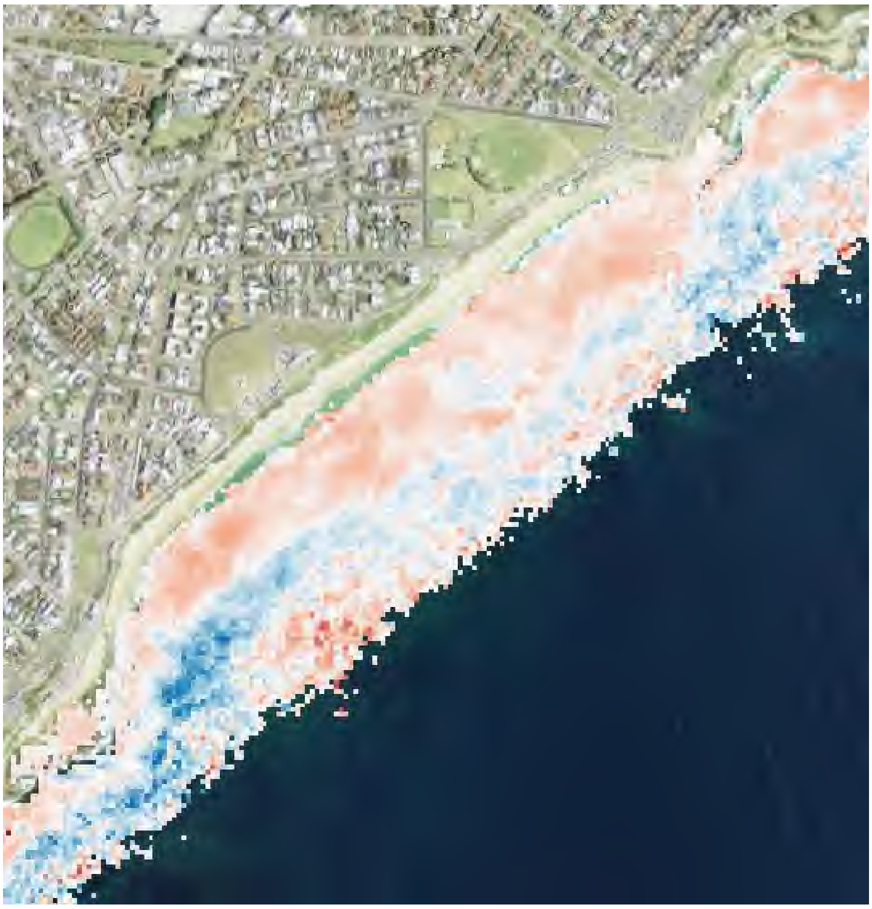

Figure 27: Detailed view of Mereweather Beach and Bar Beach showing the elevation difference of the average summer bathymetry subtracted from the average winter bathymetry. Blue values represent areas where the winter bathymetry is higher than the summer bathymetry.

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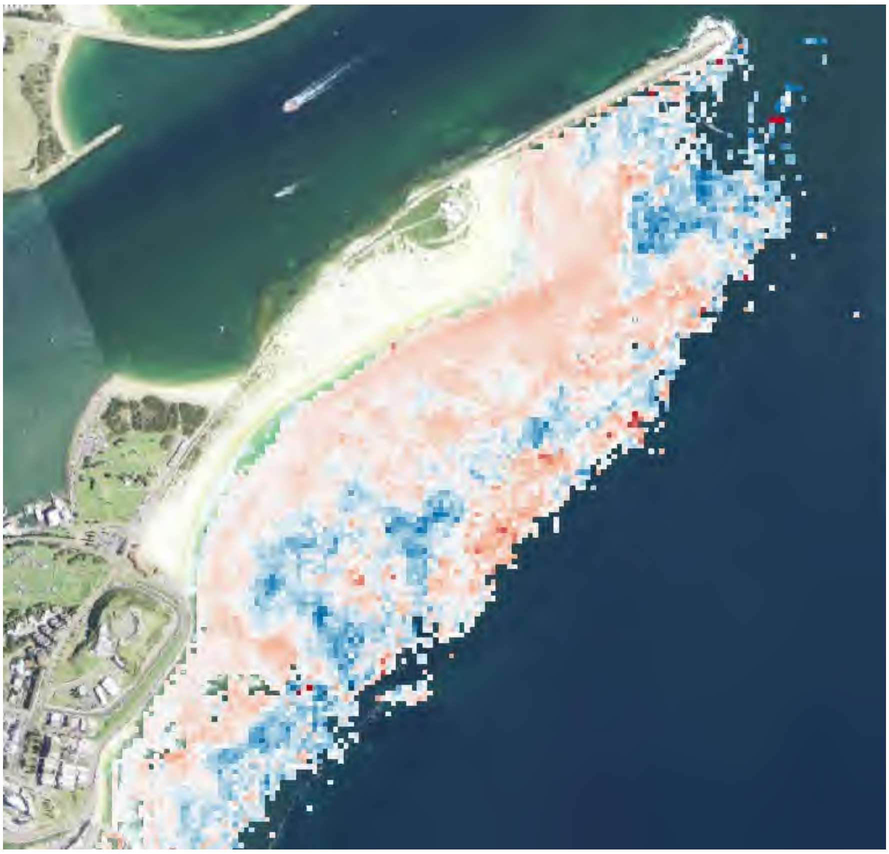

Figure 28: Detailed view of Nobbys Beach showing the elevation difference of the average summer bathymetry subtracted from the average winter bathymetry. Blue values represent areas where the winter bathymetry is higher than the summer bathymetry.

4.3.2 Other bathymetry changes

Generally, sand movement along the NSW coastline is from South to North and varies from year to year in an episodic fashion (DHI, 2006). Using the SDB data, observations can be made about changes during the time period from 2015 to 2021. **Figure 29** shows a comparison of an average pre and post 2019, that indicates there has generally been a loss of sediment from the nearshore area of Nobby's Beach. This is potentially onshore movement after the significant storm event in 2016 deposited sand in this area (discussed further below).

While the southern section of Nobby's foreshore has been prograding steadily over the medium term (since the late 1980s), the north-eastern shore adjacent to the breakwater wall varies in a more cyclical pattern over interannual timescales (Bishop-Taylor et al., 2019). To the south of Nobby's Beach the erosion and deposition patterns very alongshore with typical length scales between approximately 500m and 1km.

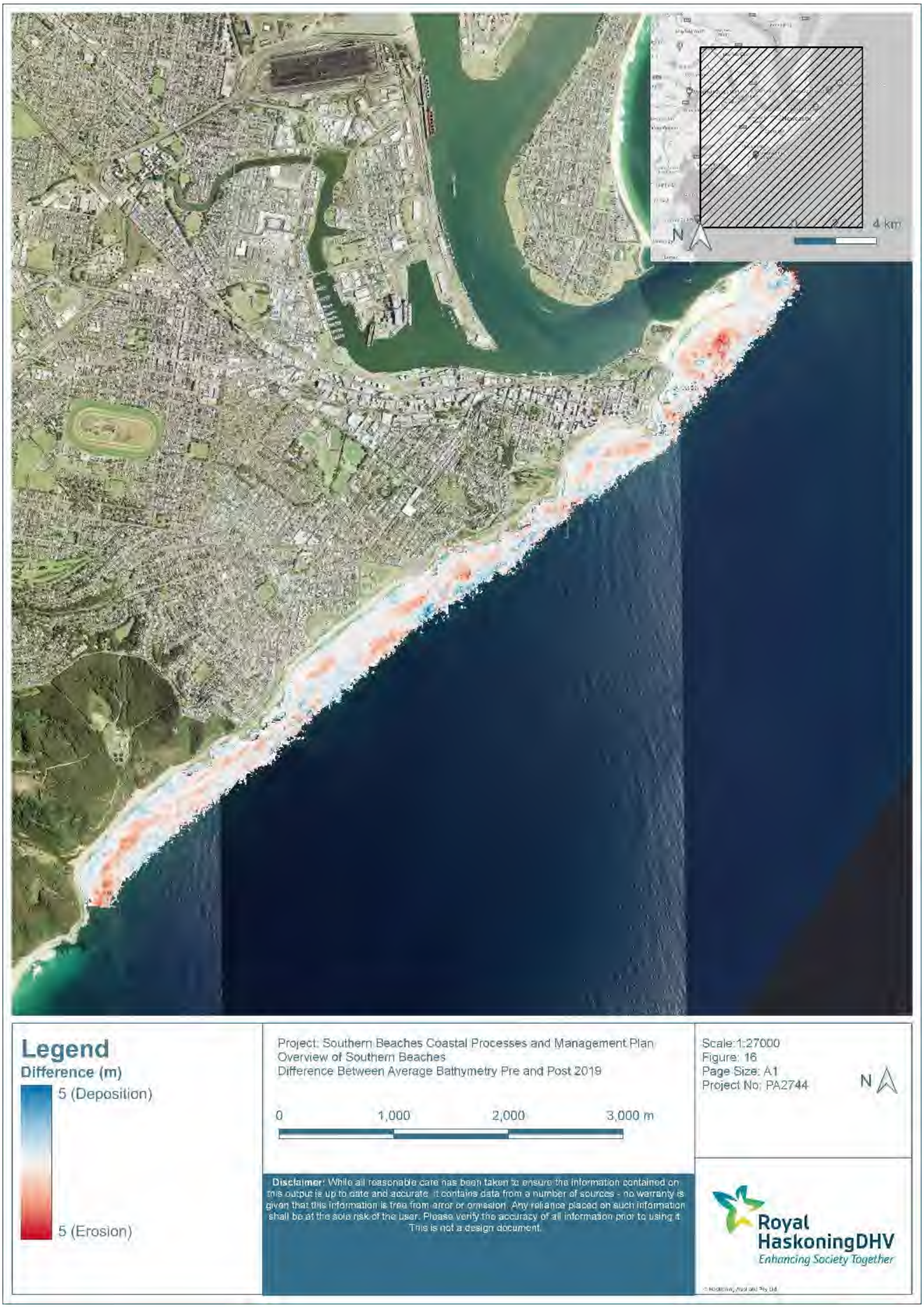

Figure 29: The difference between an average of the 5 surveys during and after 2019, and the 8 surveys before 2019. Blue values represent areas of deposition .

Previous studies have noted features in deeper water of significance along this coastline, such as an accreting sand lobe in water depths of around 20m to the East of Nobby's Beach (Nielsen et al., 2011). However, at this site SDB does not have the ability to adequately resolve the bathymetry at such depths. Accordingly, a focus is placed on features closer to shore. At depths of less than ~5 m, smaller scale rip and alongshore variable sandbar features can be observed in the SDB data. **Figure 30** shows an example at Burwood Beach from August 2018 in which common features are be observed in both satellite imagery and the SDB data. This gives good confidence in the data in replicating features in shallow water depths.

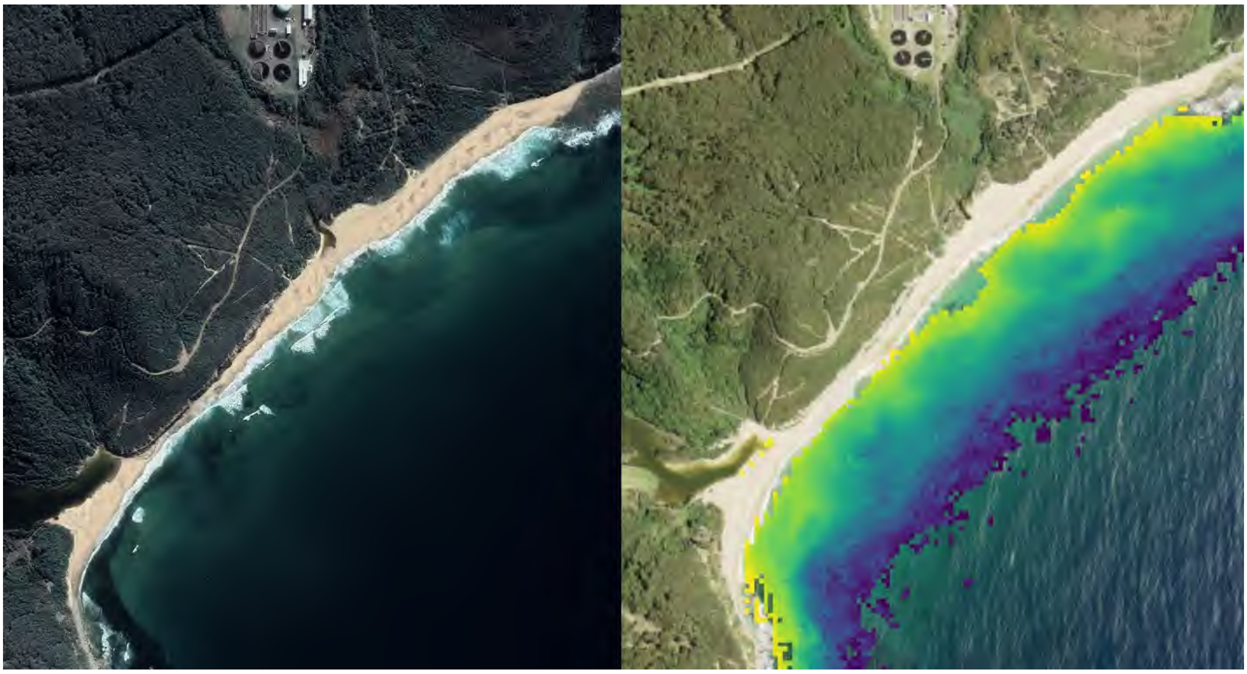

Figure 30: Example of smaller scale features observed in the SDB data at Burwood Beach. The left image was capture on 01/08/2018 (source: Google Earth) and the right image shows the SDB data from 03/08/2018.

On an event scale, large scale deposition in the nearshore area can be seen in Figure *31* following the June 2016 foreshore erosion event during which large waves from the northeast impacted the shoreline. The SDB data shows the alongshore variable nature of foreshore erosion and nearshore deposition during and after a large storm event and highlights the complexity of the process in response to nearshore bathymetry features, intertidal reef platforms, headlands, and other coastal features.

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Figure 31*: Difference between the July 2016 and the December 2015 SDB data. Blue values represent areas of deposition in the July 2016 data.*

4.3.3 Summary of Results

Key results from the SDB analysis completed for this study are summarised below:

- the analysis successfully derived bathymetric survey data from satellite images down to a seabed depth of approx. -15m AHD;
- the analysis identified a seasonal trend across the sandy beaches of the study region with a seaward migration of the sandbar evident in winter resulting from the natural cross-shore adjustment of the beach in response to increased wave energy;
- on an event scale, large scale deposition in the nearshore area was observed following the June 2016 storm event from the northeast;
- the SDB data highlighted the alongshore variation in foreshore erosion and nearshore deposition resulting from a large storm event and highlights the complexity of the process in response to nearshore bathymetry features, intertidal reef platforms, headlands, and other coastal features;
- there was evidence of increased build-up against the breakwater at Nobby's Head in the winter months, indicating both cross-shore and northerly alongshore sediment transport accumulating against the structure in the more energetic and southerly winter wave climate; and
- a seasonal tendency for the bypassing of the rocky headlands with winter bathymetry measurements showing deposition in the lee of these features and at the southern ends of each of the embayed beaches e.g. the southern end of Merewether Beach (just north of the ocean pool).

4.3.4 Limitations

While these data present a valuable investigation of sediment mobility in the nearshore over time, the SDB data have a few limitations of note:

- The sparse and recent (2015 onwards) nature of the data means that it cannot be used to make meaningful conclusions around long terms trends in the offshore sediment supply along this stretch of coastline. For these trends, data from the subaerial beach is relied upon as a proxy for broader changes in sediment budget.
- The SDB data has an inherent error/uncertainty that increases with water depth. For this reason, results here present only the data to a water depth of 15 m, beyond which meaningful conclusions cannot be drawn about total sediment volume in the system over time.
- The uncertainty in the data means that comparing averaged surveys (e.g., seasonal averages) is preferrable to comparing individual surveys for which the noise to signal ratio is less favourable.

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5 Inundation Assessment

5.1 Introduction

Coastal storm inundation occurs when the sea encroaches onto land. In New South Wales (NSW), this usually occurs when several oceanographic processes combine, in particular as a result of storm conditions coinciding with a higher-than-normal high tide. Determination of the extent and severity of a coastal inundation hazard is of considerable significance in relation to land use and maximising the benefits of coastal lands, while minimising the risks to people and property. This section aims to update the inundation analysis for broad scale hazard identification, appropriate for a CMP.

5.2 Methodology

5.2.1 Components of Coastal Inundation Hazard

The various components of coastal inundation hazards are shown in **Figure 32.**

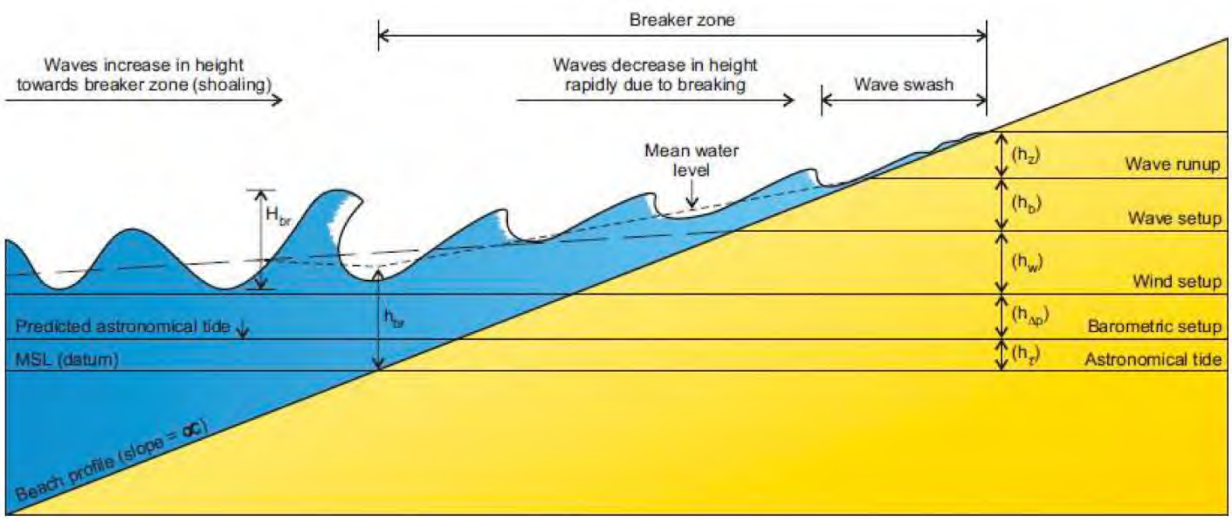

Figure 32: Components of Elevated Ocean Water Levels (adapted from DECCW, 2010).

The elevation of the coastal inundation hazard, h_{CIH}^T at a point in time, T, and at a particular locality is a function of the depth of inundation and the local wave height.

The sea level comprises a number of components and, as indicated in **Figure 32**, may be calculated from:

$$h_{CIH}^T = \underset{\text{Mean sea level}}{MSL} + \underset{\text{Astronomical Tide}}{h_\zeta} + \underset{\text{Barometric Setup}}{h_{\Delta p}} + \underset{\text{Wind setup}}{h_w} + \underset{\text{Wave setup}}{h_b} + \underset{\text{Wave runup}}{h_z} \quad (1)$$

Wave action contributes to the overall coastal inundation hazard through two terms, the wave setup (h_b) and the wave runup (h_z). Wave set-up is the increase in ocean water level at the shoreline due to wave breaking and the onshore conservation of momentum flux. This process contributes a steady super-elevation of the water level at the shoreline which is influenced by both the beach morphology and the prevailing wave conditions. Wave runup is the uprush of water onto the beach face and represents the instantaneous boundary between land and water for any given wave. The inundation level contribution of wave runup is typically measured as the 2% runup height - the height exceeded by only 2% of the waves for a given set of conditions.

Accordingly, coastal inundation hazard is typically presented as two different levels, the quasi-steady inundation and the dynamic inundation. The quasi-steady inundation corresponds to the peak steady water level (PSWL) which is often defined as the elevation of the sea level due to the combined effects of storm surge (barometric setup and wind setup), tide (including sea level rise) and wave setup.

As wave runup acts over the timescales of individual wave events the area of dynamic inundation is likely to be much more transient. As such, the overall dynamic inundation (h_{CIH}^{T}) is presented separately, consisting of the quasi-steady component plus the contribution due to wave runup.

For the purposes of this report the quasi-steady component will be noted as “Inundation Hazard” and the dynamic component shall be noted as “Wave Runup Hazard’’.

5.2.2 Zone of Application for Wave Processes

Inundation components derived from wave setup and runup processes are largest at the beach face where waves are breaking and running up over the shore and dunes. Wave setup requires sustained wave action to establish an equilibrium water level (USACE, 1984). Where, waves are interreacting with river entrances, studies have shown wave setup at these locations to be minimal (Hanslow and Nielsen, 1992). Quantifying the coastal inundation hazard contribution becomes more difficult for these processes where elevated storm-tide and sea level rise components drive the water level to exceed dune barriers and flood vegetated and urban areas inland of the beach. Simplified empirical models used in the calculation of wave processes use parameters like beach slope which, in the dune exceedance scenario, become less clearly defined and the roughness of the vegetation and built environment must be accounted for.

Very little research has been done regarding the impact of vegetation on wave setup values as waves propagate inland. The most useful information comes from a study by van Rooijen et al. (2016) which used the numerical model XBeach to evaluate the impact of a varied length of vegetation in the surf zone on the wave setup at the shoreline on a planar beach. This study found that wave setup at the shoreline decreased significantly over a range of beach slopes when vegetation extended from the shoreline out to greater water depths. For the beach slopes and wave conditions of most interest in this study, wave setup at the shoreline was greatly reduced (60-100% reduction) over distances equivalent to 110 to 300m inland.

For this study, wave setup and runup have been applied seaward of the vegetation line and for a distance of 250 m inland. The contribution of the wave setup and runup are reduced linearly from; 100% of the calculated beach face values at the vegetation line, to 0 at a location 250 m inland of the vegetation line.

5.3 Mapping methodology

The Inundation Hazard and Wave Runup Hazard were mapped separately using a ‘bathtub’ approach to identify areas of highest risk. The Wave Runup Hazard was determined with spatially varying wave components.

Each hazard (in m AHD) was interpolated onto DEM data derived from the NSW Marine LiDAR Project 2018 data at a resolution of 5 m (i.e. the average level in a 5m square grid). Inundated or wet cells were defined as those where the hazard level exceeded the DEM level and were categorised into direct and indirect inundation, as follows:

- direct inundation - where wet cells are directly connected to the sea; and
- indirect inundation - where wet cells are not directly connected to the sea.

The hazard maps produced show only the areas of direct inundation, though GIS data are available for both direct and indirect inundation.

5.4 Adopted Input Conditions

For the purpose of broad scale hazard identification, appropriate for a CMP, input water level and wave conditions for the coastal inundation hazard assessment have been derived from the existing Newcastle Coastal Zone Hazards study (BMT WBM, 2014) with adjustments made to the SLR components to allow projection of coastal inundation risks to 2120. BMT WBM (2014) provide two estimates of the coastal inundation hazard components for the 1% Annual Exceedance Probability (AEP) event, a best estimate and an extreme scenario. In this study three scenarios are mapped:

1. 1% AEP: best estimate of the 1% AEP event with present and future sea levels;
2. 1% AEP extreme: upper bound extreme 1% AEP event with present and future sea levels; and
3. 1% AEP extreme increasing with climate change: upper bound extreme 1% AEP event for which storm surge (by 0.03 m over 100 years) and wave heights increase (10% over 100 years) through time due to climate change, with present and future sea levels.

BMT WBM (2014) used established values for the 1% AEP storm tide (tide and storm surge) level at the Fort Denison tide gauge (DECCW, 2010). These values have been supplemented with an extreme case which considers the possible increase due to a very extreme event, informed by cyclone storm surge values in south-east Queensland (comparing 100 and 1000 year return period events). Wave heights were taken for a 6 hour storm, likely to intersect with a high tide, from MHL analysis of Sydney waverider buoy data from 1993 to 2009. Wave setup was calculated using a well-established rule of 15% of the offshore significant wave height, while wave runup was calculated using the Nielsen and Hanslow (1991) equation to calculate the $R_{2\%}$ value.

While additional data may be available from tidal gauges and wave buoys to refine extreme value estimates, the values adopted from BMT WBM (2014) provide conservative estimates which cover an appropriate range to access risk on a broad scale. As noted in **Section 5.6** detailed site-specific analyses could be undertaken incorporating more accurate estimates of the alongshore wave processes (spatial variability captured with greater resolution), consideration of the joint probability relationship between waves and water level, and the use of numerical modelling to resolve wave setup and runup processes.

5.4.1 Storm Tide

The storm tide values for the three scenarios, consisting of the astronomical tide and storm surge components, are shown below in **Table 5**.

Table 5: Storm tide scenarios considered in this analysis (noting SLR has not been included in these values)

Storm tide scenario	2020 Still Water Level (m AHD)	2040 Still Water Level (m AHD)	2070 Still Water Level (m AHD)	2120 Still Water Level (m AHD)
1% AEP	1.44	1.44	1.44	1.44
1% AEP Extreme	1.64	1.64	1.64	1.64
1% AEP Extreme increasing with climate change	1.64	1.65	1.65	1.67

5.4.2 Sea Level Rise

Future coastal inundation hazard scenarios consider the influence of ongoing sea level rise on extreme water levels. Sea level rise values noted in **Table 6** were applied for each of the future scenarios considered in this analysis. These values are based on updated projections by the International Panel for Climate Change (IPCC), outlined in IPCC (2019).

Table 6: Sea level rise scenarios considered in this analysis.

SLR Scenario	SLR Value (m relative to 2020)
Present Day*	0.00
SLR 2040 RCP8.5 maximum	0.14
SLR 2070 RCP8.5 maximum	0.50
SLR 2120 RCP8.5 maximum	1.33

5.4.3 Waves

The wave setup and runup values for the three scenarios, based on the astronomical tide and storm surge components, are shown below in **Table 7.**

Table 7: Wave components for scenarios considered in this analysis.

<table>
<tr><th>Location</th><th>Scenario</th><th>Year</th><th>Wave Setup (m)</th><th>Wave Runup (m)</th></tr>
<tr><td rowspan="6">Nobbys Beach</td><td>1% AEP</td><td rowspan="2">2020, 2040, 2070, 2120</td><td rowspan="2">1.31</td><td rowspan="2">2.90</td></tr>
<tr><td>1% AEP Extreme</td></tr>
<tr><td rowspan="4">1% AEP Extreme increasing with climate change</td><td>2020</td><td>1.31</td><td>2.90</td></tr>
<tr><td>2040</td><td>1.35</td><td>2.93</td></tr>
<tr><td>2070</td><td>1.38</td><td>2.97</td></tr>
<tr><td>2120</td><td>1.44</td><td>3.04</td></tr>
<tr><td rowspan="6">Newcastle Beach</td><td>1% AEP</td><td rowspan="2">2020, 2040, 2070, 2120</td><td rowspan="2">1.31</td><td rowspan="2">3.00</td></tr>
<tr><td>1% AEP Extreme</td></tr>
<tr><td rowspan="4">1% AEP Extreme increasing with climate change</td><td>2020</td><td>1.31</td><td>3.00</td></tr>
<tr><td>2040</td><td>1.35</td><td>3.03</td></tr>
<tr><td>2070</td><td>1.38</td><td>3.07</td></tr>
<tr><td>2120</td><td>1.44</td><td>3.15</td></tr>
<tr><td rowspan="6">Mereweather Beach and Bar Beach</td><td>1% AEP</td><td rowspan="2">2020, 2040, 2070, 2120</td><td rowspan="2">1.31</td><td rowspan="2">2.90</td></tr>
<tr><td>1% AEP Extreme</td></tr>
<tr><td rowspan="4">1% AEP Extreme increasing with climate change</td><td>2020</td><td>1.31</td><td>2.90</td></tr>
<tr><td>2040</td><td>1.35</td><td>2.93</td></tr>
<tr><td>2070</td><td>1.38</td><td>2.97</td></tr>
<tr><td>2120</td><td>1.44</td><td>3.04</td></tr>
</table>

5.5 Key Findings

Sections 5.5.1 contains summary mapping outputs for Inundation Hazard and Wave Runup Hazard extents. Scenario 2, i.e. the upper bound extreme 1% AEP event with present and future sea levels, has been selected for the mapping outputs as it is considered to provide a suitably conservative estimate. Mapping for other scenarios and planning periods is provided in **Appendix D.** From the plots, the areas where assets, or life, are potentially at risk can be seen for each planning period. These are summarised in **Table 8** below:

Table 8: Summary of risk to life and assets affected by inundation and wave runup

<table>
<tr><th>Scenario</th><th>Planning Period</th><th>Assets that become at risk in this period*</th><th>Risk to Life</th></tr>
<tr><td rowspan="4">1% AEP Extreme Inundation</td><td>Immediate</td><td>• Bathers Way between Newcastle Baths and Nobbys Beach
• Newcastle Ocean baths
• Canoe Pool
• Bogie Hole</td><td rowspan="8">Risk to life occurs on all promenades, breakwater walkway and ocean baths listed unless pedestrian access is managed.</td></tr>
<tr><td>2040</td><td>• Merewether Ocean baths and low level promenades
• Susan Gilmore Beach south to Bar Beach
• Bathers Way between Newcastle Ocean Baths and Nobbys SLSC and along the Newcastle breakwater</td></tr>
<tr><td>2070</td><td>• Newcastle low level promenades at northern end of beach
• The Esplanade roadway between Newcastle Baths and Nobbys Beach</td></tr>
<tr><td>2120</td><td>• Newcastle low level promenades
• Nobbys SLSC promenade</td></tr>
<tr><td rowspan="4">1% AEP Extreme Wave Runup</td><td>Immediate</td><td>• Merewether Ocean baths and low level promenades
• Heritage shelter on lower promenade in front of Surfhouse
• Cooks Hill SLSC
• Bar Beach low level promenades
• Newcastle low level promenades
• Newcastle Baths and carpark and Canoe Pool
• The Bathers Way and Esplanade roadway between Newcastle Baths and Nobbys Beach
• Residential properties on The Esplanade opposite the Cowrie Hole
• Newcastle breakwater walkway
• Nobbys Beach promenade in front of café and SLSC</td></tr>
<tr><td>2040</td><td>• Newcastle Ocean baths and low level promenades
• Mid-level promenades at Newcastle Beach</td></tr>
<tr><td>2070</td><td>• Ramp access to Cooks Hill SLSC
• Bathers Way at top of beach access ramp from Dixon Park carpark
• Lower level promenade east of Nobbys Beach main carpark
• Horseshoe beach carpark</td></tr>
<tr><td>2120</td><td>• Upper promenade between Merewether SLSC and Surfhouse
• Newcastle kiosk and
• Nobbys SLSC northern building</td></tr>
</table>

* Note: Risk to life and assets then increases in subsequent planning periods (but assets are not repeated in the table).

5.5.1 Inundation Hazard and Wave Runup Hazard Summary Maps

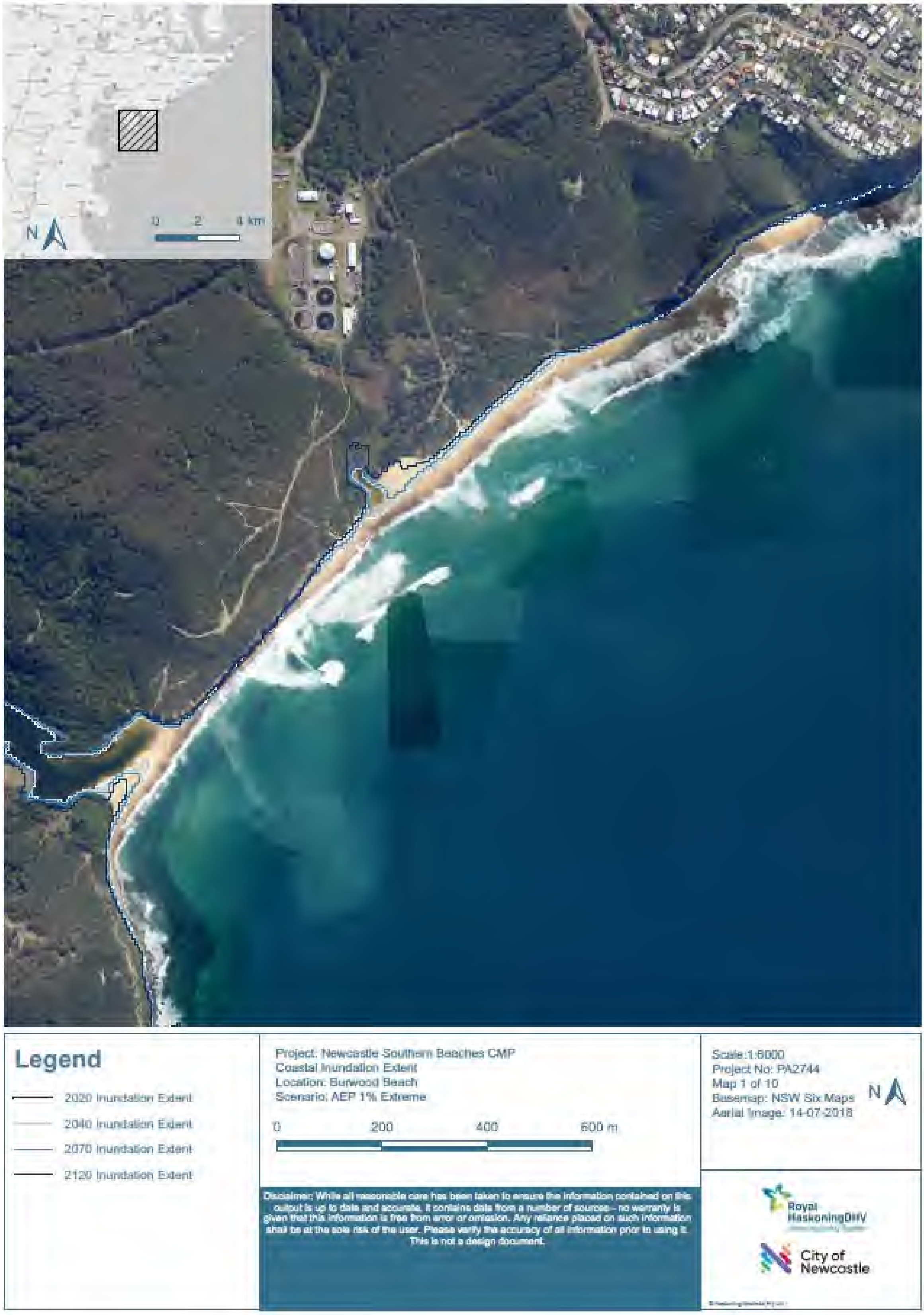

Figure 33: 1% AEP extreme Inundation Hazard extent map Burwood Beach

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Figure 34: 1% AEP extreme Wave Runup Hazard extent map Burwood Beach

Figure 35: 1% AEP extreme Inundation Hazard extent map Merewether, Dixon Park and Bar Beach

Figure 36: 1% AEP extreme Wave Runup Hazard extent map Merewether, Dixon Park and Bar Beach

Figure 37: 1% AEP extreme Inundation Hazard extent map Newcastle Beach

Figure 38: 1% AEP extreme Wave Runup Hazard extent map Newcastle Beach

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Figure 39: 1% AEP extreme Inundation Hazard extent Newcastle Ocean Baths to Nobbys Beach (Shortland Esplanade).

Figure 40: 1% AEP extreme Wave Runup Hazard extent map Newcastle Ocean Baths to Nobbys Beach (Shortland Esplanade).

Figure 41: 1% AEP extreme Inundation Hazard extent Nobbys Beach

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Figure 42: 1% AEP extreme Wave Runup Hazard extent map Nobbys Beach

5.6 Recommendations

The areas at risk in the immediate and 20 year planning period as outlined in **Table 8** are:

- **Merewether to Bar Beach**
  As shown in **Figure 33** and **Figure 34**, Merewether Ocean baths and low level promenades are at risk from inundation and wave runup/overtopping. Bar Beach low level promenades are also at risk from inundation and wave runup/overtopping. From these results it is also evident that coastal inundation is not a hazard for Dixon Park over a 20 year planning period to 2040.

- **Newcastle Beach**
  As shown in **Figure 35** and **Figure 40**, Newcastle Ocean baths and low level promenades along Newcastle Beach are at risk from inundation and wave runup/overtopping within a 20 year planning period.

- **The Esplanade and Nobbys Beach**
  As shown in **Figure 42**, there is risk of overtopping of the walkway stretching from The Esplanade from Newcastle Ocean Baths to Nobbys SLSC and along the Newcastle breakwater. The risk of wave runup reaching into the Nobbys Beach carpark and the Camp Shortland section of Foreshore Park exists for all scenarios and increases with SLR.

These areas warrant further detailed investigation to solidify trigger levels for which access should be restricted in order to reduce the risk from overtopping hazards through preventing exposure (reducing the consequences). Further detailed investigation could be useful to quantify the hazard of inundation more accurately (i.e. at a higher spatial resolution to identify localised high risk areas), especially in light of any coastal erosion into the future. To a lesser extent these hazards also exist on Burwood Beach. However the risk there is lower due to the setback distance to infrastructure from the vegetation line making consideration of the erosion hazard more relevant.

While the hazard exists, with controls, the risk to life can be low given:

- coastal storms (large waves and elevated water levels) are generally foreseeable at least 24 hours in advance, with warnings issued by the Bureau of Meteorology;
- a large component of elevated water levels is astronomical tide, which can be accurately predicted decades into the future; and
- the State Emergency Service (SES), if mobilised, has powers to warn and evacuate people if required (as does NSW Police).

Particular infrastructure located within the coastal inundation hazard zone should be investigated in more detail to assess hazards and any required mitigation actions into the future. These include Shortland Esplanade, Cooks Hill Surf Life Saving Club and adjacent buildings, and the northern Nobbys Beach Surf Life Saving Club building.

This broad scale analysis helps to identify the areas most exposed to inundation hazard across the Newcastle southern beaches coastline. For areas of with high value assets and/or essential infrastructure at risk, more detailed analysis could be undertaken in site specific studies to more appropriately quantify inundation levels considering:

- refined extreme scenarios considering joint probability of waves and water levels;
- alongshore variations in wave energy and morphology leading to local effects; and

- the complexity of over wash processes along the foredune which cannot be adequately captured by a bathtub analysis

Further analysis would require the use of detailed numerical modelling to; transform wave conditions to the nearshore, considering the offshore bathymetry, and simulate wave runup at specific targeted locations.

6 Probabilistic Coastal Erosion Hazard Assessment

6.1 Introduction

Coastal erosion is the short term fluctuation of sediment in the nearshore zone, with sediment being redistributed from the subaerial (dry) portion of the beach profile and deposited in the subaqueous (wet) portion, as a response to high energy coastal processes events, typically wave action and currents. Erosion events are followed by a period of "beach recovery" which reverses (totally or partially) this process. Recession is the landward movement of the shoreline as a result of a long term loss of sediment from the beach compartment, due to a sediment deficit in cross shore or longshore fluctuations, or an increase in sea level. Coastal erosion and recession become problematic when assets are at risk or public safety is impacted. Hazard lines provide an estimated location of the future coastline alignment based on an assessment of storm erosion volumes, long term recession trends and sea level rise. The hazard lines then inform the development of coastal management options across various planning periods.

An updated coastal erosion hazard assessment has been completed for the Newcastle Southern Beaches coastline to understand the present and future erosion risks, based on an updated probabilistic approach and new information as outlined in the following sections.

6.2 Approach

Previously, the coastal hazard assessment for Newcastle Southern Beaches was undertaken using a deterministic approach. In a deterministic approach, each parameter that is an input to calculation of the hazard, e.g. design storm demand, SLR projection, etc. is assigned a single value. The single value is typically a conservative estimate for the parameter. Industry leading practice hazard modelling applies a probabilistic approach, to account for uncertainty and also feed into economic analysis.

In the probabilistic approach, each input parameter varies randomly according to an appropriate probability distribution function and are combined to form a discrete sample. This is then repeated in a process known as Monte Carlo simulation in which a very large number (>100,000's) of sample are synthesised. All outputs of the Monte Carlo simulation are collected to develop a probability curve for the shoreline position at the end of a particular adopted planning period.

In the probabilistic approach applied by RHDHV, the Monte Carlo simulation involves one million values of a parameter for each year of the planning period.

The three key input parameters to the probabilistic analysis are:

- shoreline recession due to net sediment loss (sediment budget differential), sometimes referred to as 'underlying recession';
- sea level rise and the recession in response to sea level rise; and
- event based erosion due to storm activity – referred to as 'storm demand'.

The general approach for the probabilistic analysis applied to this study is outlined below:

- where an input parameter can vary randomly but has a distribution that is not fully known, a triangular distribution is typically assigned for the parameter. The triangular distribution is defined by a minimal value, a maximum value, and a peak/modal value (most likely or best estimate value). The peak/modal value does not need to be equidistant between the minimum and maximum values hence a skewness can be assigned to the probability distribution. The triangular distribution is depicted in **Figure 43**;

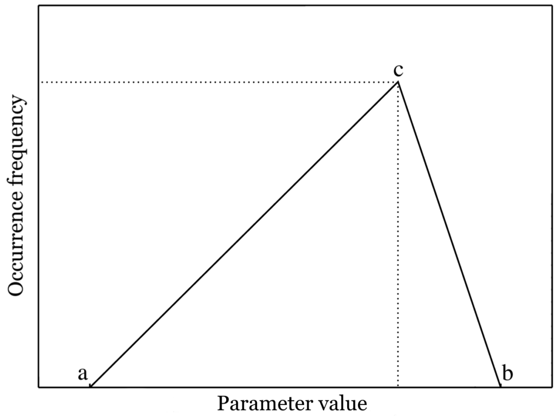

Figure 43: The probability density function of a triangular distribution

- recession due to sea level rise is estimated based on application of the Bruun rule, which requires an estimate of the magnitude of sea level rise and the inverse of the average beach slope extending to the depth of closure. For the Monte Carlo simulations, both of these parameters (sea level rise and inverse beach slope) are defined by separate triangular probability distributions;
- in the case of sea level rise, the minimum, maximum and modal values in successive years over a given planning period are set so that they follow a specified trajectory, e.g. an International Panel for Climate Change (IPCC) concentration pathway, hence random sea level rise trajectories are generated in the Monte Carlo simulations in the case of sea level rise;
- the total long-term recession at each year is calculated by simply summing the separate Monte Carlo results for underlying recession and for recession due to sea level rise for that year;
- in the case of storm demand, annual exceedance probabilities (AEP values) of storm demand are randomly sampled in each year of the planning period and then converted to a volume using empirical relationships. So-called 'high demand' (rip head) values for storm demand are adopted;
- storm demand volume is then converted to a setback distance using the methodology outlined in Nielsen et al (1992), allowing separate determination of Zone of Wave Impact (ZWI), Zone of Slope Adjustment (ZSA) and Zone of Reduced Foundation Capacity (ZRFC), refer **Figure 44.** These zones are briefly described below:

    - Zone of Wave Impact (ZWI) - the landward extend of the zone that is directly impacted by waves i.e. the landward extent of the initial storm bite.
    - Zone of Slope Adjustment (ZSA) - following the swell event causing the initial erosion, a steep (almost vertical) erosion scarp often remains at the back of the beach. As the sand dries, the internal angle of friction of sand will cause this scarp to slump or collapse to a stable angle of repose. The landward extent of this slumped area (at the crest) defines the landward edge of the ZSA.
    - Zone of Reduced Foundation Capacity (ZRFC) – directly landward of the ZSA, the ground does not have the stability to found structures directly onto due to the exposed erosion scarp adjacent. It is necessary to found structures on piles that extend through the ZRFC and into more stable material. The landward extent of the ZRFC is dependent on the vertical height of the erosion scarp and the internal angle of friction of the beach dune material.

- the total setback for each zone (ZWI, ZSA, ZRFC) is calculated by adding the storm demand setback to the combined long-term recession, randomly, on a year by year basis;
- calculations are performed for each beach profile along a section of shoreline of interest (profiles generally established by a photogrammetric analysis); and
- it is assumed that the beach has recovered from the storm-driven erosion that occurs in a year at the beginning of the subsequent year[4].

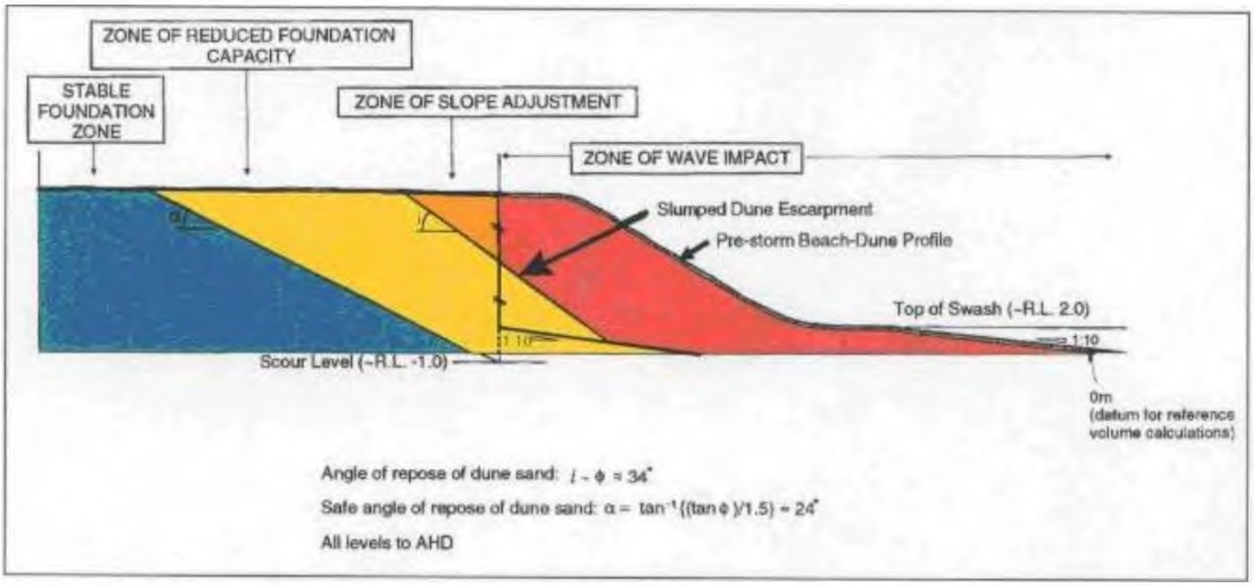

Figure 44: Wedge Failure Plan Model (Source: Nielsen et al., 1992)

Example output from the Monte Carlo process is provided in **Figure 45** and **Figure 46.**

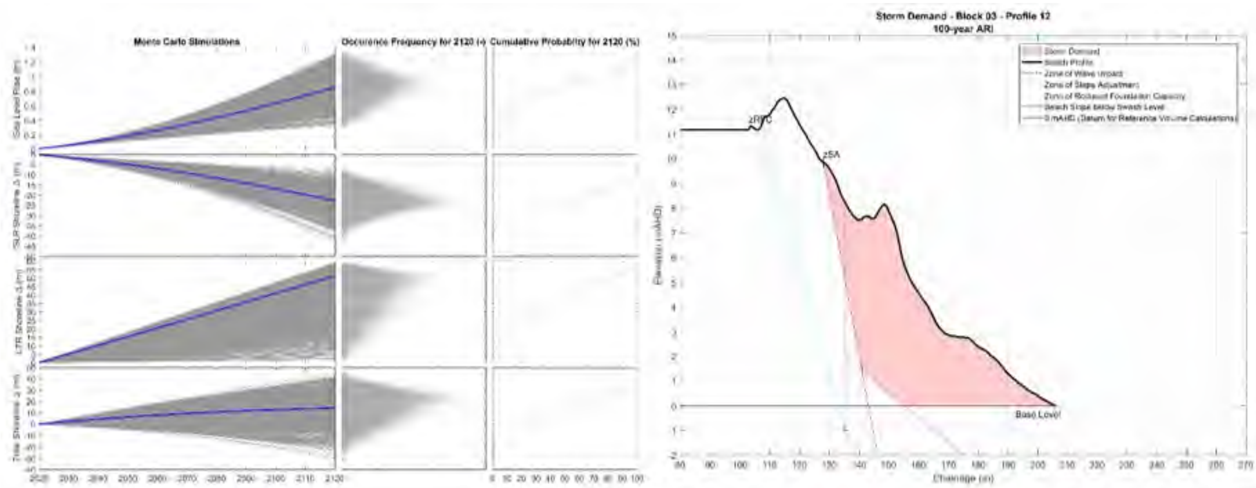

Figure 45 Example typical auxiliary output of the Monte Carlo process: statistical distributions of SLR and recession input parameters (left) and storm demand for a given profile (right)

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[4] This assumption is made to reduce computational effort, as the actual storm demand is a function of beach state. It would otherwise be necessary to continually track the beach state, including a recovery algorithm, and continually adjust the storm demand in response to beach state, particularly the larger values of storm demand (by reducing these values). Beaches in an eroded state have lower storm demands due to dissipation of wave energy on offshore bars formed during previous erosion events.

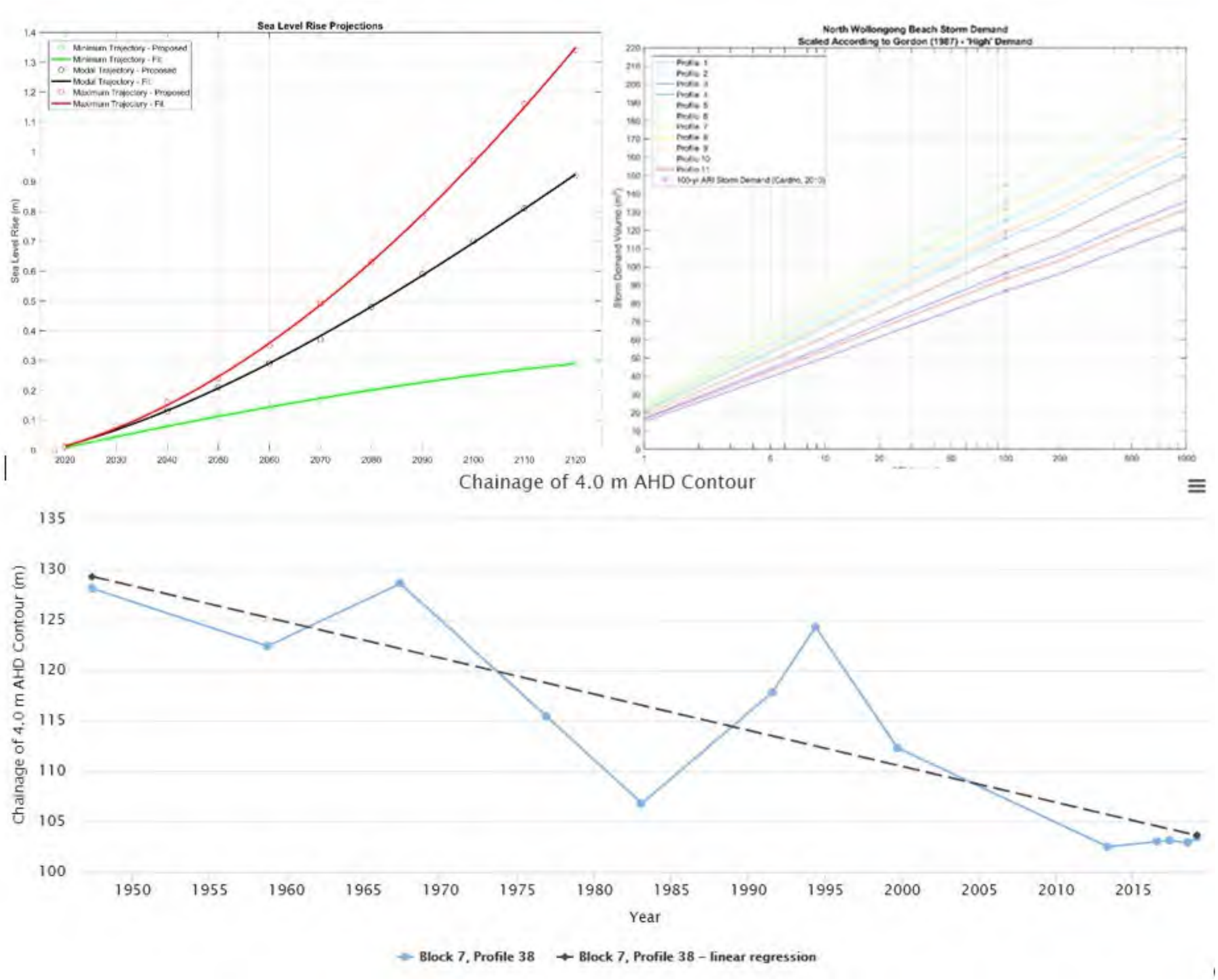

Figure 46: Example input: projected SLR (top left), storm demand (top right) and underlying recession for a given profile (bottom)

A flow chart showing the methodology for the probabilistic hazard assessment is provided in **Figure 47**.

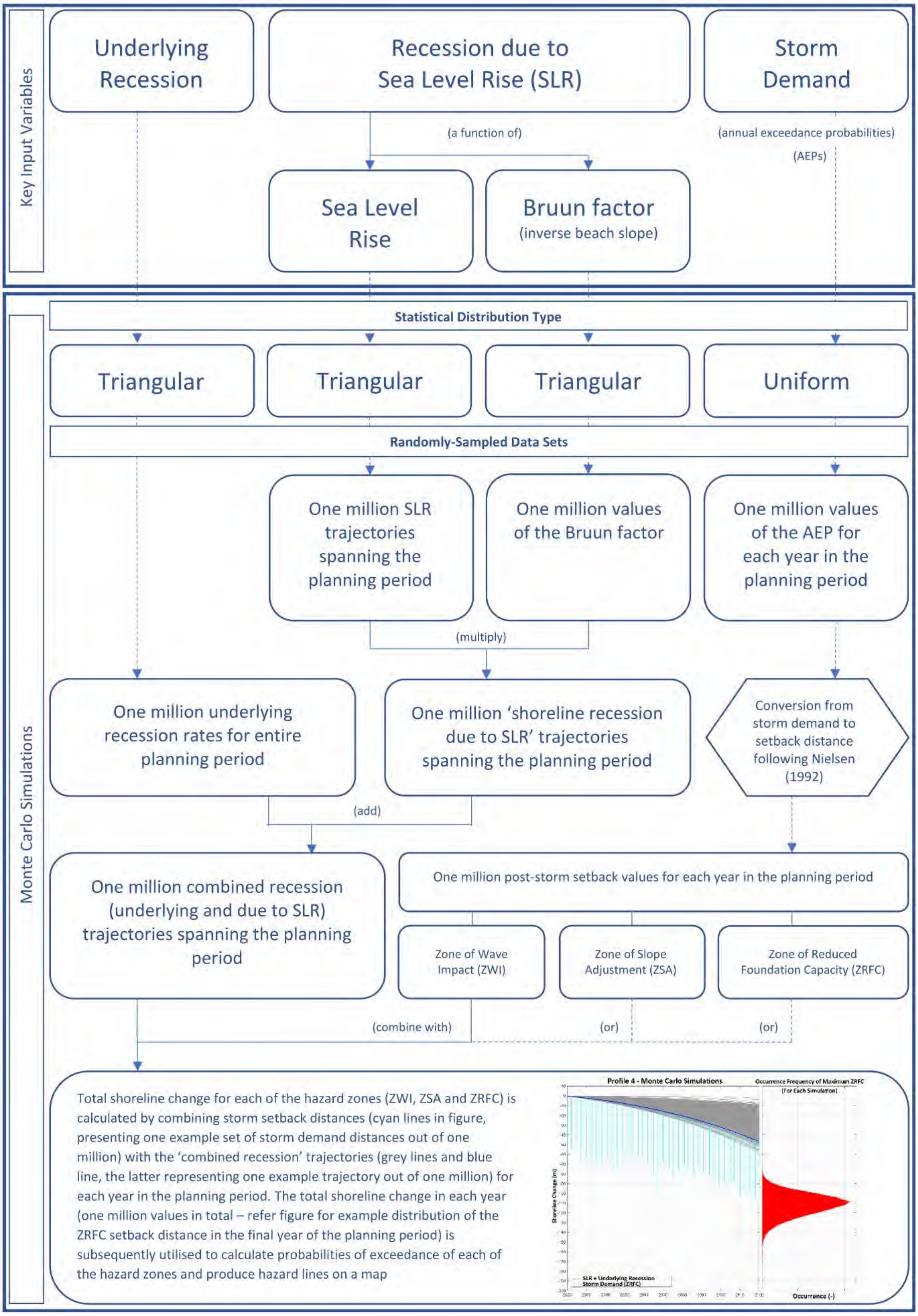

Figure 47: Flow chart for the probabilistic assessment of coastal hazard

6.3 Input Parameters

The probabilistic coastal erosion hazard assessment includes revised hazard mapping for the entire study area, i.e., including the DPE photogrammetric profile locations in Blocks 1, 2, 5, 6, 7, 8 and 9, as indicated in **Figure 16.** Separate probability curves have been developed for regularly spaced profiles distributed across the Study Areas as shown in **Figure 16.**

The following sections set out the values for the key parameters adopted in the probabilistic assessment based on the following information:

- the 2014 *Newcastle Coastal Zone Hazard Study* (BMT WBM, 2014); and,
- up to date photogrammetry data, covering the period from 1954 to 2021.

The adopted pre-storm profile and planning periods are also described in the following sections.

6.3.1 Pre-Storm Profile

Selection of the pre-storm profile upon which to apply the shoreline recession and storm demand is important as this influences the ultimate position of the future coastal hazard.

In selecting the pre-storm profile the aim should be to adopt a relatively accreted beach profile, typically referred to by coastal engineers and scientists as an 'average beach full' profile, as the high storm demands selected in hazard assessments can only be realised in practice if accreted profiles exist (as noted in Footnote 4, in the situation of eroded profiles there is typically large quantities of sand in offshore bars which dissipate wave energy giving lower storm demands). The selected pre-storm profile should also, ideally, be a 'real' profile (not synthesised) and be contemporary, i.e. recent.

Figure 48, **Figure 49** and **Figure 50** show beach profiles available from the NSW Beach Profile Database at Dixon Park Beach at; Profile 3-7, 3-8 and 3-11, respectively, for the years 1954-2021.

Figure 51, Figure 52 and **Figure 53** show beach profiles available from the NSW Beach Profile Database at Bar Beach at; Profile 3-19, 3-21 and 3-24, respectively, for the years 1954-2021. The locations of the profiles are shown in **Figure 16**.

The trends evident in **Figure 48** through to **Figure 53** are representative of all the beach profiles in the CBA Study Area over this period.

It is evident that the 1974 beach profiles are not suitable for adoption because it represents a highly eroded beach state, with the survey taken following the significant May/June storm event. The 2011 profiles are relatively accreted. The more contemporary 2018 profiles are somewhat less accreted than the 2011 profiles, hence its adoption for the calculation of coastal hazard would be more conservative. This initial conservatism was considered in selection of the storm demand values to adopt in the probabilistic assessment.

Adoption of the 2018 profile is proposed for all beaches except for Nobbys Beach where the most contemporary profile (2021) will be adopted due to the progradation trend over the historical data period.

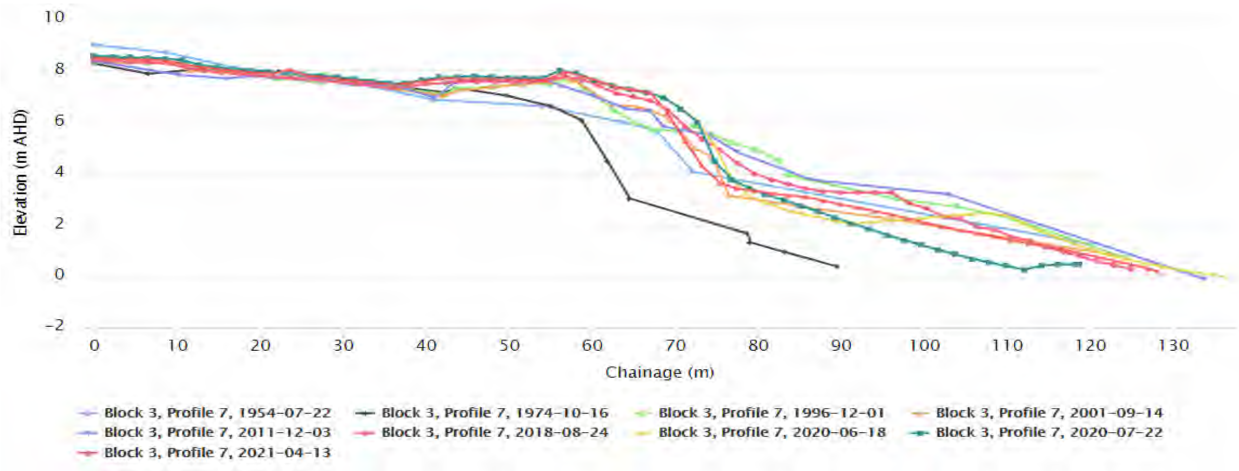

Figure 48: Beach profiles at Profile 3-7 for the period 1954 -2021 (Dixon Park)

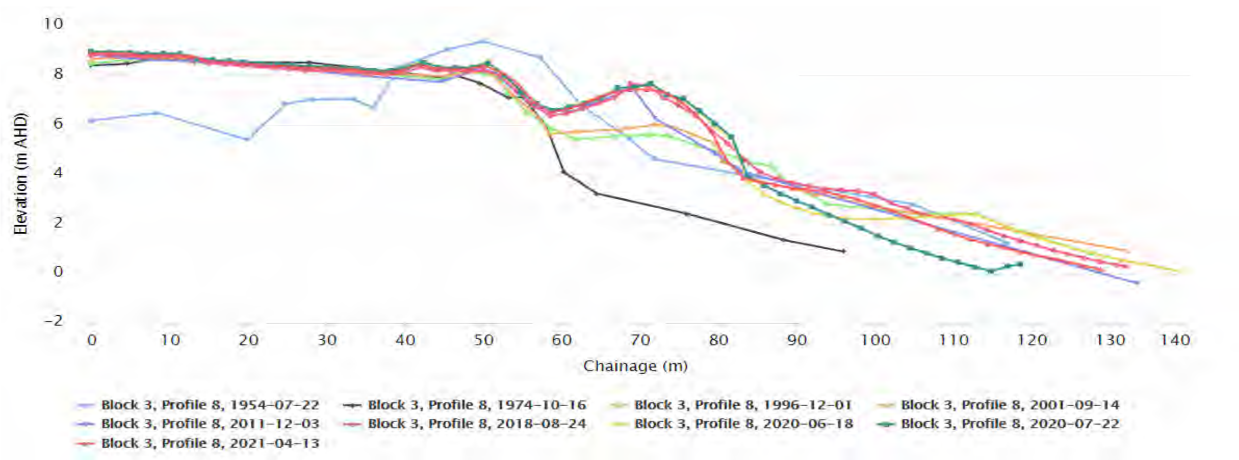

Figure 49: Beach profiles at Profile 3-8 for the period 1954-2021 (Dixon Park)

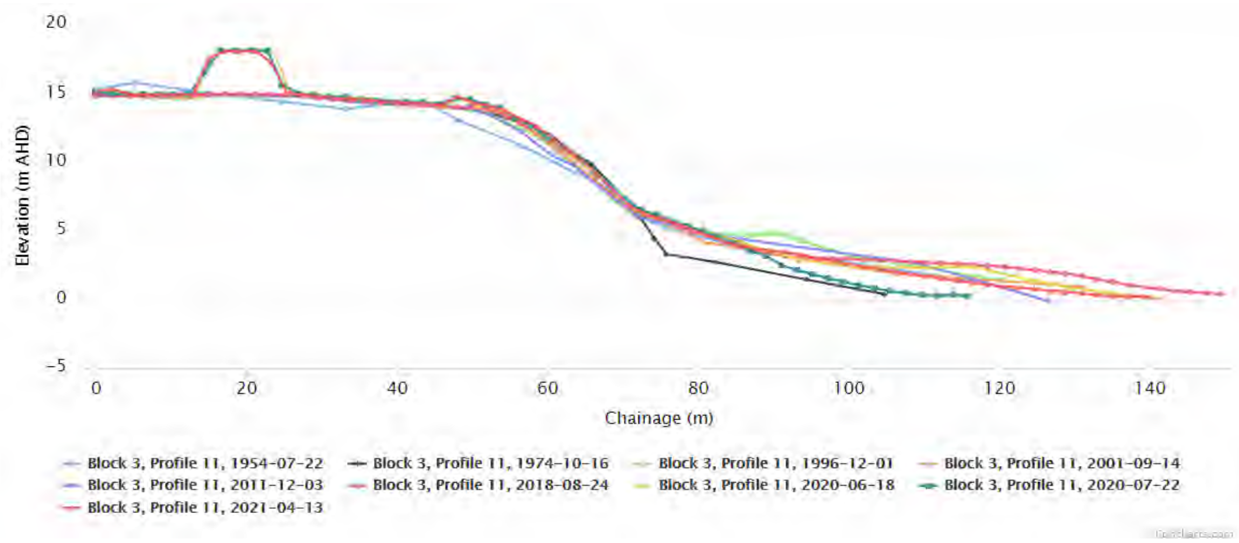

Figure 50: Beach profiles at Profile 3-11 for the period 1954-2021 (Dixon Park)

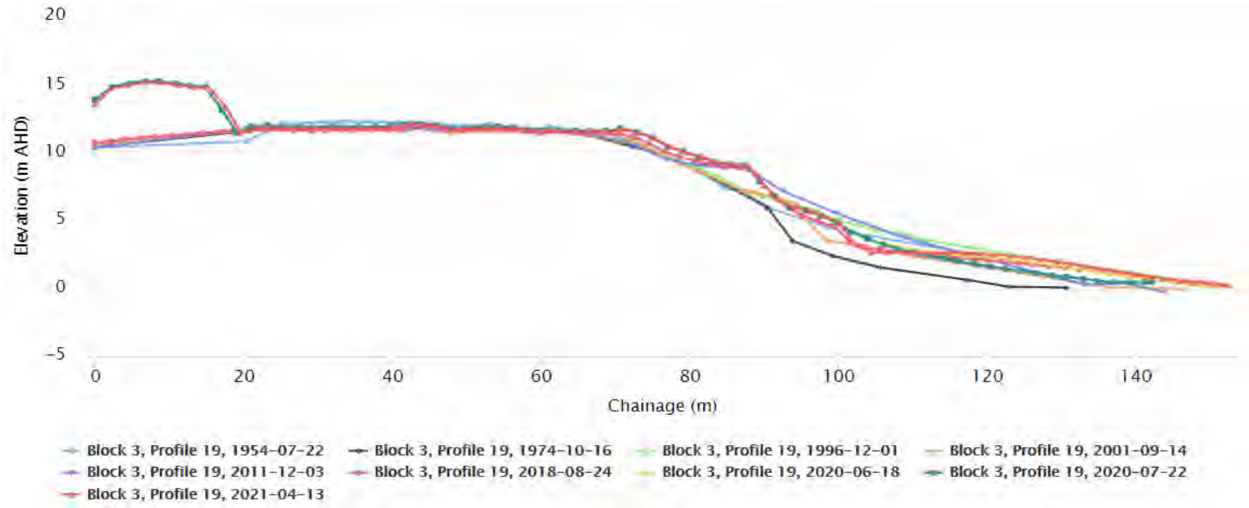

Figure 51: Beach profiles at Profile 3-19 for the period 1954-2021 (Bar Beach)

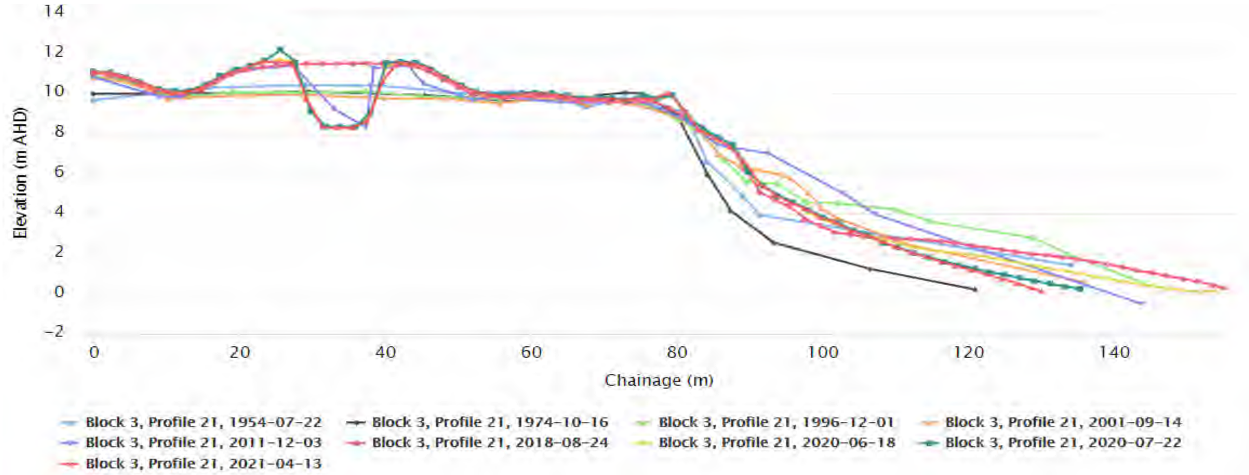

Figure 52: Beach profiles at Profile 3-21 for the period 1954-2021 (Bar Beach)

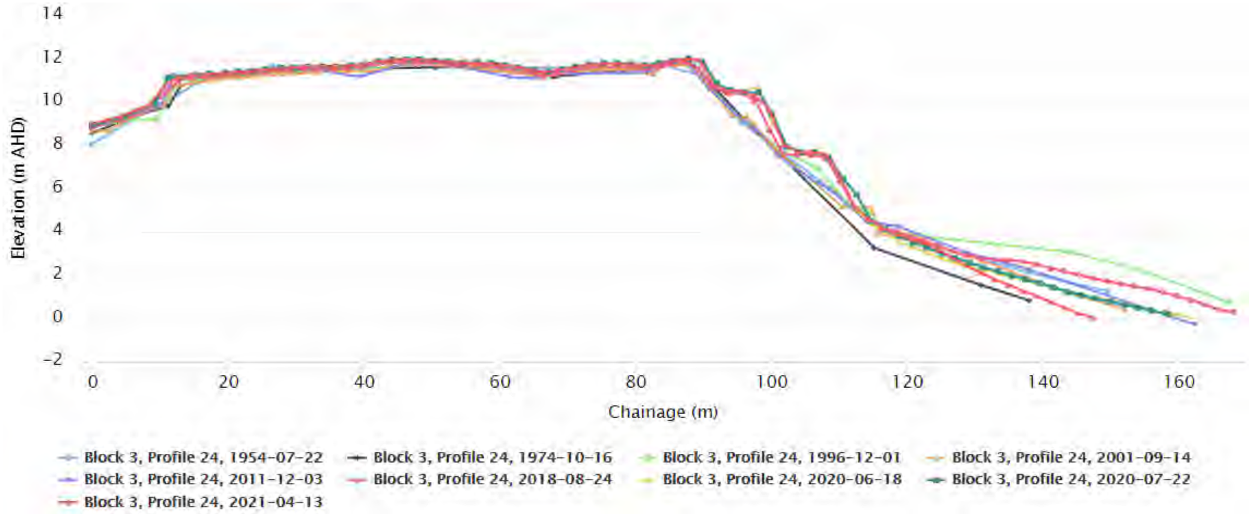

Figure 53: Beach profiles at Profile 3-24 for the period 1954-2021 (Bar Beach)

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6.3.2 Planning Period

A number of planning periods need to be assessed for the production of hazard lines for coastal management planning purposes. These hazard lines then enable assets/land at risk to be identified over a range of timeframes, and facilitate informed coastal management planning for the CMP.

A mandatory requirement of the Coastal Management Manual specifies that a CMP is to consider a range of timeframes and planning horizons including; immediate, 20 years, 50 years, 100 years and beyond (if considered relevant based on expert advice).

Planning periods of 20 years, 50 years and 100 years were assessed for the purpose of providing information to Council for local planning considerations only, covering the Study Area indicated in **Figure 1**. The adopted planning periods are therefore; present day (2021), 2040, 2070 and 2120.

6.4 Underlying Recession

WBM (2000)
In the WBM (2000) study it was determined through analysis of photogrammetric data (up to 1996) and CN surveys that the southern beaches were generally not experiencing any discernible long-term recession. While the long term recession rate was assessed as being nil, it was noted that a medium term cycle of shoreline retreat and advance associated with beach rotation (shifting sand from one end to the other) could be expected to be about 5-10 metres. A potential net longshore transport rate of 30,000m^3/year to the north was estimated using CERC analytical formulation based on 40 years of directional wave data. It was noted by WBM that actual rates could be closer to 10,000m^3/year due to rocky foreshores and the groyne effect of headlands limiting losses.

BMT WBM (2014)
Similar to the 2000 report, it was concluded in 2014 that "*Merewether to Bar Beach and Newcastle Beach are found to be stable on average over time*".

The methodology adopted for qualitatively assigning likelihoods to beach erosion extents, included the use of a "shoreline evolution model"; and combining future long term recession and beach erosion hazard extents to derive the 2050 and 2100 hazard likelihood zones (from BMT WBM, 2014). Unfortunately, this methodology and associated reporting does not allow the long-term recession rate or storm demand volume utilised in the analysis to be readily seen in isolation.

RHDHV assessment incorporating 2011-2021 photogrammetry data[5]
As outlined in **Section3** the updated photogrammetry data was analysed in detail to determine appropriate input parameters for the probabilistic assessment.

Based on the information presented in **Section 3** and having regard to our conceptual understanding of long-term sand movements in the study area, the proposed input values for the probabilistic analysis, according to the triangular distribution, are summarised in **Table 9**.

The minimum and maximum values adopted correspond with the minimum and maximum value, respectively, obtained from either the 1954-2021, 1996-2021 or 2001-2021 data sets (excl. outlier values at water course entrances, stormwater channels etc).

[5] *Specifically, this comprises photogrammetric data available from the NSW Beach Profile Database (available online: www.nswbpd.wrl.unsw.edu.au,) for years 2011, 2018, 2020 and 2021.*

The modal value or best estimate corresponds to the block average shoreline change using the linear regression slope for the1954 to 2021 dataset, which is the longest available record.

Table 9: Shoreline Recession – Proposed Inputs for Probabilistic Analysis

Beach	Rate of Positional Change (m/year)								
	Burwood	Merewether Sth	John Pde/ Dixon/Bar	Newcastle Sth	Newcastle Nth	Cowrie Hole	Nobbys Sth	Nobbys Central	Nobbys Nth
Block	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Min.	-0.3	-0.2	-0.5	-0.5	-0.5	-0.05	-0.1	0.4	0.2
Mode (best estimate)	-0.1	0.0	0.0	0.0	0.0	0	0.7	1	0.5
Max.	0.4	0.12	0.4	0.3	0.2	0.05	1.4	1.4	1.3

6.4.1 Recession due to Sea Level Rise

SLR may result in shoreline recession due to readjustment of the beach profile to the new coastal water levels. Bruun (1962; 1983) proposed a methodology to estimate shoreline recession due to SLR, the so-called Bruun Rule. The Bruun Rule is based on the concept that SLR will lead to erosion of the upper shoreface, followed by re-establishment of the original equilibrium profile adjusted for the higher water level. This profile is re-established by shifting it landward and upward. The Bruun Rule is illustrated in **Figure 54**.

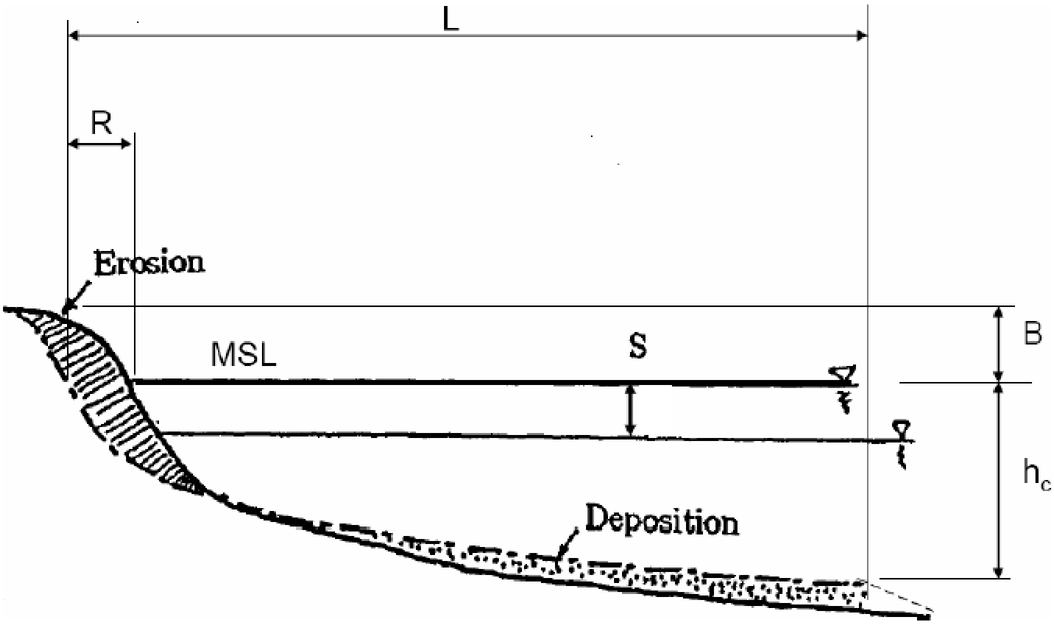

Figure 54: Bruun Rule

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The Bruun Rule equation is given by:

$$R = \frac{S}{(h_c + B)/L}$$

where: R = shoreline recession due to sea level rise;

S = sea level rise (m)

hc = closure depth

B = berm height; and

L = length of the active zone.

The denominator in the above equation ($(h_c + B)/L$) is the offshore beach slope extending to the depth of closure, h_c, which is defined by Bruun (1962) as *"the outer limit for the nearshore littoral drift and exchange zone of littoral material between the shore and the offshore bottom area"*. The inverse beach slope is also referred to as the 'Bruun factor'.

SLR recession is therefore a function of both SLR and the Bruun factor (i.e. R = S × BF). There is uncertainty regarding the selection of both of these parameters, as discussed below. As such, for the Monte-Carlo simulations, both of these parameters were defined by separate triangular probability distributions.

Sea Level Rise

BMT WBM (2014) adopted SLR projections consistent with NSW Government's *Sea Level Rise Policy Statement* (DECCW, 2009), which included SLR planning benchmarks of 0.4 m at 2050 and 0.9 m at 2100 (both relative to 1990), with the two benchmarks allowing for consideration of SLR over different timeframes. However, it should be noted that DECCW (2009) is no longer NSW government policy. Furthermore, advice was provided by the NSW Government in April 2014 that Councils are to obtain expert advice in using a range of sea level rise projections as well as document the methodology and approach applied.

The latest advice from IPCC (2019) on SLR calls for increases to the allowances in previous documents. The latest global SLR (above 1986 - 2005 baseline) projections for the 'likely' scenario are 0.43m and 0.84m (i.e., 0.1m higher than previous projections in IPCC, 2013) by 2100 for RCP2.6 ('very stringent') and RCP8.5 ('worst-case') greenhouse gas concentration scenarios, respectively.

For the probabilistic assessment, the minimum and maximum SLR projections were adopted as the corresponding RCP 2.6 (median) and RCP 8.5 (upper bound) projections from IPCC (2019) whereas the mode (most likely) values were adopted as mean value between the two scenarios. A summary of the adopted SLR allowances for the relevant planning periods are presented in **Table 10**.

Table 10: Adopted SLR allowances above 2021 baseline (adjusted from IPCC, 2019).

Planning Period (year)	Sea level rise (m)		
	Min (RCP2.6 - median)	Mode (mean)	Max (RCP8.5 – upper bound)
2021	0.00	0.00	0.00
2040*	0.10	0.12	0.14
2050*	0.14	0.18	0.21
2070	0.22	0.36	0.50
2100	0.33	0.63	0.93
2120**	0.41	0.87	1.33

*based on IPCC (2018) range 2046 to 2065, as not provided in IPCC (2019)
**extrapolated using 4mm/year and 20mm/year SLR rate for RCP2.6 - likely and RCP8.5 – upper bound scenario, respectively (IPCC, 2019)

Bruun Factor

Selection of an appropriate Bruun factor depends on the adopted depth of closure, h_c. There are numerous methods available to estimate the closure depth, including:

- methods based on wave characteristics;
- slope discontinuity in the offshore profile based on survey data; and
- field methods based on sedimentological data.

WBM (2000) noted that the depth of closure was likely in the range of 10-15m. A detailed assessment of closure depths at Merewether to Bar Beach is provided in (RHDHV, 2021). Based on analysis of bathymetry data, closure depths are around -15m. These depths are valid representations of the modal ('best estimate') closure depths at the site. The "inner" and "outer" Hallermeier (1981, 1983) depths are considered to be reasonable estimates of the minimum and maximum closure depths, respectively. Based on these results, the Bruun factors presented in **Table 11** are proposed for the probabilistic assessment.

Table 11: Bruun Factor – Proposed Inputs for Probabilistic Analysis

Beach	Bruun Factor		
	Min	Mode	Max
Burwood	39	40	60
Merewether	39	40	56
Dixon	39	40	56
Bar	39	40	40
Newcastle	39	40	40
Cowrie	30	33	40
Nobbys (Block 7,8)	39	40	40
Nobbys (Block 9)	30	30	30

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6.4.2 Storm Demand

As outlined in **Section 3.4.1**, RHDHV have reviewed the storm erosion volumes using the photogrammetric data and are in general agreement with the storm demand volume of 200m^3/m previously adopted for the study. The proposed storm erosion value adopted as the 100-year ARI storm demand for the probabilistic assessment is therefore 200m^3/m as shown in **Figure 55.**

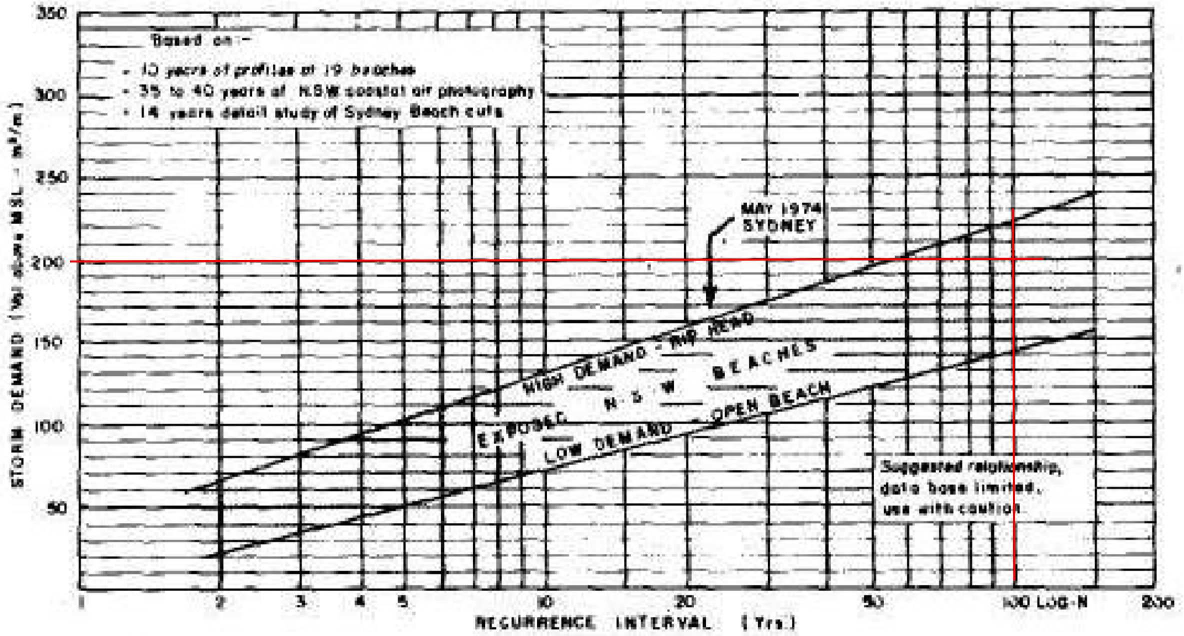

Figure 55: Storm demand estimates for NSW open coast beaches (Gordon, 1987)

6.4.3 Influence of Erosion Resistant Material

The presence of non-erodible materials at the back of the beach and rock platforms beneath the beach will limit the supply of sand to accommodate the potential storm demand volume as can be seen in the pattern of storm demand volumes in **Figure 21.** This geological limitation to the formation of this storm bite will be considered in the derivation of the hazard lines based on the assumption that erosion would be limited at the back of the beach by cliffs and rock features. The extent of rock cliffs and bedrock landward of the shoreline has been adopted from the seamless geology GIS layer (dated 21/5/2020) available on the NSW Geosciences Minview web platform. It is noted that this data is relatively broad based and does not pick up smaller scale rock outcrops such as those that are occasionally exposed in the dunes at Bar Beach. Due to lack of detailed and accurate mapping of these outcrops, it was originally assumed (for the first issue of this Coastal Processes report) that all material other than the bedrock mapped in Minview (as noted above) is soft erodible material and any rock platforms beneath the beach sands are located at depths below 0m AHD and therefore do not limit the erosion storm demand in the horizontal plane.

Additional geotechnical investigations were then undertaken at Bar Beach and Dixon Park Beach to better define the presence of inerodible material within the dunes. These investigations at Bar Beach and Dixon Park Beach were completed by RCA Australia between January and May 2023 (RCA, June 2023). The hazard lines were then modified to reflect the findings of these investigations. Appendix X contains a memo outlining the methodology for the modification of the hazard lines.

6.4.3.1 Influence of Existing Protective Structures

In general, the existing protective structures would be expected to limit (either entirely or partially) the amount of shoreline erosion that occurs landward of the structure during extreme erosion events. However, the ability of the existing protective structures to limit the amount of landward shoreline erosion that occurs during extreme erosion events would depend on a variety of factors including:

- basis of design (design life, design storm event, design wave height, design water level etc);
- critical structural design features (e.g. constructed toe level, size of armour units etc);
- pre-storm ('existing') condition of the structure; and
- intensity of erosion event resulting in damage to the structure.

For the purposes of the coastal hazard assessment, two scenarios have been assessed:

1. Seawalls maintained - all existing structures are maintained to limit erosion 100%
2. No seawalls - existing structures do not exist (or fail as soon as erosion reaches them).

This will provide the envelope of risk and allow CN to focus on the need to maintain structures (or not). The rationale behind this approach is that the timing of structure failure is either; an arbitrary estimate, or is done accurately on the basis of a detailed assessment of the design and condition of the structure. A detailed assessment is not currently included in the scope. It is not considered good use of time/budget to estimate structure failure timing arbitrarily (based on no real data) and may even provide a false sense of security.

At Dixon Park where there is significant uncertainty regarding the details and condition of the structure, the second scenario should also be considered. An action from the CMP could be to have a detailed design and condition assessment of all coastal protection structures undertaken.

6.5 Probabilistic Hazard Lines

The probabilistic hazard lines represent the annual exceedance probability (AEP) of the landward end of the ZRFC for the specified planning years. The 1% AEP is comparable to the 100-year annual recurrence interval (ARI) event for the presented years. It is noted that these hazard lines were developed on the basis of the assumption that all existing seawalls were effective in halting erosion and recession. This has been depicted as the "Seawalls maintained'' scenario.

An alternative scenario, "No seawalls" where all seawalls were considered ineffective against erosion and recession, was also considered to show the risks of not maintaining and/or upgrading this coastal protection as required.

For the purpose of reporting, summary maps of the 1% annual exceedance probabilities (AEP) erosion hazard have been shown across the study area for the immediate, 2040, 2070 and 2120 planning periods. **Figure 56** to **Figure 65** show the summary 1% AEP erosion hazard lines for the 'No seawalls' and 'Seawalls maintained' scenarios for Burwood, Merewether/Dixon/Bar Beach, Newcastle and Nobbys Beaches, respectively. .

Additional erosion hazard mapping of the ZRFC and ZSA 50%, 10% and 1% AEPs for the "Seawalls maintained'' and 'No seawalls'' scenarios for the various planning periods was also prepared and is provided in **Appendix B.**

It is noted the hazard lines represent the probabilistic analysis results as derived from the Monte Carlo analysis, without influence from adjacent hard structures or rock features. They have been truncated at hard structures or rock features and therefore appear to 'end in space'. This approach has been taken to the mapping as there are numerous complex factors influencing how the coastline might behave adjacent to hard structures/rock features and to map this area differently or more specifically would not be representative of the possibilities. These possibilities include exacerbated erosion or 'end effects' adjacent to a hard structure/feature on one hand or the hard structure effectively 'holding out' the shoreline at this point. The degree of complexity involved in these opposing influences is beyond the scope of a CMP assessment and should be looked at in detail on a case by case basis.

Figure 56:Summary 1% AEP coastal erosion hazard lines, Burwood Beach (No seawalls scenario).

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Figure 57: Summary 1% AEP coastal erosion hazard lines, Burwood Beach (seawalls maintained scenario).

Figure 58: Summary 1% AEP coastal erosion hazard lines, Merewether to Dixon Park Beach (No seawalls scenario).

Figure 59: Summary 1% AEP Coastal erosion hazard lines for Merewether to Dixon Park Beach (seawalls maintained scenario).

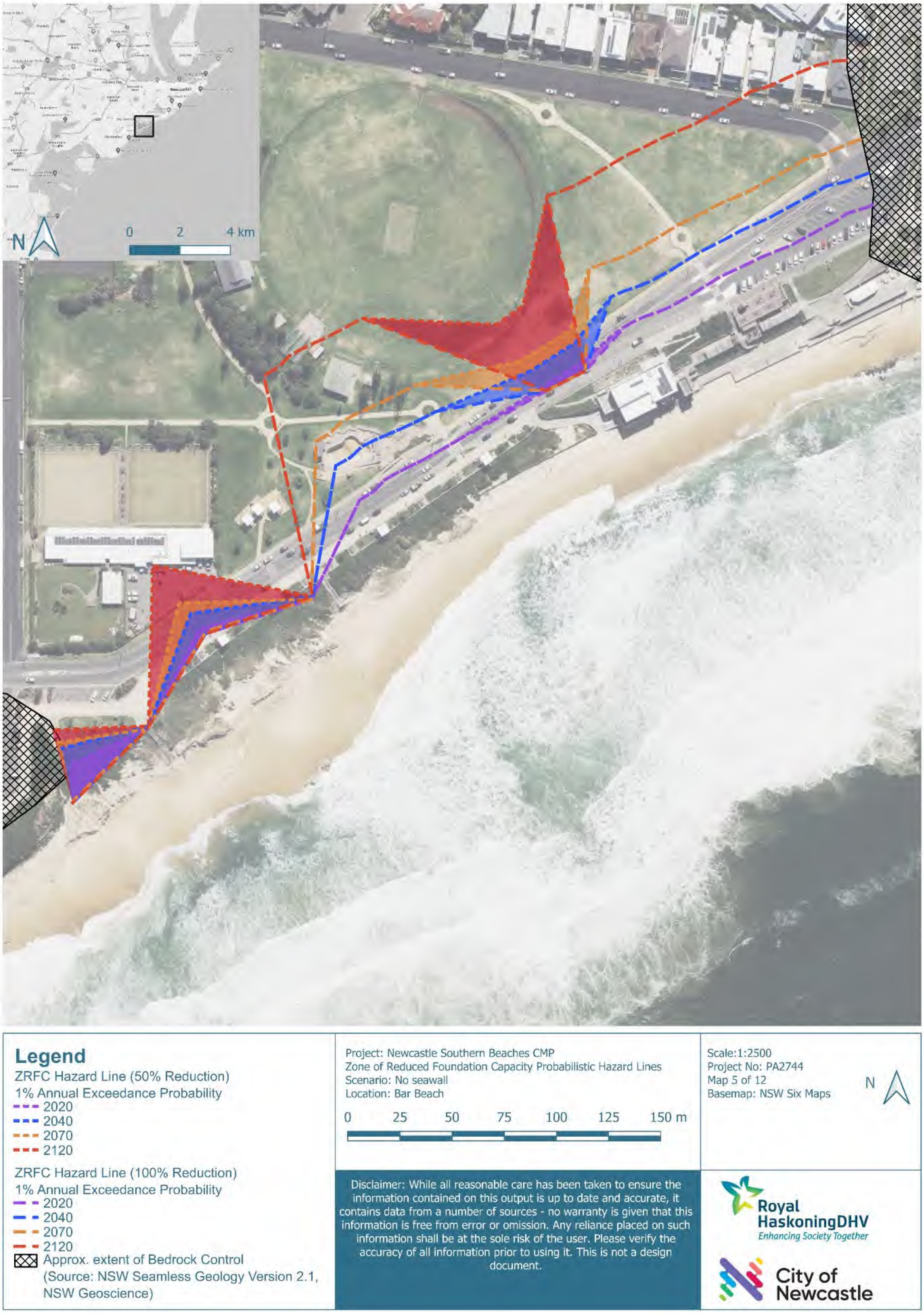

Figure 60: Summary 1% AEP Coastal erosion hazard lines for Bar Beach (No seawalls scenario).

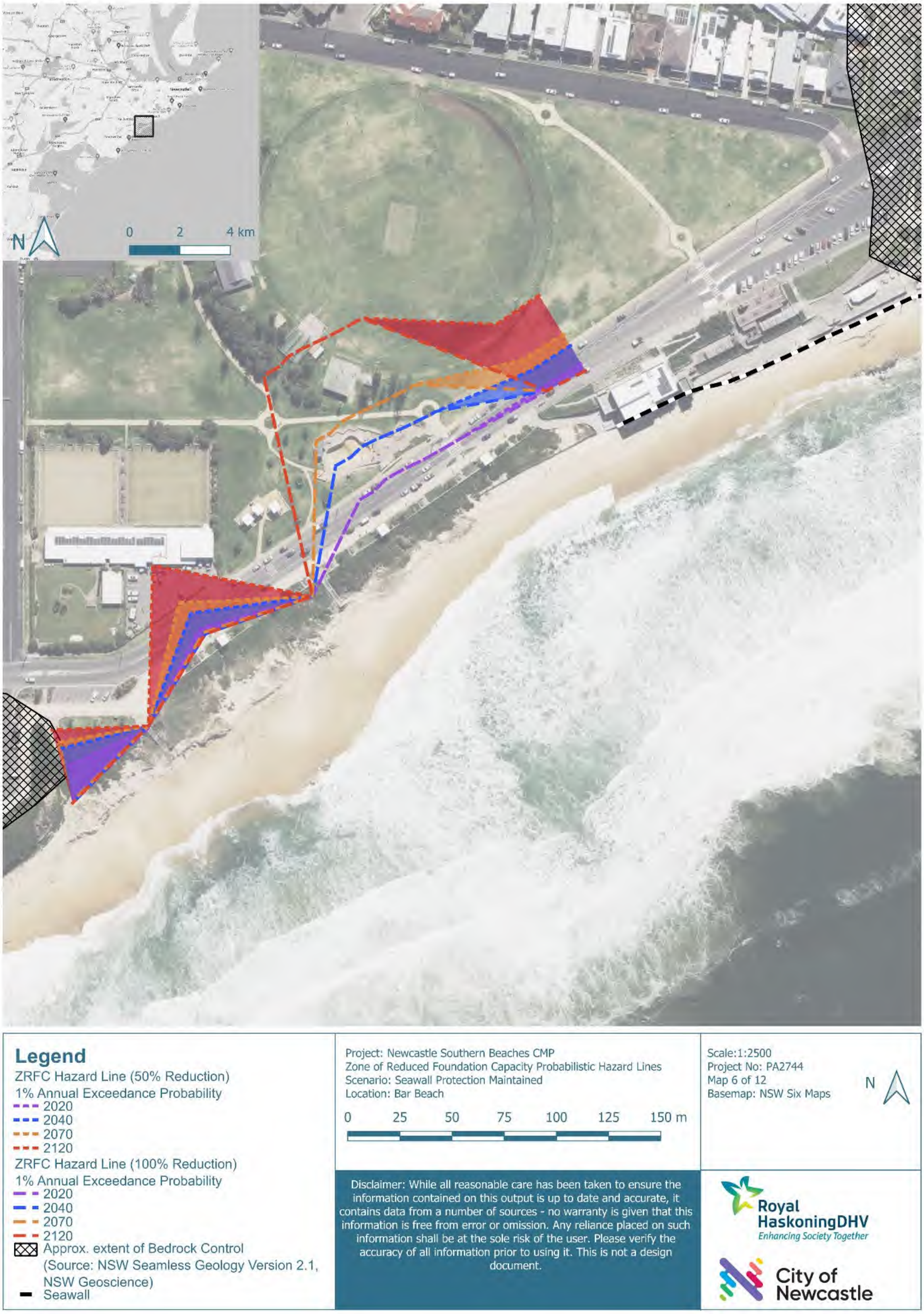

Figure 61: Summary 1% AEP Coastal erosion hazard lines for Bar Beach (seawalls maintained scenario).

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Figure 62: Summary 1% AEP Coastal erosion hazard lines for Newcastle Beach (no seawalls scenario).

Figure 63: Summary 1% AEP Coastal erosion hazard lines for Newcastle Beach (seawalls maintained scenario).

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Figure 64: Summary 1% AEP Coastal erosion hazard lines for Nobbys Beach (no seawalls scenario).

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Figure 65: Summary 1% AEP Coastal erosion hazard lines for Newcastle Beach (no seawalls scenario).

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6.5.1 Key Findings

Table 12 summarises the high value assets/essential infrastructure at risk from the 1% AEP coastal erosion ZSA hazard and the planning period in which this occurs.

Table 12: Summary of assets affected by the 1% AEP ZSA coastal erosion hazard

Scenario	Planning Period	Assets that become at risk in this period*	Risk to Life
Seawalls maintained	Immediate	• portion of Bathers Way path directly north of The Cliff • Bathers Way path near middle of Bar Beach (opposite Empire Park skatepark) • Cooks Hill SLSC building (via outflanking from the south)	Risk to life occurs on all promenades, breakwater walkway and ocean baths listed unless pedestrian access is managed.
	2040	• Grass area at northern side of The Cliff • Bathers Way path along Memorial Drive • Memorial drive roadway (between Bar Beach Bowling Club and Cooks Hill SLSC)	
	2070	• Empire Park skatepark • Bar Beach Bowling Club carpark	
	2120	• Bar Beach Bowling Club buildings and bowling green • Kilgour Ave roadway (at southern end) • Empire Park tennis wall • Empire Park southern picnic shelters/BBQs/infrastructure	
No seawalls	Immediate	• Merewether Ocean baths and low level promenades • Heritage shelter on lower promenade in front of Surfhouse • Cooks Hill SLSC • Bar Beach low level promenades • Bar Beach high level promenade and kiosk • Newcastle low level promenades • Newcastle Baths and carpark and Canoe Pool • The Bathers Way and Esplanade roadway between Newcastle Baths and Nobbys Beach • Residential properties on The Esplanade opposite the Cowrie Hole • Newcastle breakwater walkway • Nobbys Beach promenade in front of café and SLSC	
	2040	• Newcastle Ocean baths and low level promenades • Mid-level promenades at Newcastle Beach i.e. seating area in front of kiosk and old skatepark area.	
	2070	• Ramp access to Cooks Hill SLSC • Bathers Way at top of beach access ramp from Dixon Park carpark • Lower level promenade east of Nobbys Beach main carpark • Horseshoe beach carpark	
	2120	• Upper promenade between Merewether SLSC and Surfhouse • Newcastle kiosk	

* Note: Risk to life and assets then increases in subsequent planning periods (but assets are not repeated in the table).

Additionally, the following assets are within the ZRFC and are therefore also at risk unless they are founded within the Stable Foundation Zone i.e. piles through the deeper, stable material. Further investigation is warranted to determine the details of the foundations of these assets.

Table 13: Summary of assets affected by the 1% AEP ZRFC coastal erosion hazard

Scenario	Planning Period	Assets that become at risk in this period*	Risk to Life
Seawalls maintained	Immediate	• Bathers Way path between The Cliff and Cooks Hill SLSC • Cooks Hill SLSC building (via outflanking from the south)	
	2040	• Memorial drive roadway (between Bar Beach Bowling Club and Cooks Hill SLSC) • Empire Park skatepark • Bar Beach Bowling Club carpark • Empire Park southern picnic shelters/BBQs/infrastructure	
	2070	• Bar Beach Bowling Club buildings	
	2120	• Bar Beach Bowling Club bowling green • Kilgour Ave roadway (at southern end) • Empire park tennis wall and cricket nets	
No seawalls	Immediate	• Merewether Ocean baths, associated buildings and low level promenades • Heritage shelter on lower promenade in front of Surfhouse • Henderson Pde roadway • Merewether Surfhouse • Merewether SLSC and café • John Pde Bathers Way, roadway and residential properties • Dixon Park Bathes Way • Bathers Way - The Cliff to Bar Beach carpark • Memorial Drive roadway • Cooks Hill SLSC • Bar Beach low level promenades • Bar Beach high level promenade and kiosk • Bar Beach carpark • Newcastle low level promenades • Newcastle Beach Kiosk, SLSC and high level promenade between Ocean St and Zaara St • The Bathers Way and Esplanade roadway between Newcastle Baths and Nobbys Beach • Nobbys Beach promenade in front of café, SLSC and carpark	Risk to life occurs on all promenades, breakwater walkway and ocean baths listed unless pedestrian access is managed.
	2040	• Dixon Park carpark • Dixon Park SLSC • Bar Beach Bowling Club carpark • Empire Park southern picnic shelters/BBQs/infrastructure • Shortland Esplanade roadway 50m either side of Zaara St • 48 and 29 Zaara St (cnr Zaara and Shortland Esplanade) • Newcastle Ocean baths and low level promenades	

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Scenario	Planning Period	Assets that become at risk in this period*	Risk to Life
		• Nobbys Beach carpark • Nobbys Beach SLSC and café • Entrance path to Newcastle (southern) breakwater	
	2070	• Bar Beach Bowling Club buildings • 55 Shortland Esplanade (Tyrell Towers) • Shortland Esplanade roadway from Ocean St to Moroney Ave • Rowing storage shed at Horseshoe Beach	
	2120	• Bar Beach Bowling Club bowling green • Kilgour Ave roadway (at southern end) • Empire Park tennis wall and cricket nets • 49 Telford St, 38 and 40 Zaara St	

* Note: Risk to life and assets then increases in subsequent planning periods (but assets are not repeated in the table).

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7 Coastal Processes Understanding

On the basis of the various assessments outlined in the previous sections, a review of the coastal processes understanding has been undertaken.

7.1 General

The study area coastline typically comprises embayed, south-east facing beaches, varying in length from approximately 600m to 1500m. As noted in WBM (2014), the predominant wave energy emanates from the south eastern sector as shown in the sea and swell wave roses from the Newcastle wave rider buoy (WRB) (operated by Port Authority of NSW) located in approximately 22 m water depth just south of the Hunter River entrance, as presented in **Figure 66.** Wave roses from Sydney (110km south) and Crowdy Head (150km north) are also presented in **Figure 67**.

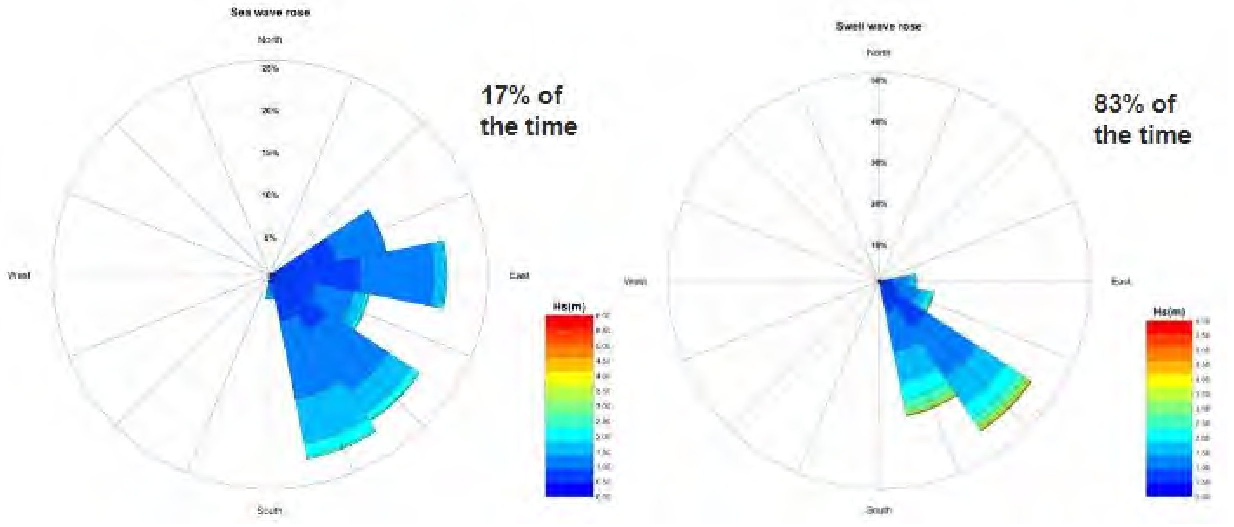

Figure 66: Long term wave roses at Newcastle WRH for sea conditions (Tp<8s) and swell conditions (Tp>8s) from November 2009 to March 2020. The percentage occurrence of each sea state is annotated (Source: Bluecoast, 2021)

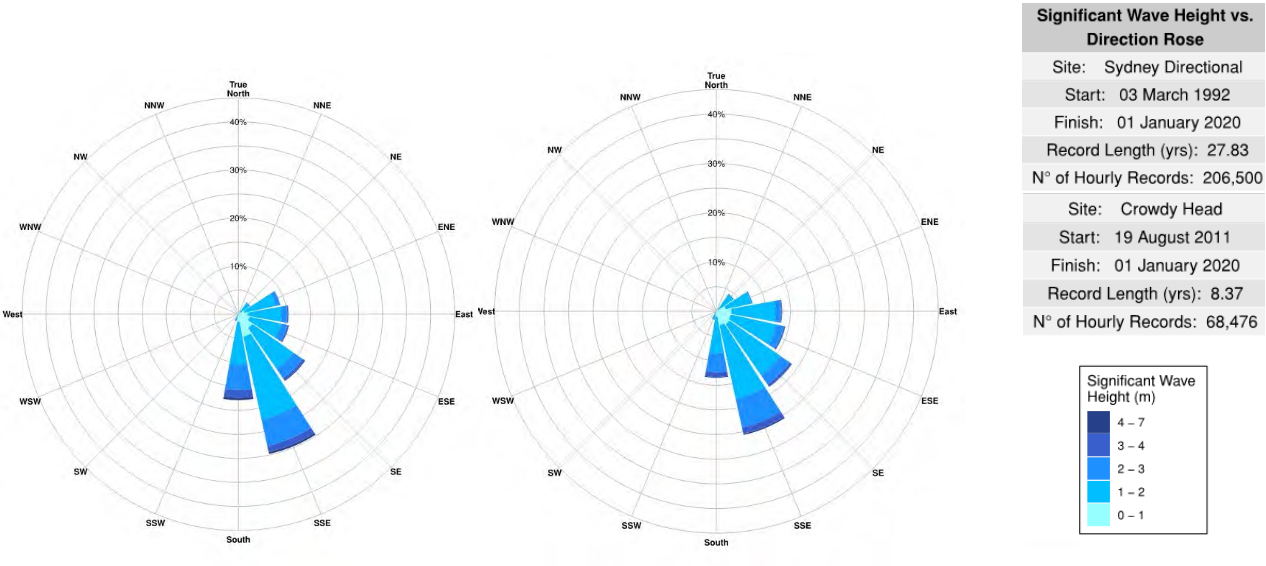

Figure 67: Sydney (left) and Crowdy Head (right) wave roses (acknowledging DPIE as owner of the data and to MHL for the collection and provision of the data).

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7.2 Key findings

BMT WBM (2014) provided an understanding of the coastal processes on the Newcastle southern beaches as outlined in **Section 2.1**. The review of additional data has provided an updated understanding and the key findings are outlined below.

The updated photogrammetric analysis indicated that in terms of historical recession trends, most of the beaches were considered to be stable which is consistent with the previous findings.

The updated analysis of Nobbys Beach indicated that it is continuing to prograde at a long-term rate between 0.5m/year (northern end) and 1m/year (central section). This deviates from the previous assertion that progradation of Nobbys Beach was slowing and was expected to stabilise without sea level rise.

In agreement with previous studies, the updated coastal processes understanding indicates that complete sediment removal from upper beaches with cliffs or seawalls would occur more frequently as sea level rises and wave action occurs at a higher position on the beach. Timeframes for some areas to be comprised of exposed rock revetment or seawall without a sandy beach seaward of the structures were previously 2100, or even 2050. The recent analysis suggested this may occur earlier than previously considered likely based on the probabilistic hazard assessment.

Back beach areas at Burwood Beach and The Cliff to the Cooks Hill SLSC (CHSLSC) at Bar Beach are comprised of dunal sands, and therefore can retreat landward. However, at Bar Beach, this would necessitate the relocation of the roadway and Skate Park, and the sacrifice of sections of Empire Park. The updated analysis supports this projection, and the updated probabilistic erosion hazard assessment has brought the likely timing forward approximately 10 years.

Lower promenades at Newcastle, Merewether and Bar Beach, the Dixon Park boat ramp and Merewether and Newcastle Ocean Baths and Shortland Esplanade experience overtopping, and as noted in previous studies, this is expected to increase in frequency and volume into the future, impacting on the condition and use of the structures and assets.

As noted in previous studies, wind blow sand drift continues to occur mainly; up the ramps at Bar Beach (south of the CHSLSC) and Dixon Park, and from Nobbys Beach over into Horseshoe Beach and the Hunter River.

This updated review of the coastal processes had the benefit of additional data and satellite bathymetry analysis which has highlighted the complexity of the sediment pathways around natural control features. Much of the sub aqueous nearshore and offshore areas are underlain by rock platforms or reefs that act as these control features (refer **Figure 5** and **Figure 6**). This effectively limits any lowering of the seabed level that would otherwise result from erosive wave forces. The rock features also influence the currents and can influence the location of rip cells.

The satellite bathymetry analysis identified a seasonal pattern of nearshore erosion and offshore deposition over winter and return of sediment onshore during summer months. The seaward migration of the sandbar in winter shows the natural cross-shore adjustment of the beach in response to increased wave energy in the winter. Calmer summer conditions tend to result in lower energy beach states (e.g. reflective and low tide-terrace) with welded or welding sandbars (Wright and Short, 1984). Conversely, high energy states tend to prevail in winter leading to high energy beach states (e.g. rhythmic bar beach) with offshore sandbars.

The satellite bathymetry analysis showed some evidence of increased build-up against the breakwater wall at Nobby's Head in the winter months, indicating both cross-shore transport of sand from Nobby's Beach itself, but also alongshore transport of sand from South to North accumulating against the wall in the more energetic and southerly winter wave climate. There is also evidence to indicate a seasonal tendency for the bypassing of the rocky headlands and points which delineate the embayed beaches along this coastline. Winter deposition can be seen in the lee of these features and at the southern ends of each of the embayed beaches.

The beaches experience significant cross-shore sediment transport during episodic short-term events. However, longer-term trends indicate relative stability (refer **Section 2.2**). Net northerly sediment transport bypasses the headlands and smaller control features in an episodic and often seasonal regime whereby the larger winter swell events from the south/southeast, transport sediment around the rocky headlands. This net northerly sediment transport is obstructed by the southern breakwater to the Hunter River and as a result Nobbys Beach has been prograding since the breakwaters construction in the early 1900's.

Figure 68 provides a comparison of the hazard lines from the BMT WBM (2014) study and the updated analysis for the erodible section of coastline at Bar Beach. Both of these map the ZSA line, though RHDHV map the 2040 timeframe versus BMT WBM which maps the 2050 timeframe. It is noted that the BMT WBM 'Unlikely' line is most closely represented by the RHDHV '1% AEP' hazard line. From the figure it is evident that the lines are very similar with a similar degree of erosion hazard likelihood occurring approximately 10 years earlier than previously estimated. Noting that this comparison is between a qualitative, deterministic approach (BMT WBM, 2014) and the quantitative, probabilistic approach applied herein. The difference in approach could account for a significant proportion of the estimated difference in timing.

Many of the subaerial beaches are also underlain by rock and rock platforms which are exposed intermittently. These natural rock formations have afforded the beaches protection from erosion as evidenced in some of the significant storm events when the beaches were striped back to rock (refer **Figure 3** of Merewether/Dixon Park Beaches and **Figure 7** to progressing south from Bar Beach to Merewether Beach).

The updated coastal erosion hazard analysis has assumed that the dunes are comprised of soft erodible sediment. It is noted that there are some areas of harder rock evident and further geotechnical investigations to identify and define further rock outcrops or platforms could have a significant impact on the delineation of erosion hazard, by limiting the full realisation of the long-term coastal erosion hazard reported herein.

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Figure 68: 2040 coastal erosion hazard lines for Bar Beach area and BMT WBM (2014) 2050 hazard lines (INSET)

A summary graphic of the coastal processes is provided in **Figure 69** to **Figure 72.**

Figure 69: Coastal processes graphic – Burwood Beach

Figure 70: Coastal processes graphic – Merewether, Dixon Park and Bar Beach

Figure 71: Coastal processes graphic – Newcastle Beach

Figure 72: Coastal processes graphic – Nobbys Beach

7.3 Conclusions

The probabilistic erosion and inundation hazard assessments and the updated coastal processes understanding have highlighted a number of areas of particular vulnerability along Newcastle's southern beaches. The level of risk is higher than previously understood and there is an increased urgency to plan and implement management strategies in these areas.

The Bar Beach frontage is particularly exposed to coastal erosion and inundation and numerous assets including; SLSC buildings, ramps, Bathers Way pathway and the Memorial Drive roadway have been identified as being currently at risk. Recent storm events and the resulting denuding of the Bar Beach frontage and damage to Cooks Hill SLSC access structures have also brought this issue into particular focus.

Merewether and Dixon Park beaches have been similarly impacted by recent storm events and the updated assessment illustrates the dependence on the existing coastal protection structures along this frontage.

The updated coastal processes understanding has highlighted the complexity of processes particularly along the Merewether to Cooks Hill frontage due to the numerous influences and complex rock features.

7.3.1 Limitations

As noted in the coastal erosion hazard assessment, one of the main limitations of the current hazard assessment and understanding is a lack of geotechnical data defining the presence of non-erodible materials at the back of the beach and beneath the beach. Due to lack of detailed and accurate mapping of these rock features, it is assumed that all material other than the bedrock mapped in Minview (as noted above) is soft erodible material and that rock platforms beneath the beach sands are located at depths below 0m AHD and therefore do not limit the erosion storm demand in the horizontal plane. These assumptions may lead to overestimation of erosion setbacks.

The other main limitation to the current assessment is the lack of condition assessment data for existing coastal protection structures to enable their effectiveness and remaining service life to be evaluated and considered in the assessment. As noted previously, two scenarios have therefore been considered i.e. 'no seawalls' and 'seawalls maintained'. These scenarios illustrate the spectrum of risk to assets landward of these structures, if these structures are neglected and fail, or maintained and upgraded to a functional standard.

Cliff instability was not included in the scope of this study. However, it is noted that with increased erosion of the beaches fronting many of the coastal cliff areas, such as The Cliff (between Bar Beach and Dixon Park), the stability of these cliffs will require ongoing assessment and monitoring.

The coastal processes understanding has been improved as a result of the review undertaken. However, it is noted that the coastal processes will continue to evolve as the coastline changes into the future. The recent exposure of significant rock platforms in front of The Cliff near the centre of this frontage and their influence on rip locations and sediment transport between the Merewether/Dixon Park end of the beach and Bar Beach is an example of how coastal processes may evolve and change over time.

7.3.2 Recommendations

Based on the limitations outlined above it is recommended that the following be undertaken:

- additional geotechnical to better define non-erodible back beach material at Bar Beach and Dixon Park and rock platform extents and levels on these beaches.
- detailed technical condition assessment of all existing coastal protection structures by qualified coastal engineers to enable their effectiveness and remaining service life to be evaluated and remediation/maintenance works to be designed and implemented as required;
- ongoing cliff stability monitoring and assessment;
- ongoing review of coastal processes understanding and sediment transport to review and inform future management of these frontages.

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9 Glossary

The contents of this glossary are included with acknowledgement of the Coastal Management Glossary developed by State of NSW and Office of Environment and Heritage (2018)

This glossary provides definitions of terms that are in common use when describing coastal processes and coastal management. It is not a comprehensive dictionary of coastal terminology. It supplements definitions provided in the *Coastal Management Act 2016* (CM Act) and State Environment Planning Policy (Coastal Management) 2018 (CM SEPP).

The definitions used in the glossary are sourced from the US Army Corps of Engineers and from glossaries provided in relevant Standards, as well as from other coastal management guidelines in current use in Australia.

Acceptable risk – a risk that, following an understanding of the likelihood and consequences, is sufficiently low to require no new treatments or actions to reduce risk further. Individuals and society can live with this risk without feeling the necessity to reduce risks further. Positive and negative risks are negligible or so small that no risk treatments are needed.
Accretion – as the build-up of sediments to form land or shoaling in coastal waters or waterways. It may be either natural or artificial. Natural accretion is the build-up of land on the beach, dunes, or in the water by natural processes, such as waves, current and wind. Artificial accretion is a similar build-up of land resulting from built structures such as groynes or breakwaters, or activities such as filling and beach nourishment, or also aggradation. (USACE)
Adaptation – adjustment in natural or human systems in response to actual or expected climate change or its effect, to moderate harm or to take advantage of beneficial opportunities.
Alongshore or Longshore – parallel to and near the shoreline.
Ambulatory – in relation to the coastal foreshore, this means the movement of the foreshore seaward or landward over time, in response to coastal processes and sediment budgets. The movement of the foreshore may occur at different rates or in different directions along a beach or within a sediment compartment.
Annual Exceedance Probability (AEP) – the probability (expressed as a percentage) of an exceedance (e.g. large wave height or high water level) in a given year.
Artificial nourishment – see ‘beach nourishment’
Asset – something of value and may be environmental, economic, social, recreational or a piece of built infrastructure.
Audit – independent appraisal of social, financial and environmental performance.
Average Recurrence Interval (ARI) – the average time between which a threshold is reached or exceeded (e.g. large wave height or high water level) of a given value. Also known as Return Period.
Back beach or back shore – the zone of the shore or beach lying between the foreshore and the coastline comprising the berm or berms and acted upon by waves only during severe storms, especially when combined with exceptionally high water.
Bathymetric data – measurements of the shape of the bed or the depth of a body of water.
Beach – the CM Act defines beach as an area that is generally composed of sand or pebbles or similar sediment that extends landward from the lowest astronomical tide to the line of vegetation or bedrock or structure.
Beach erosion – refers to landward movement of the shoreline and/or a reduction in beach volume, usually associated with storm events or a series of events, which occurs within the beach fluctuation zone. Beach erosion occurs due to one or more process drivers; wind, waves, tides, currents, ocean water level, and downslope movement of material due to gravity.

Beach fluctuation zone – CM Act defines beach fluctuation zone as ‘the range of natural locations a beach profile occupies from its fully accreted condition to its fully eroded condition, with
a) a landward limit defined by the escarpment resulting from the erosion associated with a 1% storm event or a more extreme event of record, whichever is the greater landward limit, and
b) a seaward limit that is the 40m depth seaward of the highest astronomical tide for the open coast and 10m depth seaward of the highest astronomical tide for estuaries or tidal coastal lakes.’
Beach material – granular sediments, usually sand or shingle moved by the sea.
Beach nourishment – beach restoration or augmentation using clean dredged or fill sand. Dredged sand is usually hydraulically pumped and placed directly onto an eroded beach or placed in the littoral transport system. When the sand is dredged in combination with constructing, improving, or maintaining a navigation project, beach nourishment is a form of beneficial use of dredged material.
Beach plan shape – the shape of the beach in plan; usually shown as a contour line, combination of contour lines or recognisable features such as beach crest and/or the still water line.
Beach profile – a cross-section taken perpendicular to a given beach contour; the profile may include the face of a dune or seawall, extend over the backshore, across the foreshore, and seaward underwater into the nearshore zone.
Beach ridge – a nearly continuous mound or ridge of beach material (including sand, shell, coral and gravel) that has been shaped by wave or other action. Beach ridges may occur singly or as a series of approximately parallel deposits. A beach ridge plain is composed of a series of parallel beach ridges. The ridges may be of different heights and spacing. They provide evidence of changes to deposition and erosion rates over time.
Beach scraping – also referred to as ‘nature assisted beach enhancement’ (NABE) is a mechanical intervention to speed up the natural processes of berm and foredune recovery after a storm event.
Beach system – the CM Act defines as ‘the processes that produce the beach fluctuation zone and the incipient foredunes and foredunes landward of the relevant beach’. In general, this means coastal lands, composed of sand, gravel or shell, between a seaward limit of 40 metres depth in the State coastal waters and a landward limit at the lee side of the dunes.
Bedrock – a general term for the rock, usually solid, that underlies soil or other unconsolidated, superficial material.
Beneficial uses – placement or use of dredged material for some productive purpose. May involve either the use of the dredged material or the placement site as the integral component of the use.
Benthic – of, pertaining to, or related to, the bottom of a stream or other body of water.
Berm – on a beach, a nearly horizontal plateau on the beach face or backshore, formed by the deposition of beach material by wave action or by means of a mechanical plant as part of a beach renourishment scheme. Some natural beaches have no berm, others have several.
Breaker zone – the zone within which waves approaching the coastline commence breaking, typically in water depths of between five and 10 metres for ocean coasts, but sometimes in shallower water.
Breakwater – a man-made structure protecting a shore area, harbour, anchorage or basin from waves.
Bruun Rule – a commonly used method for estimating the response of a sandy shoreline to rising sea levels.
Bypassing, sand – hydraulic or mechanical movement of sand from the accreting up–drift side to the eroding down-drift side of an inlet or harbour entrance. The hydraulic movement may include natural movement as well as movement caused by humans.
Catchment area – the area which drains naturally to a particular point on a river, thus contributing to its natural discharge.
Cliff – a high, steep face of rock; a precipice.
Climate – the characteristic weather of a region, particularly regarding temperature and precipitation, averaged over some significant interval of time (years).

Climate change – occurs naturally in response to long-term variables, but often used to describe a change of climate that is directly attributable to human activity that alters the global atmosphere, increasing change beyond natural variability and trends.
Closure depth – do not detect vertical seabed changes, generally considered the seaward limit of littoral transport (collected over several years). The depth can be determined from repeated cross-shore profile surveys or estimated using formulas based on wave statistics. Note that this does not imply the lack of sediment motion beyond this depth.
Coast – a strip of land of variable width that extends from the shoreline inland to the first significant landform that is not influenced by coastal processes (such as waves, tides and associated currents).
Coastal asset – includes natural features of the coastal zone, including landforms, ecosystems and species; and built assets such as infrastructure, public and private buildings or structures.
Coastal dune – vegetated and unvegetated sand ridges built-up at the back of a beach. They comprise dry beach sand that has been blown landward and trapped by plants or other obstructions. Stable sand dunes act as a buffer against wave damage during storms, protecting the land behind from salt water intrusion, sea spray and strong winds. Coastal dunes also act as a reservoir of sand to replenish and maintain the beach at times of erosion.
Coastal engineering – a branch of civil engineering that applies engineering principles specifically to projects within the coastal zone (nearshore, estuary, marine, and shoreline).
Coastal environment – the landscape, functions and communities in the coastal zone.
Coastal environment area – land identified in the CM Act as land containing coastal features such as coastal waters of the State, estuaries, coastal lakes, coastal lagoons and land adjoining those features, including headlands and rock platforms. The CM SEPP maps the extent of the coastal environment area for planning purposes.
Coastal forcing – the natural processes which drive coastal hydro and morpho-dynamics (e.g. winds, waves, tides, etc.).
Coastal hazard – defined in the CM Act to mean the following:

- beach erosion
- shoreline recession
- coastal lake or watercourse entrance instability
- coastal inundation
- coastal cliff or slope instability
- tidal inundation
- erosion and inundation of foreshores caused by tidal waters and the action of waves, including the interaction of those waters with catchment floodwaters.

Coastal inundation – coastal inundation occurs when a combination of marine and atmospheric processes raises the water level at the coast above normal elevations, causing land that is usually ‘dry’ to become inundated by sea water. Alternatively, the elevated water level may result in wave run-up and overtopping of natural or built shoreline structures (e.g. dunes, seawalls).
Coastal Management Area – any one of four areas that make up the coastal zone as defined in the CM Act. These are the coastal wetlands and littoral rainforests area, coastal vulnerability area, coastal environment area, and the coastal use area.
Coastal management objectives – specific objectives identified in the CM Act for each of the four coastal management areas.
Coastal management program – a long-term strategy for the coordinated management of land within the coastal zone, prepared and adopted under Part 3 of the CM Act.
Coastal management units – may be identified for the purposes of coastal management at a local or community level. They are sections of the coast that are affected by similar coastal hazards and risks or have several important social and economic features in common.
Coastal model – model of a coastal area. Often a movable bed model used to reproduce coastal sediment transport; or a model of estuary circulation.

Coastal processes – marine, physical, meteorological and biological activities that interact with the geology and sediments to produce a particular coastal system.
Coastal protection works – the CM Act defines coastal protection works as:
a) beach nourishment
b) activities or works to reduce the impact of coastal hazards on land adjacent to tidal waters, including (but not limited to) seawalls, revetments and groynes.
Coastal risk – a risk that relates to the likelihood and consequences of coastal hazards or threats affecting coastal values.
Coastal sediment compartment – an area of the coast defined by its sediment flows and landforms. Coastal sediment compartments may be mapped at primary, secondary or tertiary (local) scales. Boundaries are generally defined by structural features related to the geologic frameworks that define the planform of the coast.
Coastal threat – a process or activity that is putting pressure on or impacting on the health or function of a coastal ecosystem, or on the amenity and social or cultural value of the coastal landscape. Examples include the discharge of effluent or poor-quality stormwater into coastal lakes and lagoons, discharges from acid sulfate soils, or the spread of invasive species. High recreational demand can also be a threat to coastal ecosystem health.
Coastal use area – land identified by the CM Act and CM SEPP as being land adjacent to coastal waters, estuaries, coastal lakes and lagoons where development is or may be carried out (now or in the future). The CM SEPP maps the extent of the coastal use area for planning purposes.
Coastal vulnerability area – defined in the CM Act as land subject to seven coastal hazards.
Coastal wetland – wetlands are areas that are inundated cyclically, intermittently or permanently with fresh, brackish or saline water and have soils, plants and animals in them that are adapted to, and depend on, moist conditions for at least part of their lifecycle. Coastal wetlands include marshes, mangroves, swamps, melaleuca forests, casuarina forests, sedgelands, brackish and freshwater swamps and wet meadows.
Coastal zone – as defined in the CM Act and CM SEPP: the area of land comprised of the following coastal management areas: the coastal wetlands and littoral rainforest area, the coastal vulnerability area, the coastal environment area and the coastal use area.
Coastal zone (general) – the transition zone where the land meets water, the region that is directly influenced by marine and lacustrine hydrodynamic processes. Extends offshore to the continental shelf break and onshore to the first major change in topography above the reach of major storm waves. On barrier coasts, includes the bays and lagoons between the barrier and the mainland.
Coastal zone management – the integrated management of issues affecting the coastal zone. Coastal zone management is not restricted to coastal protection works, but also includes development and activities to manage the economical, ecological, cultural and social values of the coast.
Coastal zone management plan – a management plan for the open coast, an estuary or a coastal lake, prepared under the *Coastal Protection Act 1979*.
Community objectives – local scale objectives for management of the coast, based on the aspirations and priorities of local communities. When included in a coastal management program, these objectives will be based on, and must align with, the objectives expressed in a council's Community Strategic Plan.
Conceptual model – a simplified representation of the physical hydro-geologic setting. This includes the identification and description of the geologic and hydrologic framework, media type, hydraulic properties, and sources and sinks of flow.
Consequence – the outcome or impact of a hazard or threat.
Cost analysis – evaluation of the specific cost elements of a contract or proposal to appraise their statutory compliance, distribution, and reasonableness.
Cross-shore transport – refers to the sediment moved in a cross-shore direction to the coastline induced by water motions due to waves and currents.

Current, coastal – one of the offshore currents flowing generally parallel to the shoreline in the deeper water beyond and near the surf zone; these are not related genetically to waves and resulting surf, but may be related to tides, winds, or distribution of mass.
Current, littoral – any current in the littoral zone caused primarily by wave action; e.g. longshore current, rip current.
Current, longshore – the littoral current in the breaker zone moving essentially parallel to the shore, usually generated by waves breaking at an angle to the shoreline.
Cusp (or beach cusp) – one of a series of short ridges on the foreshore separated by crescent-shaped troughs spaced at more or less regular intervals. Between these cusps are hollows. The cusps are spaced at somewhat uniform distances along beaches. They represent a combination of constructive and destructive processes.
Design storm – a hypothetical extreme storm with waves that coastal protection structures will often be designed to withstand. The severity of the storm (i.e. return period) is chosen in view of the acceptable level of risk of damage or failure. A design storm consists of a design wave condition, a design water level and a duration.
Design wave – in the design of harbour works, coastal protection works etc., the type or types of waves selected as having the characteristics against which protection is desired.
Diffraction of water waves – the phenomenon by which energy is transmitted laterally along a wave crest. When a part of a train of waves is interrupted by a barrier, such as a breakwater, the effect of diffraction is manifested by propagation of waves into the sheltered region within the barrier's geometric shadow.
Drowned river valley – a type of wave-dominated estuary, usually a deep bedrock embayment, with a wide, deep mouth.
Dune – underwater: flow-transverse bedform with spacing from under one metre to over 1000 metres that develops on a sediment bed under unidirectional currents.
Dune – subaerial (see coastal dune).
East Coast Low – an intense low-pressure system that occurs off the east coast of Australia, bringing storms, high waves and heavy rain. East coast lows generally occur in autumn and winter off NSW, southern Queensland and eastern Victoria.
Economic evaluation – an assessment that helps decision-makers to understand the socioeconomic implications of adopting alternative management options and to make choices that will provide net benefits to the community. Cost-benefit analysis is a type of economic evaluation that considers and evaluates a wide range of costs and benefits associated with a proposal, in qualitative or quantitative (monetary) terms (with future costs and benefits reduced to today's prices), compared with a base case. It may be used in conjunction with other criteria (such as technical feasibility, community acceptance or environmental impact) to select optimal management responses. A multi-criteria assessment is not an economic evaluation but may assist decision-making in other ways.
Ecosystem – the living organisms and the non-living environment interacting in an area, encompassing the relationships between biological, geochemical, and geophysical systems; or a community and its environment including living and non-living components.
El Niño southern oscillation (ENSO) – a year to year fluctuation in atmospheric pressure, ocean temperatures and rainfall associated with El Niño (warming of the oceans in the equatorial eastern and central Pacific). El Niño tends to bring below average rainfall.
Environment – surroundings, the physical and biological system supporting life, including humans and their built environment. Includes cultural features of archaeological or historical interest.
Eolian or Aeolian processes – pertaining to the wind, especially used with deposits such as loess and dune sand, and sedimentary structures like wind-formed ripple marks.
Erosion – the wearing away of land by the action of natural forces. On a beach, the carrying away of beach material by wave action, tidal currents, littoral currents, or by deflation.

Escarpment (storm bite) – the landward limit of erosion in the dune system caused by storm waves. At the end of a storm the escarpment may be nearly vertical; as it dries out the sand slumps to a typical slope of one vertical to 1.5 horizontal.
Essential infrastructure – CM Act defines to include infrastructure for the following purposes: electricity generation, transmission and distribution, telecommunications, rail, roads, gas, sewerage systems, water supply systems or stormwater management systems, airports, ports shipping and harbours.
Essential services – those services that are considered essential to the life of communities and include energy, transport, health services, sanitation services, water and welfare institutions (*State Flood Plan and Essential Services Act 1988*).
Essential utilities – those services that are considered essential to public safety and organised communities. Such services include electricity, gas, water, sewerage, sanitation, telecommunications and waste collection (*State Flood Plan and Essential Services Act 1988*).
Estuary – CM Act defines as any part of a river, lake, lagoon, or coastal creek whose level is periodically or intermittently affected by coastal tides, up to the highest astronomical tide.
Estuary inundation – flooding around the shoreline of an estuary or coastal lake, by a mixture of tidal water and catchment flood water.
Exposure – the potential for assets to be impacted by a hazard based on data or modelling of the hazard.
Extreme storm event – storm for which characteristics (wave height, period, water level etc.) were derived by statistical 'extreme value' analysis. Typically, these are storms with average recurrence intervals (ARI) ranging from one to 100 years.
Fit for purpose – right for the job it is intended to do. A fit for purpose assessment considers the level of data detail and the types of consultation required to make a reasonable management decision. In general, the detail and consultation required will increase with risk, complexity and impact.
Foredune – the larger and more mature dune lying between the incipient dune and the hind-dune area. Foredune vegetation is characterised by grasses and shrubs. Foredunes provide an essential reserve of sand to meet the erosion demand during storm conditions. During storm events, the foredune can be eroded back to produce a pronounced dune scarp.
Foreshore – the part of the shore, lying between the crest of the seaward berm (or upper limit of wave wash at high tide) and the ordinary low water mark, that is ordinarily traversed by the uprush and backrush of the waves as the tides rise and fall; or the beach face, the portion of the shore extending from the low water line up to the limit of wave uprush at high tide. The CM Act defines the foreshore as 'the area of land between highest astronomical tide and the lowest astronomical tide'.
Gabion – steel wire mesh basket to hold stones or crushed rock to protect a bank or bottom from erosion; or structures composed of masses of rocks, rubble or masonry held tightly together usually by wire mesh to form blocks or walls. Sometimes used on heavy erosion areas to retard wave action or as a foundation for breakwaters or jetties.
Geomorphology – that branch of physical geography which deals with the form of the earth, the general configuration of its surface, the distribution of the land, water, etc.; or the investigation of the history of geologic changes through the interpretation of topographic forms.
Geotechnical investigations – subsurface investigation of soils, rock, and other strata for the purposes of engineering design.
Geotextile – a synthetic fabric which may be woven or non–woven and used as a filter.
Global warming – the increase in the earth's temperature due to the emissions of greenhouse gases.
Groyne – a shore protection structure built (usually perpendicular to the shoreline) to trap littoral drift or retard erosion of the shore; or a narrow, roughly shore normal structure built to reduce longshore currents, and/or to trap and retain littoral material. Most groynes are of timber or rock and extend from a seawall, or the backshore, well onto the foreshore and rarely even further offshore.
Hard defences (protection) – general term applied to impermeable coastal defence (protection) structures of concrete, timber, steel, masonry, etc., which reflect a high proportion of incident wave energy.

Hazard – a process, or activity that affects an asset or value. See also 'coastal hazards' which are the specific hazards defined in the CM Act.

Highest astronomical tide (HAT) – the highest level which can be predicted to occur under average meteorological conditions and any combination of astronomical conditions. In Australia HAT is calculated as the highest level from tide predictions over the tidal datum epoch (TDE), this is currently set to 1992 to 2011.

The HAT and the **Lowest Astronomical Tide (LAT)** levels will not be reached every year. LAT and HAT are not the extreme water levels which can be reached, as storm surges may cause considerably higher and lower levels to occur.

Holocene – an epoch of the Quaternary period, from the end of the Pleistocene, about 8000 years ago, to the present time.

Hydrodynamic – relates to the specific scientific principles that deal with the motion of fluids and the forces acting on solid bodies immersed in fluids, and in motion relative to them.

Impacts – include damage, harm or losses to exposed communities, property, services, livelihoods, access, use and amenity, heritage, ecosystems and the environment because of exposure and sensitivity. Impacts may also be positive.

Incipient dune – the most seaward and immature dune of the dune system. Vegetation characterised by grasses such as spinifex. On an accreting coastline, the incipient dune will develop into a foredune.

Inshore zone – in beach terminology, the zone of variable width extending from the low water line through the breaker zone.

Interdecadal Pacific Oscillation (IPO) – an irregular interdecadal sea surface temperature in the Pacific Ocean that modulates the strength and frequency of the El Niño Southern Oscillation.

Intertidal – that land area between mean low water and mean high water that is inundated periodically by tides.

King tides – any high water level that is well above the average, commonly applied to two spring tides that are the highest for the year, one during summer and one in winter.

La Niña – the opposite state to El Niño, occurring when the SOI is positive. La Niña tends to bring above average rainfall over much of Australia.

Lagoon – a shallow body of open water, partly or completely separated from the sea by a coastal barrier or reef. Sometimes connected to the sea via an inlet.

Likelihood – the chance of something happening, whether defined, measured or determined objectively or subjectively, qualitatively or quantitatively, and described using general terms or mathematically (such as a probability or a frequency over a given time period).

Littoral – of or pertaining to a shore, especially of the sea. Often used as a general term for the coastal zone influenced by wave action, or, more specifically, the shore zone between the high and low water marks.

Littoral transport rate – rate of transport of sedimentary material parallel or perpendicular to the shore in the littoral zone. Usually expressed in cubic metres per year. Commonly synonymous with longshore transport rate.

Local council – for the purposes of the coastal management manual, a council that is wholly or partly within the coastal zone of NSW.

Longshore transport (littoral drift) – refers to the sediment moved along a coastline under the action of wave-induced longshore currents (Dean and Dalrymple, 2002). The net drift is the sum of the positive (conventionally northwards direction in NSW) and negative (southwards in NSW) direction. The gross drift is the sum of the drift magnitudes (absolute values). The differential drift is the difference between the net drift into and out of a coastal compartment. Both gross and net drift are typically averaged over a year and expressed in m3/yr.

Macro-invertebrates – large invertebrates which may be found in waterways and consisting largely of larval insects, worms, and related organisms.

Maintenance dredging – the recurrent dredging of sediment from a waterway, including existing navigation channels, approaches and berths, to allow safe navigation by commercial or recreational boating traffic.
Managed retreat – also referred to as managed realignment. For the coastal zone (generally the coastal vulnerability area), managed retreat allows the shoreline to migrate landward unimpeded. It allows an area that was not previously exposed to coastal processes and hazards to become exposed, for instance by removing or breaching coastal protection works. Managed retreat may involve the relocation landward, out of a coastal risk area, of homes and infrastructure under threat from coastal erosion, recession or inundation. It may also involve the deliberate setting back (moving landward) of the existing line of sea defence to obtain engineering or environmental advantages. During a managed retreat process, a new foreshore area or new intertidal habitat may be created.
Marine sediment – sediment originating from the sea.
Mean high water mark – the line of the medium high tide between the highest tide each lunar month (the springs) and the lowest tide each lunar month (the neap) averaged over out over the year. In NSW, the methods for determining the position of the MHWM are outlined in the Crown Directions to Surveyors - No. 6 Water as a Boundary.
Mean sea level – the arithmetic mean of hourly heights of the sea at a tidal station, observed over a long period of time.
Multi-criteria analysis – a logical and structured decision-making tool for complex problems involving multiple factors or criteria, where a consensus is difficult to achieve. It may involve processes such as ranking, rating (with relative or ordinal scales) or pairwise comparisons. The process allows participants to consider, discuss and test complex trade-offs among alternatives
Natural character – includes all-natural aspects of the land and sea, including the underlying ecological, hydrological and geomorphological processes that shape landforms (including underwater features) and the natural movements of water and sediment. Natural character also includes aspects of the environment that affect human experience including the natural darkness of the night sky, the sounds and smell of the coast, and the context and setting of natural places.
Natural coastal processes – the coastal processes over which people have no control, such as wind, waves and tides.
Natural heritage – the natural living and non-living components, that is, the biodiversity and geodiversity, of the world that humans inherit.
Near shore – the area of ocean close to the coast that is affected by waves, tides and longshore currents.
NSW Coastal Council – established under Part 4 of the CM Act. A group of three to seven coastal experts, appointed by the Minister to provide advice on coastal management issues.
Outflanking or end effects – erosion behind or around the land-based end of a groyne, jetty or breakwater or the terminus of a revetment or seawall, usually causing failure of the structure or its function.
Overfill ratio - also known as the **overfill** factor, describes the volume of borrow sediment that, in theory, will ultimately yield a residual unit volume of sediment on the beach, after grain sorting and losses.
Overwash – the part of the wave uprush that runs over the crest of a berm or structure and does not flow directly back to the ocean or lake. When waves overtop a coastal protection structure they often carry sediment landwards which is then lost to the beach system. Also defines a process in which waves penetrate inland of the beach, which is common on low barriers.
Pollution – the condition caused by the presence of substances of such character and in such quantities that the quality of the environment is impaired; or the human-induced alteration of the chemical, physical, biological or radiological integrity of an aquatic ecosystem.
Probabilistic hazard assessment – a risk-based approach to managing coastal hazard that takes uncertainty into account by considering both the likelihood and consequence of hazard occurrence. It applies a stochastic simulation to evaluate coastal processes. The technique uses a distribution of values for each parameter to account for expected variation, or uncertainty, rather than single values. Parameters

are then combined by a monte-carlo technique to produce a probabilistic forecast of future shoreline position. This is quite different to traditional deterministic hazard assessments that produce single values for beach erosion and shoreline recession.

Probabilistic model – mathematical model in which the behaviour of one or more of the variables is either completely or partially subject to probability laws.

Progradation – the building forward or outward toward the sea of a shoreline or coastline (as with a beach, delta, or fan) by nearshore deposition of river-borne sediments or by continuous accumulation of beach material thrown up by waves or moved by longshore drifting.

Public Authority – defined in the CM Act as a Minister of the Crown of the State, a State-owned corporation, an electricity supply authority, a department or instrumentality of the State, a local council and any other public or local authority constituted by or under any Act and includes any prescribed body.

Recession – a continuing landward movement of the shoreline; or a net landward movement of the shoreline over a specified time.

Reflection – the process by which the energy of the wave is returned seaward.

Refraction – the process by which the direction of a wave moving in shallow water at an angle to the contours is changed. The part of the wave advancing in shallower water moves more slowly than that part still advancing in deeper water, causing the wave crest to bend toward alignment with the underwater contours; or the bending of wave crests by currents.

Residual risk – the risk which remains after managing and reducing risks. It may include for example, risks due to very severe storms or from unexpected hazards.

Resilience – the ability of a system (human or natural) to adapt to changing conditions (including hazards or threats, variability and extremes), and rapidly recover from disruption due to emergencies. Resilient systems or communities have the capacity to ‘bounce back’ after a disrupting event such as a major storm or an extended heat wave, to moderate potential damages, take advantage of opportunities, maintain or restore function or to cope with the consequences.

Revetment or seawall – a type of coastal protection work which protects assets from coastal erosion by armouring the shore with erosion–resistant material. Large rocks/boulders, concrete or other hard materials are used, depending on the specific design requirements.

Rip – a narrow, strong shore normal current in the nearshore area of most wave-dominated beaches (i.e. most beaches along the open coast of NSW). They are fed by along shore feeder currents initiated by the deflection of waves at the shoreline. There are diverse types of rips on NSW beaches, and they affect beach safety.

Riparian – pertaining to the banks of a body of water, such as an estuary.

Risk – effect of uncertainty on planning and management objectives, usually characterised by reference to potential hazards, their consequence and their likelihood. Consequence combines the concepts of magnitude, sensitivity and duration.

Sand drift – the movement of sand by wind. On the coast, this generally describes sand movement resulting from natural or human-induced degradation of dune vegetation, resulting in either nuisance or major sand drift (dune transgression).

Sea level rise – an increase in the mean level of the oceans. Relative sea level occurs where there is a local increase in the level of the ocean relative to the land, which might be caused by ocean rising, the land subsiding, or both. In areas with rapid land level uplift (e.g. seismically active areas), relative sea level can fall.

Sediment cells (tertiary) – small and relatively contained sediment compartments. A tertiary sediment cell may apply to a single beach/embayment.

Sediment transport – the process whereby sediment is moved offshore, onshore or along shore by wave, current or wind action.

Sensitivity – the degree to which a built, natural or human system is directly or indirectly affected by changes in hazards, threats or climate conditions.

Shoreline recession – refers to continuing landward movement of the shoreline, that is, a net landward movement of the shoreline, generally assessed over a period of several years. As shoreline recession occurs the beach fluctuation zone is translated landward.
Southern Oscillation Index – the normalised mean atmospheric pressure difference between Tahiti and Darwin, measured at sea level. The SOI is negative during El Niño and positive during La Niña.
Stakeholder – a person or organisation with an interest or concern in something.
State objectives – the state's objectives for the coast are set out in the CM Act.
Storm surge – the increase in coastal water level caused by the effects of storms. Storm surge consists of two components – the increase in water level caused by the reduction in barometric pressure and the increase in water level caused by the action of wind blowing over the sea surface (wind set-up).
Storm tide – an abnormally high water level that occurs when a storm surge combines with a high astronomical tide. The storm tide must be accurately predicted to determine the extent of coastal inundation.
Strategic management of the coast – planning and management that is wide-ranging, considers multiple issues at multiple spatial scales and multiple timeframes. It identifies the opportunities and constraints of different broad options to achieve big-picture objectives and defines the best way forward.
Surf zone – defined in CM Act as the area from the line of the outer most breaking waves to the limit of wave run-up on the beach.
Sustainable management – develops and implements proposals that meet the needs of present communities without compromising the ability of future generations to meet their own needs.
Swash zone – the zone of wave action on the beach, which moves as water levels vary, extending from the limit of run down to the limit of run-up.
Swell waves – ocean waves that travel beyond the area where they are generated.
Threats – see Coastal threats. In the coastal management context, a threat is a process or activity which puts pressure on one or more coastal assets or values. Threats may include land uses (e.g. urban, recreation), land management, climate change, industrial discharges, stormwater runoff, overfishing, invasive species as well as the pressures from coastal hazards.
Threshold – can be identified for aspects of coastal systems, to highlight tipping points for irreversible change.
An ecological threshold is the point at which there is an abrupt change in the structure, quality, or functioning of an ecosystem or where external changes produce large and persistent responses in an ecosystem. A species threshold may disrupt aspects of the species population, productivity, reproduction, or habitat in response to a stressor. Such 'tipping points' can lead to unwanted changes in ecosystems and may slow the recovery of ecosystems or limit their ability to achieve more resilient states following a disturbance.
Similarly, a social or economic threshold of change in a coastal community indicates the point at which the structure, function, social connectedness, equality or economic activity of the community changes beyond recovery.
Thresholds can also be defined for coastal water levels as they relate to the resilience of certain types of development.
Tidal channel – a major channel followed by tidal currents, extending from offshore into a tidal marsh or a tidal flat; tidal inlet.
Tidal circulation – the movement of fresh water and seawater that are mixed by currents and flows in an estuary, in response to ocean tides.
Tidal delta – where an inlet of a barrier estuary or open coastal lake is dominated by tidal processes, a flood tide delta develops inside the entrance, as tidal currents transport marine sand into the estuary. Ebb tide deltas may also occur, outside the mouth of an estuary.
Tidal inundation – the inundation of land by tidal action under average meteorological conditions and the incursion of sea water onto low lying land that is not normally inundated, during a high sea level event such as a king tide or due to longer-term sea level rise.

Tidal limit – the maximum upstream location on a watercourse at which a tidal variation in water level is observed.
Tolerable risk – a risk that, following an understanding of the likelihood and consequences, is low enough to allow the exposure to continue, and at the same time high enough to require new treatments or actions to reduce risk. Society can live with this risk but believe that as much as is reasonably practical should be done to reduce the risks further. Note that individuals may find this risk unacceptable and choose to take their own steps, within reason, to make this risk acceptable. Residual risks are considered tolerable only if risk reduction is impractical.
Training walls – walls constructed at the entrances of estuaries and rivers to improve navigability.
Trigger – pre-negotiated decision-making points and commitments, so that action on coastal risks is taken when necessary, and when it is most convenient and affordable for the affected community
Tropical cyclone – intense low-pressure system in which winds of at least 63km/hour whirl in a clockwise direction, in the southern hemisphere around a region of calm air.
Tsunami – a long period water wave caused by an underwater disturbance such as a volcanic eruption or earthquake. Sometimes (incorrectly) called a 'tidal wave'.
Unacceptable risk – a risk that, following an understanding of the likelihood and consequences, is so high that it requires actions to avoid or reduce the risk. Individuals and society will not accept this risk and measures should be put in place to reduce risks to at least a tolerable level.
Vulnerability – a function of exposure and sensitivity of assets to a hazard, which determines the potential impacts of the hazard. For instance, the vulnerability of coastal assets may be influenced by the extent and impact of environmental, social and economic factors such as saline contamination of soils from flooding, erosion of built-up and natural areas, loss of vegetation, disruption to use, or access, or continuity of service, or loss of amenity, corrosion of built structures, undermining of foundations or damage to contents. Vulnerability also considers the adaptive capacity which is the capacity to adapt or the resilience in the system to manage the impacts and changes.
Wave amplitude – the magnitude of the displacement of a wave from a mean value. An ocean wave has an amplitude equal to the vertical distance from the still water level to wave crest. For a sinusoidal wave, amplitude is one–half the wave height. (USACE).
Wave climate – the seasonal and annual distribution of wave height, period and direction.
Wave-dominated coast – the coast of southeastern Australia is a wave-dominated system. This affects the beach type and the types of estuaries that occur in the landscape.
Wave energy – the capacity of waves to do work. The energy of a wave system is theoretically proportional to the square of the wave height; a high–energy coast is characterised by breaker heights greater than 50 centimetres and a low–energy coast is characterised by breaker heights less than 10 centimetres. Most of the wave energy along equilibrium beaches is used in shoaling and in sand movement. The NSW coast is a high wave energy coast.
Wave run-up – the vertical distance above mean water level reached by the uprush of water from waves across a beach or up a structure.
Wave set-up – the rise in the water level above the still water level when a wave reaches the coast. It can be very important during storm events as it results in further increases in water level above the tide and surge levels.
Wind waves – ocean waves resulting from the action of the wind on the surface of the water.
Zone of profile fluctuation – the area within which the subaerial beach profile can be expected to fluctuate under the current patterns of climate and weather conditions (i.e. including storms and decadal scale cycles).
Zone of slope adjustment – the area landward of an escarpment cut by storm bite, which may be affected by slumping to the angle of repose of the sand as it dries.

Royal HaskoningDHV

10 Abbreviations

Abbreviation	Meaning
CM Act	*Coastal Management Act 2016*
CM SEPP	State Environmental Planning Policy (Coastal Management) 2018
CMP	Coastal Management Program
CSIRO	Commonwealth Scientific and Industrial Research Organisation
CZMP	Coastal Zone Management Plan (a plan prepared under the former Coastal Protection Act 1979)
DPIE	NSW Department of Planning, Industry and Environment
GIS	Geographical Information System
IAP2	International Association of Public Participation
IP&R	Integrated Planning and Reporting (in accordance with the Local Government Act 1993)
ISO	International Organisation for Standardization
LGA	Local Government Area
OEH	NSW Office of Environment and Heritage
SEPP	State Environmental Planning Policy

APPENDIX A – Photogrammetric Analysis

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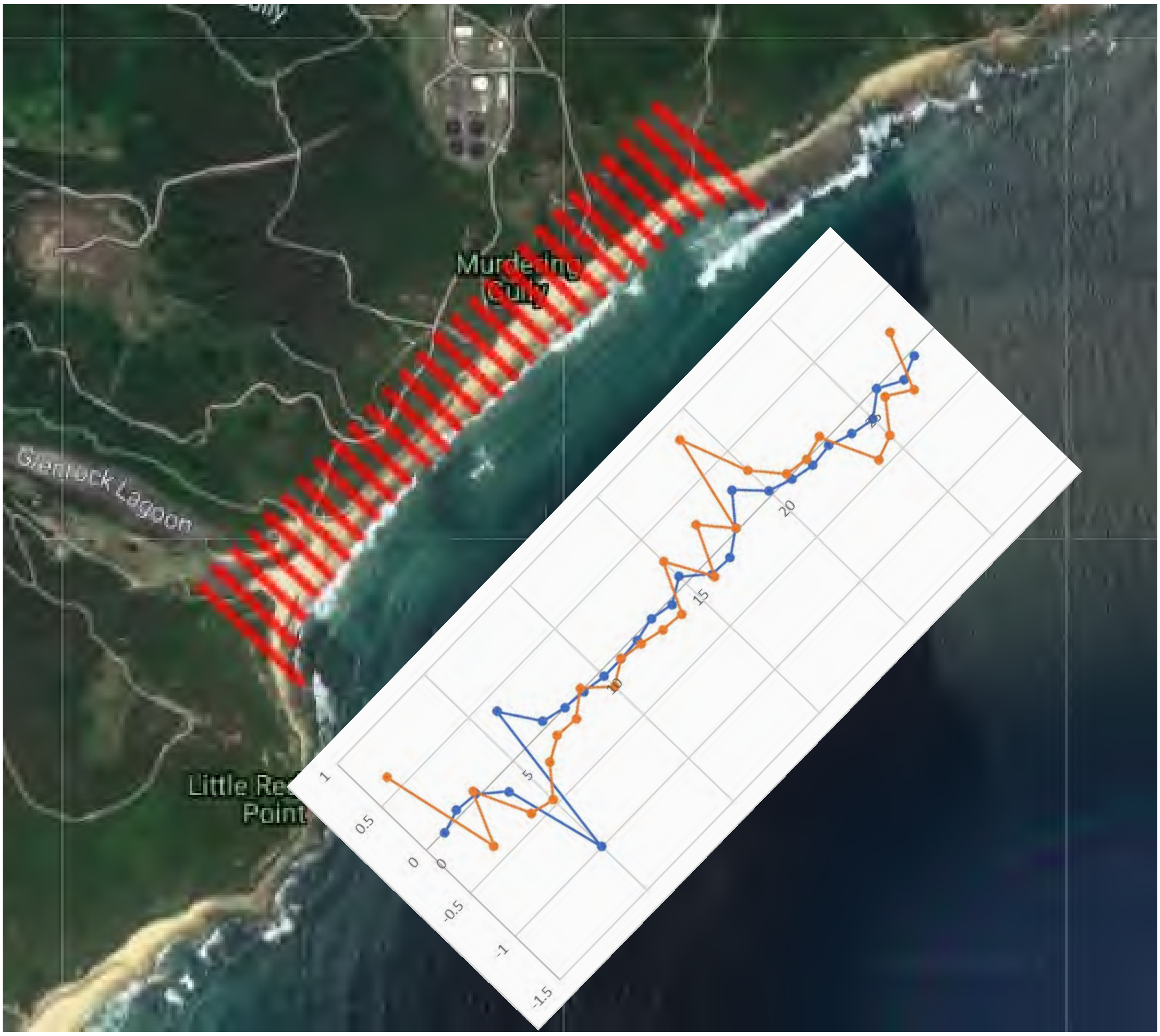

Figure A1: Block 1 Burwood Beach volume change, above 0m AHD, in m3/m/year (orange line) and 4m AHD contour movement in m/year (blue line) for 1954-2021 (positive values indicating accretion/ progradation and negative values indicating erosion/recession).

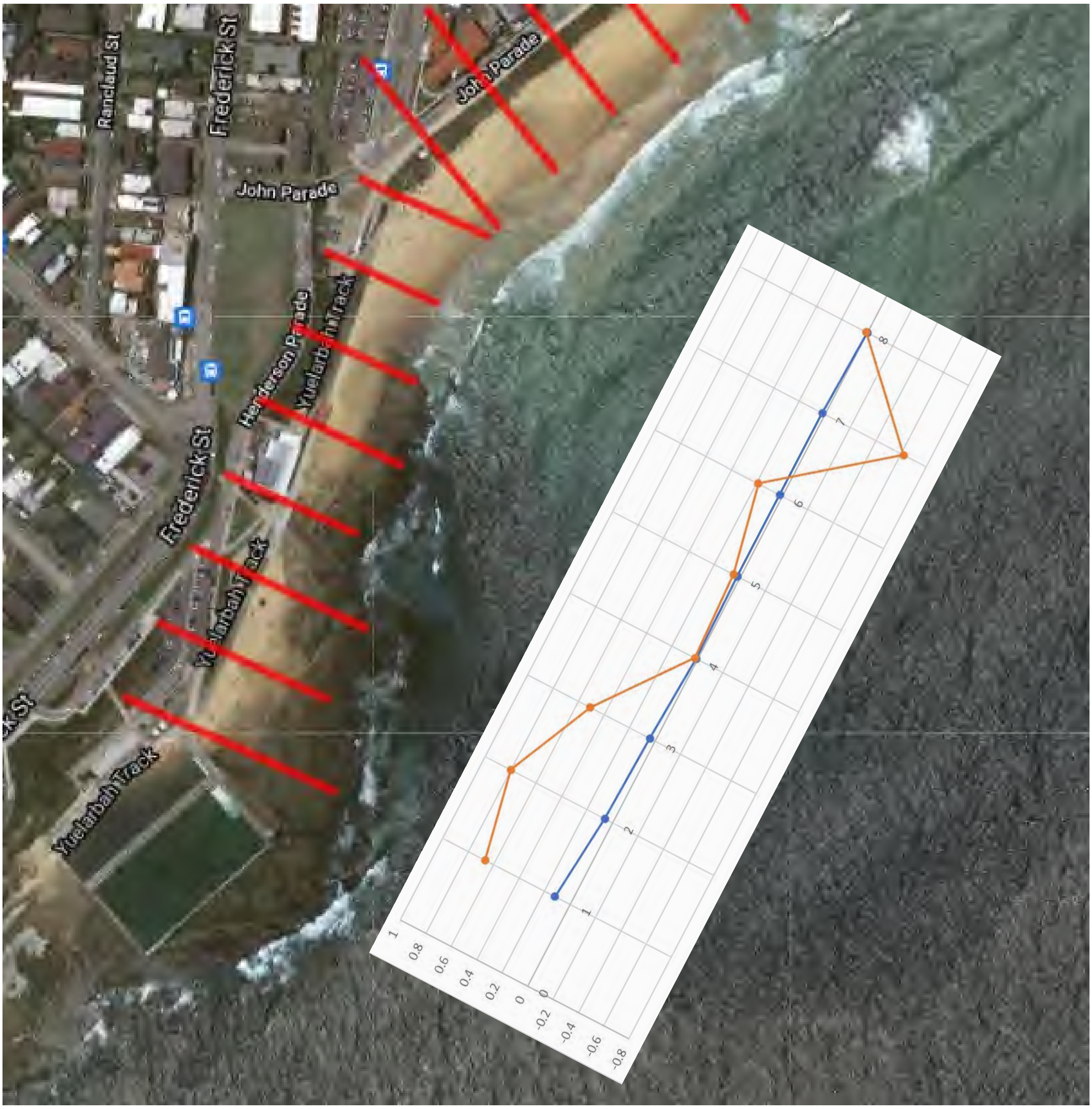

Figure A2: Block 2 Merewether South Beach volume change, above 0m AHD in m3/m/year (orange line) and 4m AHD contour movement in m/year (blue line) for 1954-2021 (positive values indicating accretion/ progradation and negative values indicating erosion/recession).

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Figure A3: Block 3 John Parade, Dixon Park and Bar Beach volume change, above 0m AHD in m3/m/year (orange line) and 4m AHD contour movement in m/year (blue line) for 1954-2021 (positive values indicating accretion/ progradation and negative values indicating erosion/recession).

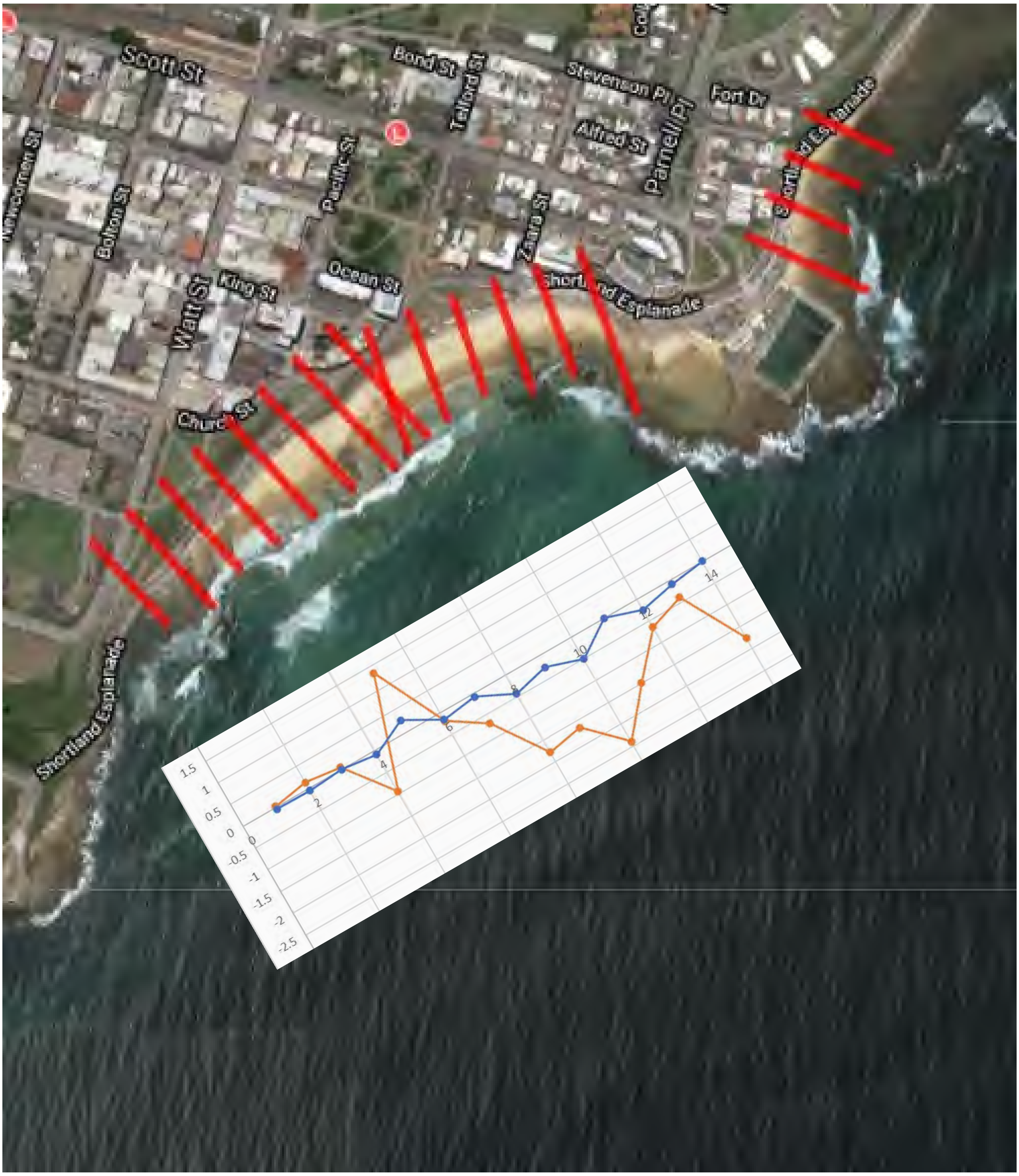

Figure A4: Block 4 and 5 Newcastle Beach volume change, above 0m AHD in m3/m/year (orange line) and 2.5-3m AHD contour movement in m/year (blue line) for 1954-2021 (positive values indicating accretion/ progradation and negative values indicating erosion/recession).

Figure A5: Block 6 at Cowrie Hole Beach volume change, above 0m AHD in m3/m/year (orange line) and 2.5m AHD contour movement in m/year (blue line) for 1954-2021 (positive values indicating accretion/ progradation and negative values indicating erosion/recession).

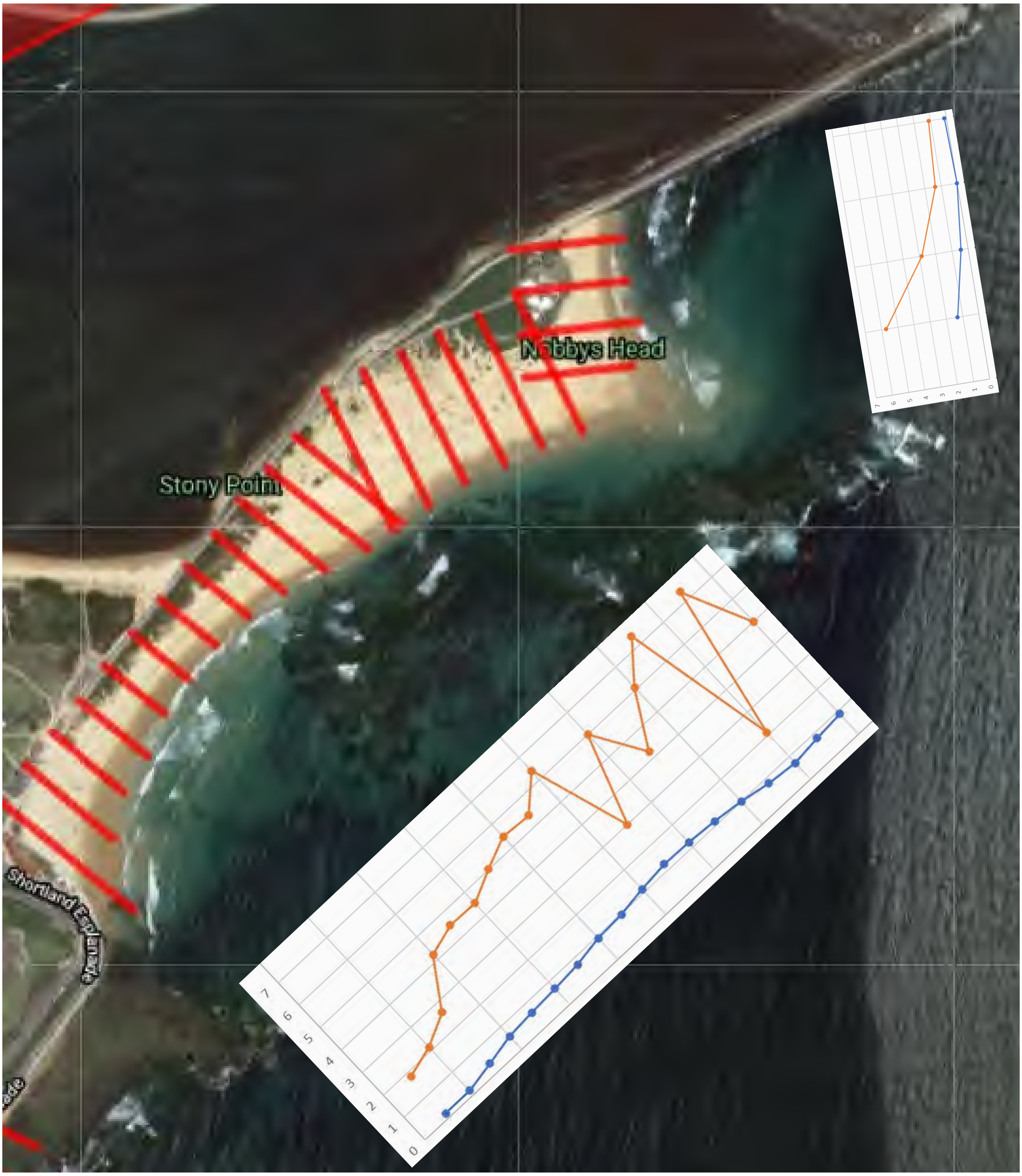

Figure A6: Blocks 7, 8 and 9 at Nobbys Beach volume change, above 0m AHD in m3/m/year (orange line) and 2.5m AHD contour movement in m/year (blue line) for 1954-2021 (positive values indicating accretion/ progradation and negative values indicating erosion/recession).