Supporting Documentation C.

Stage 2 Reports – Sediment Transport Study and Probabilistic Hazard Assessment Summary (Bluecoast 2020, 2020a)

City of Newcastle

City of Newcastle

Sediment transport study within Stockton Bight

Report #: P19028_PartA-StocktonBightStudy_TN0.0A

18 June 2020

Technical Note

To:	City of Newcastle
From:	Evan Watterson, Holly Watson and Heiko Loehr
Review:	Evan Watterson
Reference:	P19028_PartA-StocktonBightStudy_TN3.0
Date:	18 June 2020
Subject:	Long-term loss of sand from Stockton Beach and other relevant findings from the Stockton Bight sediment transport study to inform the Stockton Coastal Management Program

1 Introduction

Bluecoast Consulting Engineers were engaged by the City of Newcastle (CN) to prepare a sediment transport study of the entire Stockton Bight. This was identified as a knowledge gap in the Scoping Study undertaken as part of Stage 1 of the Newcastle Coastal Management Program (CMP) (CN, 2019). The sediment transport investigation is a technical study under Stage 2 of the CMP processes. It is intended to inform the development of a Newcastle-wide CMP for the higher-risk area of Stockton Beach. Due to a time constraint imposed by Ministerial direction to complete the Stockton CMP by 30 June 2020, CN are preparing a CMP specifically for Stockton Beach. The area included in the Stockton CMP is the area north of the Stockton Breakwater (northern training wall of the Hunter River) to Meredith Street.

The Stockton Beach CMP is being prepared in line with the Coastal Management Act 2016 and the NSW Coastal Management Manual Part A (the Manual). This technical note describes the elements of the sediment transport study undertaken to-date that inform the Stockton Beach CMP.

The Stockton Bight sediment transport study, in its entirety, is expected to be completed by July 2020 for inclusion in Newcastle CMP which will include the full extent from Stockton Breakwater to the LGA boundary. The full study will involve:

- critical review of previous literature on coastal processes in Stockton Bight
- compilation and review of all available data sets, including:
  - metocean data
  - sediment grain size distribution
  - bathymetric, beach and topographic survey
  - geophysical and geotechnical data
- geological and geomorphic description of the Bight, including the sand dunes

- volumetric analysis of beach and bathymetric surveys to establish observed historical changes in sand volumes
- development of a quantified conceptual sediment transport model to explain the sediment budget and movement of sediments within the Stockton Bight compartment.

The history of long-term sand loss from the coastal profile at Stockton Beach is considered a pivotal piece of information. This key element of the sediment transport study was brought forward along with the following to inform the Stockton CMP:

- a timeline of key anthropogenic changes
- metocean conditions effecting Stockton Beach
- a summary of coastal management issues based on work completed to-date.

2 Statement of assumptions and uncertainty

The approach developed herein is reasonable and valid for estimating the long-term sand loss rate from the coastal profile in the CMP area. However, it is important that decision-makers recognise the assumptions underlining the estimates as well as the inherent uncertainties. The key assumptions and uncertainties in this assessment relate to the comparative volumetric analysis of available survey data. The estimated sand loss rates are therefore subject to the accuracy of these surveys, noting that most recent surveys are more accurate.

It is further recommended that CN:

- communicate the assumptions and uncertainties to the community and stakeholders
- seek to reduce the number of assumptions and degree of uncertainty through the completion of the Stockton Bight sediment transport study
- seek to reduce the degree of uncertainty through on-going monitoring of the full coastal profile at Stockton, nearshore coastal processes (wave, currents etc) and sand movements (e.g. trial groynes or similar).

3 Summary of coastal management issues

Stockton Beach and the adjacent Hunter River has been continually modified over the course of European settlement. Modifications that have impacted the beach response include the construction of the Hunter River breakwaters, capital and maintenance dredging of the navigation channel, revetment construction, beach nourishment, beach scraping and temporary and emergency protection works.

Stockton Beach has been the subject of numerous studies to assess coastal processes. However, further investigation has been identified as being required to underpin the identification of appropriate options for management of coastal hazards on the Stockton coastline. Based on the Stage 2 sediment transport studies completed at this time, a summary of the most relevant processes is provided below.

A key knowledge gap identified in the Scoping Study (CN, 2019) was to determine the changes in the sub-aqueous part of the coastal profile. An assessment of the change in the sand volume in the Stockton Beach area was undertaken. This assessment considered both the sub-aqueous and sub-aerial changes. The combined rate of long-term sand loss from the Stockton CMP area is recommended as 112,000m^3/yr, which is based on the historical observations of:

- 100,000m^3/yr of sand loss from the sub-aqueous part of the coastal profile in the southern Stockton embayment between the northern breakwater and Fort Wallace (inshore of 20m depth contour) between 1988 and 2018.
- 12,000m^3/yr of sand loss from sub-aerial part of the coastal profile in Block A, Block B and Block C between 1985 and 2020.

This rate of sand loss is significantly greater than previously estimated and has implications for the on-going management of the coastal erosion issue at Stockton Beach. Given the long-term nature of the sand loss (i.e. not cyclic) and the accelerated rate of loss observed since the channel deepening project was completed in 1983, the most likely cause is the development and operation of the port within the Hunter River (i.e. breakwater construction and capital and maintenance dredging). However, it is noted that there are other possible causes for the observed erosion that will require further consideration and assessment as part of the Stockton Bight sediment transport study.

Further investigations are required to review the key coastal processes and quantify the sediment pathways that adequately explain these observations. A robust understanding of these processes is fundamental to developing coastal management options. It is recommended that long-term plans for Stockton Beach are reviewed once the sediment transport study is completed.

4 Key anthropogenic influences

A summary of the key anthropogenic influences on the coastal processes at the study site is given by:

1818 The construction of the Macquarie Pier linking Nobbys to the mainland is commenced.

1846 Macquarie Pier completed, but continually breached by storms and wave action.

1859 Continuous dredging began using ladder dredges to remove mud, sand and surface rock.

1861 Work began on Private Point breakwater at the tip of Stockton peninsula (or sand spit). Work was completed by 1866.

1875 First breakwater extension beyond Nobbys. Work was completed by 1883.

1875 Extension to Private Point breakwater. Completed by 1896.

1898 Work began on new northern breakwater, later known as Shipwreck Walk in recognition of the wrecked vessels that were incorporated into the construction.

1941 Dredging at the entrance of the harbour increases depths to 24 feet 6 inches (~7.5 meters).

1952 Dutch dredge carried out contract dredging 2,000,000 cubic yards (~1.5M cubic meters) of material.

1955 Almost 3,500,000 tons of silt and sand removed from Newcastle Harbour and the lower reaches of the Hunter River.

1962 Between 1962 and 1966 approximately 450,000 cubic meters of rock and 620,000 cubic meters of soft sediment were dredged. While most of the material was disposed offshore some of the dredged sand was placed on Stockton Beach via a pipeline (DHI, 2006).

1977 Contract 76/2 was awarded to Westham Dredging for works required to deepen the harbour approaches to 17.7 meters and the harbour channels to 15.2 meters. Works were completed by 1983 and included the removal of approximately 2 million cubic meters of rock and over 8 million cubic meters of sand and clay was dredged from the main entrance to the port and dumped offshore for a total cost of $103,300,000 (NPC, 2014). A special harbour levy of $1 per tonne on overseas exports of coal and interstate imports of iron ore used to fund the cost of channel deepening.

1989 The rock revetment at Mitchell Street was constructed. This structure protects shoreward assets and property for approximately 600m of shoreline in the southern Stockton embayment. A geotextile sandbag wall was also constructed in front of the SLSC club.

2005 Maintenance dredging of 153,000 cubic meters of sand was dredged from the harbour entrance areas using *TSHD Brisbane* and dumped offshore (DHI, 2006).

2016 The rock revetment fronting the SLSC was constructed. This structure protects shoreward assets for approximately 145m of shoreline in the southern Stockton embayment.

Given their relevance to sediment budgets at Stockton Beach, this summary highlights key activities related to the development and operations of the port within Newcastle Harbour. The beach nourishment volumes placed at Stockton Beach nearshore area during recent years is discussed in Section 5.1.1.

5 Long-term loss of sand from Stockton Beach

A key knowledge gap identified in the Scoping Study (CN, 2019) was to determine the changes in the sub-aqueous part of the coastal profile. The coastal profile is the part of the cross-shore profile that is highly dynamic largely due to the action of waves, as well as tide, wave-driven currents and wind. The coastal profile can be divided into several zones, herein we will discuss the sub-aerial part (i.e. the land-based part above 0m AHD) and of the sub-aqueous part (i.e. the part below the water approximated by 0m AHD).

An assessment of the change in the sand volume in the Stockton Beach area was undertaken. This assessment considered both the:

- Sub-aqueous part of the profile using historical bathymetric surveys from the period from 1866 to 2018, which was deemed to have reliable data (see Table 8, Attachment A).
- Sub-aerial part of the profile using the NSW beach profile dataset for the period from 1953 to 2020 (see Table 8, Attachment A).

5.1 Sub-aqueous sand losses

To determine the changes in the sub-aqueous zone, the sand volume relative to the 2018 survey was calculated for each survey. Where survey coverage allowed volumes were determined for the compartments shown in Figure 2. A timeseries showing the sub-aqueous sand volume change in compartment 4 and compartment 5 offshore of Stockton Beach is shown in Figure 1. Sand volumes are provided in Table 1.

The observations show a long-term trend of sand loss from the sub-aqueous part of the coastal profile. Over the 152-year record, over 8 million cubic meters of sand has been lost from compartments 4 and 5. Using linear regression this is equivalent to a long-term rate of approximately 76,000m^3/yr. Until 1988 the rate of sand loss, as determined by linear regression, was 70,000m^3/yr. Since 1988 the rate of loss has increased to just over 100,000m^3/yr. While not presented herein, a similar magnitude of sand loss has been observed to the north in compartments 6 and 7.

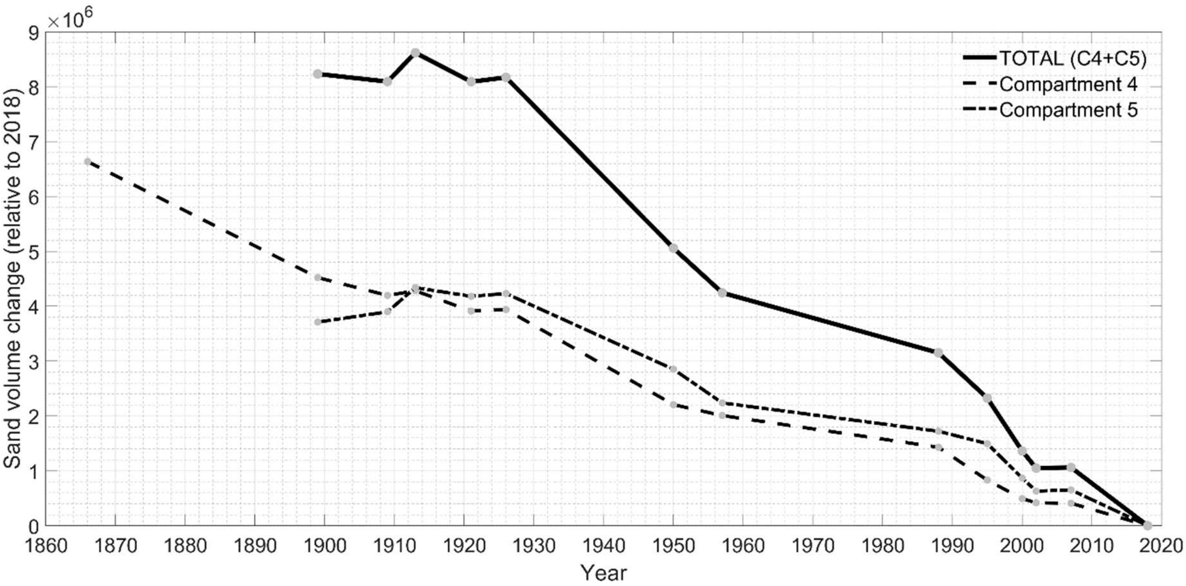

Figure 1: Long-term sand volume change at Stockton Beach (Compartments 4 and 5).

Table 1: Cubic meters of sand relative to 2018 seabed levels in compartments 4 and 5.

Year of survey	Compartment 4 Area = 2,211,858m^2	Compartment 5 Area = 1,642,237m^2	Sum of compartment 4 and 5 (sub-aqueous)
1866	6,635,863	na	na
1899	4,5217,95	3,710,343	8,232,138
1909	4,1960,72	3,897,621	8,093,692
1913	4,2809,22	4,338,313	8,619,235
1921	3,910,804	4,180,107	8,090,911
1926	3,938,704	4,230,474	8,169,178
1950	2,206,424	2,850,520	5,056,944
1957	2,006,998	2,237,630	4,244,627
1988	1,429,336	1,721,124	3,150,461
1995	829,893	1,494,680	2,324,573
2000	493,237	867,584	1,360,820
2002	417,654	630,852	1,048,507
2007	409,488	651,785	1,061,274
2018	0	0	0

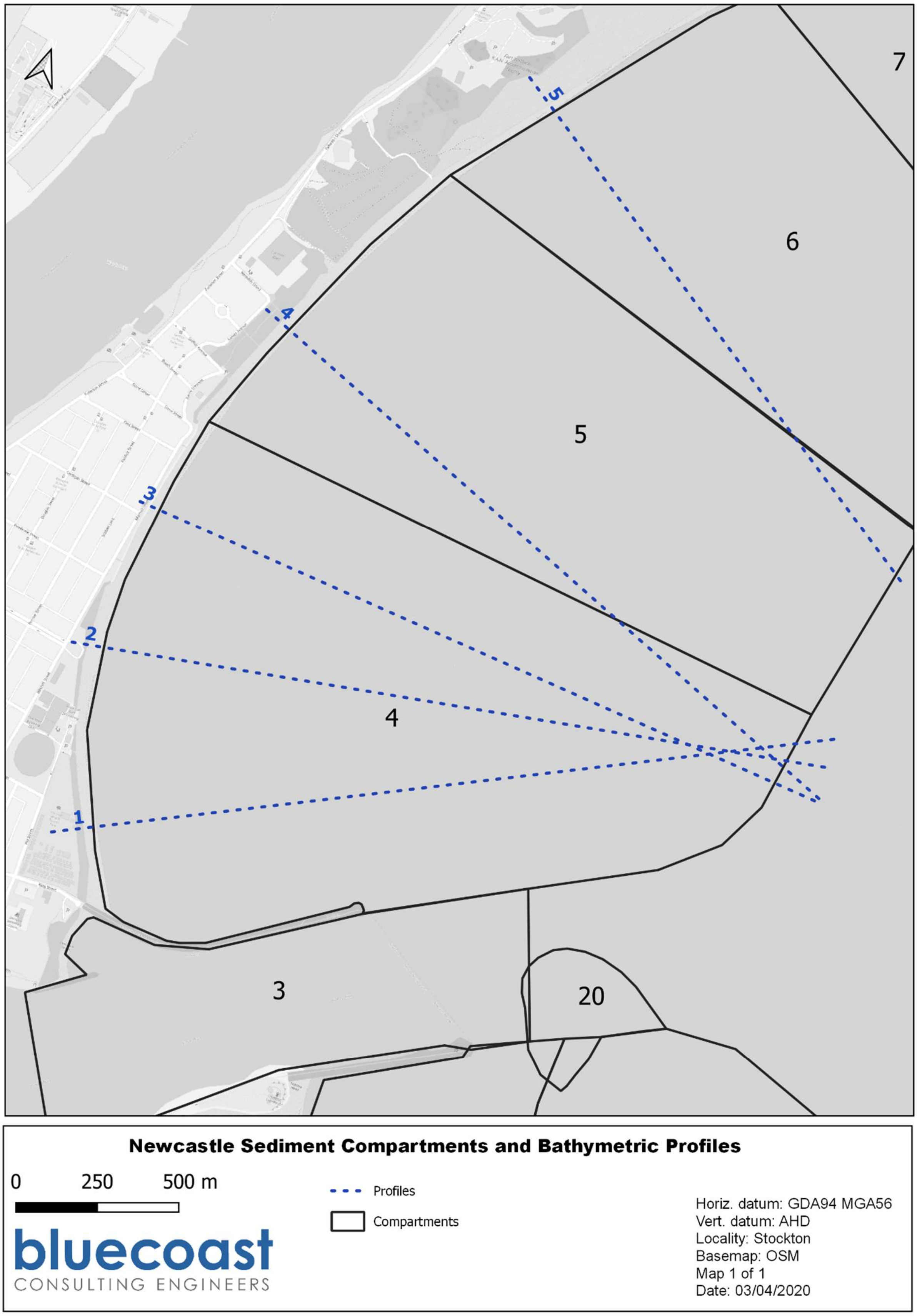

Figure 2: Sediment compartments and coastal profiles in the Stockton Beach area.

5.1.1 Accounting for sand placement activities

The sand volume changes presented in Figure 1 and Table 1 are based on the bathymetric surveys only, they do not consider any sand placed in the compartments as part of beach nourishment efforts.

The Port of Newcastle (PoN)[1] are responsible for maintaining safe depths in the port's navigation channel. This requires maintenance dredging of significant annual quantities of silts and sands (~500,000m^3/yr) from the port's channels. A small proportion of this material is sand dredged from Area E (the port entrance), which PoN place in the nearshore area of Stockton Beach as a beneficial reuse of the dredged material. This sand is placed within an area prescribed by then NSW Office of Environment and Heritage (now DPIE). The placement area is within compartments 4 and 5. The remainder of the maintenance material dredged from the port channels is dumped offshore.

Table 2 presents the known sand nourishment volumes[2] placed in compartment 4 or 5 from Area E. Based on the quantities in the table, approximately 34,000m^3/yr of sand was placed in compartment 4 and 5 between 2009 and 2019. Had this sand not been placed as beach nourishment the rate of sand loss from these compartments would have been higher (i.e. approximately 100,000m^3/yr + 34,000m^3/yr).

It is unclear if beach nourishment placements were carried out prior to 2009 although there is reference to some sand placements in the 1960s. It is known that in May 2005, approximately 150,000 cubic meters of sand from Area A was dredged and dumped offshore (WorleyParsons, 2009) without any additional sand placements on Stockton Beach. Between 1979 and 1983, capital dredging was undertaken to deepen the channel. Approximately 2 million cubic meters of rock and 8 million cubic meters of sand and clay was dredged from the main entrance to the port and dumped offshore for a total cost of $103,300,000 (NPC, 2014). It is also understood that no sand was placed on Stockton Beach during these capital dredging works but further clarification should be sort from the relevant authorities.

Table 2: Cubic meters of beach nourishment sand placed in compartments 4 and 5 because of port operations.

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[1] Prior to 2014, the Newcastle Port Corporation (NPC) were responsible for the operations of the port, including channel maintenance dredging.

[2] The volumes presented in this table have been sourced from various sources including records from PoN. However, the table may not present a complete and accurate picture and sand volumes placed at Stockton Beach. It is important that efforts are made to ensure full and accurate records are obtained from the relevant authorities such that coastal management can be properly informed.

Year	Sand volume placed at Stockton (m^3)
2009/2010	130,000*
2010-2011	unknown
2012	9,233
2013	29,845
2014	6,309
2015	58,280
2016	27,945
2017	25,839
2018	25,542
2019	30,958**
TOTAL	**343,951**

*Volume sourced from WorleyParsons (2012).
**In December 2019 approximately 3,500m^3 of nourishment material that had been sourced from local quarries and was placed on the upper beach at the southern end of Stockton Beach. This was undertaken as part of a pilot study. Sand sourced from local quarries is finer grained that the native beach sand. This effective sand trial volume has been added to the volume placed by PoN.

5.1.2 Comparisons to previous studies

WBM (1998) presented a volume for one million cubic meters as the net loss of sand from the 3km of beach north of the breakwaters for the period between 1957 to 1995. This is equivalent to a sand loss rate of approximately 26,500m^3/yr. The 3km alongshore extent is similar to that of compartments 4 and 5 but the WBM (1998) sand loss rate is only half of that value that can be obtained from the volumes in Table 1 for the equivalent period. The reason for the difference in the estimated sand loss rates is unknown but may be due to the cross-shore extent of the surveyed area used by WBM.

Umwelt (2002) undertook a comprehensive analysis of historical bathymetric surveys to estimate sand loss rates for two areas (Area 1 and Area 2). Area 2 extends alongshore from the northern breakwater to south of Fort Wallace (see Figure 3) and is similar in extent to the combined area of compartment 4 and 5. Umwelt estimated Area 2 to experience an average sand loss rate of:

- 1921 to 2000: 67,000m^3/yr
- 1988 to 2000: 370,000m^3/yr

The long-term loss rate calculated by Umwelt for Area 2 is consistent with the sand loss rate from 1866 to 1988 calculated herein (70,000m^3/yr). However, the rate of 370,000m^3/yr given for the period from 1988 to 2000 is much higher than the rate of 100,000m^3/yr estimated herein for the period between 1988 and 2018. It is noted that the lower rate presented herein does not discount the beach nourishment quantities. However, when these are included (i.e. equivalent loss rates of 134,000m^3/yr) the rates are still lower than Umwelt's 1998 to 2000 rate and the difference is likely due to the shorter period of the analysis using the data available at the time of Umwelt's 2002 report.

DHI (2006) analysed bathymetry surveys from 1995, 2000 and 2002 and presented survey difference plots that showed erosion occurring in the surf zone, similar to the patterns presented below in Section 5.4. While no volumetric analysis was presented in DHI (2006), that report did refer to the sand loss volumes and rates provided in the Umwelt (2002) report. Sand loss rates from Umwelt's Area 1 were used by DHI to justify the calculated net northward alongshore sediment transport rates of 20,000 to 30,000m^3/yr for the period between 1866 and 2004. However, it is recommended that littoral drift rates and the sediment pathways and fluxes calculated by DHI (2006), see Figure 26, be revisited based on the volumetric analysis completed herein.

Figure 3: Sand loss analysis areas used in the Umwelt (2002) report – (left) Area 1 and (right) Area 2.

5.2 Sub-aerial sand losses

Based on beach profile data from the NSW photogrammetry database, Figure 4 presents a timeseries of sub-aerial beach volumes for Stockton Block A, B and C (see Figure 5). Similar to sub-aqueous extents, the Stockton CMP area (i.e. northern breakwater to Meredith Street) is conservatively considered to cover Block A, Block B and Block C. Between 1985 and 2020 the combined beach volume in these blocks has reduced by approximately 420,000m^3, an average loss rate of 12,000m^3/yr.

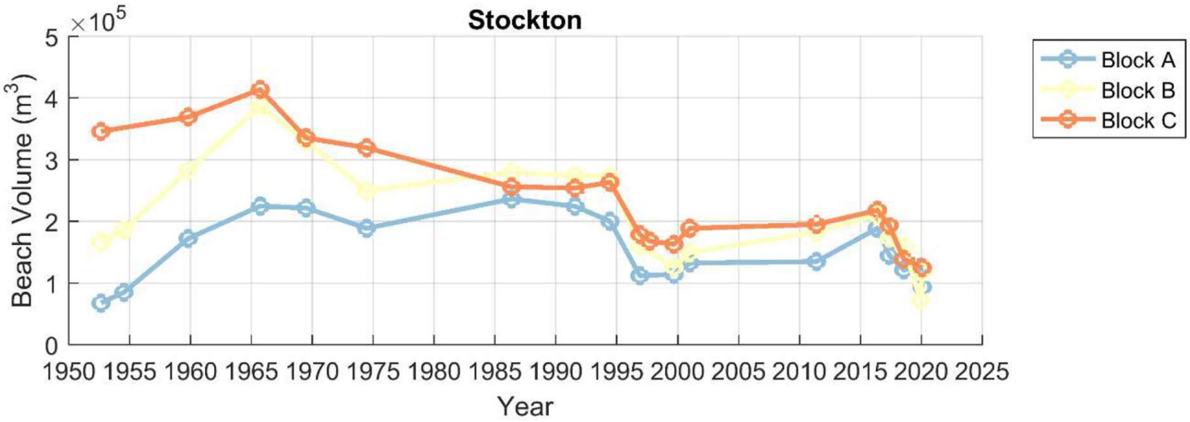

Figure 4: Timeseries of sub-aerial beach volumes for Stockton Block A to C.

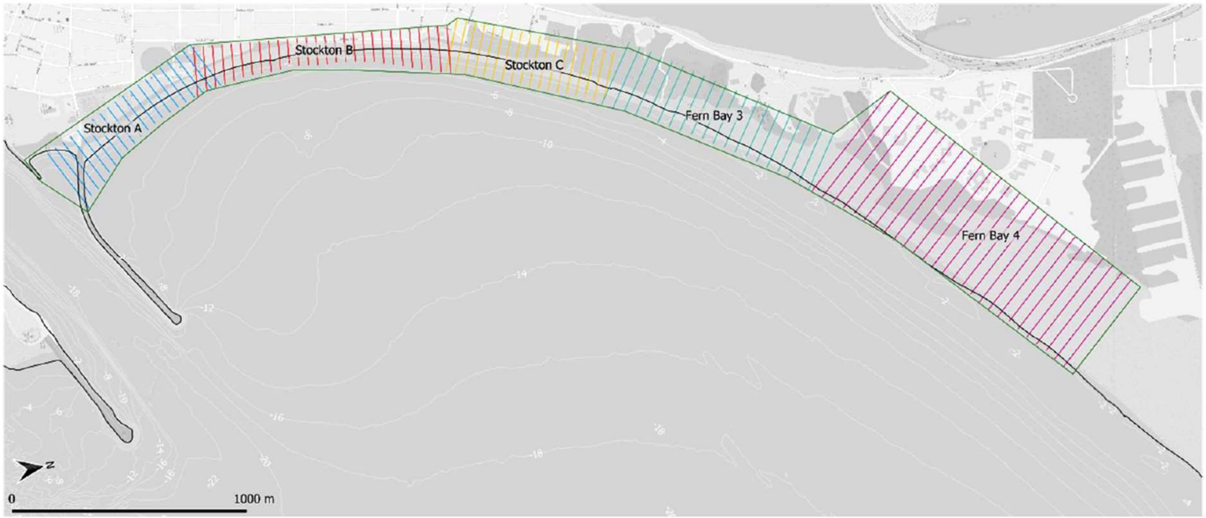

Figure 5: NSW photogrammetry blocks and profiles (coloured lines) at Stockton Beach.

5.3 Combined coastal profile sand losses

The combined rate of long-term sand loss from the Stockton CMP area was estimated to be 112,000m^3/yr, which is based on the historical observations of:

- 100,000m^3/yr of sand loss from sub-aqueous part of the coastal profile in compartments 4 and 5 between 1988 and 2018; and
- 12,000m^3/yr of sand loss from sub-aerial part of the coastal profile in Block A, B and C between 1985 and 2020.

Due to the alongshore extents selected, some conservativism is built into these numbers. However, the beach nourishment quantities delivered by port operations have not been discounted and if these placement activities were to cease the sand loss rates would be higher.

5.4 Pattern of sub-aqueous losses

To examine the pattern of sub-aqueous sand loss at Stockton Beach, the following analysis results are provided:

- Maps of the changes in seabed levels relative to 2018 were produced for selected surveys and are shown in Figure 6 to Figure 9. In these maps, red indicates areas where the seabed has lowered, either by erosion (e.g. Stockton Beach) or by port dredging (e.g. entrance channel). Blue areas indicate areas of accretion. Areas of accretion are either formed by deposition of sediment (e.g. accumulation of littoral drift in the 'sediment trap' created by the port dredging – see compartment 20) or by sand placement activities (e.g. the effect of the beach nourishment placements that can be observed in compartment 4).
- Plots of the coastal profiles observed in the surveys at profile 3 and profile 4 (see Figure 2) along with the survey differences relative to 2018 are provided in Figure 10 and Figure 11, respectively.

There are several important features noted in these patterns:

- Erosion of the seabed has predominately occurred on the shallow slope inshore of the ~8m AHD depth contour indicating littoral processes by wave driven currents (i.e. alongshore drift). More work is required to interpret the survey differences but it appears that most of the sand lost from the southern embayment has moved north along the surf zone and shoreline. The erosion is likely to be due to sediment starvation from an interruption in the supply from the updrift coast (south of Hunter River).
- The effect of sand placement from Area E are evident. It is noted, however, that sand placements were undertaken shortly before the 2018 Marine LiDAR being captured. The majority of the approximately 340,000m^3 of sand placed in this area since 2009 is no longer evident in the survey difference maps. The bulk of the material is assumed to have moved onshore and then been transport/dispersed by alongshore and cross shore transport process. However, what is evident in the survey difference maps are two pathways, one indicating sand dispersing to the north-east as well as a second potential pathway along the outer surf zone to the south.
- Erosion of the inner surf zone is still observed in compartment 4 inshore of the dispersed sand nourishment, this <u>may</u> be due to the response of the shoreline to erosion occurring to the north (i.e. realignment of the zeta shaped embayment in response to lack of sediment supply), see Figure 12.
- There has been accretion of the north-eastern aspects of the sand lobe (compartment 1), indicating a sediment pathway from the entrance area offshore to the sand lobe located offshore of Nobbys Head. This sand lobe is likely to have been

formed over 100-1,000’s of years. Accretion of littoral sand in this location in recent years is, however, significant as it indicates a potential additional source of sand for beach nourishment for Stockton Beach under a ‘working with nature’ approach (i.e. keep sediment moving along the coast). Other potential sources of offshore sand for beach nourishment also exist (MEG, 2020) and further investigations are recommended to determine the suitability of each source for this purpose.

The question of accuracy is often raised regarding the use of historical surveys. Bluecoast have reviewed all survey data provided and discarded surveys that appeared inconsistent. We also note that the survey differences observed display a consistent pattern of large differences in discrete areas (rather than small differences over large areas). However, as noted in Section 2, a degree of uncertainty remains in these estimates. Quantification of the uncertainty and other validating line of evidence should be sort from the further studies planned as part of the Stockton Bight sediment study.

Previous studies have suggested that the erosion problem at Stockton Beach was progressively worsening, with significant volumes of sand being permanently lost from the beach system (Umwelt, 2002). Moreover, studies have suggested that the on-going erosion is, at least in part, a result of the cessation of littoral drift past the entrance to the Hunter River and into the southern Stockton Bight compartment. These findings are supported by the analysis of long-term sand losses from Stockton Beach completed herein.

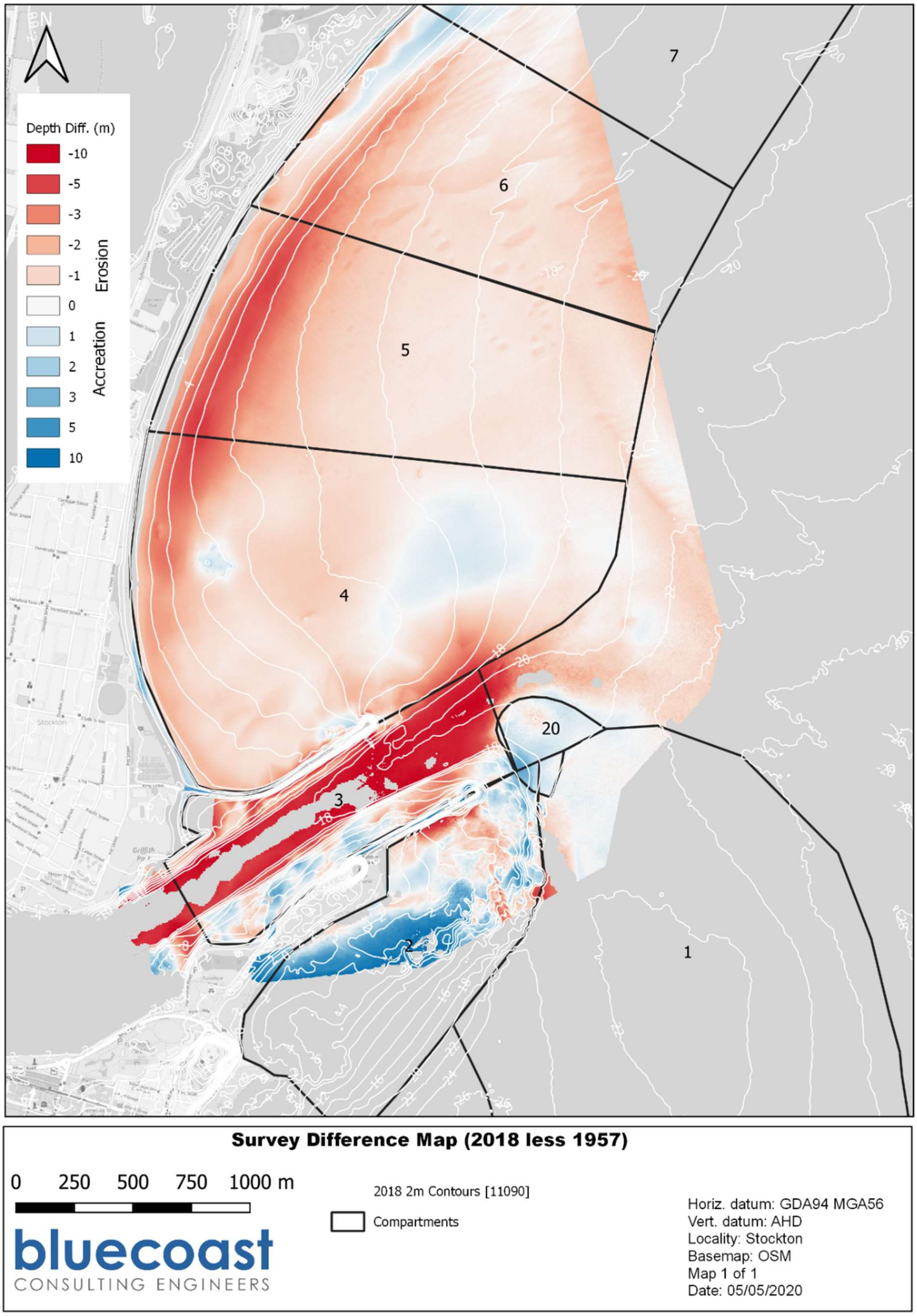

Figure 6: Survey difference map for 1957 relative to 2018.

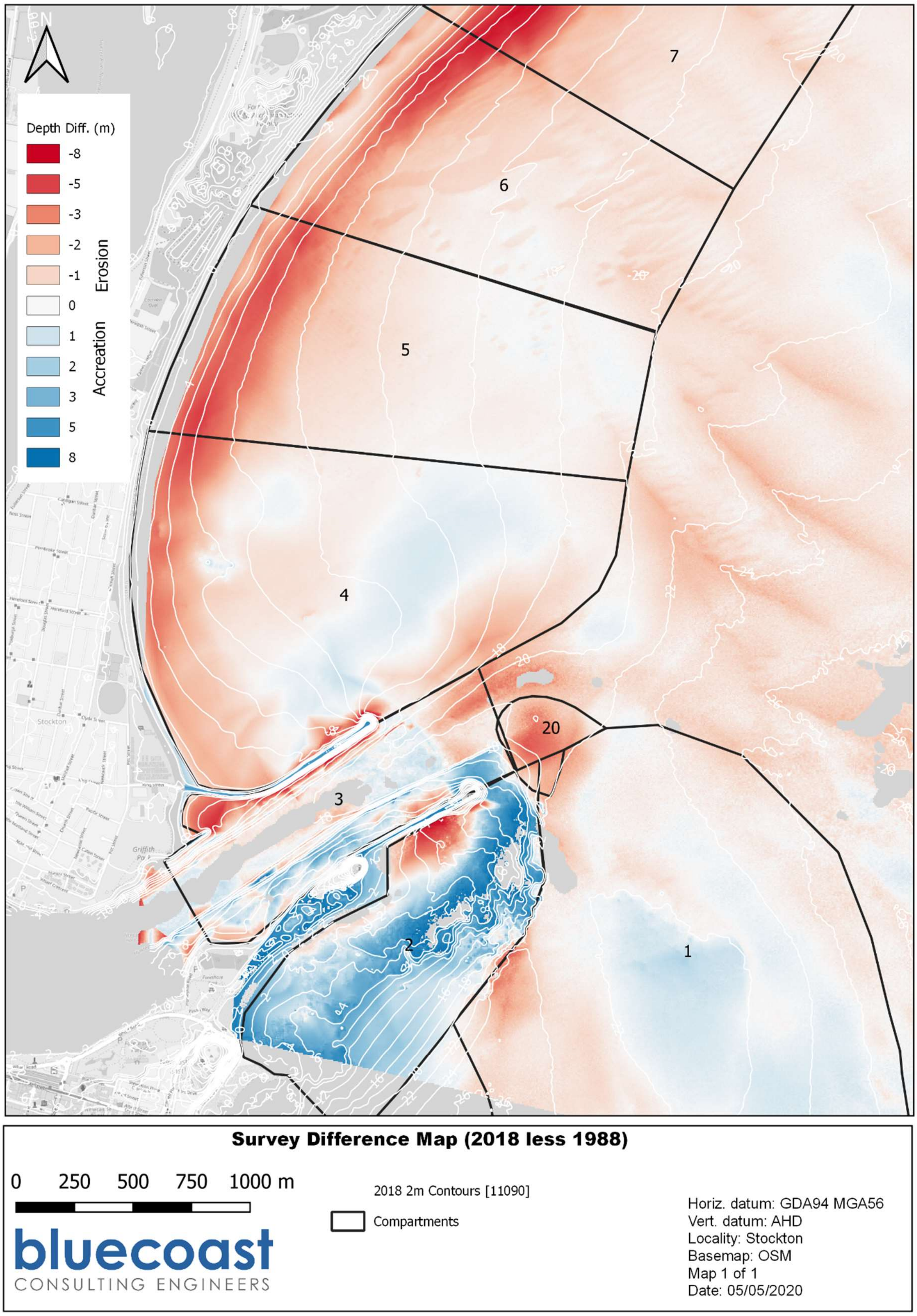

Figure 7: Survey difference map for 1988 relative to 2018.

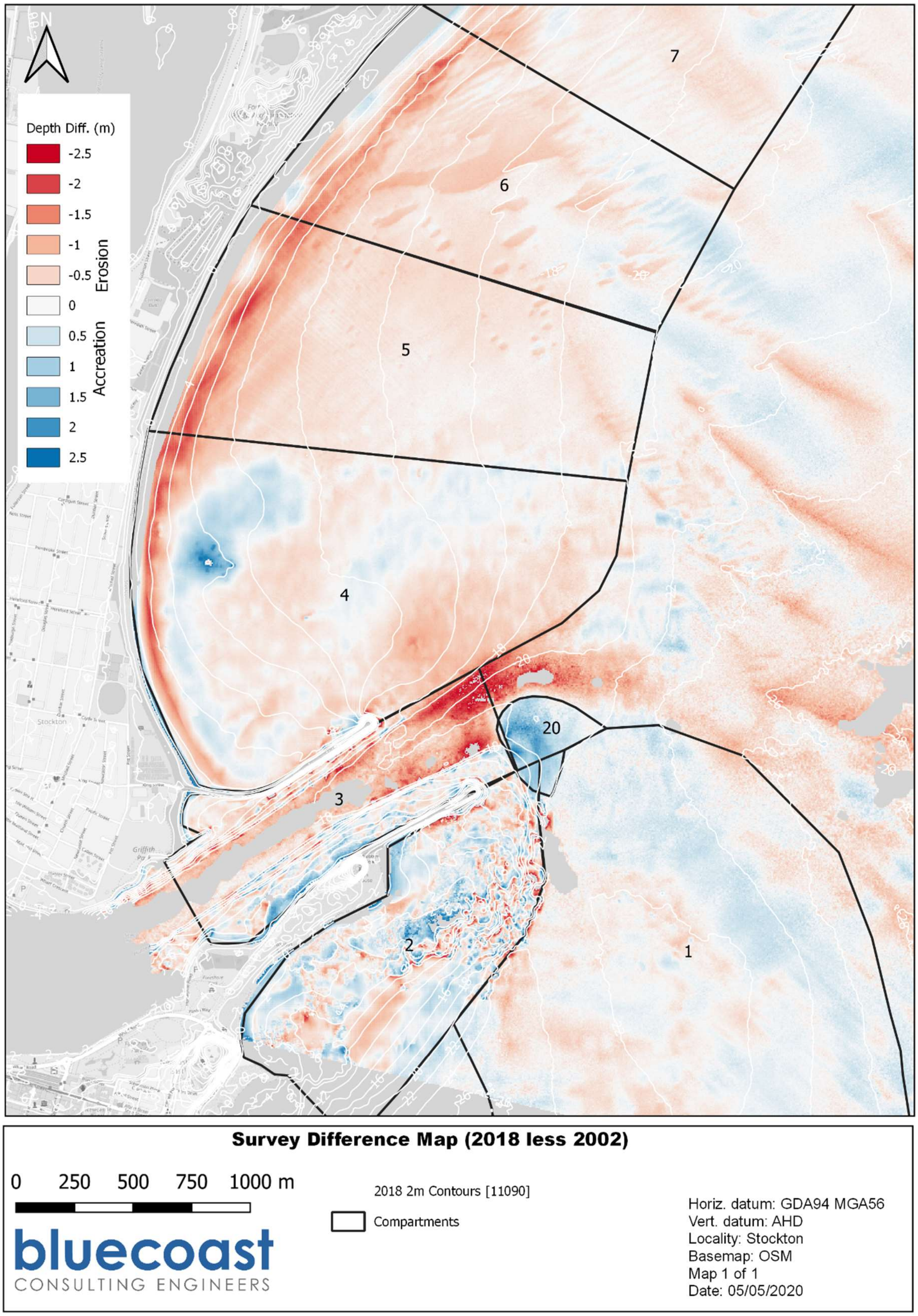

Figure 8: Survey difference map for 2002 relative to 2018.

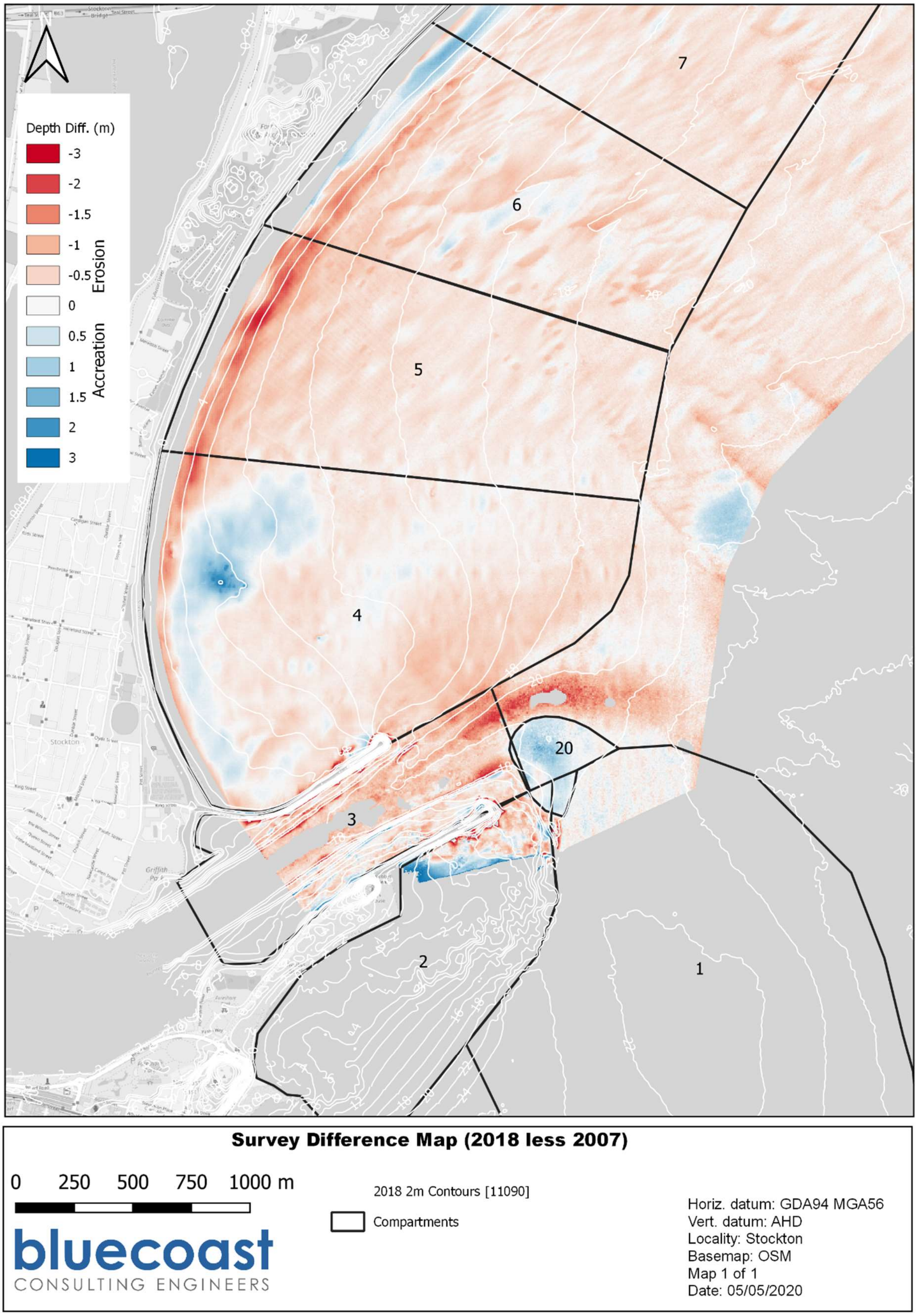

Figure 9: Survey difference map for 2007 relative to 2018.

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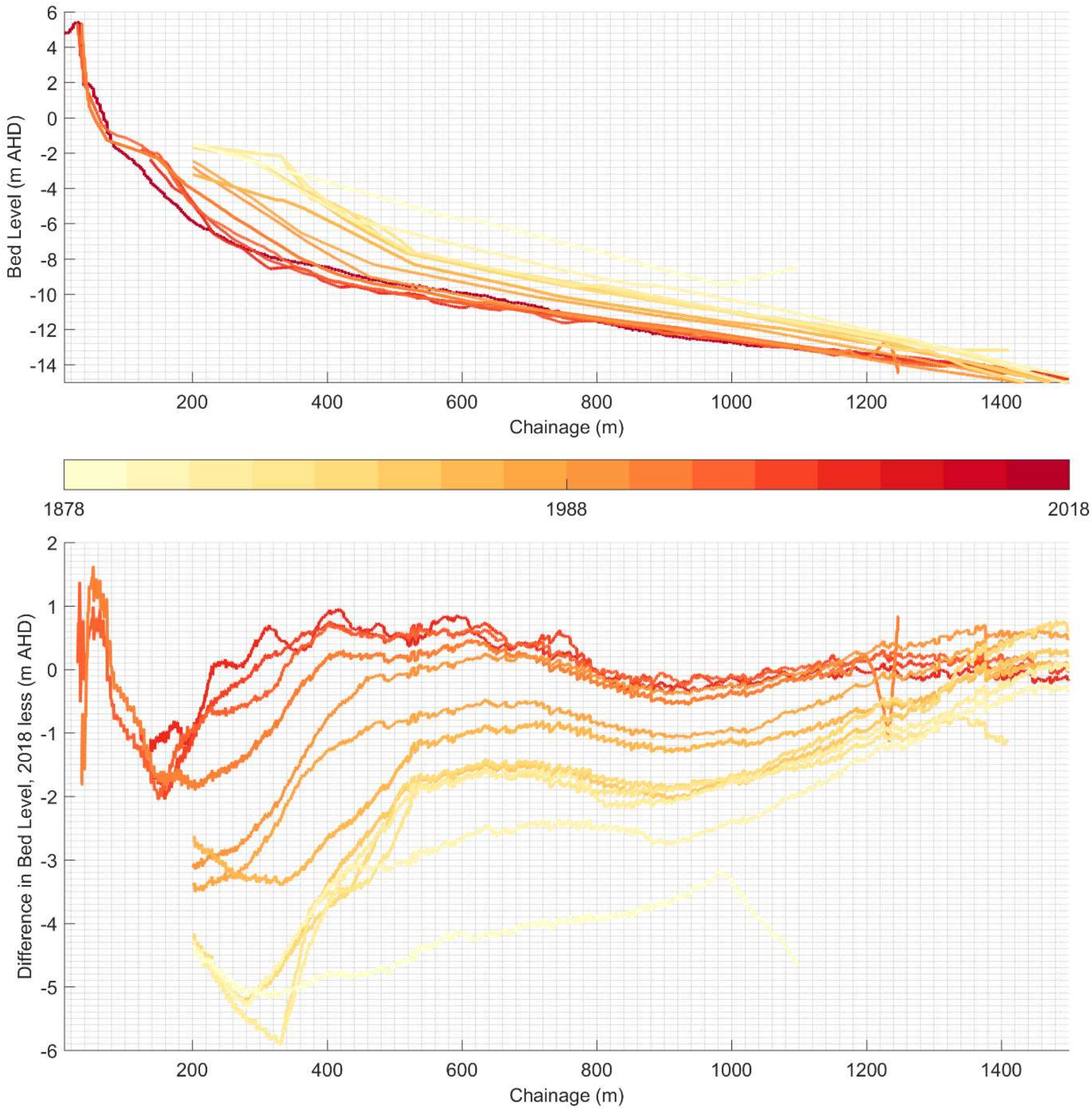

Figure 10: Historical coastal profiles (top) and profile change (bottom) based on historical bathymetric surveys for profile 3.

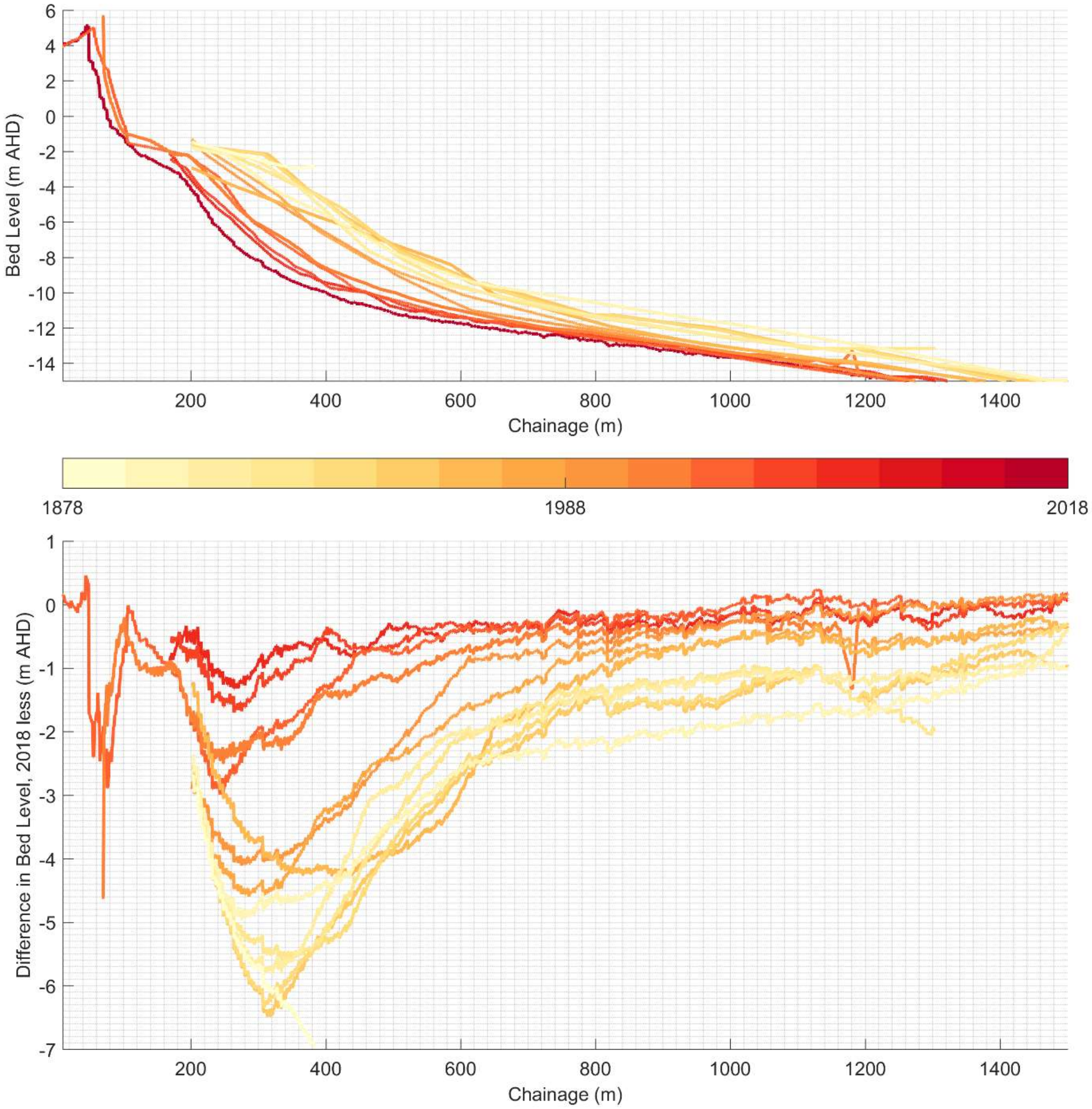

Figure 11: Historical coastal profiles (top) and profile change (bottom) based on historical bathymetric surveys for profile 4.

Figure 12: Mean sea level (0m AHD) shorelines from 2018 (inner) and 1994 (outer) showing realignment of the southern embayment.

6 Metocean setting

This section details the analyses of metocean datasets nearby the Stockton Bight study area. Figure 13 displays the location of the monitoring instruments used within the analysis.

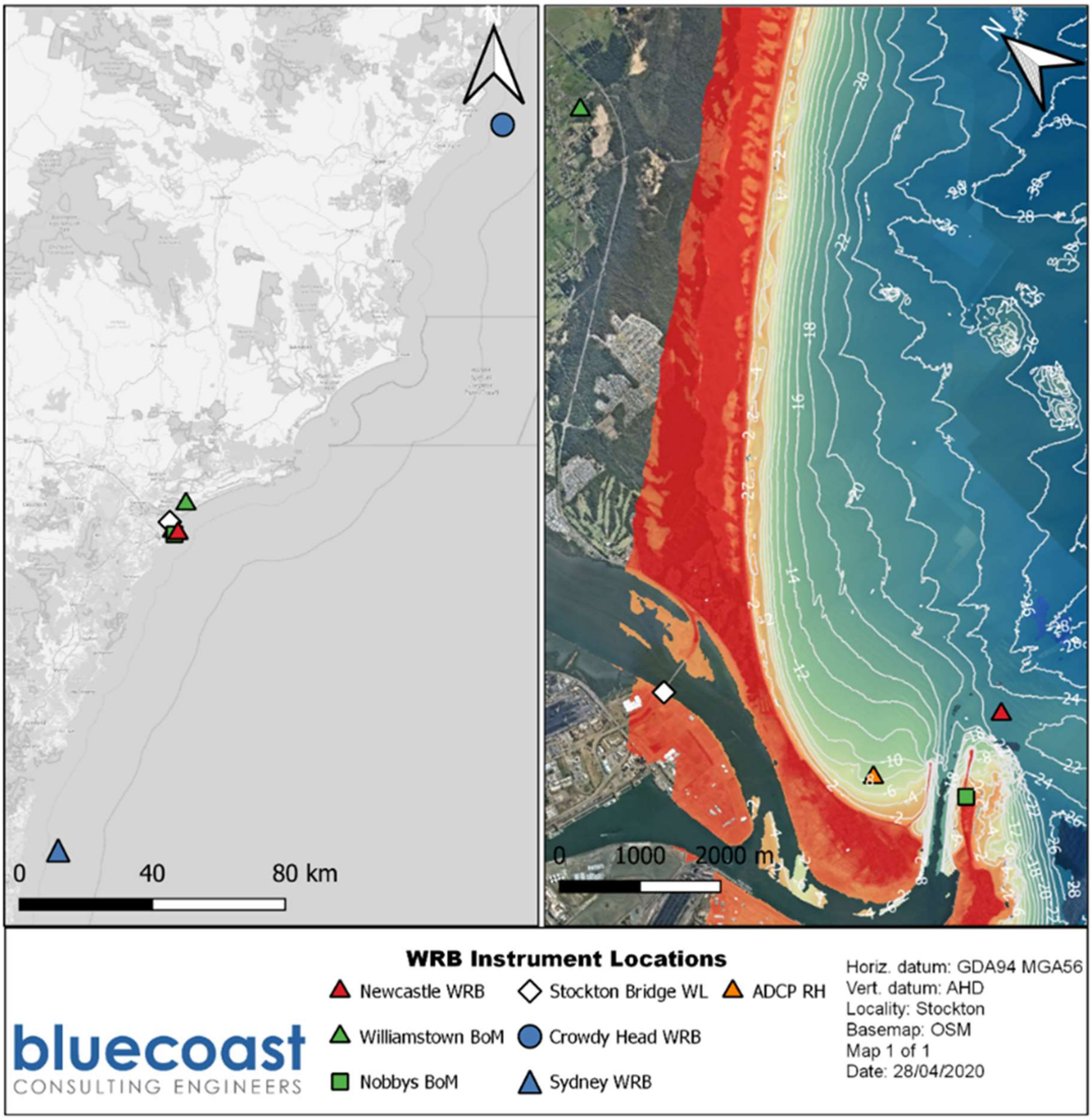

Figure 13: Location of the instruments utilised within the study area and 2018 Marine LiDAR contours.

6.1 Wave climate

The Stockton Bight section of the NSW coastline experiences waves generated from three primary sources: Tasman Sea swells, locally generated wind-waves and waves from East Coast Lows (ECL) systems. At the study site, measured wave data is available from the following directional wave rider buoys (WRBs):

- Crowdy Head record available from August 2011 to January 2020 (9-years) located 15.5 km to the north of the study site in 79m water depth.
- Sydney record available from March 1992 to January 2020 (28-years) in 90m water depth.
- Newcastle WRB which has data from November 2009 to March 2020 (11-years) and is operated by Port Authority of NSW (PANSW). This WRB is the closest to the study site being located at the entrance to the Hunter River in approximately 22m water depth (see Figure 13).

The average as well as seasonal wave climate statistics for the Newcastle WRB can be seen in Table 3 and the wave roses for swell (swell waves, Tp >8s) and sea (local sea, Tp <8s) are provided in Figure 14. Similar descriptive statistics for the Crowdy Heads WRB are provided in Table 4 and wave roses of the measured wave heights and periods in Figure 15 and in Table 5 and Figure 16 at Sydney WRB.

The deep water Crowdy Head and Sydney sites are dominated by moderate energy, swell waves, with mean significant wave heights of 1.56 m and 1.62 m, respectively. At the nearshore Newcastle WRB, the mean significant wave height is 1.41m, with a 75th percentile wave height of 1.71 m annually and some seasonal variation seen over summer which on average measured lower wave heights. Due to the narrow continental shelf and the orientation of the coastline with the direction of the prevailing storms and ECL events the site is subject to larger wave events. Over the period of measured wave heights at Newcastle, the 99.5th percentile was 4.41 m whereas the maximum was 8.52 m.

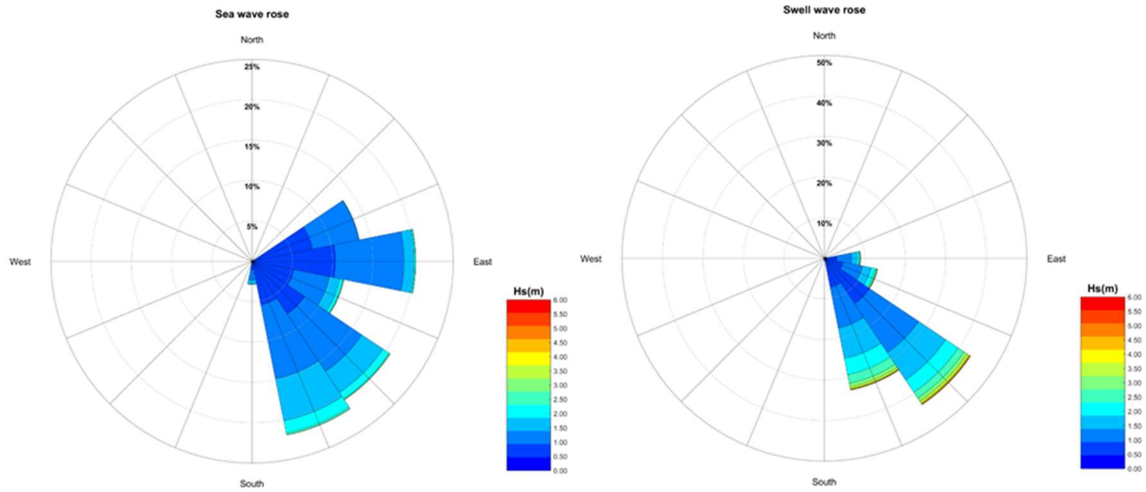

Figure 14: Long-term wave roses at Newcastle WRB for sea conditions (Tp < 8sec) and swell conditions (Tp > 8sec) from November 2009 to March 2020.

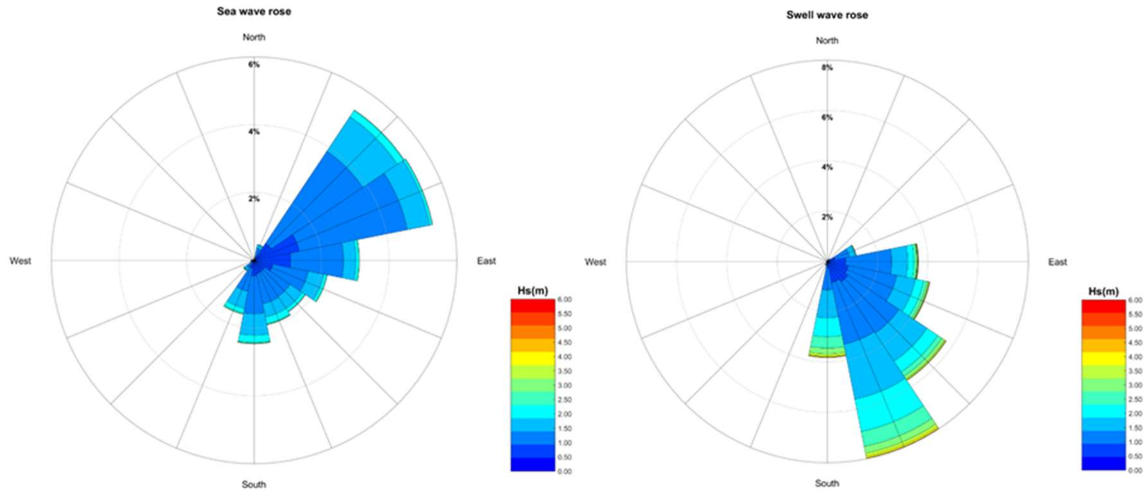

Figure 15: Long-term wave roses at Crowdy Head WRB for sea conditions (Tp < 8sec) and swell conditions (Tp > 8sec) from August 2011 to January 2020.

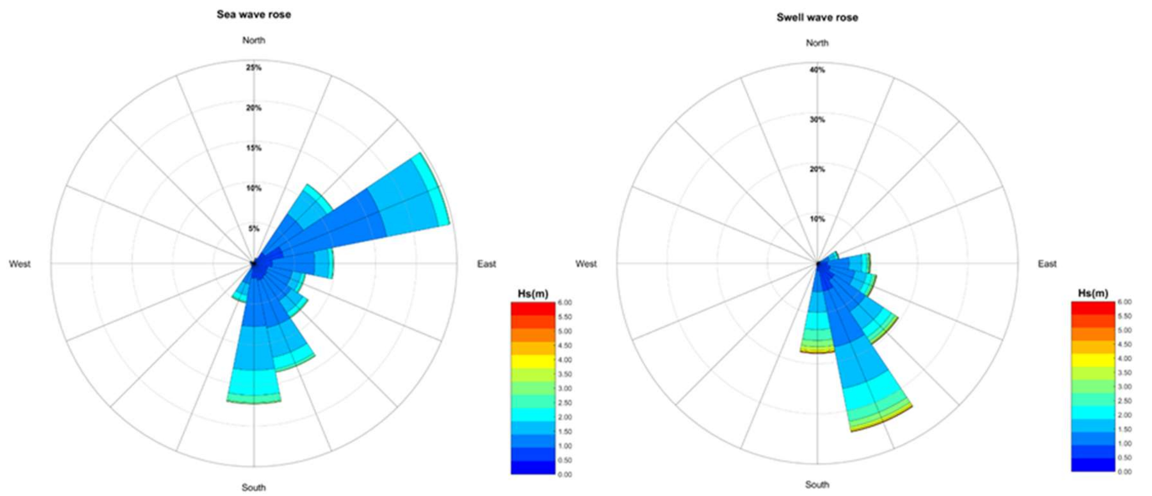

Figure 16: Long-term wave roses at Sydney WRB for sea conditions (Tp < 8sec) and swell conditions (Tp > 8sec) from March 1992 to January 2020.

Table 3: Wave measurement statistics for the Newcastle WRB from November 2009 to March 2020.

Parameters	Statistics	All Seasons	Long term averages (12 years)			
			Winter	Spring	Summer	Autumn
Significant wave height (H_s) [m]	Mean	1.41	1.49	1.40	1.32	1.43
	20%ile	0.88	0.83	0.88	0.90	0.87
	50%ile	1.24	1.31	1.25	1.18	1.25
	75%ile	1.71	1.86	1.70	1.53	1.78
	90%ile	2.30	2.59	2.24	2.02	2.35
	99%ile	3.90	4.37	3.58	3.49	3.86
	99.5%ile	4.41	4.88	4.13	3.97	4.26
	Max	8.52	8.17	7.14	6.33	8.52
Peak wave period (T_p) [s]	Mean	10.7	11.6	10.6	9.7	11.1
	20%ile	8.5	9.7	8.2	7.5	8.9
	50%ile	10.8	11.5	10.7	9.7	11
	75%ile	12.6	13	12.6	11.5	12.9
	90%ile	13.9	14.6	13.9	12.9	14.3
	99%ile	17.1	17.5	17	15.9	17.4
	% time sea (Tp < 8s)	0.2	0.1	0.2	0.3	0.1
	% time swell (Tp > 8s)	0.8	0.9	0.8	0.7	0.9
Peak wave direction (D_p) [°TN]	Weighted mean	125.7	135.8	144.6	93.5	313.4
	Mean	133.4	136.7	137.5	125.8	133.9
	Standard deviation	23.1	19.2	22.6	27.2	20.9

Table 4: Wave measurement statistics for the Crowdy Head WRB from August 2011 to January 2020.

Parameters	Statistics	All Seasons	Long term averages (10 years)			
			Winter	Spring	Summer	Autumn
Significant wave height (H_s) [m]	Mean	1.56	1.65	1.52	1.51	1.56
	20%ile	1.05	1.04	1.05	1.06	1.05
	50%ile	1.40	1.47	1.39	1.35	1.41
	75%ile	1.84	2.02	1.79	1.72	1.86
	90%ile	2.42	2.65	2.31	2.25	2.43
	99%ile	3.80	4.17	3.37	3.76	3.74
	99.5%ile	4.19	4.45	3.58	4.27	4.09
	Max	6.62	6.62	4.81	6.40	5.15
	Mean	10.0	10.8	9.7	9.3	10.3
	20%ile	8.2	8.9	7.6	7.6	8.5

Parameters	Statistics	All Seasons	Long term averages (10 years)			
			Winter	Spring	Summer	Autumn
Peak wave period (T_p) [s]	50%ile	9.8	10.8	9.8	9.3	10.3
	75%ile	11.5	12.1	11.5	10.8	11.5
	90%ile	12.9	13.8	12.9	12.1	12.9
	99%ile	16.0	16.0	16.0	14.9	16.0
	% time sea (T_p < 8s)	0.2	0.1	0.3	0.3	0.1
	% time swell (T_p > 8s)	0.8	0.9	0.8	0.7	0.9
Peak wave direction (D_p) [°TN]	Weighted mean	146.4	150.7	152.8	133.5	146.5
	Mean	131.0	144.4	134.3	114.8	130.9
	Standard deviation	**37.7**	32.5	41.1	37.5	33.8

Table 5: Wave measurement statistics for the Sydney WRB from March 1992 to January 2020.

Parameters	Statistics	All Seasons	Long term averages (29 years)			
			Winter	Spring	Summer	Autumn
Significant wave height (H_s) [m]	Mean	1.62	1.65	1.59	1.58	1.66
	20%ile	1.05	0.97	1.06	1.06	1.06
	50%ile	1.45	1.43	1.43	1.43	1.48
	75%ile	1.93	2.01	1.87	1.87	2.02
	90%ile	2.55	2.78	2.44	2.44	2.62
	99%ile	4.17	4.65	3.96	3.59	4.10
	99.5%ile	4.64	5.18	4.43	3.93	4.62
	Max	8.43	7.76	6.22	5.53	8.43
Peak wave period (T_p) [s]	Mean	9.8	10.5	9.4	9.0	10.2
	20%ile	7.7	8.8	7.3	7.0	8.3
	50%ile	9.8	10.5	9.3	8.9	10.2
	75%ile	11.5	12.1	10.8	10.5	11.8
	90%ile	12.9	13.5	12.5	12.1	13.3
	99%ile	15.4	16.0	15.4	14.9	16.0
	% time sea (T_p < 8s)	0.2	0.1	0.3	0.3	0.2
	% time swell (T_p > 8s)	0.8	0.9	0.7	0.7	0.8
Peak wave direction (D_p) [°TN]	Weighted mean	150.4	154.3	153.6	141.9	147.5
	Mean	136.6	145.4	136.6	126.1	136.3
	Standard deviation	37.4	32.1	40.1	40.4	34.9

6.1.1 Wave direction

Changes to the mean wave direction can occur due to seasonal variations as well as with the larger scale oscillations in climate. The average annual wave direction at each measurement location in Figure 17 shows that for the past decade the wave directions were around 130°N. Sydney WRB has the longest record and displays only a small annual oscillation in the change in wave directions. Figure 18 and Figure 19 display the variation in wave direction over the year around the median wave direction, only minor differences are seen over the measured period.

Nearshore waves at the Stockton site were modelled in the DHI (2006) analysis where 12 years of offshore measured data was transformed to give the shallow water wave heights and directions along the Stockton Bight at the 17 m contour (Figure 20). The analysis showed that for north of Fern Bay, at the 17 m contour and for the location reviewed, there was little transformation in wave direction from the measured deep-water waves.

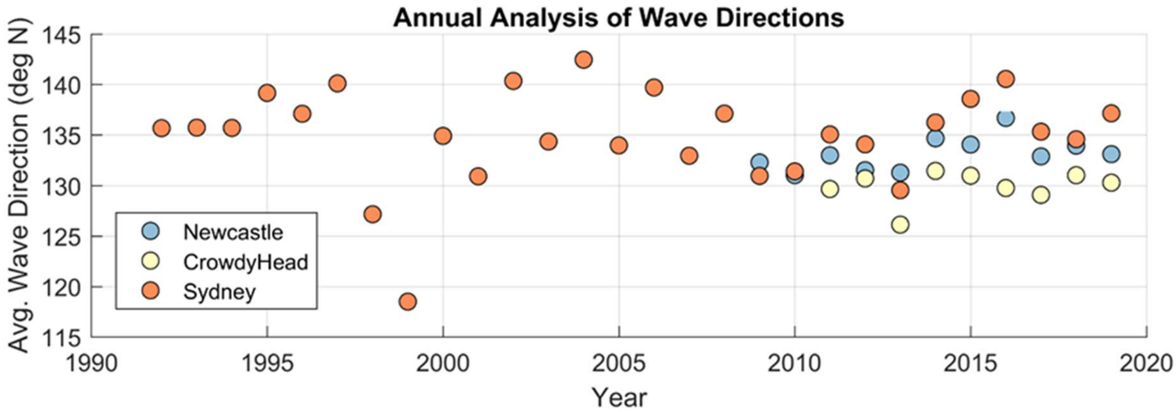

Figure 17: Annual average wave direction at Newcastle, Crowdy Head and Sydney WRB.

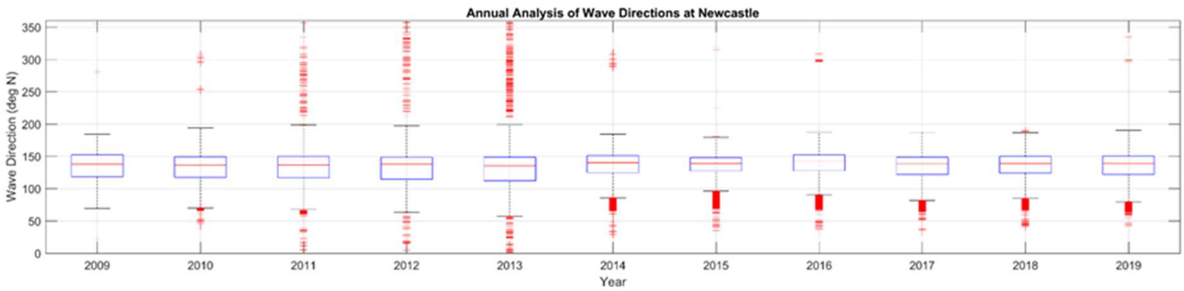

Figure 18: Annual wave directions at Newcastle WRB.

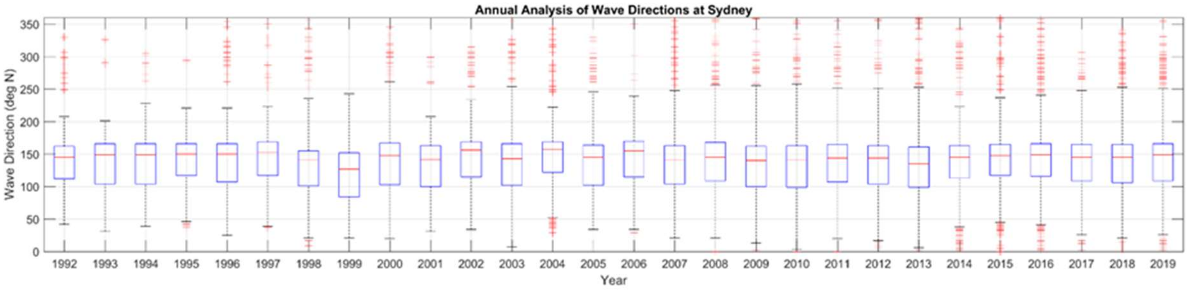

Figure 19: Annual wave directions at Sydney WRB.

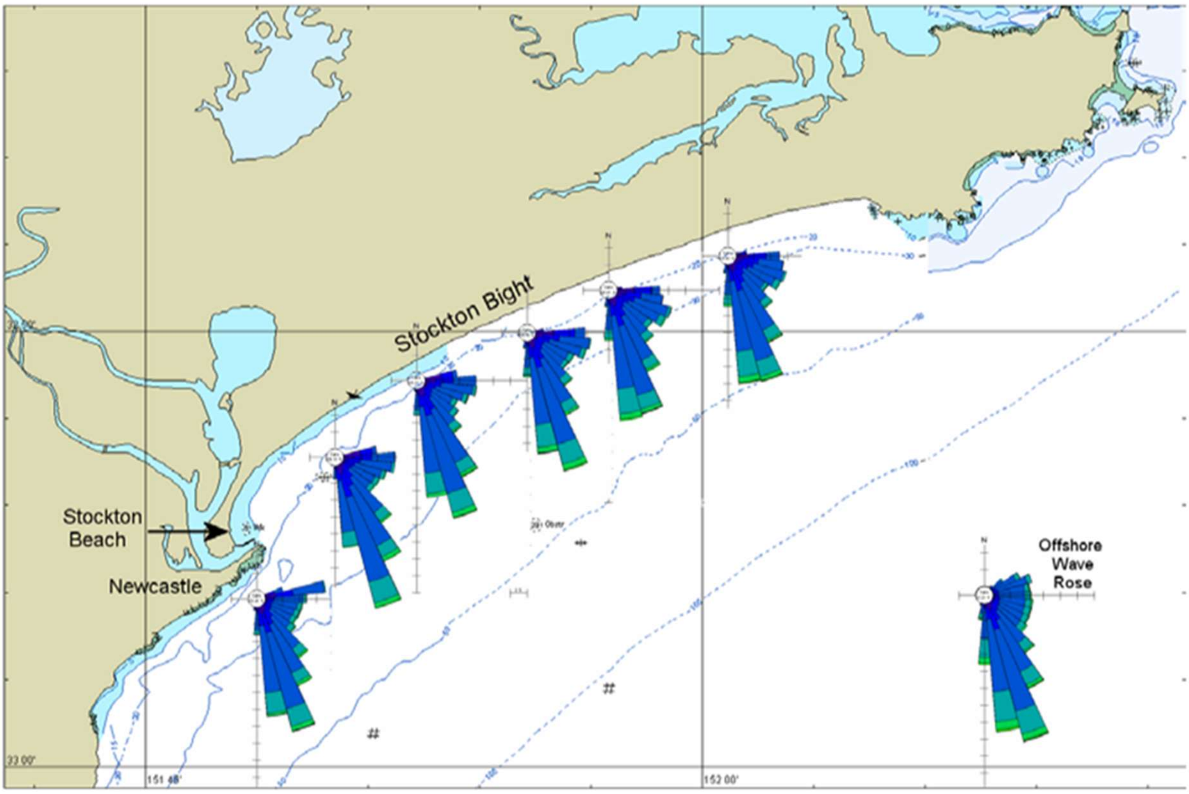

Figure 20: Wave roses from 12 years of transformed offshore measured wave data (Source: DHI, 2006).

6.1.2 Extreme wave events

At the study site, extreme wave events are usually associated with ECL weather systems. An Extreme Value Analysis (EVA) of the Newcastle WRB spanning the 12 years of available data was undertaken. A peak over threshold analysis of the measured wave heights identified the extreme events (Figure 21) and a Weibull distribution was fitted to the extremes wave heights to provide the ARI wave heights in Table 6. These values will be reviewed using longer but offshore wave height records as part of the full Stockton Bight sediment transport study.

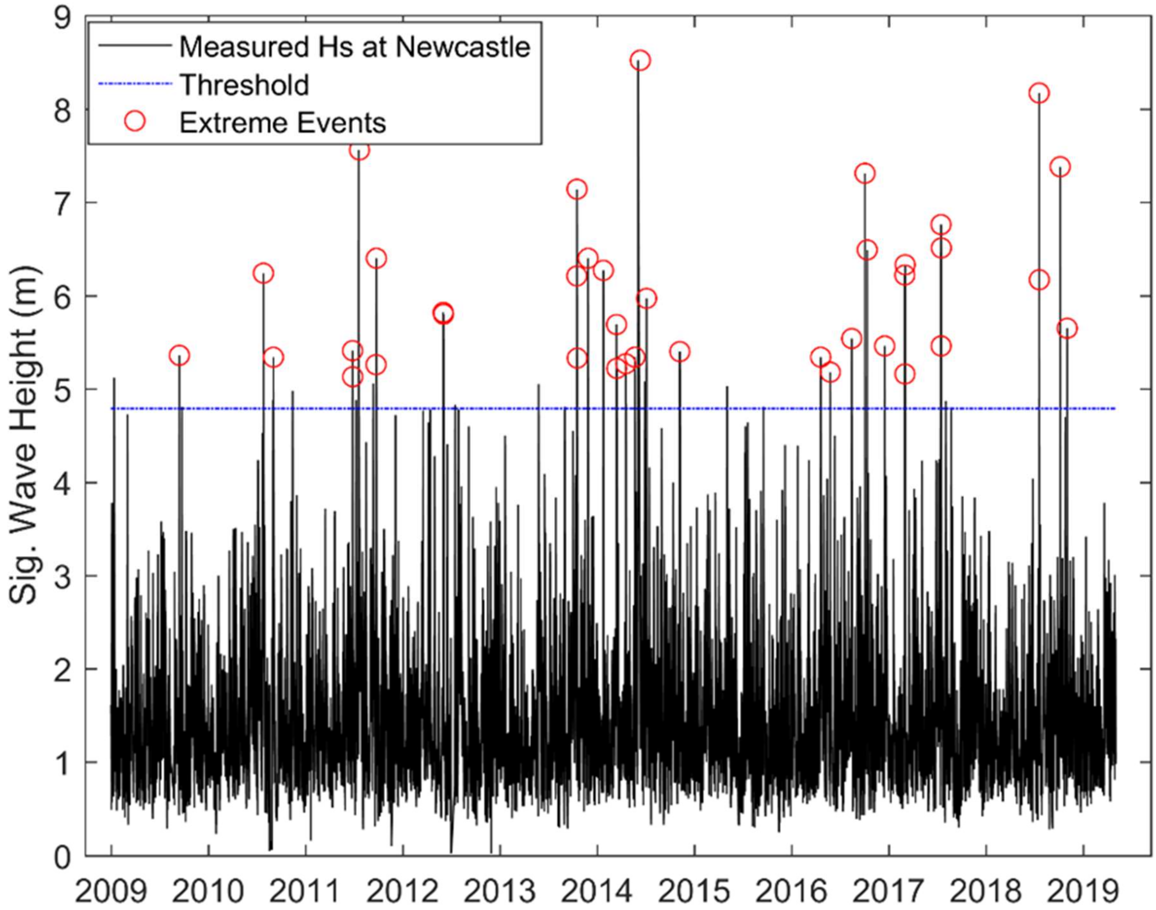

Figure 21: Identification of extreme wave events in measured wave heights at the Newcastle WRB managed by PANSW from all wave directions.

Table 6: Average recurrence interval (ARI) wave heights for Newcastle WRB from the PANSW.

ARI (year)	H_s (m)	98% confidence limits (m)
1	6.3	5.9 - 6.6
5	7.6	7.0 - 8.2
10	8.1	7.4 - 8.8
25	8.8	7.9 - 9.7
50	9.3	8.3 - 10.3
100*	9.8	8.6 - 11.0

*Values should be used with caution given it is derived from a 12-year wave height record.

6.2 Water level climate

The astronomical tide is the periodic rise and fall of the sea surface caused by the combination of the gravitational force exerted by the moon and the sun upon the earth and the centrifugal force due to rotations of the earth and moon, and the earth and the sun around their common centre of gravity. Tides are subject to spatial variability due to hydrodynamic, hydrographic and topographic influences. The Stockton Bight experiences semi-diurnal tides (two highs and two lows a day) with tidal planes shown in Table 7 from the Australian Tidal Planes produced by the National Tide Centre.

Measured water levels at the site are available at Stockton Bridge tide gauge within Newcastle Port from October 2017 to March 2020 displayed in Figure 13. Water levels observed in 2019 are displayed in Figure 22.

Table 7: Tidal planes at Newcastle from the National Tide Centre 2013.

Tidal planes	Elevation (m CD)	Elevation (m AHD)
HAT	2.1	1.1
MHWS	1.7	0.7
MHWN	1.4	0.4
MSL	1.0	0.0
MLWN	0.6	-0.4
MLWS	0.4	-0.6
ISLW	0.1	-0.9

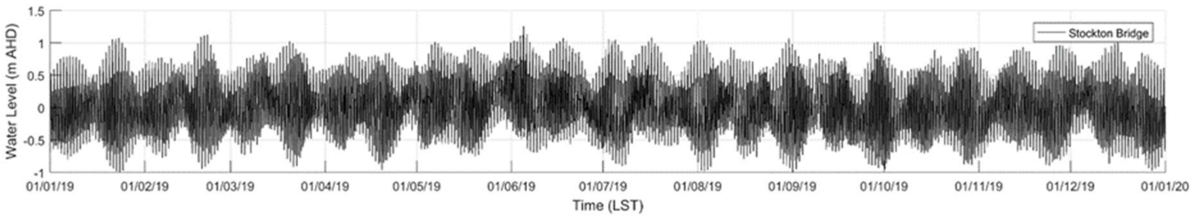

Figure 22: Measured water levels at Stockton Bridge

6.3 Tidal, fluvial and other currents and circulation patters

Complex currents at the study site have been documented in previous studies on the impacts of the anthropogenic developments at the location. The impacts of port structures (e.g. breakwaters) and seawalls on the sediment transport pathways and resulting shoreline position was presented in the 2006 study undertaken by DHI.

Measured currents from both bottom mounted ADCP and ADCP transects were collected within the entrance channel over a spring and neap tide, recording stronger currents on the eastern side of the channel on both the ebb and flood tides. Measured ebb currents were swifter than flood currents (i.e. ebb velocity asymmetry). Modelled tidal and fluvial current speeds at the Hunter River entrance for a spring tide are presented in Figure 23. Current magnitudes through the entrance reach approximately 0.6 m/s on a flood and 0.8 m/s on an ebb tide which is expected with the addition of seaward fluvial currents on the ebb tide; however these current vectors are directed offshore (northeast) of the study site and diminish in magnitude after 1 km from the entrance channel. Overall, DHI (2006) found that the role of fluvial included currents at Stockton is minimal.

Further analysis on the hydrodynamics at the site during different wave propagation directions in Figure 24 showed that waves propagating from the east and east south-east produce uniform longshore currents north of the study site and minimal currents at the southern end of Stockton Beach due to wave refraction and a resulting perpendicular approach to the shoreline (DHI, 2006). Also evident in some of the east south east cases was the nodal point at the north of the seawall where the currents split north and south due to the different angles in wave approach. Whereas waves propagating from the south to south-east in Figure 24 show the largest impact on flow it is the breakwaters which induce secondary circulation currents. On the leeward side of the breakwaters, the differences in wave setup from the sheltered areas as well as diffracted waves generate circulation currents. At the northern end of the seawall the longshore currents are uniform. The few spatial variations evident are produced by wave focusing. The study also identified the complex flow patterns at Nobbys Head which was identified as being due to the uneven bathymetry and sand lobe present offshore (DHI, 2006).

Larger-scale ocean currents offshore of the study area are dominated by the East Australian Current. The southerly ocean current (Figure 25) is located along eastern seaboard of NSW offshore of Newcastle (CSIRO, 2014).

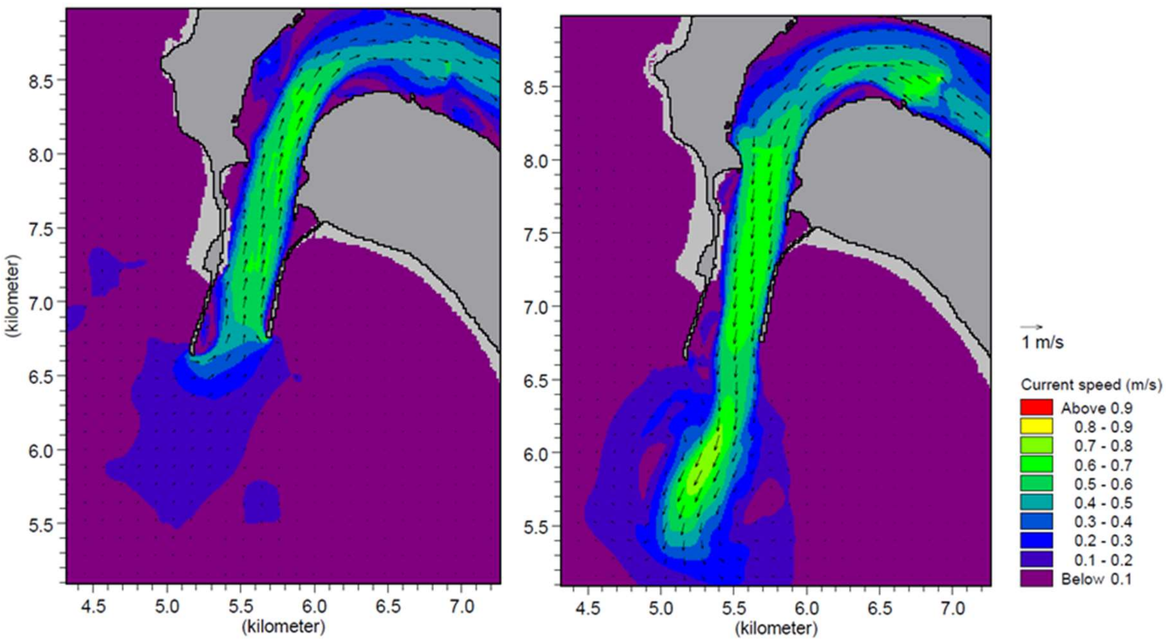

Figure 23: Peak flood (left) and ebb (right) tidal current speed map for a spring tide at the Hunter River entrance (source: DHI, 2009).

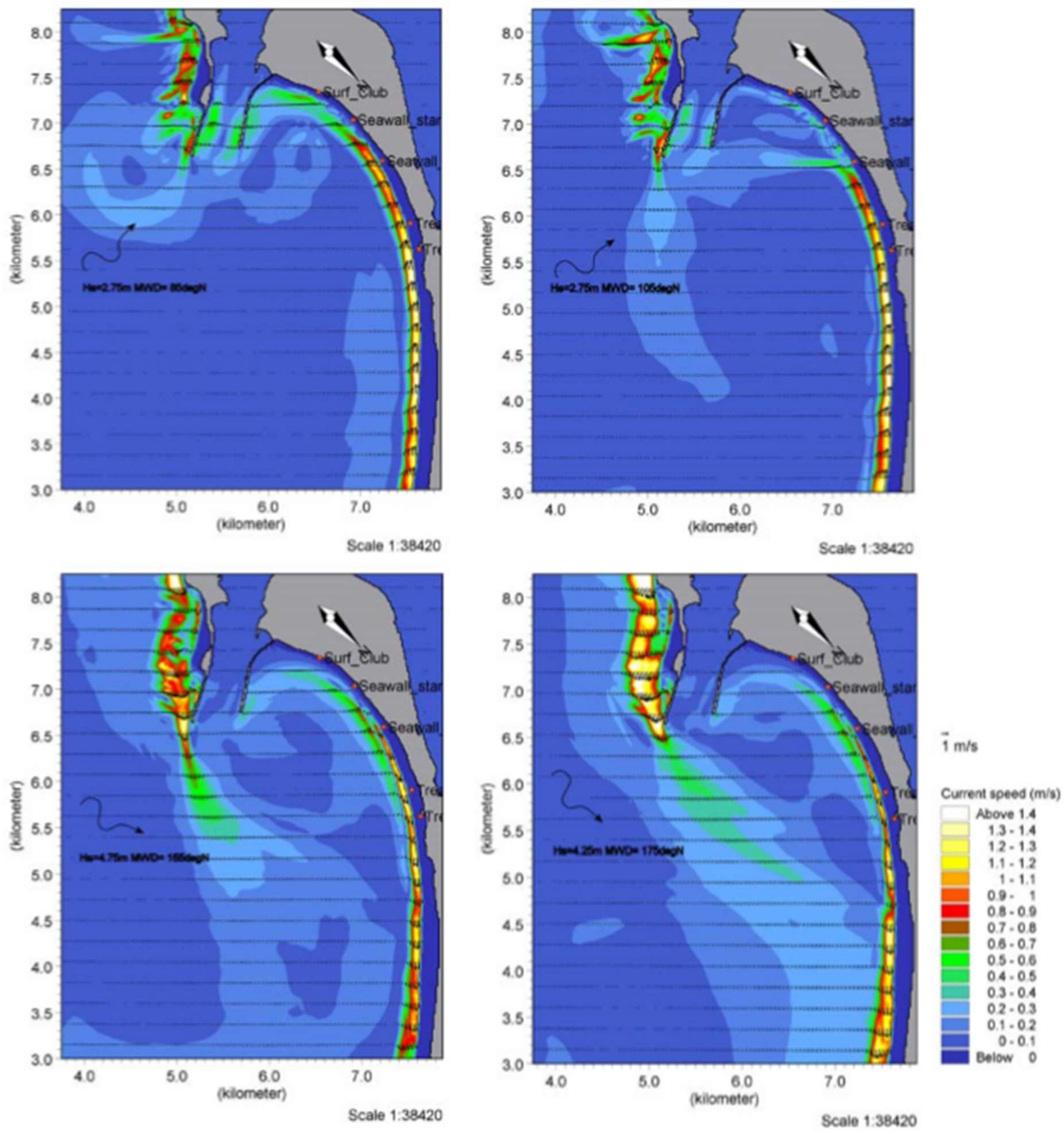

Figure 24: Average currents over a full tidal cycle at Newcastle for four wave cases propagating from (top) east to east southeast and (bottom) south to southeast (source: DHI, 2006).

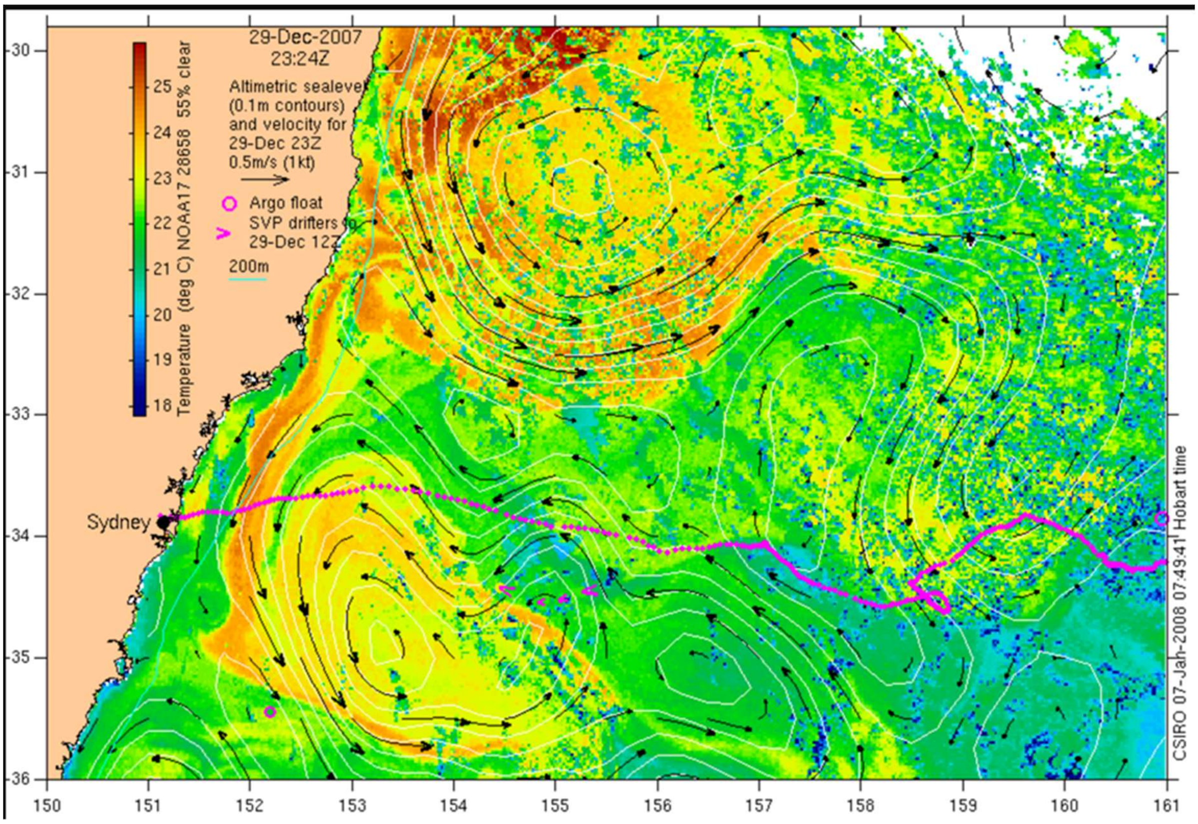

Figure 25: Snapshot of the East Australian Current along eastern seaboard of NSW showing southerly ocean currents offshore of Newcastle (source: CSIRO).

The DHI 2006 study presented current vectors and predicted sediment transport from wave driven currents at Stockton based on a typical yearly condition from, 1992-2005 in Figure 26. Wave-driven current along the coastline are influenced by the port structures which diffract waves from the southeast around the tip of the breakwater. Currents at the shoreline in front of the Mitchell Street seawall are driven by differences in wave setup and have a southerly and northerly alongshore movement from a nodal point located at the northern end of the seawall (DHI, 2006).

It is too soon in the process of the full 2020 sediment transport study to validate the sediment pathways and fluxes presented in Figure 26. However, the findings of the volumetric analysis for the Stockton Beach embayment outlined above (Section 5) raises questions about the cross-embayment pathway (i.e. the pathway from south of the river entrance to Stockton Bight).

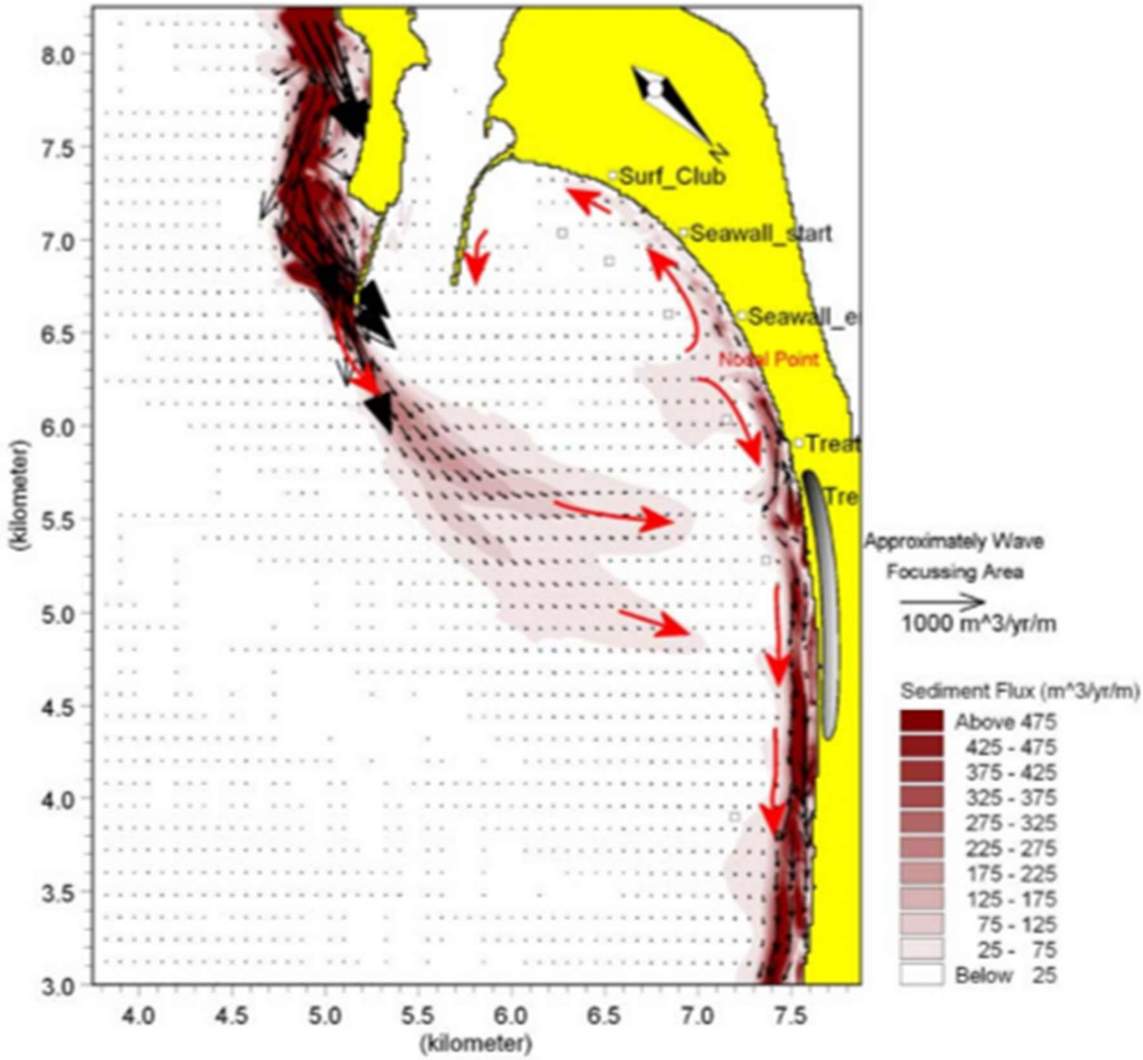

Figure 26: Current Vectors and predicted sediment transport at Stockton based on a typical yearly condition from 1992-2005 (source: DHI, 2006).

Local measured currents are available from four deployments of an Aquadopp ADCP undertaken by Royal Haskoning DHV offshore of Stockton Beach (Figure 13). The measured data available covers the 3rd to 21st December 2019 and 18th January to 1st February 2020. A time series of the measured data for the first period is displayed in Figure 27 and current speeds in U (east-west) and V (north-south) directional space for the depth averaged currents during both periods are displayed in Figure 28. Figure 28 shows the depth averaged currents during both deployment periods were predominately offshore towards south-east. Maximum current speeds were measured at the surface (Figure 27) and reached over 0.8 m/s and 0.45 m/s in the first and second deployment periods respectively, with the highest current speeds occurred at the bottom of the ebb tide.

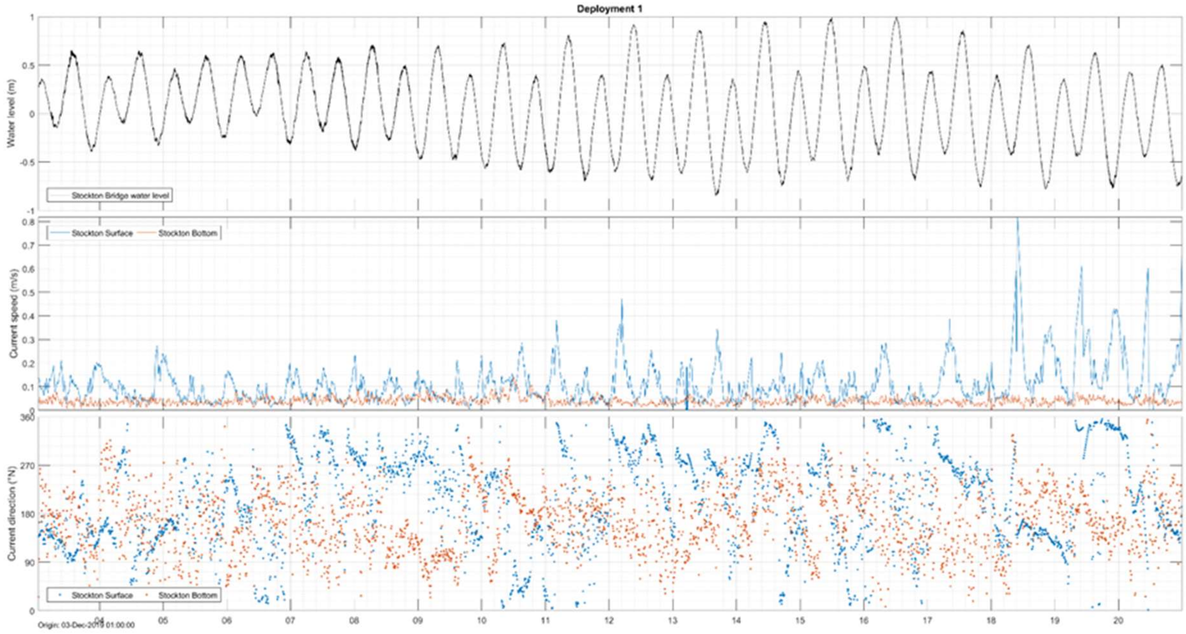

Figure 27: Measured currents at Stockton during deployment 1 and 2 and water levels at Stockton.

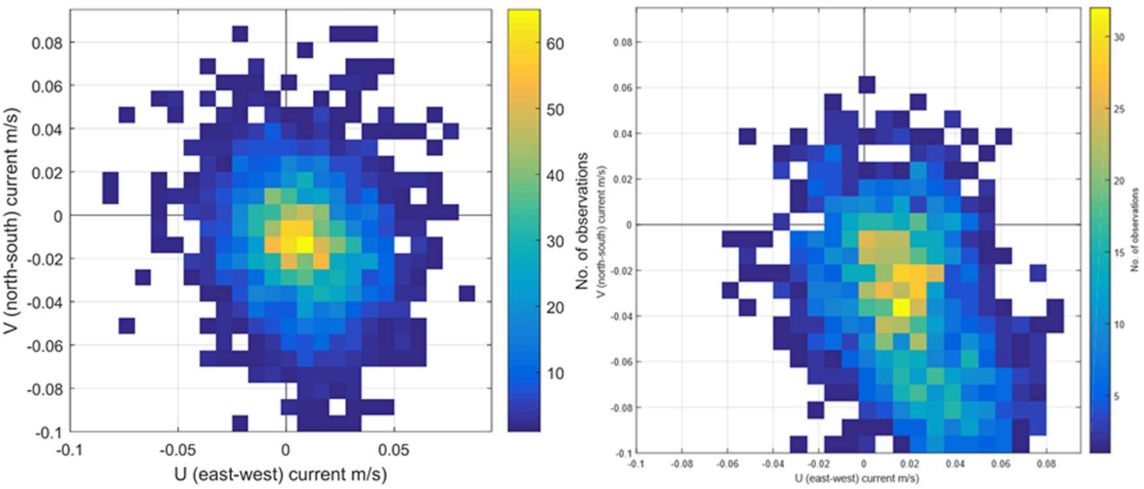

Figure 28: Depth averaged current speeds at SB01 during (left) deployment 1 and 2 (18 days duration) and (right) deployment 4 (14 days duration).

6.4 Wind climate

Measured wind data at Newcastle is available at Nobbys and Williamstown BoM weather station (Figure 13) with three hourly, half hourly and one minute temporal frequencies recorded from 1979. One-minute wind data has been collected from July 2004 at Nobbys and August 1999 at Williamstown.

Overall and seasonal wind roses for Nobbys BoM station are presented in Figure 29 for the one-minute data. Over the summer period, winds predominantly arrive from the north-east to the south whereas over the winter synoptic period, winds are predominantly from a north-westerly direction. Similar descriptive wind roses are presented for the one minute wind speeds and directions at Williamstown in Figure 30 which also show winds coming from a predominately north-westerly direction. The Summer synoptic period has the largest percentage of onshore winds at the Williamstown location.

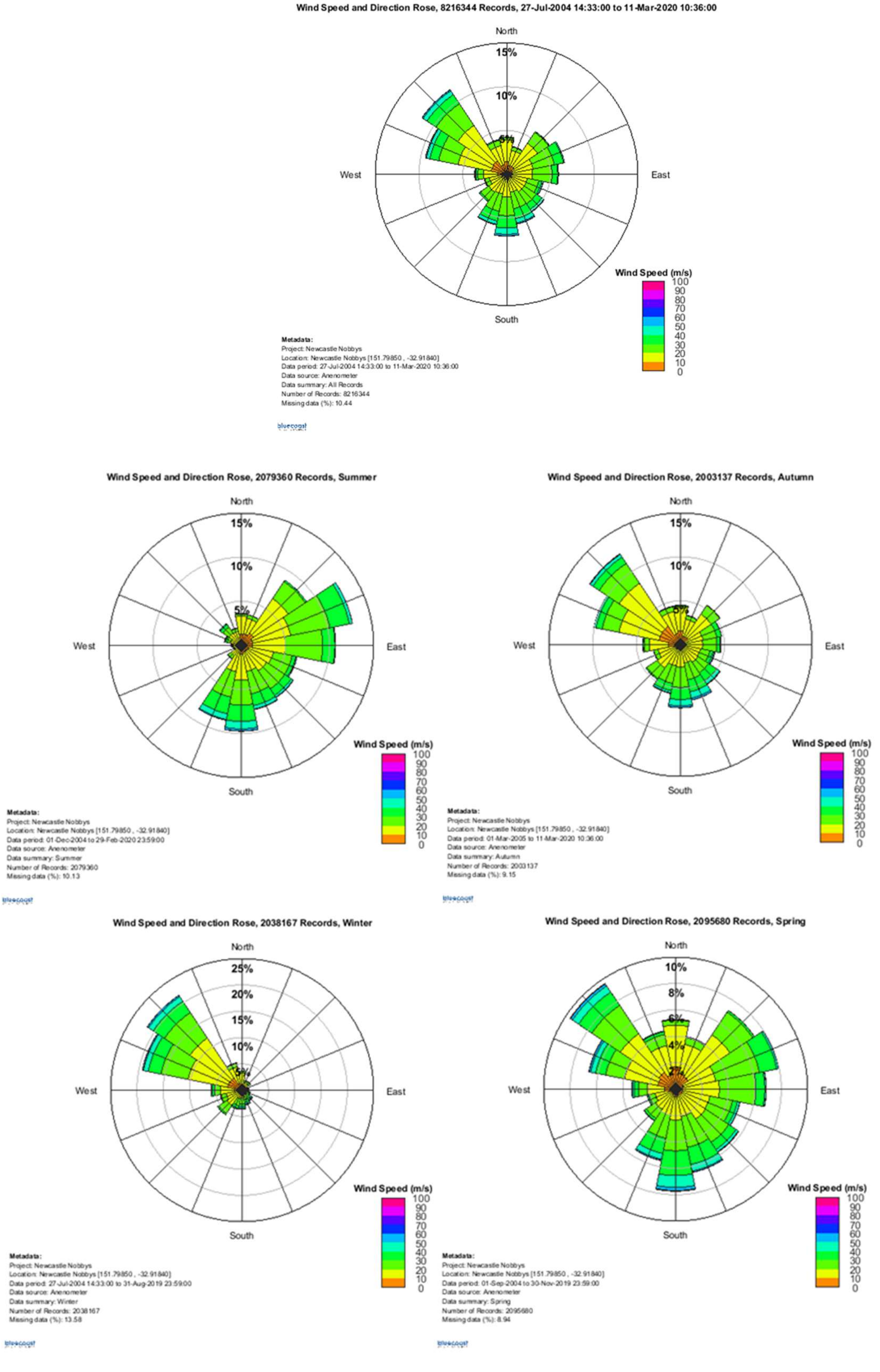

Figure 29: Annual (top) and seasonal wind roses at Nobbys Newcastle BoM station from one-minute data between July 2004 and March 2020.

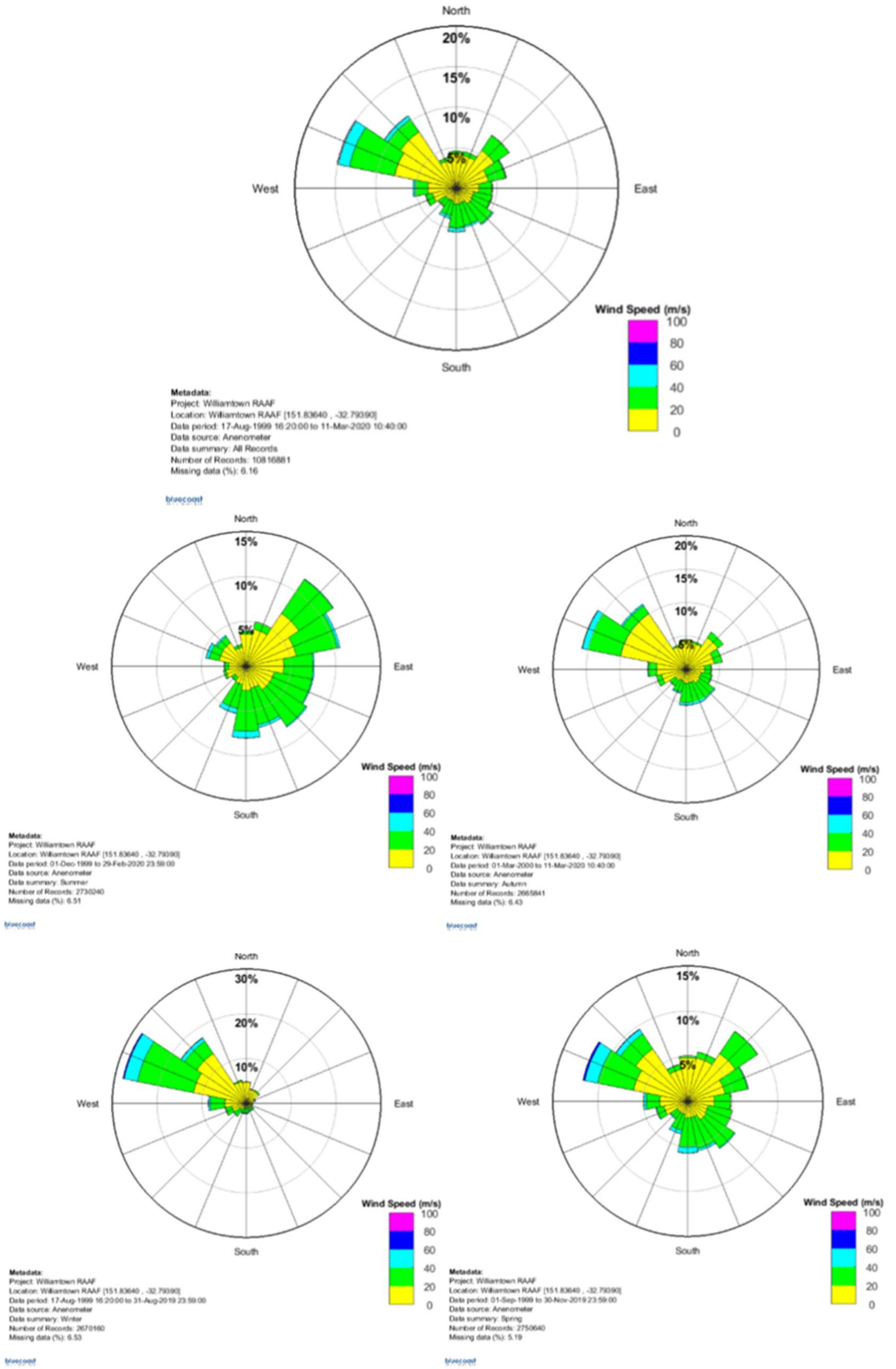

Figure 30: Annual (top) and seasonal wind roses at Williamstown BoM station from one-minute data between August 1999 and March 2020.

7 References

DHI, 2006. *Stockton Beach Coastal Processes Study: Stage 1 – Sediment Transport Analysis and Description of On-going Processes*. Report prepared for City of Newcastle.

CSIRO, 2014. *East Australia Current*.

City of Newcastle [CN], 2019. *Newcastle Coastal Management Program Scoping Study.* Report prepared by City of Newcastle.

NPC, 2014. *A Harbor from a Creek*. Book prepared for NPC by Rosemary Melville.

Mining, Environment and Geoscience [MEG] 2020 *Review of potential marine sand resources for beach renourishment in the Hunter–Newcastle region*. Report published by Regional NSW.

Umwelt, 2002. *Shifting sands at Stockton Beach.* Report prepared for Newcastle City Council.

WBM, 1998. *Newcastle Coastline Hazard Definition Study*. Report prepared for Newcastle City Council.

WorleyParsons, 2012 *Stockton Beach Sand Souring and Funding Feasibility Study*. Report prepared for City of Newcastle.

Attachment A – Summary of datasets

Summary of the datasets available for the preparation of this technical note is presented in Table 8. The list of data will be expanded for the full sediment transport study.

Table 8: Overview of coastal monitoring datasets used in this study.

ID	Description	Source	Dates
Topography and bathymetry	LiDAR at 5 m resolution	DPIE	2018
	High-resolution UAV derived topography	CN	2019 and 2020
	Beach profile data (photogrammetry)	DPIE	1953 – 2020
	Hydrographic surveys from assorted periods and coverage extents	DPIE, Umwelt, CN, PoN	1816 - 2018
	Satellite Derived Bathymetry	Bluecoast/Eomap	
Aerial imagery	High resolution, rectified aerial imagery	Nearmap	2020
Metocean and meteorological			
Water levels	Water levels from Stockton Bridge at a one-minute measurement period	Port Authority of NSW (PANSW)	Oct 2017 -Mar 2020
Waves	Measured wave heights, directions periods and directional spreading at Sydney and Crowdy Head directional WRB at a 1-hour sampling period	MHL	1992-2020 2011-2020
	Measured wave heights, directions and periods at Newcastle WRB at a 10-minute sampling period	PANSW	2009-2020
Currents	Measured currents at Stockton at 8 m water depth over four deployments	Royal HaskoningDHV	Dec 2019 and Jan 2020
Winds	Measured wind speeds, directions at atmospheric pressure at 10m for Newcastle Nobbys and Williamstown RAFF at three hourly, half hourly and one-minute sampling periods	BoM	1979-2020 (1 min since 2004 and 1999 respectively)

City of Newcastle

Stockton Beach coastal erosion hazard assessment

Report #: P19028_PartB_R00.0A

18 June 2020

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1. INTRODUCTION

1.1 General

In line with the Coastal Management Act 2016 and the NSW Coastal Management Manual Part B (the Manual), a probabilistic coastal hazard assessment for Stockton Beach has been undertaken. The City of Newcastle (CN) engaged Bluecoast Consulting Engineers (Bluecoast) and their sub-consultants Salients Pty Limited (Salients) to undertake the coastal hazard assessment. The hazard assessment is limited to the area north of the Stockton Breakwater (northern training wall of the Hunter River), and the northern boundary of the Stockton Centre, which marks the boundary of CN's Local Government Area (see Figure 1).

The hazard assessment for Stockton Beach (Part B) is being undertaken concurrently to a sand transport study for Stockton Bight (Part A), namely the 'Stockton Bight Study'. During Stage 1 of the Newcastle coastal management program (CMP) processes, CN identified the need for the two investigations. The two studies are being delivered as part of Stage 2 of the Newcastle CMP. Due to a time constraint imposed by Ministerial direction to complete a Stockton CMP by 30 June 2020, CN are preparing a CMP within the area bound by the northern breakwater of the Hunter River and Corobba oval, Stockton. In addition, a cost benefit analysis (CBA) has been undertaken for the Stockton Beach CMP informed by findings of the Part A and Part B investigations (Bluecoast, 2020c). Given the urgency for coastal management actions at Stockton Beach, the CBA was fast-tracked and undertaken concurrently to the Part A and Part B investigations incorporating information readily available during the study time frame.

Furthermore, the studies were undertaken during state and federal government enforced restrictions on public gatherings, in response to the COVID-19 pandemic. This, in conjunction with the truncated timeframes, has meant, that a proposed stakeholder workshop could not be completed to inform the risk assessment. Necessary assumptions were made through desktop review of previous assessment and relevant literature and are described in more detail where relevant in this report.

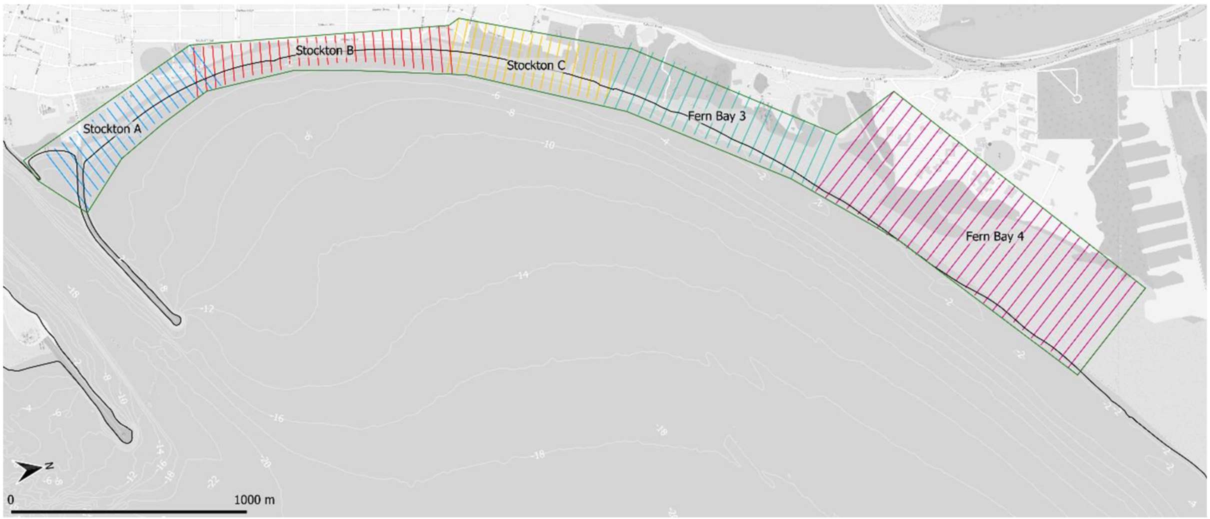


Figure 1: Coastal hazard assessment study area and NSW photogrammetry (DPIE, 2020) blocks and transects (coloured lines) at Stockton Beach.

1.2 Study objectives

CN are in the process of developing a CMP in accordance with the Coastal Management Act (2016) and are developing long-term actions to address on-going beach erosion and shoreline recession. The main objective of this assessment is to inform the planning of long-term actions via the erosion hazards identified herein.

1.3 Scope of this report

This report sets out the approach and results of the probabilistic erosion hazard assessment and the associated mapping. An inundation hazard assessment is deferred and will be completed for inclusion in the Newcastle CMP.

A brief summary of the key findings from the Stockton Bight Study most relevant to the hazard assessment is provided in Section 2.1.

2. BACKGROUND

2.1 Previous hazard assessments

A deterministic coastal hazard assessment for Stockton Beach was undertaken by DHI in 2006 and a re-assessment of the 2050 and 2100 hazard lines by DHI in 2011. More recently, an LGA-wide coastal hazard assessment was undertaken for CN by BMT WBM in 2014. This study mapped coastal hazards using a 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 assigned by combining estimated storm erosion 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.

The LGA-wide hazard assessment was undertaken according to the Guidelines for Preparing Coastal Zone Management Plans (OEH, 2013; now DPIE). These guidelines have been superseded by the abovementioned Coastal Management Act 2016 and the associated Manual.

The probabilistic assessment described herein, include the following updates to the hazard assessment approach:

- a detailed, quantified coastal processes investigation as part of the Part A – Stockton Bight Study being undertaken in parallel (Bluecoast, 2020a)
- recommendations set out in the Manual (OEH, 2019)
- probabilistic modelling approach to account for uncertainties in the coastal processes definitions and provide robust risk levels (likelihoods), i.e. not qualitatively assigned
- use of high quality 2020 and 2018 topography data as baseline
- latest sea level rise projections
- consideration of built coastal protection structures.

2.2 Stockton Bight Study

Beach erosion processes and quantitative sediment transport estimates for the coastal zone within the Stockton Bight sediment compartment have been assessed as part of the Stockton Bight study (Part A) in Bluecoast (2020a). A brief summary of the most relevant key findings is presented in the following paragraphs.

Stockton Beach and the adjacent Hunter River has been continually modified over the course of European settlement. Modifications that have impacted the beach response include the construction of the Hunter River breakwaters, capital and maintenance dredging of the navigation channel, revetment construction, beach nourishment, beach scraping and temporary and emergency protection works.

Stockton Beach has been the subject of numerous studies to assess coastal processes. However, further investigation has been identified as being required to underpin the identification of appropriate options for management of coastal hazards on the Stockton coastline. Based on the Stage 2 sediment transport studies completed at this time, a summary of the most relevant processes is provided below.

A key knowledge gap identified in the Scoping Study (CN, 2019) was to determine the changes in the sub-aqueous part of the coastal profile. An assessment of the change in the sand volume in the Stockton Beach area was undertaken. This assessment considered both the sub-aqueous and sub-aerial changes. The combined rate of long-term sand loss from the Stockton CMP area is recommended as 112,000m^3/yr, which is based on the historical observations of:

- 100,000m^3/yr of sand loss from the sub-aqueous part of the coastal profile in the southern Stockton embayment between the northern breakwater and Fort Wallace (inshore of 20m depth contour) between 1988 and 2018.
- 12,000m^3/yr of sand loss from sub-aerial part of the coastal profile in Block A, Block B and Block C between 1985 and 2020.

This rate of sand loss is significantly greater than previously estimated and has implications for the on-going management of the coastal erosion issue at Stockton Beach. Given the long-term nature of the sand loss (i.e. not cyclic) and the accelerated rate of loss observed since the channel deepening project was completed in 1983, the most likely cause is the development and operation of the Port of Newcastle (i.e. breakwater construction and capital and maintenance dredging).

Further investigations are required to review the key coastal processes and quantify the sediment pathways that adequately explain these observations. A robust understanding of these processes is fundamental to developing coastal management options. It is recommended that long-term plans for Stockton Beach are reviewed once the sediment transport study is completed.

2.3 Key coastal hazards

The assessment relates to risks arising from coastal hazards as defined by the *Coastal Management Act 2016*. A simplistic assessment would see beach erosion as comprising that hazard relating to the erosion and recovery of a beach around a stable ‘equilibrium’ position. However, these beach fluctuations are often super imposed on a trend of ongoing shoreline recession or gradual adjustment of the shoreline location with time. Additional shoreline recession is expected to result from future sea level rise along the NSW coast. Hazard lines prepared herein incorporate the below hazards as required by that Act:

- Long term recession – historic shoreline recession due to deficits in longshore sediment transport.
- Sea level rise and associated recession – future shoreline recession as a result of projected sea level rise.
- Beach erosion – upper beach erosion as a result of large wave events and high-water levels.
- Coastal slope instability – selecting the Zone of Reduced Foundation Capacity (ZRFC) following the schema published by Nielsen et al. (1992), the ZRFC represents the extent landward behind an eroded beach where special considerations would need to be adopted when designing footings for structures.

2.3.1 Long-term recession

The NSW beach profile (photogrammetry) data (DPIE, 2020) was analysed to determine appropriate input parameters for long-term recession for the probabilistic hazard assessment. The adopted analysis period included photogrammetry data collected between 1955 and 2018. Where survey extents allowed the photogrammetry record was extended to February 2020 using recent drone survey data collected by CN. The drone survey only covered analysis blocks Stockton Block A, B and C. A series of historic beach profiles for selected profile locations within each of the analysis blocks are shown in Figure 2.

The historic recession rates were estimated by extracting the cross-shore position of a defined elevation contour for each year in the data set. A linear regression analysis was then undertaken to estimate the long-term trends in recession or accretion. An appropriate contour elevation used for the analysis was determined for each analysis block. Where possible, the 4m AHD elevation contour was specified to avoid accounting for any short-term profile changes. Given the anthropogenic influence on the coastal processes at Stockton Beach, various time periods were considered as part of the analysis. It was concluded that the most representative time period for the historic analysis was between 1985 and 2020. Prior to 1985, the year of the channel deepening of the

Port of Newcastle entrance, the recession rates are not representative of the more recent shoreline change at Stockton Beach (i.e. the changes observed following that perturbation). Beach profiles at the Surf Club and Mitchell Street seawalls have been excluded from the analysis. Cyclic rotation of the beach, particularly expected to affect southern areas of Stockton, typically occur over time periods of months to several years (DHI, 2006) and was not found to affect the long-term (35-years) recession analysis presented herein.

Results of the linear regression analysis for selected profiles used to derive historic recession statistics is provided in Figure 6. A statistical summary of the calculated average rates of shoreline change for each analysis block (see Figure 1) is provided in Table 1. Note that positive values indicate shoreline accretion, and negative values indicate shoreline recession. The variation in estimated recession rates for each profile within the analysis blocks and over the study area is demonstrated in Figure 4.

The presented recession rates were adjusted to account for any recession caused by sea level rise (SLR) during the analysis period between as this is considered independently. As described in Section 3.3.2, the SLR recession was estimated using the Bruun Rule (Bruun, 1962 and 1983). An average SLR rate of 1.2mm/year based on historic tide gauge records between 1966 to 2010 (White et al., 2014) was adopted to estimate the SLR recession during the analysis period. While appreciating the uncertainty in this simplified analysis, this resulted in a minor reduction of 0.06m/year (Fern Bay, Block 4) to 0.09m/year (Stockton, Block A) from the historic recession rates.

Overall, the trends identified in this analysis were verified with volumetric changes in the full coastal profile as observed in bathymetric analyses undertaken as part of Part A (Bluecoast, 2020a). The results of both recession analyses agree reasonably well as a long-term volumetric rate of sand loss over the full profile was estimated at 112,000m^3/year between the northern breakwater and the Hunter Water site (Block C).

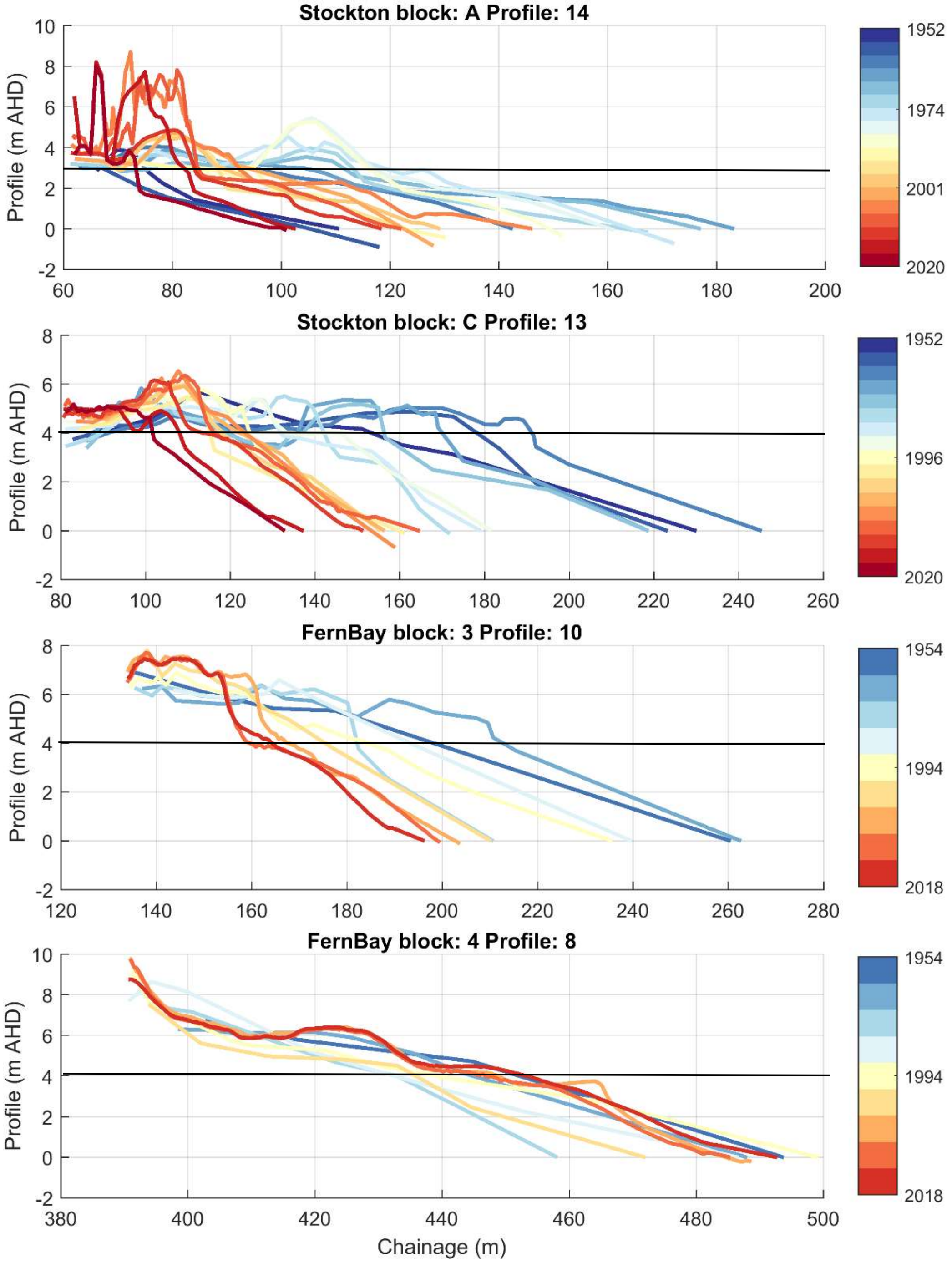


Figure 2: Photogrammetry profiles at blocks Stockton A to Fern Bay 4. The contour elevation adopted for recession analysis is shown in black.

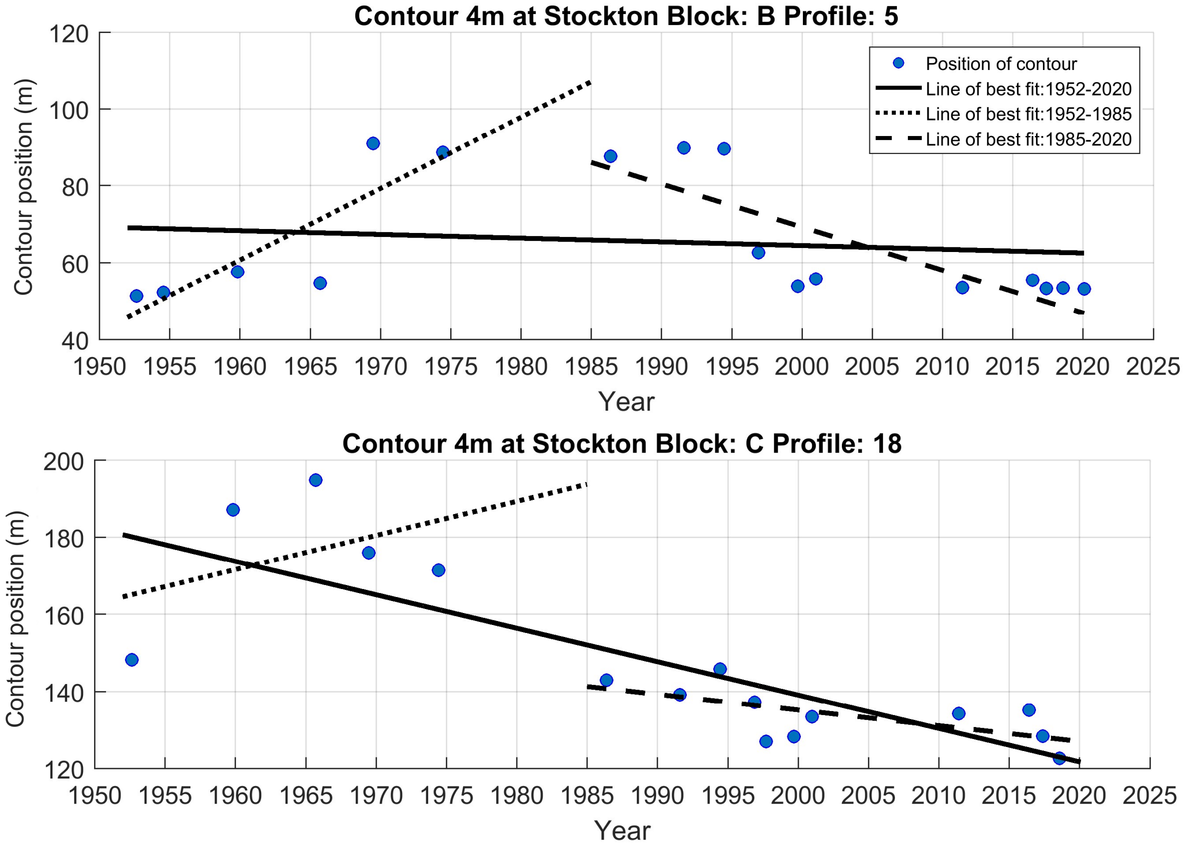


Figure 3: Results of linear regression analysis of 4m contour position for three defined time periods for Stockton (top) Block B, Profile 5 and (bottom) Block C, Profile 18.

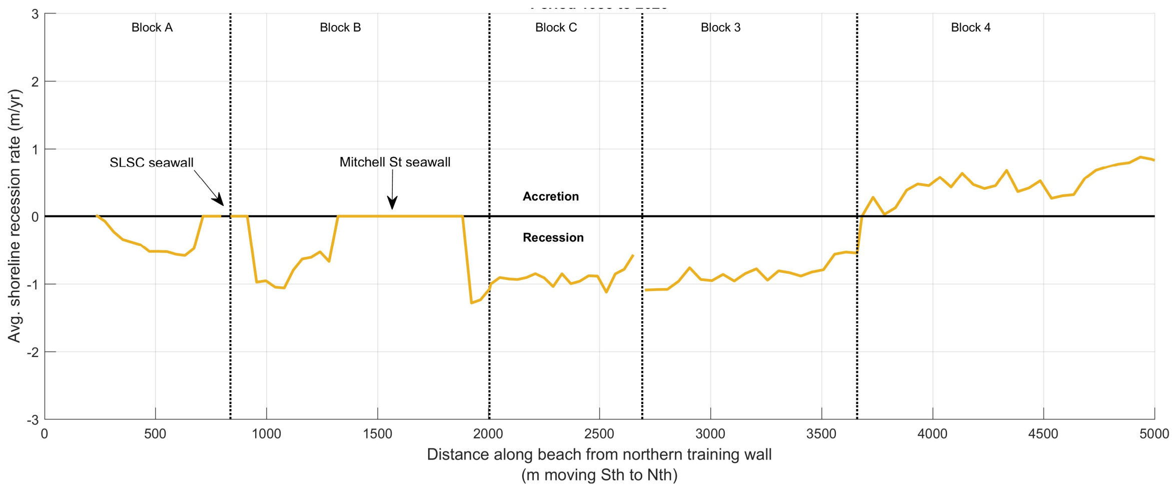


Figure 4: Estimated average shoreline change rates for the period 1985 to 2020.

Table 1: Spatial statistics of calculated average recession rates (discounted for SLR recession).

	Average long-term recession rates (m/year)					
	Stockton A	**Stockton B**	**Downdrift Mitchell St seawall**	**Stockton C**	**Fern Bay 3**	**Fern Bay 4**
Contour (m AHD)	3	4	4	4	4	4
Minimum	-0.36	0.56	-	-0.32	-0.47	0.06
Maximum	-1.25	-1.19	-	-1.03	-1.03	0.94
Median	**-0.99**	**-0.86**	**-1.08**	**-0.82**	**-0.79**	**0.52**
Mean	-0.88	-0.78	-	-0.79	-0.79	0.54
5th percentile	**-0.39**	**-0.39**	**-0.92**	**-0.38**	**-0.48**	**0.08**
95th percentile	**-1.22**	**-1.18**	**-1.20**	**-1.00**	**-1.02**	**0.91**

2.3.2 Sea level rise

The latest advice from IPCC (2019) on sea level rise 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 AR5 projections in IPCC, 2013) by 2100 for RCP2.6 and RCP8.5, respectively (see Figure 5). The adopted sea level rise values and associated recession calculations are described in Section 3.3.2.

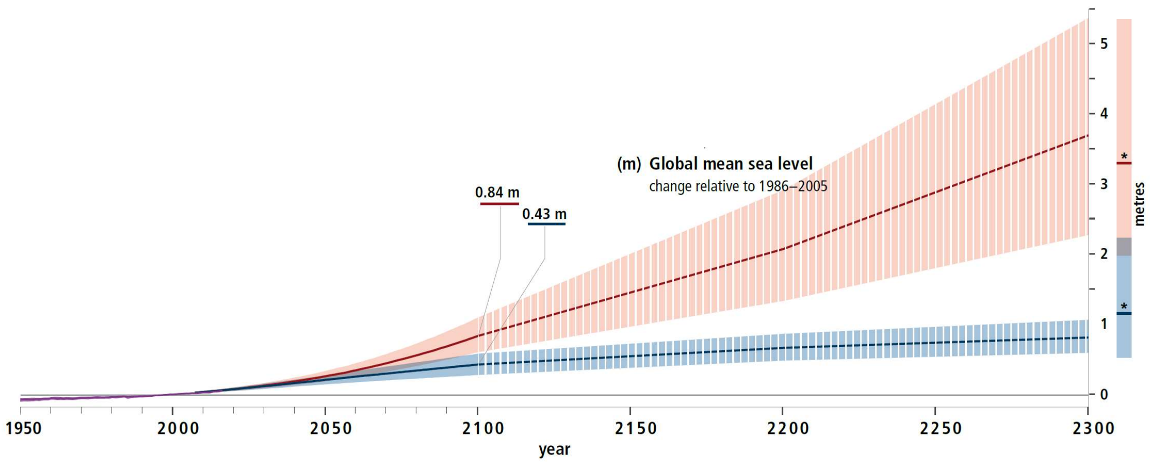


Figure 5: Global sea level rise projections above 1986 to 2005 baseline (IPCC, 2019): (blue) low (RCP2.6) and (red) high (RCP8.5) greenhouse gas emission scenarios.

2.3.3 Beach erosion

Historical measurements of beach erosion volumes due to major storm events, or a series of storms in succession, at Stockton Beach are limited to recent drone surveys and approximate values that can be obtained from the photogrammetry profiles. Potential short-term erosion for Stockton Beach was analysed by DHI (2006) using a dune erosion model and application of storm conditions from May and June 1974, as well as a storm in June 1999 that arrived from a more easterly direction. Both historical measurements and DHI's dune erosion modelling indicate that the extent of storm erosion experienced at Stockton increases from south to north in line with increased wave exposure from southerly storms. However, the alongshore distribution of storm erosion is sensitive to storm wave direction with more easterly or northerly storms leading to higher storm demands in the southern parts of the beach, as occurred in February 2020. A summary of measured and modelled beach erosion values along Stockton Beach are presented on Table 2.

Stockton Beach is experiencing long term recession, and therefore it is difficult to separate short term events from the long-term recession signal in beach survey and photogrammetric data. The maximum erosion estimates adopted by DHI (2006) ranged from 5 m at the Stockton Holiday Park to 17 m at Meredith Street, and 24.5 m at the LGA Boundary. The deepening of the sub-aqueous profile due to an on-going sediment deficit in the Stockton Beach compartment is likely to increase storm erosion volumes into the future. DHI (2016) completed an analysis to determine the impact on deepening on dune face erosion. It was estimated that a further deepening of the nearshore zone by 1 m would increase erosion rates by 5%.

Table 2: Measured and estimated storm erosion recession and volumes along Stockton Beach.

Alongshore area (south to north)	Calculated based on photogrammetry/surveyed profiles		Predicted maximum storm erosion (DHI, 2006)
	Landward movement of the erosion scarp (m)	Storm erosion volume (m^3/m)	
Holiday Park	-	May 1974: 35* June 2016: >55 February 2020: 38***	5m or ~20m^3/m
SLSC	June 1945: 15**** May 1974: na May 1997: na July 1999: 5-10 June 2016: na	June 1945: 63 May 1974: >50* May 1997: 130** July 1999: 42 June 2016: >40	5m or ~20m^3/m
Hereford Street to Pembroke	June 1945: 15**** May 1974: na May 1997: na July 1999: 5-10 June 2016: na	June 1945: 63 May 1974: >100* May 1997: 130** July 1999: 50 June 2016: >35	8.6m or ~38m^3/m
Barrie Crescent	-	June 1945: na May 1974: >85* May 1997: 150-200** July 1999: na June 2016: >40	12.1m or ~71m^3/m
Meredith Street	-	June 1945: na May 1974: >55* May 1997: 150-200** July 1999: na June 2016: >40	17.0m or 94m^3/m
Sewage ponds	May 1997: 20	May 1997: 12	17.9m or 99m^3/m
CN boundary			24.5m or ~135m^3/m

*NSW beach profile database – volume change from 1-7-69 to 19-6-74
**Moratti (1997)
***Based on UAV survey data from 19-12-19 to 5-02-20
****DHI (2016)

Table 3: Offshore wave conditions during storm events listed in Table 2 based on Sydney Waverider Buoy.

Storm event/sequence of events	Significant wave height (Hs (m))	Peak still water level (m AHD)	Approximate ARI of wave height (year)	Storm direction
June 1945		Unknown		
May 1974*	9.1	1.5	25-50-year	South-south east
May 1997	9.9	1.2	100-year	South-south east
July 1999	6.1	1.2	5-year	East-south east
June 2016	6.6	1.3	10-year	East
February 2020	4.8	1.2	1 to 2 year	East

*Reconstructed by Foster et al. (1975)

3. HAZARD ASSESSMENT

3.1 Approach

The probabilistic approach allows adopting probability distribution functions for each input parameter to the erosion hazard model. Random sampling of input parameters (within limits) is considered a more 'realistic' approach in comparison to deterministic (fixed or single value) inputs and allows calculation of likelihoods. In this study, a Monte-Carlo model is applied that repeatedly combines these inputs (one million simulations) and produces probability curves for shoreline erosion during the defined planning periods. Shoreline erosion curves are produced for each of the NSW photogrammetry transects within the study area, as shown in Figure 1.

Based on the probability curves for each profile location erosion hazard lines for the extent of the study area were extracted for a series of probabilities.

During the development of the hazard model, the approach and proposed inputs and outputs were discussed with CN and DPIE as outlined in Bluecoast (2020c).

3.2 Planning periods

The adopted planning periods for which the coastal erosion hazards have been determined are present day (2020), 2040, 2060 and 2120.

3.3 Probabilistic input parameters

To incorporate ranges associated to the hazard parameters simple triangular distributions were defined as input to the hazard model. A triangular distribution is defined by three values, a minimum value, a maximum value and a peak/mode (most likely) value, as schematised in Figure 6. These inputs and justification for adopted ranges are described in detail in the following sections.

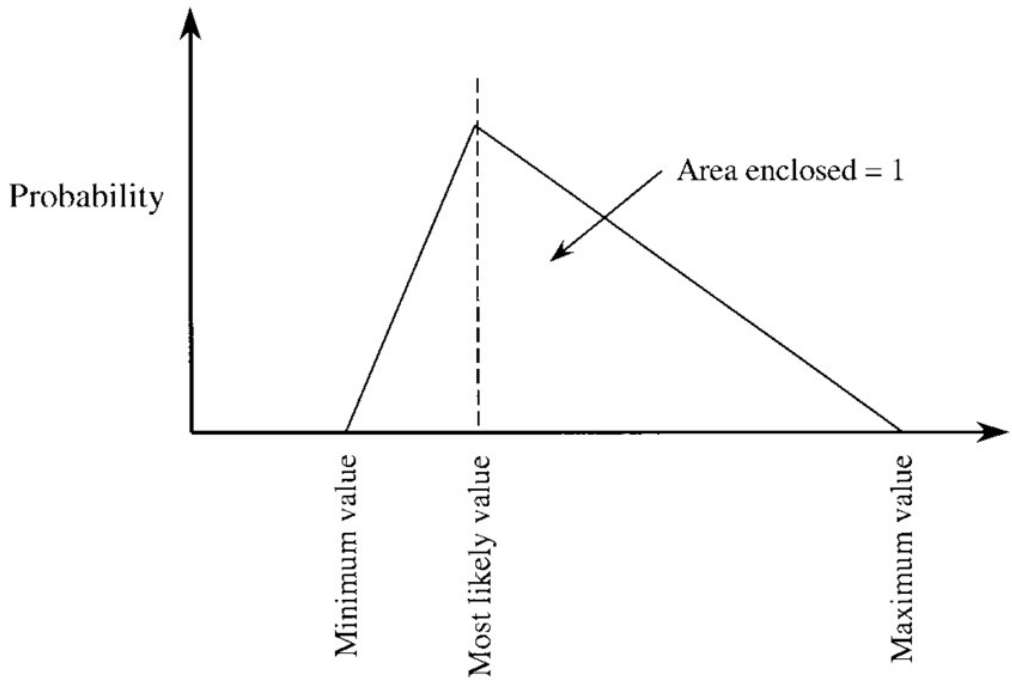


Figure 6: Schematic of a triangular distribution to describe probabilities of input parameters.

3.3.1 Long-term recession

The adopted minimum and maximum values for the triangular distribution correspond to the 5th and 95th percentile values of shoreline change of each block, see Table 4. To exclude any potential outliers, the actual statistical spatial minimum and maximum values were neglected. In a similar fashion, the mode or most likely value is suggested as the median rate of change for each analysis block.

It can be seen in Figure 4 that downdrift of the Surf Club and Mitchell Street seawalls higher recession rates are observed. This is particularly the case north of the Mitchell Street seawall and hence higher recession rates compared to the block averages have been adopted for profiles immediately downdrift from the northern end of the seawall.

Table 4: Adopted long-term recession rates for the hazard assessment.

	Adopted long-term recession rates (m/year)					
	Stockton A	**Stockton B**	**Downdrift Mitchell St seawall**	**Stockton C**	**Fern Bay 3**	**Fern Bay 4**
Minimum (5th percentile)	-0.39	-0.39	-0.92	-0.38	-0.48	0.08
Mode (median)	-0.99	-0.86	-1.08	-0.82	-0.79	0.52
Maximum (95th percentile)	-1.22	-1.18	-1.20	-1.00	-1.02	0.91

3.3.2 SLR recession

The minimum and maximum sea level rise 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 was adopted as mean value between the two scenarios. A summary of the adopted sea level rise allowances for the relevant planning periods are presented in Table 5.

Table 5: Adopted sea level rise allowances above 2020 baseline (adjusted from IPCC, 2019).

Planning period	Sea level rise (m)		
	Minimum (RCP2.6 - median)	**Mode (average)**	**Maximum (RCP8.5 – upper bound)**
2020	0.00	0.00	0.00
2050*	0.14	0.18	0.21
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)

For the purposes of this study, SLR recession can be estimated using a simplified predictive equation termed 'the Bruun Rule' (Bruun, 1962 and 1983). The Bruun Rule is based on the concept that sea level rise will lead to erosion of the upper shoreface, followed by re-establishment of the original equilibrium profile. This profile is re-established by shifting it landward and upward. SLR recession (R) is therefore a function of both SLR and the inverse beach slope, or the so-called Bruun factor (i.e. $R = SLR \times BF$).

It is noted that the application of the Bruun Rule is a highly simplified method to estimate SLR recession and its use in complex coastal processes areas such as the southern end of Stockton Beach and its proximity to the entrance is challenging. While it is common practice in NSW to adopt this approach, careful consideration of the input parameters and engineering judgement is required. Again, to allow consideration of value ranges, statistical sampling is adopted for the depth of closure, as described in the following sections.

Depth of closure

The offshore beach slope extends to the depth of closure 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'. In this study, the closure bed contour was established having regard to the following methods:

- The depth of the seaward limit of surf related processes after Hallermeier (1983) taken to be 1.75 times the local significant wave height exceeded 12 hours per year.
- Slope discontinuity in the offshore profile.
- DHI (2006) numerical modelling.
- Consideration of entrance training wall and channel on offshore limits of the active profile.

DHI (2006) estimated a depth of closure of -9m AHD at Stockton based on the offshore wave height exceedance and confirmed this with numerical modelling (1D profile model location approx. 4km north of training wall). However, they also determined the discontinuity of the offshore profile to be at -20m AHD. Finally, an average value of -15m AHD was adopted for the 2006 hazard assessment.

As inputs for this study, DHI's 2006 closure depths were reviewed and adjusted to account for spatial variation throughout the study area due to effects of the northern breakwater and entrance channel on wave exposure and bathymetry. At the northern areas (Stockton C to Fern Bay), a conservative maximum closure depth of -35m AHD was selected in consideration of the 100-year planning time frame. The profile slopes were determined using the 2018 LiDAR bathymetry. A summary of the adopted parameters is shown in Table 6.

Table 6: Overview of closure depth and Bruun factor range adopted in this study.

		Minimum	Mode	Maximum
Stockton A	Closure depth (m AHD)	-7	-12	-15*
	Bruun factor	17	37	77
Stockton B	Closure depth (m AHD)	-9	-15	-20*
	Bruun factor	20	50	80
Stockton C	Closure depth (m AHD)	-9	-15	-30*
	Bruun factor	23	50	142
Fern Bay 3	Closure depth (m AHD)	-12	-18	-35
	Bruun factor	25	50	150
Fern Bay 4	Closure depth (m AHD)	-12	-18	-35
	Bruun factor	25	50	150

*Closure depth at southern areas of Stockton is controlled by entrance channel and reduced wave exposure.

3.3.3 Beach erosion

Probabilities of beach erosion volumes for each year in the planning period in the probabilistic hazard modelling were determined. Randomly generated AEP values were used to sample from the adopted distribution of storm erosion volumes. This adopted distribution of storm erosion volumes were based on the observed and modelled volumes presented in Section 2.3.3 and findings of the Stockton Bight Study (Part A; Bluecoast, 2020a). To account for the spatial variation of the storm erosion volumes over the study area (due to sheltering effects of the breakwater), a 50-year ARI erosion volume of $80m^3/m$ was adopted for the areas just north of the breakwater and an erosion volume of $220m^3/m$ for the more exposed areas at the northern end of the study area and linear interpolation was applied for areas in between. The adopted 50-year ARI storm erosion volumes are presented in Table 7.

To extrapolate the adopted 50-year ARI storm erosion volumes for each area to higher and lower occurrence probabilities (e.g. a 100-year ARI event), curve-fitting to the commonly used distribution of storm demands in NSW by Gordon (1987) was undertaken. An example for the Block B distribution of storm erosion volumes is provided in Figure 7. The associated slope stability zones for each profile have been calculated as described in the following paragraphs.

Table 7: Adopted storm erosion volumes.

	50-year ARI storm erosion				
	Stockton A	**Stockton B**	**Stockton C**	**Fern Bay 3**	**Fern Bay 4**
Volume (m^3/m)	80	120	150	170	220

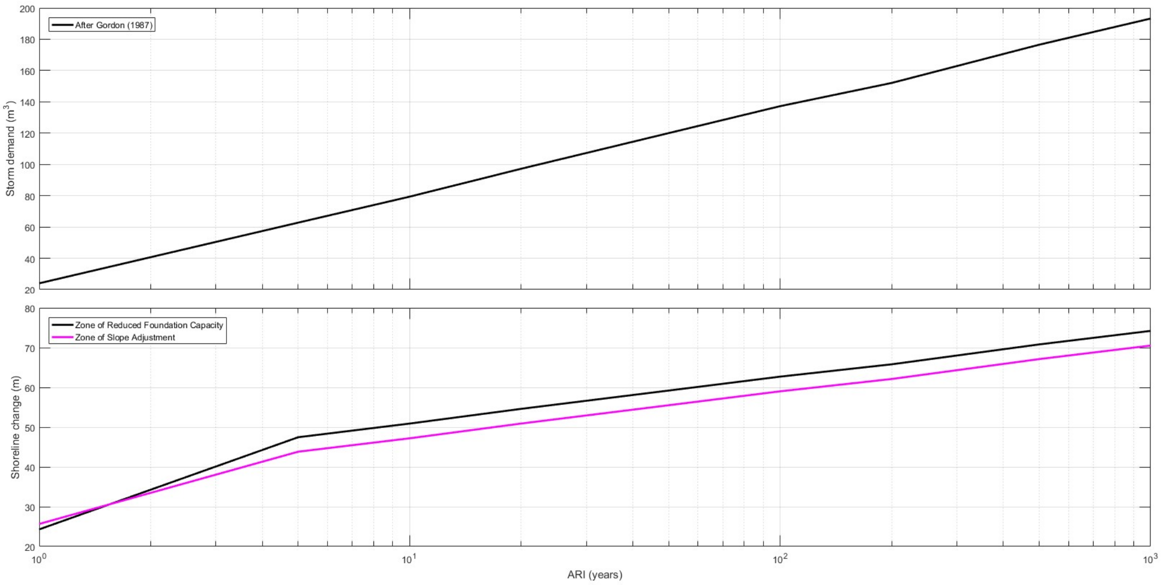


Figure 7: Results of (top) the distribution of storm erosion volumes for Block B, Profile 2 based on curve-fitting of the 50-year ARI erosion volume to Gordon (1987) and (bottom) associated setback of the ZRFC and ZSA.

The storm demand volumes have been converted to horizontal erosion distances to the back of the Zone of Slope Adjustment (ZSA) and Zone of Reduced Foundation Capacity (ZRFC) in accordance with the Wedge Failure Plane Model after Nielsen et al (1992), see Figure 8. These calculations have been performed for each beach profile location in the study area adopting the following uniform parameters:

- Baseline beach profile year: 2020 (Block A to C) and 2018 (Block 3 and 4)
- Scour level: -2m AHD
- Swash level: 1m AHD
- Angle of repose: 33 degrees
- Factor of safety: 1.5

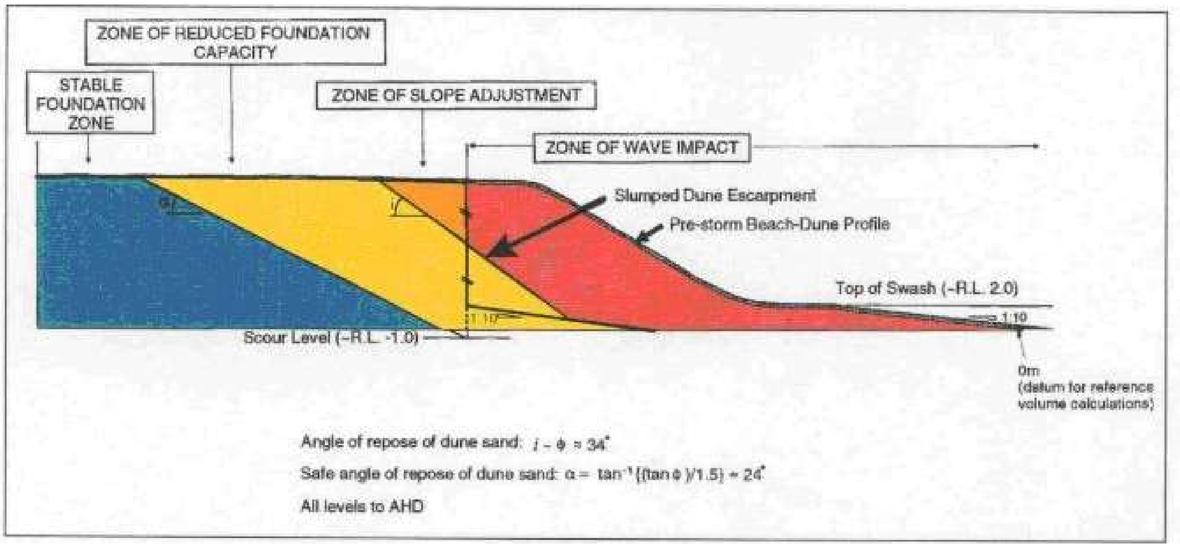


Figure 8: Wedge Failure Plane Model (Source: Nielsen et al., 1992).

3.4 Influence of coastal structures

The SLSC and Mitchell Street seawalls have been included in the hazard modelling as terminal protection (i.e. non-erodible) as CN have committed to maintaining these structures to their current level of protection throughout the planning periods. Seawall end effects (i.e. increased erosion risk at downdrift areas) have not been assessed in detail. Given the adoption of the 2020 beach profiles as the baseline for the hazard modelling the additional erosion hazard has been somewhat included due to the eroded state of the profiles in downdrift areas of the seawalls. Moreover, by including the higher shoreline recession rate for the section at the northern end of the Mitchell Street seawall, as has been observed, the model inherently includes the influence the coastal structures.

3.5 Probability distribution curves

Following the millions of Monte-Carlo simulations of combining the three erosion hazards of long-term recession, sea level rise recession and storm erosion, probability curves of the position of the Zone of Reduced Foundation Capacity (ZRFC) were produced. An example of the combining of the coastal hazards and resulting probability distribution is provided in Figure 9. A further example showing the probability curves for long-term recession and sea level rise recession and the position of ZRFC for year 2120 is provided in Figure 10. For demonstration, the results are shown for a representative profile within the centre of each analysis block.

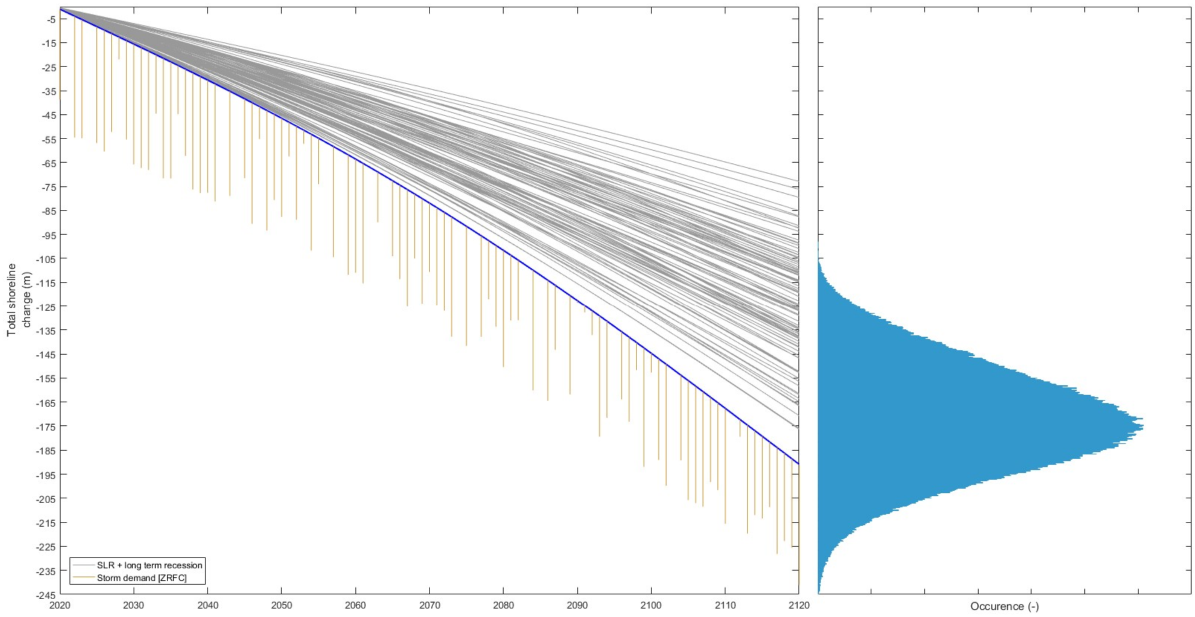


Figure 9: Probabilistic hazard model results for Block A, Profile 7: (left) Monte-Carlo simulation of long-term and sea level rise recession (grey lines) and superimposed storm erosion (yellow lines) (right) probability distribution of the position of ZRFC in year 2120.

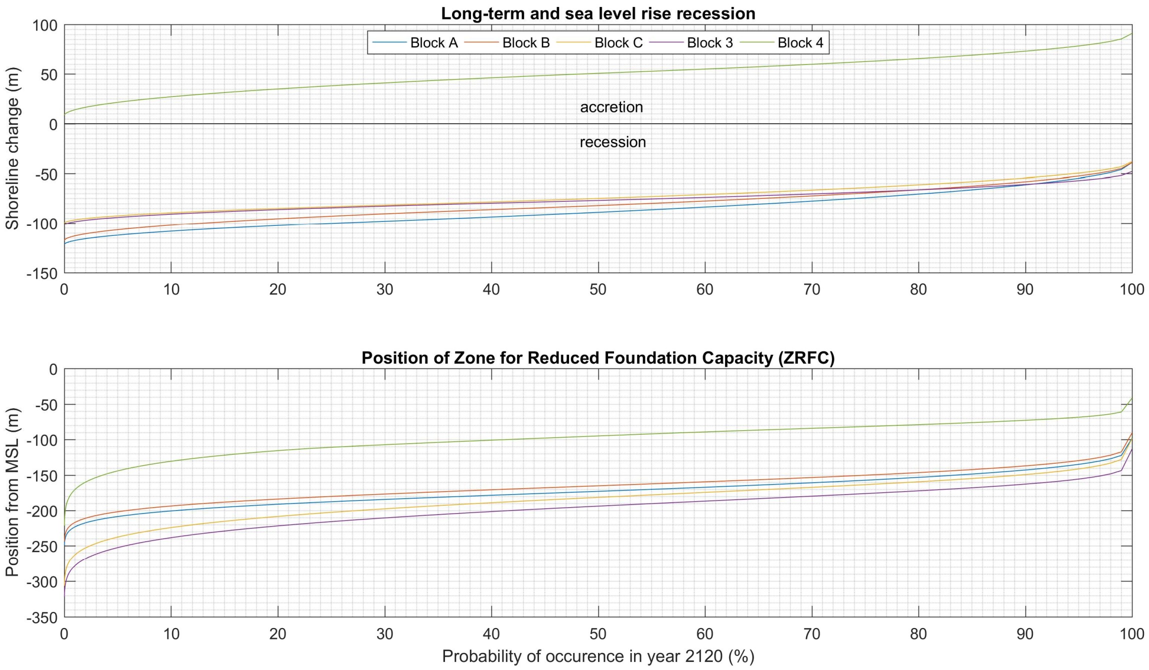


Figure 10: Probabilities of combined long-term and sea level rise recession and position of ZRFC in year 2120.

3.6 Probabilistic hazard lines

For the purpose of mapping the erosion hazard the 50%, 10% and 1% exceedance probabilities were selected, see Figure 11 to Figure 14. The associated 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.

Further presentation and mapping of the probabilistic hazard assessment results are provided in the remainder of this report.

Figure 11: Hazard lines for the erosion hazard in year 2020.

Figure 12: Hazard lines for the erosion hazard in year 2040.

Figure 13: Hazard lines for the erosion hazard in year 2060.

Figure 14: Hazard lines for the erosion hazard in year 2120.

3.7 Risk assessment

3.7.1 Risk assessment process

The risk assessment has been prepared using guidance provided by the international risk management standard, ISO 31000. That standard suggests the following steps for risk assessment:

- Establish the risk management context.
- Identify the risks.
- Assess the likelihood and consequences of those Risks.
- Evaluate the risks.

Management strategies can then be suggested for those risks which are assessed as being unacceptable, with these later stages normally falling under the scope of subsequent studies to inform a CMP. The risk assessment presented here deals with the 'Base Case' management scenario, following a 'Business as Usual' approach to managing Stockton Beach, being (Bluecoast, 2020a):

'The on-going implementation of all actions as listed under the current CZMP 2018 Part A (Stockton) as the gradual realisation of erosion in accordance with the hazard mapping and associated loss of assets at risk.'

3.7.2 Context of the assessment

The extents of the lines considered herein have certain probabilities associated with them (50%, 10% and 1% chance) and are assessed at several time frames (present day (2020), 2040, 2060 and 2120). This represents an appropriate range of lines for consideration by stakeholders as part of risk assessment, and maps showing the extents are presented below.

An important aspect of risk assessment context is understanding which stakeholders will suffer from the risks being assessed (noting that benefits may also result if risks eventuate) and who is best placed to take responsibility for those risks. Generally, coastal management in NSW is a responsibility borne by local government (e.g. CN) and, under the *Coastal Management Act 2016*, coastal councils are typically required to prepare and implement a CMP, consistent with the requirements of the Act and the *Coastal Management Manual* (NSW Government, 2018). The relevant Minister administering the Act may prepare a CMP in certain circumstances, such as a failure of the council to comply with a relevant coastal management direction of the Minister or if the Minister refuses to certify a draft CMP prepared by a council.

The above paragraph reflects how the responsibilities of local government in NSW fall under the general direction and jurisdiction of the State. Accordingly, in setting a geographical boundary around the risk assessment, it is meaningful to consider the following:

- Impacts that may be felt by stakeholders with a direct interest in the geographical extent of the coastal hazards being considered, including the local community and landowners.
- The impacts that may be felt by the broader LGA and its stakeholders, noting that costs for repairs to CN infrastructure or loss of income from caravan parks owned and/or operated by CN (as examples) need to be funded by the CN, which derives much of its income from rates levied on residents across the LGA.
- The impacts that may be felt by the State, if a local council fails in managing the coast and/or is overwhelmed by the burden which falls upon it in managing the coast.

Therefore, the local community, local council and the state government all have an interest in coastal management. In the case of Stockton, its geographical isolation from the remainder of the LGA, and the fact that it doesn't represent a thoroughfare between localities (there is presently only a single access road) means that direct impacts will be predominantly felt by the local community. Indirect impacts will also be of significance to CN and its broader community. State government also has an interest in making sure that coastal management does not become an onerous burden to local government and for this reason provides funding support alongside oversight which aims to help avoid missteps in management.

ISO 31000 formally defines risk as the *'effect of uncertainty on objectives'*. CN's Community Strategic Plan (The City of Newcastle, 2018) contains seven '*Strategic Directions*'. Laid out under each of those directions is a set of objectives under the heading '*Where do we want to be'*. Strategies to achieve each objective are also provided. Those objectives and strategies most threatened by coastal erosion are summarised in Table 8.

Table 8: Potential coastal erosion/recession hazard effects on Stockton community objectives (extracted from The City of Newcastle, 2018).

Strategic Direction	Threatened Community Objective	Relevant Strategy/Indicators
1. Integrated and Accessible Transport	1.3 Safe, reliable and efficient roads and parking networks	1.3(a) Ensure safe road networks through effective planning and maintenance. Roads and footpaths are to be in a good condition.
2. Protected Environment	2.2 Our unique natural environment is maintained, enhanced and connected	2.2.a Provide and advocate for protection and rehabilitation of natural areas
	2.3 Environment and climate change risks and impacts are understood and managed	2.3a Ensure decisions and policy response to climate change remains current and reflects community needs 2.3b Support individuals and communities to prepare, respond and recover from emergency events
3 Vibrant, Safe and Active Public Places	3.1 Public places that provide for diverse activity and strengthen our social connections	3.1a Provide quality parkland and recreation facilities that are diverse, accessible and responsive to changing needs 3.1b Enhance our beaches and coastal areas through upgraded facilities
5 Liveable Built Environment	5.1 A built environment that maintains and enhances our sense of identity	5.1a Protect and promote our unique built and cultural heritage. 5.1b Ensure our suburbs are preserved, enhanced and promoted, while also creating opportunities for growth.
7 Open and Collaborative Leadership	7.1 Integrated, sustainable long-term planning for Newcastle and the Region	7.1a Encourage and support long term planning for Newcastle, including implementation, resourcing, monitoring and reporting. 7.1b Ensure long-term financial sustainability through short, medium and long-term financial planning.

In the context of Stockton, the objectives and strategies in Table 8 point towards ensuring that Stockton remains a feasible, liveable place for its community, with some emphasis placed on natural areas, beaches and parklands.

3.7.3 Risk identification

Considering the context outlined in the preceding section, risks are going to arise from direct impacts of erosion on assets within and behind Stockton Beach. Formal identification of the risk has been made using the following word formula:

There is a risk that a **cause** will lead to **an event (or chain of events)** resulting in an **outcome** with a set of **consequences/impacts**.

In this case, a catch all description of the risk is that:

There is a risk that **ongoing coastal processes at Stockton** will lead to **the beach receding/eroding to such an extent** that **assets are either destroyed or their functionality compromised** such that the value those assets provide to the community **is permanently lost**.

There are a few notable things with this risk descriptor:

- Permanent loss is seen as the most likely outcome if assets are compromised or destroyed. Given the present legal and planning context it seems highly unlikely that land at the rear of the beach would be artificially reclaimed from the sea once it has eroded past a given landward location. With enough permanent loss of value from Stockton, the objective of retaining Stockton as a liveable place in future could become impossible.
- Loss of functionality includes erosion occurring to such an extent that an asset is considered unsafe. In recent years, this process was seen at the old North Stockton Surf Club (operating as a childcare centre). The facility was affected by erosion, initially with its beachfront playground being relocated to the side of the building, and the building eventually demolished as the erosion progressed such that its structural integrity could not be appropriately guaranteed.
- Assets can have environmental and/or less tangible values (i.e. difficult to place a monetary value upon). For example, the beach is the frontline asset threatened by coastal processes. The beach provides a sandy barrier offering a level of protection against coastal erosion and inundation. It also holds environmental values such as its own ecosystem (incorporating the services that ecosystem provides) alongside less tangible values associated with amenity and community identity. The values can be difficult to evaluate. A first pass risk assessment would ideally be informed by community consultation and stakeholder input. In early 2020, COVID-19 and the truncated timeframe of this project, made this difficult to complete. However, community consultation activities undertaken by CN have identified strong opinions regarding Stockton Beach, including:
    - The beach is highly valued and represents a critical asset to the local community.
    - The preference to maintain a clean beach area providing enough width for recreational space, including uses such as Nippers, and which supports the current foreshore amenity and character.
    - Stockton has a strong surf culture with a desire to maintain surf amenity nearby the residential areas.
    - The preference to ensure any nourishment programs utilise sand that matches the existing visual profile of Stockton Beach.
    - The preference to maintain beach connectivity along the entirety of the beach.

3.7.4 Likelihoods

Measures of likelihood

It is important that coastal risk assessment in the face of climate change is completed within the broader risk management framework adopted by a local council (Wainwright and Verdon-Kidd, 2016). CN provided its standard risk assessment tables, which have been reproduced in Appendix A.

The three hazard probabilities selected have been aligned with CN's Likelihood Selection Table (Appendix A) as presented in Table 9.

Table 9: Assignment of selected hazard lines to CN's likelihood descriptors.

CN Likelihood Descriptor	CN Frequency	Matching Hazard Line
Almost Certain	Likely to occur at least once every year	None
Likely	Likely to occur once every 1-2 years	50%
Possible	Likely to occur once every 2-5 years	None
Unlikely	Likely to occur once every 5-20 years	10%
Rare	Not Likely to occur more than once in 30 years	1%

We note that assignment of a qualitative descriptor based on an actual calculated probability degrades the level of understanding of the risks involved. For example, descriptors such as 'Possible' have been found to have a wide range of interpretation within the general public (Maboussin and Maboussin, 2018). The hazard lines have been assigned based on the description of 'Likely' in CN's likelihood selection table as having a 50 to 80% chance of occurring over the time frames indicated by the frequency descriptors.

Hazard lines

The processing of spatial data was completed to support the concurrent cost benefit analysis and three hazard lines ('Zone of Reduced Foundation Capacity' for 1% likelihood, 10% likelihood, 50% likelihood) at four future time periods (2020, 2040, 2060, 2120). Maps showing the relevant lines for the four time periods are presented in Section 3.6.

3.7.5 Consequences

Threatened assets

Spatial data were provided by CN, including value information where available, for several different classes of assets. These assets were then clipped to the zones bounded by the hazard lines enabling the assessment of consequences relating to each likelihood.

The assets for which data were provided, and for which assessment was completed have been classified for illustration into:

1. Surface and Drainage Assets: including road reserve and land parcels, surface pavements (including roads and footpaths), kerbs and stormwater pipes. For clarity, kerbs are not shown in the figures presented in Appendix B, recognising that they typically occur at the edge of road pavements.
2. Above Surface Assets: including buildings (both CN owned and private), shelters, play spaces, park and street furniture, and walls.

Due to time constraints for study completion, there are notable omissions from the data provided, including services (telecommunications, water and sewer, electricity, gas) and some delineation of environmental assets, such division of land parcels containing sandy beach and dune assets would also provide useful information.

Maps showing the distribution of affected assets, seaward of the 1% likelihood ZRFC hazard line, alongside the three hazard lines at each time period are presented in Appendix B.

Measures of consequences assessment

Similarly, to the likelihood descriptors, CN has also provided a table with its standard risk consequence categories. This table is provided in Appendix A. There are seven risk impact categories considered:

1. Financial
2. Environmental
3. Health and Safety
4. Infrastructure / ICT Systems / Utilities
5. Legislative Compliance
6. Reputation / Image
7. Service Delivery

Categories 2 through 7 cannot be easily evaluated without consulting key stakeholders. Due to the constraints on completing this assessment outlined in Section 1.1, it has not been possible to undertake that consultation within the time frame required. A qualitative assessment of those categories is provided in Section 4.

A preliminary consequences assessment has been completed using the financial category only (see Table 10). Herein, the valuation has adopted the results of analysis completed in developing the CBA (Bluecoast, 2020b), which utilised the mapping data presented in Appendix B. Use of the financial category in isolation would result in under representation of the full range of impacts that would be felt by the local community and CN, if the beach continues to erode without intervention.

Table 10: CN financial consequence classification.

CN Consequence Category	CN Description	Value of Incurred Losses
Insignificant	Minimal financial impact that can be managed within the program or services budget.	<$10,000
Minor	A financial loss that can be managed within the departmental budget.	$10,000 - $100,000
Moderate	A financial loss that can be managed within the organisational budget.	$100,000 - $500,000
Major	A financial loss unable to be managed within the organisational budget, resulting in reduction in a program or service	$500,000 - $2,000,000
Severe	A critical financial loss resulting in closure of, or significant reduction in a program or service	>$2,000,000

A mitigating factor is that the loss of assets will occur over time (e.g. for the 2120 timeframe, the shoreline is projected to erode over time, not all at once). Therefore, loss is amortised with the full amount more likely to be realised in a series of smaller losses from severe storm events. CN may well be able to absorb some of these intermittent losses.

A cost benefit analysis would commonly aim to account for intermittent losses through the process of discounting, but such analysis is beyond the scope of this risk assessment. A CBA which includes discounting has been prepared concurrently with this study (Bluecoast, 2020b).

Valuation and categorisation

The total financial loss has been calculated and categorised for the time periods and likelihoods adopted for the analysis, with results presented in Table 11.

Table 11: Valuation and classification of coastal erosion hazard consequences[1].

Chance	Loss of Value by Year: ($M AUD)			
	2020	2040	2060	2120
50%	0.18 (Moderate)	9.1 (Severe)	37 (Severe)	117(Severe)
10%	1.9 (Major)	18 (Severe)	44 (Severe)	157 (Severe)
1%	2.2 (Severe)	29 (Severe)	49 (Severe)	184 (Severe)

Within Table 11, it could be argued that the future loss totals should be processed by discounting as is done during cost benefit analyses. For present considerations, the cumulative profile of risk at different time frames has been retained for clarity and to support stakeholder consultation, should it be required at a later stage.

3.7.6 Risk evaluation

A risk matrix enables risk evaluation by combining likelihoods and consequences. The default CN risk matrix, reproduced in Appendix A, was modified (Table 12) to include only those likelihoods represented by the hazard lines being considered here.

[1] Values here are totals from Tables 17, 19 and 22 from the CBA (Bluecoast, 2020b). They represent total loss up to the time frame indicated and future values have not been discounted. The future values presented here are therefore not equivalent to present day values. The values cover private property and buildings, council property and assets, council buildings and structures, paved areas, stormwater pipes and shelters. Services not managed by CN are not included, nor intangible costs.

Table 12: Extract from CN's risk matrix.

Likelihood	Consequences				
	Insignificant	Minor	Moderate	Major	Severe
Likely	Low	Medium	High	Extreme	Extreme
Unlikely	Low	Low	Medium	High	High
Rare	Low	Low	Medium	High	High

By combining the findings of Table 10,Table 11 and Table 12, the current and future financial risk levels at Stockton Beach have been determined as presented in Table 13.

Table 13: Assessed financial risk profiles at various time frames.

Chance	Risk level by year			
	2020	2040	2060	2120
50% (Likely)	High	Extreme	Extreme	Extreme
10% (Unlikely)	High	High	High	High
1% (Rare)	High	High	High	High

Results such as those obtained herein should be considered alongside a risk manager's level of 'risk tolerance'. When combined, these considerations govern the urgency with which risks should be treated. AS5334 (Australian Standards, 2013) regards that the following treatments are suitable when considering climate change risks for settlements and infrastructure:

- *Low* risks would typically be addressed through routine maintenance and day to day operations.
- *Moderate* risks would require a change to the design or maintenance regime of assets.
- *High* risks require detailed research and appropriate planning (or design).
- *Extreme* risks would require immediate action to mitigate.

Prompt research, planning and design, as a minimum, are presently indicated to manage coastal erosion at Stockton Beach. However, these risk levels must be interpreted recognising that only financial risks have been considered. There is a strong possibility that the present-day risk profile for the suburb of Stockton would be assessed as 'Extreme' if social and environmental values were also considered
.

4. IMPACTS ON PEOPLE, INFRASTRUCTURE AND ENVIRONMENT

4.1 Preamble

Complementing the risk assessment, this discussion is viewed as a precursor to inform other activities associated with coastal management for Stockton Beach. It includes a 'high level' overview of current and future coastal hazards which were not able to be included in the risk assessment but may warrant further consideration.

4.2 Impacts on infrastructure

Several impacts on infrastructure have not been examined by this study including services such as:

- Water
- Sewer
- Gas (noting there is a gas pipeline that runs along Mitchell Street)
- Electricity
- Communications

The main issue relating to these services is that they commonly perform as a network and damage to one part of a network will degrade performance at other locations across the network. The physical nature of the different types of services affects their resilience and/or adaptability to the impacts of erosion. One example which is common in low-lying areas adjacent to beaches, is sewerage infrastructure where connectivity is necessary for the operation of gravity and/or pumping main lines. It seems likely that, for example, sewer mains exist in the vicinity of the most threatened length of public roadway within Stockton, at the southern end of the Mitchell St seawall.

The protection/retention of safe and well maintained roads, as per Strategy 1.3(a) of the current Community Strategic Plan (The City of Newcastle, 2018) will help to protect much of the buried services networks across the suburb as they are most commonly located within the road reserve.

Over the 100-year (2120) time frame, there remains a small chance that Fullerton Street is made unsafe at the northern end of the Stockton residential area (see Figures 19 & 20 in Appendix B), effectively cutting off access to Stockton from the north. Clearly, this would have an impact on CN's ability to provide services to Stockton. Worth considering is that, even if terminal protective works were provided across northern Stockton as the sole strategy for mitigating against erosion risks, outflanking of the structure to the north could possibly threaten Fullerton Street in a more northerly location. It is understood that these matters will ultimately be addressed by CN's completed CMP due in 2021.

4.3 Impacts on the environment

Considering Strategic Direction 2 of the Community Strategic Plan, protection of the environment and natural areas is an important matter for CN. Embedded within the table outlining that Strategic Direction is a strategy which encourages decisions and policy that support an up to date understanding and response to climate change.

An ongoing understanding of the potential for erosion to affect land is required. This can be maintained by revisiting and updating coastal hazard lines with reasonably regularity, as understanding improves and climate change projections are revised. By ensuring information is up to date, parts of the shoreline that could foreseeably be affected, in the short term, by a severe coastal storm can be managed to ensure that appropriate emergency management strategies are in place.

The key environmental asset at Stockton is the beach. If the beach is lost, which is possible depending on how the situation is managed, many of the environmental and social values derived from the beach are lost. This can presently be seen at the Mitchell Street seawall, as much of the usable beach width has already been lost in-front of this seawall in recent years.

There are also values associated with remnant dune systems to the rear of the beach, although the remaining vegetated dunes are typically narrow and far less significant than the dune system which exists to the north of Stockton.

4.4 Impacts on people

The CBA (Bluecoast, 2020b) reports that approximately 100,000 people utilise the beach annually. The beach has been popular for swimming, fishing, surf lifesaving, beachgoing and surfing. Coastal erosion has the potential to threaten several of the *Strategic Directions* in CN's CSP:

- **Vibrant Safe and Active Public Places:** These include the beach, which is the first asset to be lost to erosion and potentially the parkland and facilities that are behind the beach.
- **Liveable Built Environment:** The loss of parkland and public spaces, services, and the road network present a serious risk to the overall 'Liveability' of Stockton. Of course, liveability can be affected before severe physical impacts occur. It could be argued that the liveability of Stockton is already being impacted even though the loss of facilities has been limited to date. A lack of confidence in the future viability of an area affects the sense of liveability.
- **Open and Collaborative Leadership:** This follows from the previous point and the 'sense of identity' of an area. The strategies around this Direction relate to long term planning and financial sustainability. It is vitally important that planning is as strategic as it can be to appropriately follow this *Key Strategic Direction*. This implies that planning should consider the longer term (say 100 year) time frame, to ensure viability, minimise any future financial shocks and to increase the confidence of the Stockton Community in the place where they live.
- **Health and Safety:** Through appropriate strategic planning, severe health and safety impacts from coastal erosion should be appropriately mitigated. At Stockton, it appears that the current risks are close to being considered 'Severe'. The safety of structures and people need to be maximised wherever possible. One limitation of the present risk analysis is that the risks associated with inundation hazards (e.g. wave overtopping of the foreshore) have not been considered as updated information on those hazards, while it is being prepared, was not available as background information for this risk assessment. The health and safety risks to people can be largely avoided through *Open and Collaborative Leadership* and strategic planning. Unfortunately, legacy planning issues often remain and conflict with this strategic direction.

4.5 Intangible values

Some of the values discussed in the immediately preceding sections have aspects that are intangible, or less amenable to valuation. Herein, we have provided a brief comment on some of the more intangible risks outlined in CN's standard Risk Consequence Table.

- **Legislative Compliance**: Compliance with legislation is largely a risk that needs to be borne by CN. In the context of Coastal Management, compliance with the requirements of the *Coastal Management Act 2016*, the Coastal Management Manual (NSW Government, 2018) and related directions from the relevant Minister will assist CN in minimising these risks.
- **Reputation/Image:** These risks are primarily political and beyond the scope of this assessment, although we note that a positive reputation is useful in progressing projects in a timely manner.

4.6 Discussion

A risk assessment relating to coastal erosion hazards at Stockton Beach was completed. The assessment was undertaken under the limitations stated in Section 1.1.

On the consideration of financial risks alone, the current risk profile for Stockton Beach is assessed as 'High', meaning that detailed research, planning and study are indicated. If other risk categories were considered, it seems likely that the current risk profile would be assessed as 'Extreme', indicating that immediate action is required. On balance, an approach somewhere between that for a 'High' and 'Extreme' risk level is justifiable.

Given the restrictions related to the COVID-19 pandemic, the difficulty to complete community consultation as part of the risk assessment is unfortunate. However, CN’s regular engagement with the Stockton Community Liaison Group has given valuable insights into the values of the community, including an appreciation of the appetite for the risk and response to coastal hazards. If required, the community can be specifically canvased in relation to this risk assessment later. Even so, the findings of this risk assessment are that prompt attention to management options which mitigate against coastal erosion is justified.

5. REFERENCES

Australian Standards, 2013. AS 5334 Climate Change Adaptation for Settlements and Infrastructure.

Bluecoast, 2020a. *Sediment Transport Study within Stockton Bight – Part A*. Report prepared for City of Newcastle.

Bluecoast, 2020b*. Cost Benefit Analysis for Stockton Beach Coastal Management Program*. Report prepared for City of Newcastle.

Bluecoast, 2020c*. Stockton Beach Hazard Assessment – Approach (WORKING DRAFT).* Internal project update memo prepared for City of Newcastle.

BMT WBM, 2014. *Newcastle Coastal Zone Hazards Study*. Report prepared for City of Newcastle.

Bruun, P.M., 1962. *Sea-Level rise as a cause of shore erosion*, Jnl. Waterways, Harbour & Coastal Engg. Div., ASCE, Vol. 88, No. WW1, pp 117-130.

Bruun, P.M., 1983. *Review of conditions for uses of the Bruun Rule of erosion*. Jnl. Coastal Engg., Vol 7, No. 1, pp 77-89.

Church, J.A., P.U. Clark, A. Cazenave, J.M. Gregory, S. Jevrejeva, A. Levermann, M.A. Merrifield, G.A. Milne, R.S. Nerem, P.D. Nunn, A.J. Payne, W.T. Pfeffer, D. Stammer and A.S. Unnikrishnan, 2013. Sea Level Change*. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

DHI, 2006. Stockton Beach Coastal Processes Study: Stage 1 – Sediment Transport Analysis and Description of On-going Processes. Report prepared for City of Newcastle.

DPIE, 2020*. NSW Beach Profile Database.* Available online: http://www.nswbpd.wrl.unsw.edu.au/photogrammetry/about/

Foster, D.N, Gordon, A., Lawson, N., 1975. *The storms of May-June 1974, Sydney, NSW*. Proc 12th Australasian Conference Coastal & Ocean Engineering, Gold Coast, QLD.

Gordon, A.D., 1987*. Beach Fluctuations and Shoreline Change – NSW*. Eighth Australasian Conference on Coastal and Ocean Engineering, 1987: Preprints of Papers. Barton, A.C.T.: Institution of Engineers, Australia, 1987: [104]-[108].

Hallermeier, R. J., 1983. *Sand Transport limits in coastal structure design*. Proc. Coastal Structures '83, ASCE, pp 703-716.

Intergovernmental Panel on Climate Change [IPCC], 2013. Climate Change 2013, The Physical Science Basis, Working Group I Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, [Stocker, TF; Qin, D; Plattner, G-K; Tignor, M; Allen, SK; Boschung, J; Nauels, A; Xia, Y; Bex, V and PM Midgley (editors)], Cambridge University Press, Cambridge, United Kingdom and New York, New York, USA

Maboussin, A., Maboussin, M.J., 2018. If You Say Something Is 'Likely,' How Likely do People Think It Is? Harvard Business Review.

Moratti, M., 1997. *Stockton Beach Erosion, Monitoring and Management*. Combined Australasian Coastal Engineering and Ports Conference, Christchurch, New Zealand.

Nielsen, A.F., D.B. Lord & H.G. Poulos, 1992. *Dune Stability Considerations for Building Foundations.* IEAust., Aust. Civ. Eng. Trans., Vol. CE 34, No. 2, 167-173.

NSW Government, 2018. *Our future on the coast. NSW Coastal Management Manual Part B* (Comprising Parts for Stage 1 through Stage 5).

OEH, 2019. NSW Coastal Management Manual: Part B: Stage 2. State of NSW.

Salients, 2020. *Risk Assessment to Support Stockton Beach Coastal Hazard Assessment*. Report prepared for Bluecoast Consulting Engineers.

The City of Newcastle, 2018. Community Strategic Plan - Newcastle 2030.

Wainwright, D., Verdon-Kidd, D.C., 2016. *A local government framework for coastal risk assessment in Australia*. National Climate Change Adaptation Research Facility.

White N.J., Haigh I.D., Church J.A., Koen T., Watson C.S., Pritchard T.R., Watson P.J., Burgette R.J., McInnes K.L., You Z.-J., Zhang X., Tregoning P., 2014. *Australian sea levels -Trends, regional variability and influencing factors*. Earth-Science Reviews, 136:155-174. DOI: http://dx.doi.org/10.1016/j.earscirev.2014.05.011.

APPENDIX A – CN'S STANDARD RISK TABLES AND MATRIX

LIKELIHOOD SELECTION TABLE

Likelihood	Description
Almost Certain	Expected to occur in most circumstances (>80% probability). Likely to occur at least once in every year.
Likely	Will probably occur in most circumstances (50 to 80% probability). Likely to occur once every >1 -2 years.
Possible	Might occur at some time (25 to 49% probability). Likely to occur once every >2-5 years.
Unlikely	Could occur but unlikely (2 to 24% probability). Likely to occur once every >5-20 years.
Rare	May occur in exceptional circumstances (<2% probability). Not likely to occur more than once in 30 years.

Risk Consequence

Graded Consequences of risk for each Risk Impact Category.

Impact Category	Insignificant	Minor	Moderate	Major	Severe
Financial	Minimal financial impact that can be managed within the program or service budget. Less than $10,000.	A financial loss that can be managed within the department budget. $10,000 to less than $100,000.	A financial loss that can be managed within the organisational budget. $100,000 to less than $500,000.	A financial loss unable to be managed within the organisational budget resulting in reduction in a program or service. $500,000 to less than $2M.	A critical financial loss resulting in closure of or significant reduction in a program or service. Greater than $2M.
Environmental	Negligible damage that is contained on-site. The damage is recoverable with no permanent effect on the environment or the asset, The resource or asset will take less than 6 months to recover.	Minor damage to the environment or heritage asset or area that is immediately contained on-site. The resource or asset will take less than 2 years to recover or it will only require minor repair.	Moderate damage to the environment or a heritage listed asset or area, which is repairable. The resource or asset will take up to 10 years to recover.	Significant damage to an *environmentally significant* area or asset from which it will take more than 10 years to recover. OR Extensive damage to a non-heritage listed area or asset that has heritage values. OR Significant damage to a *Council Heritage Listed* area or asset that involves either extensive remediation or will take more than 10 years to recover.	Irreversible and extensive damage is caused to a *World Heritage Listed* Area*, a National Heritage Listed* Site, *a Register of the National Estate Site or a Council Heritage Listed* area or asset. OR Irreversible and extensive damage is caused to a *Matter of National Environmental Significance* under the Act (e.g. endangered species, RAMSAR wetland, marine environment).
Health and Safety	No injury / minor First Aid treatment only.	First Aid treatment or precautionary medical attention only. Person likely to immediately resume normal duties.	Person unable to resume normal duties in the short-medium term.	Hospitalisation with potential to result in permanent impairment.	Single or multiple fatality.

Impact Category	Insignificant	Minor	Moderate	Major	Severe
Infrastructure/ICT Systems/ Utilities	Minor damage where repairs are required however, assets or infrastructure are still fully operational. OR Loss of utilities/systems resulting in minor disruption to a service for up to 12 hours.	Short term loss or damage where repairs are required to allow the assets or infrastructure to remain operational using existing internal resources. OR Loss of utilities/systems resulting in minor disruption to a service (>12 hours - 24 hours).	Medium term loss of key assets and infrastructure, where are repairs required to allow them to remain operational. Cost moderate and outside of budget allocation. OR Loss of utilities/systems resulting in disruption to a department for up to 12 hours.	Widespread, medium term loss of key assets and infrastructure, where repairs required to allow the infrastructure to remain operational. Cost significant and outside of budget allocation. OR Loss of utilities/systems resulting in serious disruption to several services or more than 1 department for up to 12 hours.	Widespread, long-term loss of substantial key assets and infrastructure. Infrastructure requires total rebuild or replacement. OR Failure of utilities/systems resulting in the loss of function for several departments (> 12 hours).
Legislative Compliance	Minor technical breach but no damages. No monetary penalty. Internal query.	Minor technical non-compliances and breaches of Corporate/Council Policy or State/Commonwealth regulations with potential for minor monetary penalty.	Compliance breach of regulation with investigation or report to authority with possible fine. AND/OR Special audit by outside agency or enquiry by Ombudsman.	Major compliance breach with potential exposure to large damages or awards. Potential prosecution with penalty imposed. District court action. OR Multiple compliance breaches that together result in potential prosecution with penalty imposed.	Severe compliance breach with prosecution and/or maximum penalty imposed. Supreme Court or criminal action. OR Multiple compliance breaches that together result in prosecution with maximum penalty imposed.
Reputation/Image	Customer complaint. AND/OR Not at fault issue, settled quickly with no impact.	Non-headline community media exposure. Clear fault. Settled quickly by NCC response. Negligible impact.	Negative local (headline) and some regional media coverage. Council notification. Slow resolution.	Negative regional (headline) and some national media coverage. Repeated exposure. Council involvement. At fault or unresolved complexities impacting public or key groups.	Sustained national media coverage. Maximum multiple high-level exposure. Direct Council intervention. Loss of credibility and public/ key stakeholder support.

Impact Category	Insignificant	Minor	Moderate	Major	Severe
Service Delivery	Some non-essential tasks will not be able to be achieved. AND/OR Unable to provide service for <1 business day. AND/OR Major Project in progress delay for < 1 month.	Less than 5% of essential tasks will not be achieved. AND/OR Unable to provide service for 1-2 business days. AND/OR Major Project in progress delay for 1 - 2 months.	5% - 10% of essential tasks will not be achieved AND/OR Unable to provide service for 2-5 business days. AND/OR Major Project in progress delay for 2-3 months.	10% - 20% of essential tasks will not be achieved. AND/OR Unable to provide service for 5-10 business days. AND/OR Major Project in progress delay for 3-6 months.	Greater than 20% of essential tasks will not be achieved. AND/OR Unable to provide service for >10 business days. AND/OR Major Project in progress delay for > 6 months.

Likelihood	Consequence				
	Insignificant	Minor	Moderate	Major	Severe
Almost Certain	Medium	Medium	High	Extreme	Extreme
Likely	Low	Medium	High	Extreme	Extreme
Possible	Low	Medium	Medium	High	Extreme
Unlikely	Low	Low	Medium	High	High
Rare	Low	Low	Medium	High	High

APPENDIX B – COMBINED RISK MAPPING

Note: This map is provided for risk assessment, and should not be used for other purposes

Figure 5: Affected Surface Assets for 2020 (South)

Stockton Beach Coastal Hazard Risk Assessment

REV	DRAWN	CHECK
C	EN	DJW

Salients

GIS File:\Projects\P00083_StocktonSedimentandHazards\GIS\ThreatenedAssetFiguresC.qgs

Figure 6: Affected Above Ground Assets for 2020 (South)

Stockton Beach Coastal Hazard Risk Assessment

REV	DRAWN	CHECK
C	EN	DJW

Salients

GIS File:\Projects\P00083 StocktonSedimentandHazards\GIS\ThreatenedAssetFiguresC.qgs

Note: This map is provided for risk assessment, and should not be used for other purposes

Figure 7: Affected Surface Assets for 2020 (North)

0 50 100 150 m

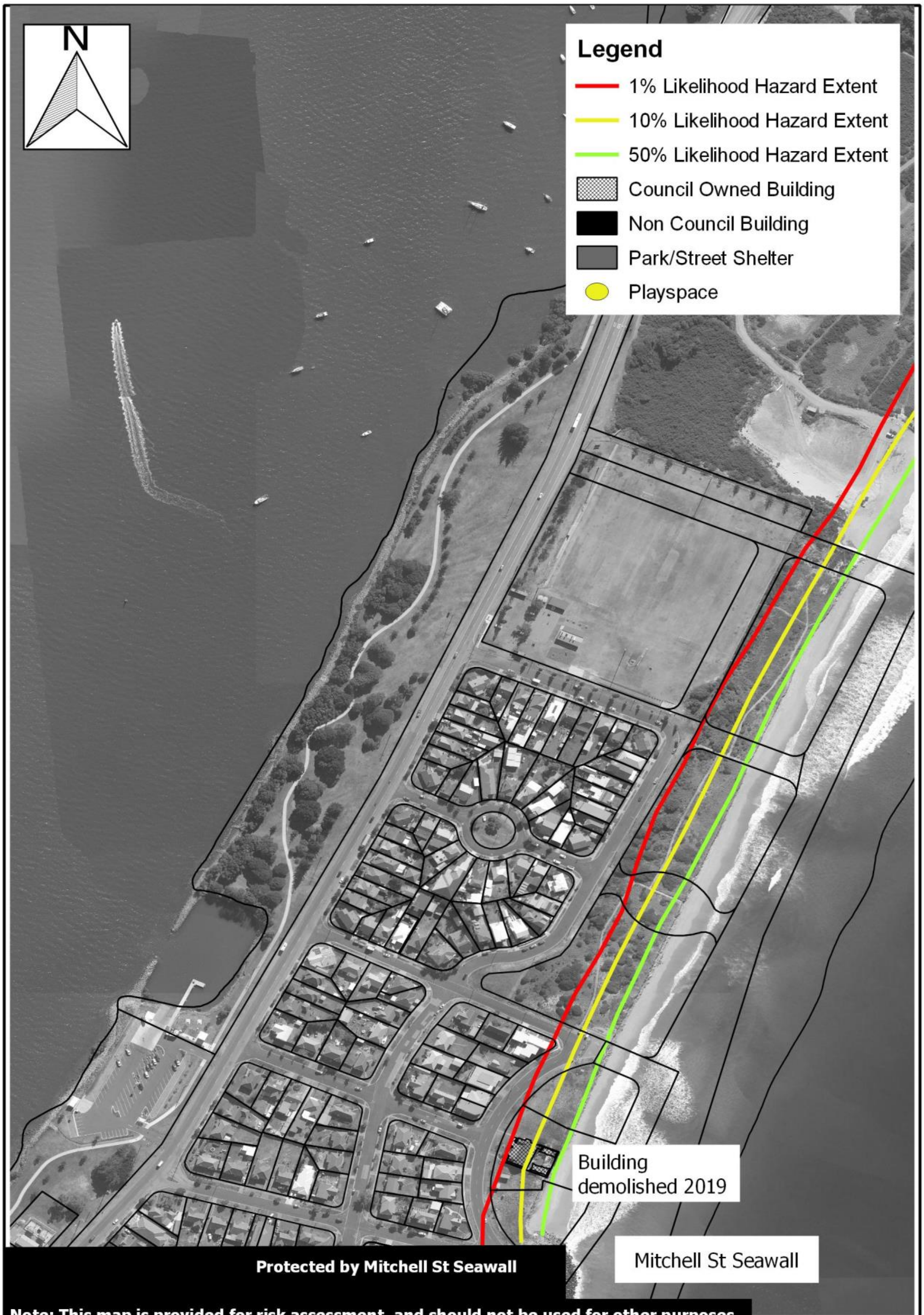
APPROX SCALE

Stockton Beach Coastal Hazard Risk Assessment

REV	DRAWN	CHECK
B	EN	DJW

Salients

GIS File:\Projects\P00083 StocktonSedimentandHazards\GIS\ThreatenedAssetFiguresB.qgs



Note: This map is provided for risk assessment, and should not be used for other purposes

Figure 8: Affected Above Ground Assets for 2020 (North)

0 50 100 150 m
APPROX SCALE

Stockton Beach Coastal Hazard Risk Assessment	REV C	DRAWN EN	CHECK DJW	Salients

GIS File:\Projects\P00083 StocktonSedimentandHazards\GIS\ThreatenedAssetFiguresC.qgs

Note: This map is provided for risk assessment, and should not be used for other purposes

Figure 9: Affected Surface Assets for 2040 (South)

0 50 100 150 m

APPROX SCALE

Stockton Beach Coastal Hazard Risk Assessment

REV	DRAWN	CHECK
C	EN	DJW

Salients

GIS File:\Projects\P00083 StocktonSedimentandHazards\GIS\ThreatenedAssetFiguresC.qgs

Figure 10: Affected Above Ground Assets for 2040 (South)

0 50 100 150 m
APPROX SCALE

Stockton Beach Coastal Hazard Risk Assessment

REV	DRAWN	CHECK
C	EN	DJW

Salients

GIS File:\Projects\P00083 StocktonSedimentandHazards\GIS\ThreatenedAssetFiguresC.qgs

Note: This map is provided for risk assessment, and should not be used for other purposes

Figure 11: Affected Surface Assets for 2040 (North)

0 50 100 150 m

APPROX SCALE

Stockton Beach Coastal Hazard Risk Assessment

REV	DRAWN	CHECK
B	EN	DJW

Salients

GIS File:\Projects\P00083 StocktonSedimentandHazards\GIS\ThreatenedAssetFiguresB.qgs

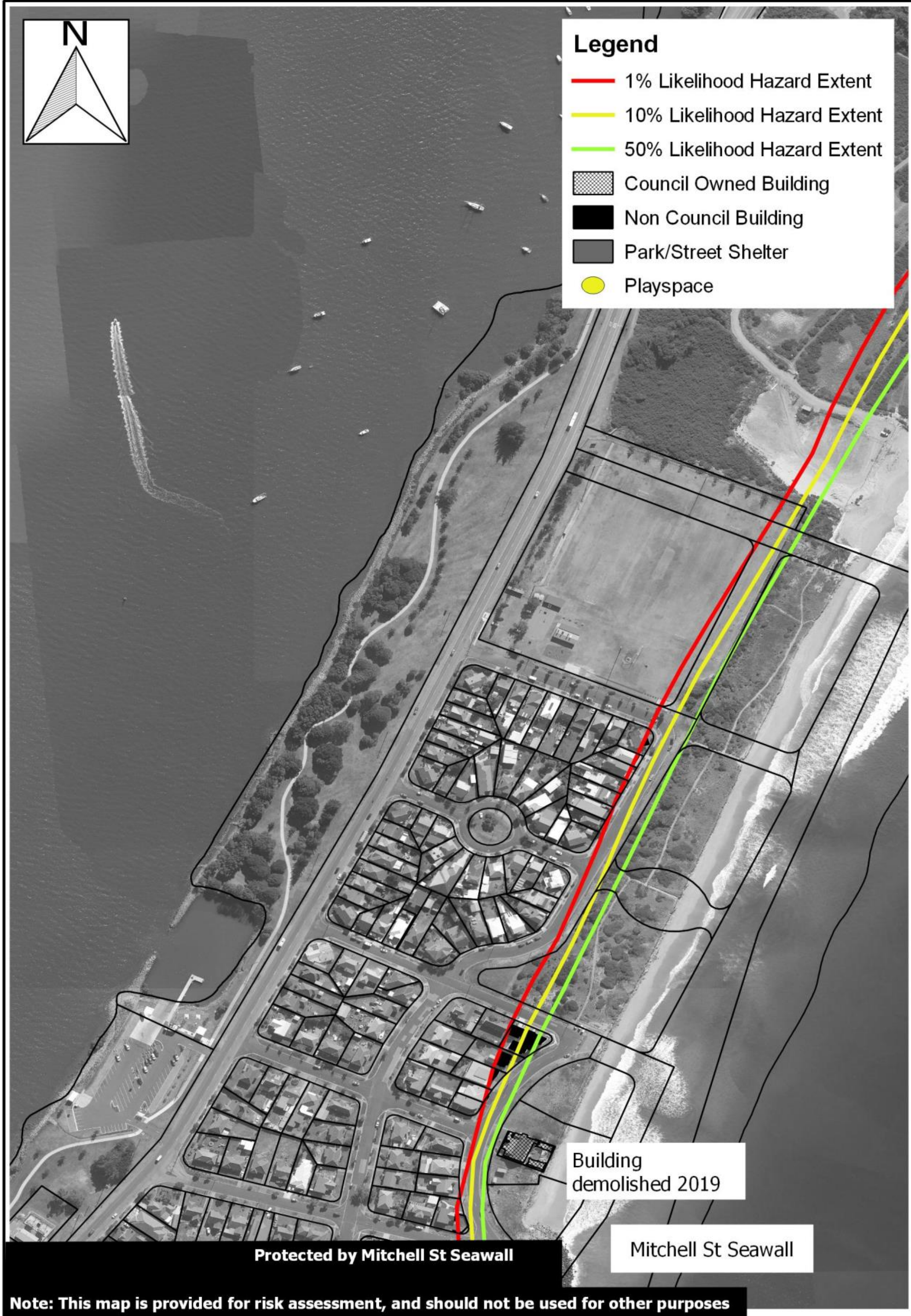


Figure 12: Affected Above Ground Assets for 2040 (North)

0 50 100 150 m

APPROX SCALE

Stockton Beach Coastal Hazard Risk Assessment

REV	DRAWN	CHECK
C	EN	DJW

Salients

GIS File:\Projects\P00083 StocktonSedimentandHazards\GIS\ThreatenedAssetFiguresC.qgs

Figure 13: Affected Surface Assets for 2060 (South)

Stockton Beach Coastal Hazard Risk Assessment

REV	DRAWN	CHECK
C	EN	DJW

Salients

GIS File:\Projects\P00083_StocktonSedimentandHazards\GIS\ThreatenedAssetFiguresC.qgs

Figure 14: Affected Above Ground Assets for 2060 (South)

Stockton Beach Coastal Hazard Risk Assessment

REV	DRAWN	CHECK
C	EN	DJW

Salients

GIS File:\Projects\P00083_StocktonSedimentandHazards\GIS\ThreatenedAssetFiguresC.qgs

Figure 15: Affected Surface Assets for 2060 (North)

0 50 100 150 m
APPROX SCALE

Stockton Beach Coastal Hazard Risk Assessment

REV	DRAWN	CHECK
B	EN	DJW

Salients

GIS File:\Projects\P00083 StocktonSedimentandHazards\GIS\ThreatenedAssetFiguresB.qgs

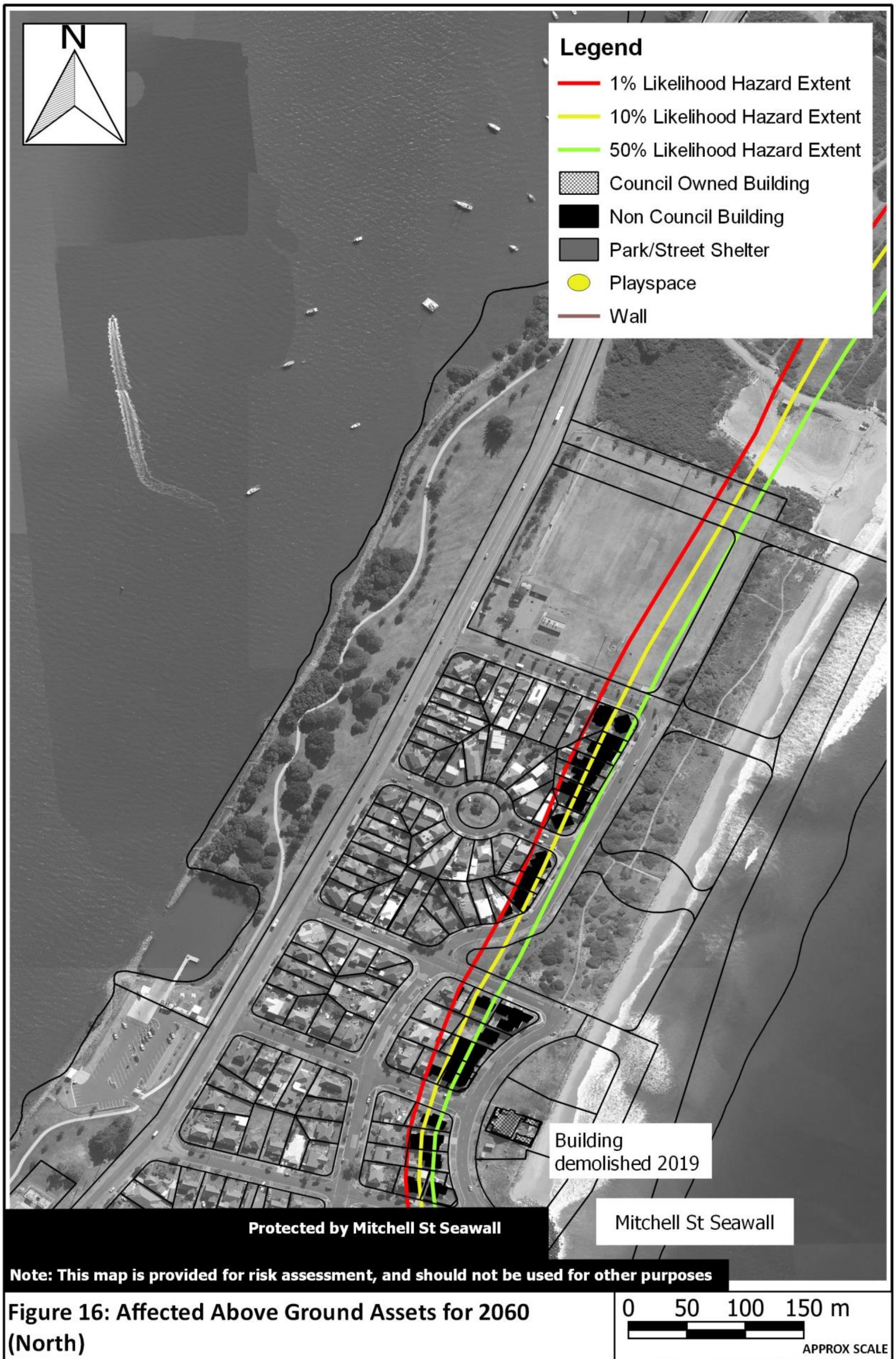


Figure 16: Affected Above Ground Assets for 2060 (North)

Stockton Beach Coastal Hazard Risk Assessment	REV C	DRAWN EN	CHECK DJW	Salients

GIS File:\Projects\P00083 StocktonSedimentandHazards\GIS\ThreatenedAssetFiguresC.qgs

Figure 17: Affected Surface Assets for 2120 (South)

Stockton Beach Coastal Hazard Risk Assessment

REV	DRAWN	CHECK
C	EN	DJW

Salients

GIS File:\Projects\P00083_StocktonSedimentandHazards\GIS\ThreatenedAssetFiguresC.qgs

Figure 18: Affected Above Ground Assets for 2120 (South)

Stockton Beach Coastal Hazard Risk Assessment

REV	DRAWN	CHECK
C	EN	DJW

Salients

GIS File:\Projects\P00083 StocktonSedimentandHazards\GIS\ThreatenedAssetFiguresC.qgs

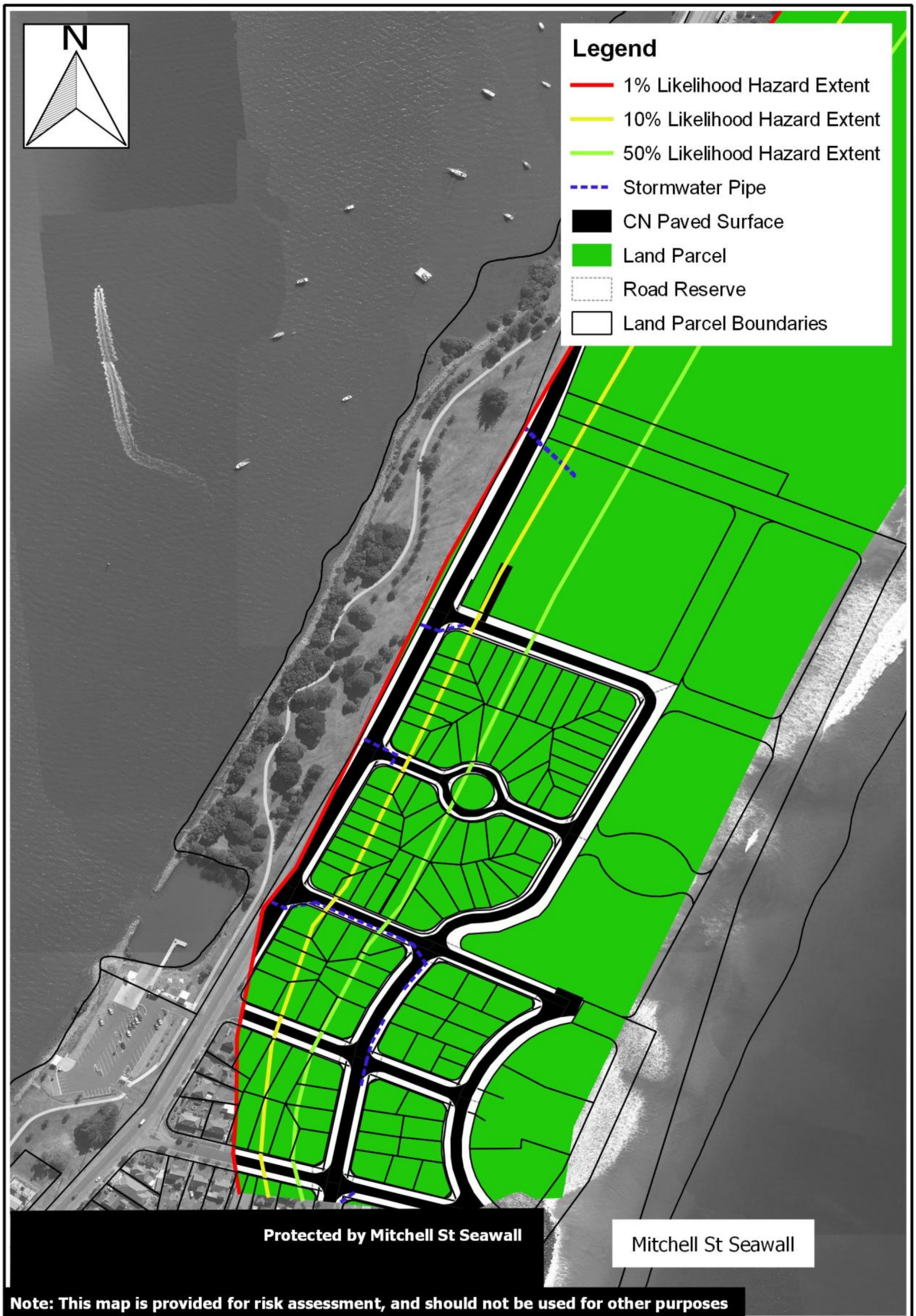


Figure 19: Affected Surface Assets for 2120 (North)

Stockton Beach Coastal Hazard Risk Assessment

REV	DRAWN	CHECK
B	EN	DJW

Salients

GIS File:\Projects\P00083 StocktonSedimentandHazards\GIS\ThreatenedAssetFiguresB.qgs

Note: This map is provided for risk assessment, and should not be used for other purposes

Figure 20: Affected Above Ground Assets for 2120 (North)

0 50 100 150 m
APPROX SCALE

Stockton Beach Coastal Hazard Risk Assessment

REV	DRAWN	CHECK
C	EN	DJW

Salients

GIS File:\Projects\P00083 StocktonSedimentandHazards\GIS\ThreatenedAssetFiguresC.qgs