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CONSULTING ENGINEERS

Technical Note – Stockton Beach Coastal Inundation Assessment

To:	City of Newcastle
From:	Bluecoast Consulting Engineers
Author(s)	Heiko Loehr and June Gainza
Reviewer:	Evan Watterson
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1 Introduction

In line with the Coastal Management Act 2016 and the NSW Coastal Management Manual Part B (the Manual - NSW Government, 2018), a coastal inundation hazard assessment for Stockton Beach has been undertaken. The City of Newcastle (CN) engaged Bluecoast Consulting Engineers (Bluecoast) to complete the coastal inundation assessment. This assessment follows on from the *Stockton Beach Coastal Erosion Hazard Assessment* (Bluecoast, 2020a) completed as part of Stage 2 of the Stockton Coastal Management Program (CMP) 2020 as well as the Stockton Bight Sand Movement Study (Bluecoast, 2020b). Due to a time constraint imposed by Ministerial direction to complete a Stockton CMP by 30 June 2020, these studies had been fast-tracked with this inundation assessment completed as an addendum to the coastal erosion assessment.

The purpose of this technical note is to identify and map the present (immediate) and future coastal inundation hazard at Stockton Beach. A vulnerability assessment of natural and built assets in the study area was not undertaken. The inundation assessment is limited to the storm-related flooding by seawater due to elevated ocean water levels (storm surge) and wave processes. Coastal inundation, as an action of the sea, is distinguished from more traditional definitions of flooding which are typically associated with rainfall and runoff. Flooding from runoff or from the Hunter River side of the Stockton peninsula is not included in this assessment and has been previously assessed in the Newcastle City-wide Floodplain Risk Management Study and Plan (BMT WBM, 2012).

This technical note is to be read as an addendum to the Stockton Beach Coastal Erosion Hazard Assessment within Supporting Documentation C - Stage 2 Reports - Sand Movement Study and Probabilistic Hazard Assessment Summary.

2 Background

As identified in the CMP Scoping Study (CN, 2019), coastal inundation at Stockton occurs because of elevated still water levels and high energy wave conditions, i.e. the wave-driven 'dynamic' inundation.

Reports of historical coastal inundation events at Stockton Beach are limited to old newspapers (DLWC, 1995). At least two events in the 1920's (1920 and 1928) reported waves overwashing a "gap in the sandhills", believed to be a low point in the dunes adjacent to Mitchell Street nearby Pembroke Street. In June 1945, the Newcastle Herald reported on the impacts of a storm event:

> *"During Monday night's gale, waves washed a channel through a sandhill in Mitchell Street near the end of Pembroke Street. At high tide big waves wash across Mitchell Street. Water carried debris 100 yards [90 metres] down Pembroke Street, which runs at right angles to the beach."*

Wave overwash along Mitchell Street, carrying debris and sand, was again reported in 1948 and in 1952 *"between Pembroke Street and the surf sheds"*.

When overwash has occurred, anecdotal observations suggest that seawater drains down the gutters of east-west orientated streets. This is supported by the street gradient which grade down from the beach ridge (believed to be the dune barrier) going west. More recently this similar pattern of overwash and seawater flows down Meredith Street was observed in the February and July 2020 storm events.

The two main components that contribute to the coastal inundation hazard are:

- a 'quasi-static' component (tide, storm surge and wave setup)
- a wave-driven 'dynamic' component (wave runup, overwash and overtopping).

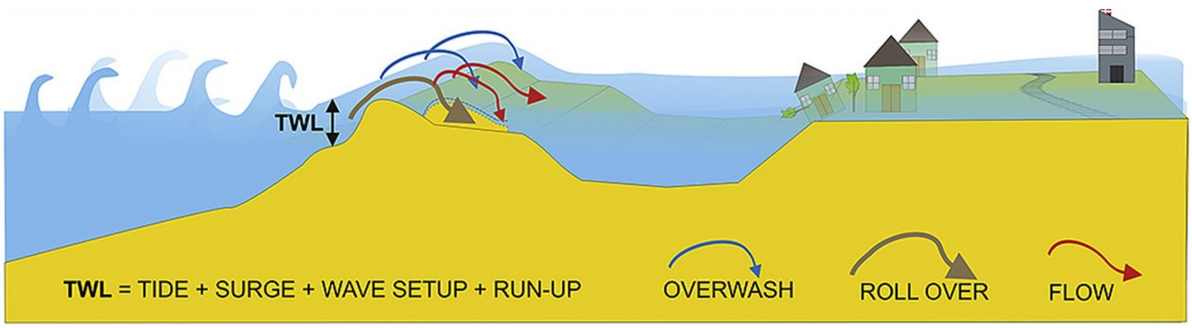

Figure 1: Schematic showing combined inundation by the total water level (TWL) comprising the 'quasi-static' elevated water level and 'dynamic' wave driven processes (source: Fernandez-Montblanc et al., 2020).

A previous coastal inundation assessment for Stockton was undertaken in BMT WBM (2014). The following key findings were identified:

- The coastal inundation risk from still water levels (i.e. quasi-static component) is low for present day as well as future sea level rise scenarios (up to 2100) with the only predicted inundation to occur at the caravan park for a 'rare likelihood' 2100 hazard scenario (worst case).
- While not assessed in detail, a high risk of wave-driven coastal inundation (overwash and overtopping) was identified along most of the Stockton coastline between Fort Wallace and the northern breakwater.

The coastal inundation mapping in BMT WBM (2014) used a 'bathtub' approach that considered static and alongshore uniform water levels. The wave-driven dynamic inundation hazard component was assessed for three profile locations at Stockton Beach and therefore only indicative mapping of overtopping and run-up areas was undertaken.

For the present study, a suitable approach has been developed that aimed to provide a more detailed assessment of the wave-driven dynamic coastal inundation hazard as described in the following sections.

3 Study area

The hazard assessment is limited to coastal inundation on the seaward side of Stockton. While the study area extends up to the northern Newcastle LGA boundary, the inundation assessment is focussed on the low-lying area north of the Stockton breakwater (northern training wall of the Hunter River) to the Hunter Water site (see Figure 2). No inundation risk is identified for the area north of the Hunter Water site to the LGA boundary due to the presence of extensive dune ridges with a typical barrier elevation of over 10m AHD.

As seen in the digital elevation model (DEM) derived from Department of Planning, Industry and Environment's (DPIE) 2018 LiDAR data in Figure 2, the coastal barrier within the study area comprises:

- a low-lying sandy beach ridge at the southern end (caravan park) and between the Corroba Oval and the old Hunter Water treatment ponds (eroded dune)
- three sections of seawalls fronting Surf Life Saving Club, Mitchell Street and Hunter Water site
- extensive dune ridges at the northern end.

Figure 2: Study area and 2018 LiDAR (DPIE) Digital Elevation Model.

4 Coastal inundation assessment

4.1 Approach

The approach to the coastal inundation assessment adopted herein involved:

- analysis of the joint probability of extreme water levels and waves
- assessment of alongshore variation of wave setup and exposure
- review of the latest climate change projections for sea level rise
- detailed assessment of wave overwash and overtopping along the Stockton coastline
- overland inundation flow modelling using Delft3D FM to assess the exposure of Stockton based on its current level of coastal protection
- production of inundation maps showing the extent and depth of inundation based existing topography (without consideration of drainage infrastructure, infiltration and physical obstructions such as vegetation and/or buildings).

4.2 Planning periods and hazard probabilities

Based on the preceding coastal erosion hazard assessment (Bluecoast, 2020a), the adopted planning periods for the inundation assessment are 2020 (present day), 2040, 2060 and 2120. As per Bluecoast (2020a), a hazard likelihood of 1% Annual Exceedance Probability (AEP) or 100-year Average Recurrence Interval (ARI) has been adopted for the coastal inundation assessment and associated mapping. This was considered appropriate to represent CN's likelihood descriptor *'rare'* which is defined as an event that is *'not likely to occur more than once in 30-years'* (see Appendix A in Bluecoast, 2020a).

4.3 Water levels and wave processes

4.3.1 Tides and storm surge

Newcastle Port at the southern end of Stockton Bight experiences semi-diurnal tides (two highs and two lows a day) with tidal planes shown in Table 1. Extreme value analyses of the Fort Denison tide gauge data in Sydney are published in MHL (2018). Measurements were undertaken since 1914 (i.e., 106 years) and provide an excellent record for such analysis and is considered representative for Stockton (Watterson et al., 2013). The highest recorded water level of 1.48m AHD occurred in May 1974 (MHL, 2018).

A water level exceedance curve is shown in Figure 3 and the estimated 100-year ARI water level for Fort Denison and, for comparison, at nearby Port Stephens are presented in Table 2.

Table 1: Tidal planes at Newcastle (source: National Tidal Centre).

Tidal plane	Water level (m AHD)
Highest Astronomical Tide (HAT)	1.1
Mean High Water Springs (MHWS)	0.6
Mean High Water Neaps (MHWN)	0.4
Mean Sea Level (MSL)	0
Mean Low Water Neaps (MLWN)	-0.4
Mean Low Water Springs (MLWS)	-0.6
Lowest Astronomical Tide (LAT)	-0.9

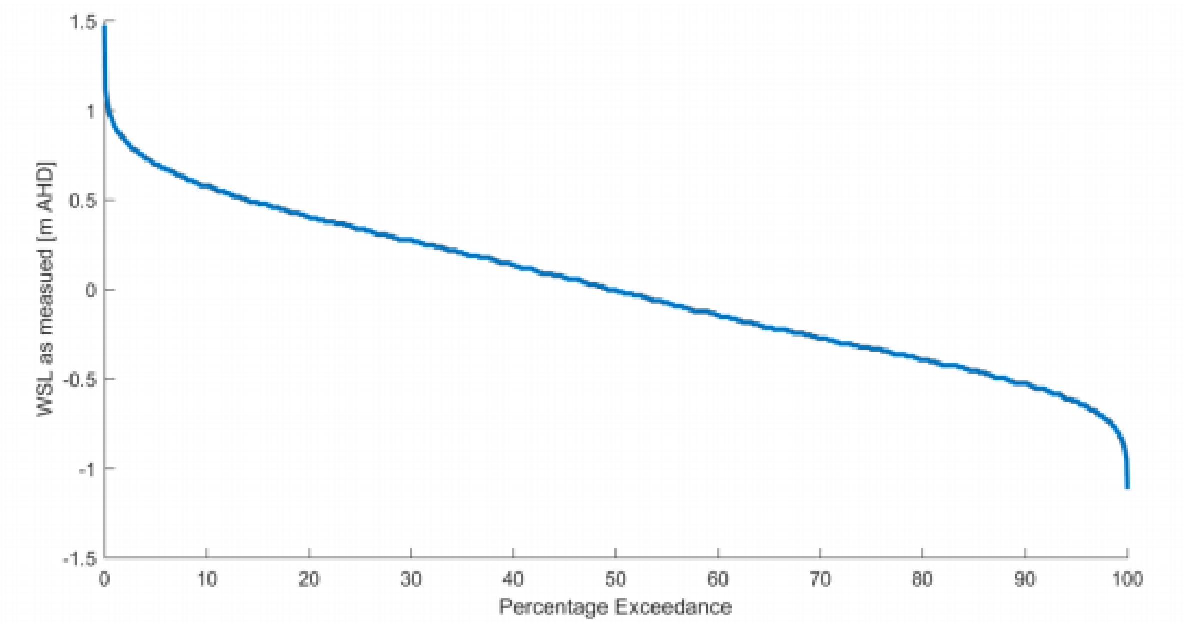

Figure 3: Water level exceedance curve for observations at Fort Denison between 1914 to 2017 (source: MHL, 2018).

Table 2: Extreme value analysis results of water level at nearby tide gauge locations using the Generalised Pareto model (MHL, 2018).

	100-year ARI water level (m AHD)		
	Model	Lower confidence limit (5%)	Upper confidence limit (95%)
Fort Denison	1.42	1.38	1.53
Port Stephens	1.36	1.31	1.50

4.3.2 Joint probability of water level and waves

Analysis of the joint occurrence of observed significant wave heights and observed water levels at Sydney was undertaken to inform the selection of appropriate scenarios for the inundation assessment. The observed water level includes the still water level components of wind setup and inverted barometric setup but exclude any wave-driven contributions. The observed joint occurrences of the two parameters are shown in Figure 4 and suggests that there is a slight positive bias between the observed wave heights and water levels, i.e., larger wave heights often coincide with higher water levels.

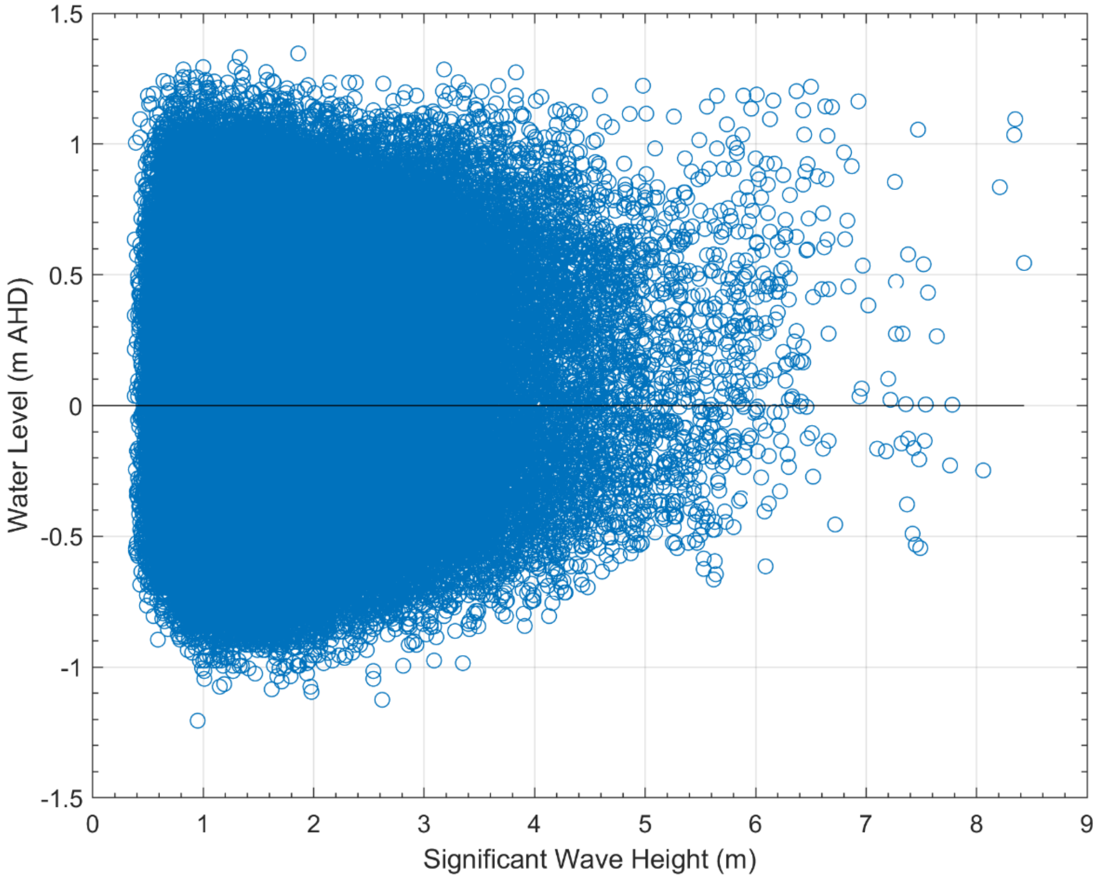

Figure 4: Joint occurrence of significant wave heights and water levels observed at Sydney between 1992 and 2020 (28-year record).

The joint probability (or return period) of extreme still water level and significant wave heights (or coincidence of the two) was calculated using a multivariate copula analysis. Copulas are mathematical functions that characterise the correlation structure among multiple time-independent random variables. Using measurements from the Sydney Waverider Buoy and Fort Denison tide gauge, the joint probability was calculated using independent extreme wave events (peak significant wave heights) as the primary variable and corresponding maximum water levels within a three-hour period before or after the peak wave event (see

Figure 5). Sensitivity tests were undertaken using a six-hour period either side of the peak wave event and differences in the ARI values were insignificant. The analysis estimated the joint 100-year ARI values as:

- Significant wave height of 8.6m.
- Total still water level of 1.18m above AHD.

These values have been adopted for the overwash and overtopping calculations as part of the coastal inundation assessment. A review of past storm events was undertaken which suggests that peak wave periods of around 12s are observed during extreme events at Sydney (MHL, 2016). A peak wave period of 12s was adopted for the inundation assessment and is considered appropriate for the design wave height.

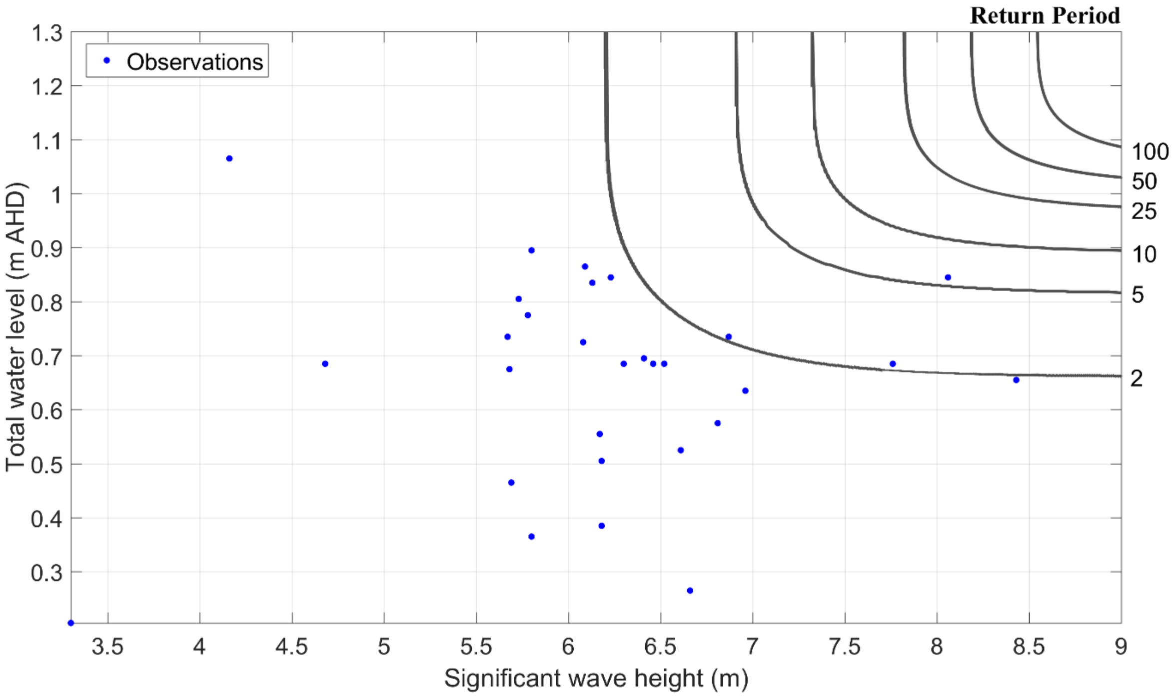

Figure 5: Joint probability return periods of water level and significant wave height.

Note: Multivariate return period isolines, as obtained from joint probability associated with an *Independence copula* are shown in dark grey.

4.3.3 Wave setup

Wave setup occurs as waves approach the coast and transform over the nearshore beach profile where radiation stresses and ultimately wave breaking force elevated water levels at the shoreline. Maximum wave setup is found at the beach face and is often approximated as ~10-20% of the offshore significant wave height (Hughes, 2016) as an increase to the total still water level (i.e. tide, surge). However, wave setup is a function of wave height and wave steepness as well as beach slope, therefore alongshore variation due to the differences in wave exposure and nearshore bathymetry at the southern end of Stockton Beach is expected. This was not considered in the previous coastal inundation assessment in BMT WBM (2014).

The numerical modelling approach undertaken herein simulates the spatial variation in nearshore wave processes resulting in wave setup and run-up. Assumptions and limitations of the numerical modelling are discussed in Section 4.5. An example of the alongshore variation in wave setup derived from the high-resolution SWASH modelling (see Bluecoast, 2020b) for a 3.5m significant wave height (peak period 12s, peak direction 135°N and 0m AHD water level) is shown Figure 6. For the coastal inundation assessment wave setup has been included in the overwash and overtopping calculations as described in Section 4.4.3.

4.3.4 Sea level rise

The latest advice from IPCC (2019) on sea level rise (SLR) calls for increases to the allowances in previous documents. The latest global SLR (above 1986 - 2005 baseline) projections for the ‘likely’ scenario are 0.43m and 0.84m (i.e., 0.1m higher than previous projections in IPCC, 2013) by 2100 for RCP2.6 (‘very stringent') and RCP8.5 ('worst-case’) greenhouse gas concentration scenarios, respectively. For this study, the ‘worst-case’ RCP8.5 SLR projections were adopted for a year 2020 baseline and have been extrapolated to 2120, as presented in Table 3.

Table 3: Adopted sea level rise allowances above 2020 baseline for upper bound scenario *RCP8.5 (adjusted from IPCC, 2019).*

Year	Sea level rise (m)
2020	0.00
2040	0.13
2060	0.30
2120*	1.33

*extrapolated using 20mm/year SLR rate IPCC (2019)

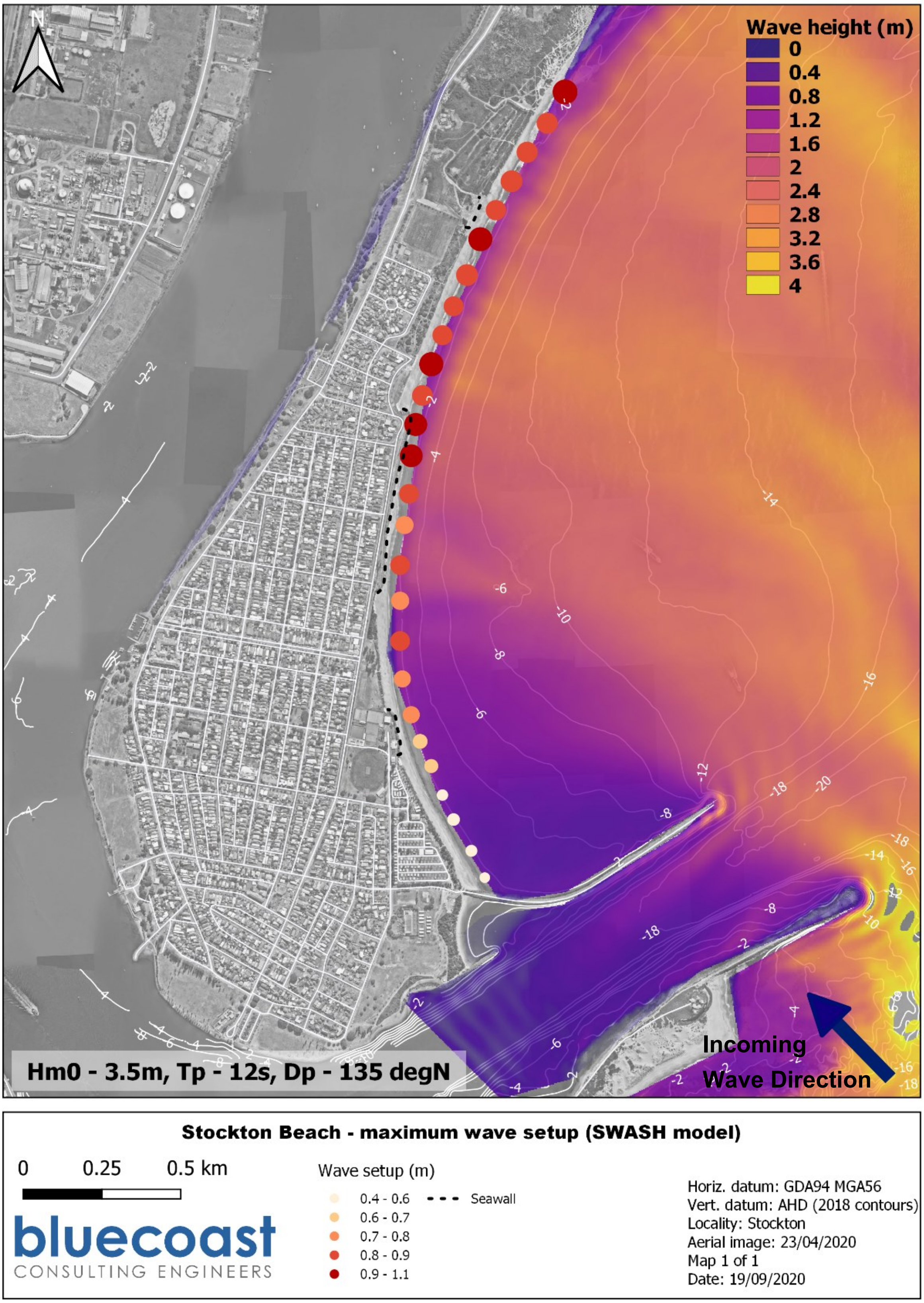

Figure 6: Spatial variation in simulated wave heights and inshore wave setup using the SWASH model for a large south-easterly wave condition.

4.3.5 Adopted wave and water level scenarios

A summary of the joint 100-year ARI (i.e., ~1% AEP) wave conditions and water levels adopted for the coastal inundation assessment is presented in Table 4. A one-hour duration has been assumed for the peak of the joint water level and wave event, which is considered appropriate given tidal variations either side of the peak.

Table 4: Overview of adopted joint wave and water level scenarios for the inundation assessment.

Planning period	Still water level (m AHD)	Significant wave height (m)	Peak wave period (s)	Duration (hours)
Present day (2020)	1.18	8.6	12	1
2040	1.31	8.6	12	1
2060	1.48	8.6	12	1
2120	2.51	8.6	12	1

4.4 Inundation modelling

4.4.1 Approach

To overcome the limitations of the 'bathtub' approach often used in inundation assessments along the NSW coast, a hybrid numerical modelling approach has been adopted using state-of-the-art computer modelling. This approach allows consideration of the dynamic wave driven inundation processes that were identified as the dominant inundation driver for Stockton in the CMP Scoping Study (CN, 2019).

For comparison, empirical wave overtopping calculations using EurOtop (2018) for two locations along Mitchell Street seawall have also been undertaken and are presented in Section 4.4.3.

4.4.2 Model setup

To simulate wave overwash and overtopping with consideration of complex nearshore wave processes (including wave setup and run-up) eight high-resolution XBeach (Roelvink et al., 2009) coastal profile models (one dimensional, shore normal) have been used to simulate a one-hour storm event (see Figure 8). XBeach has been widely adopted in coastal inundation assessments and has been validated against field measurements of runup and overtopping in physical model testing (Roelvink et al., 2017). The model was setup in surfbeat mode (wave group mode) where wave forcing in the shallow water momentum equation is obtained from a time dependent version of the wave action balance equation. Hence, in surfbeat mode short waves are not fully resolved but rather simulated as wave groups, and overtopping volumes presented herein are predominantly driven by temporary water level increases in the infragravity (wave group) spectrum (see Figure 7). While the XBeach model is capable of also accurately simulating overland inundation in a two dimensional and non-hydrostatic setup, the computational requirements were beyond the scope of the Stockton coastal inundation assessment.

Therefore, a two-dimensional Delft3D Flexible Mesh (Deltares, 2019) overland flow model was adopted and forced with alongshore interpolated peak water levels from the one-hour XBeach profile simulations (see Figure 8). The Delft3D FM suite is the successor of Delft3D-FLOW and SOBEK-FLOW (overland flow hydraulic model) and is widely used in flood studies. The water level boundary was located in the immediate lee of the crest of the coastal barrier (see black diamonds in Figure 8) which allows the simulation of the overland inundation extent and depth (Delft3D FM) based on the predicted overwash and overtopping peak water levels (XBeach). An overview of the model setup and key parameters is presented in Table 5. For mapping of the coastal inundation extent and depth, the maximum water depth at each grid cell during the one-hour simulation was extracted.

The one dimensional XBeach models assume a shore-normal wave direction for each of the profiles which is a conservative assumption for the simulation of wave setup and runup at the shore especially along the southern beach area and given the south to east typical storm wave directions (Bluecoast, 2020b). However, this also considers any potential future changes to the extreme wave climate at Stockton which is expected to increase the frequency and intensity of ex-tropical cyclones with north-east to easterly wave directions (Bluecoast, 2020b). To account for the sheltering effect offered from the northern breakwater an alongshore gradient in the nearshore wave height between the Surf Life Saving Club and the training wall based on two dimensional SWASH simulations has been applied to the XBeach boundary conditions (i.e. 15% reduction in wave height at most southern profile).

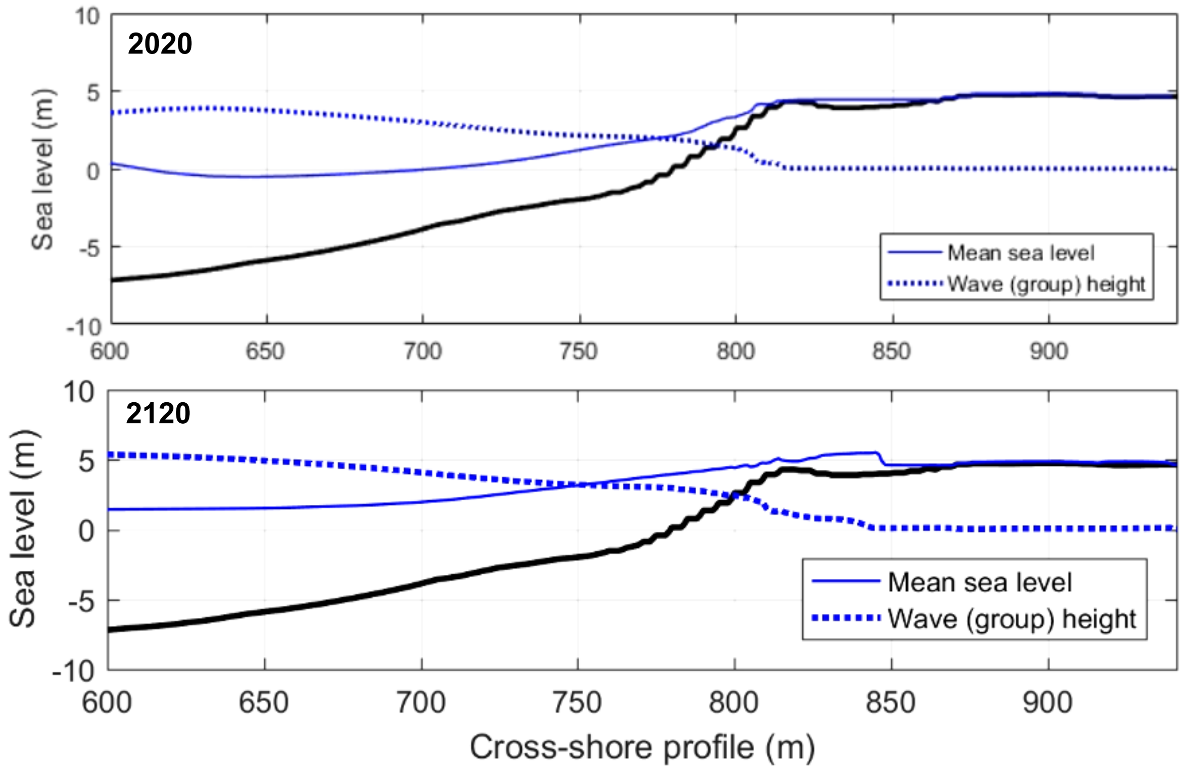

Figure 7: Model setup and example results from one dimensional XBeach profile model (T5) showing wave overtopping at the Mitchell Street seawall for one timestep during the 1% AEP event for (top) year 2020 and (bottom) year 2120.

Table 5: Overview of key model parameters.

	Dimensions	Grid resolution	Time step	Cross-shore extent
XBeach	1D	1 metre (max)	1 second	-12m to approx. 7m (AHD)
Delft3D FM	2D	5 metres (max)	1 second	Coastal barrier to Hunter River (overland)

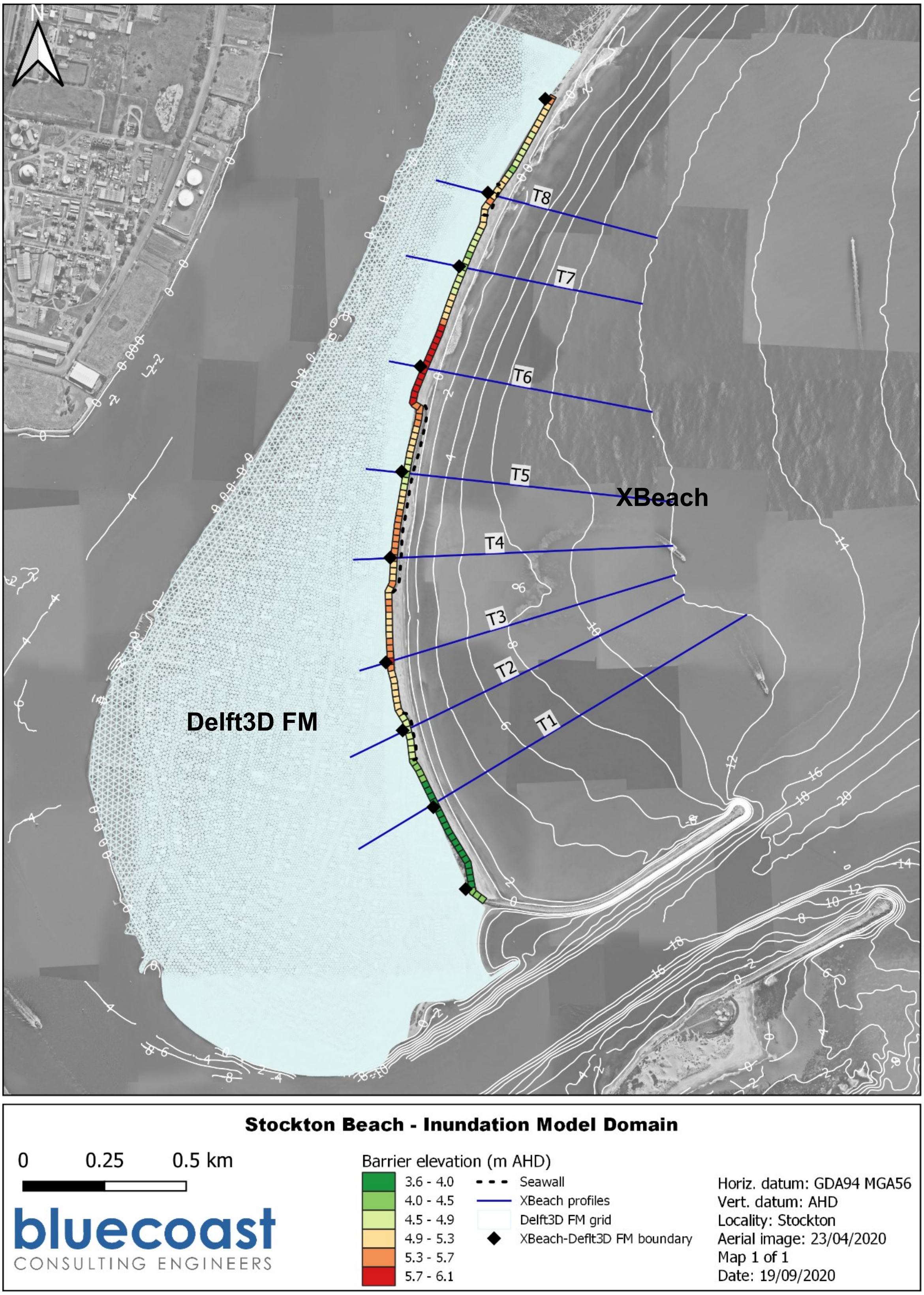

Figure 8: Delft3D FM (overland) and XBeach (profile) model domain. The maximum elevation of the top of the coastal barrier from the 2018 LiDAR DEM is also shown (colours).

4.4.3 Overwash and overtopping volumes

Wave overtopping of the coastal barrier (overwash) and seawalls at Stockton has been assessed using the XBeach model for the four selected joint water level and waves scenarios. A summary of the overwash and overtopping discharge volumes for each of the scenarios and location is provided in Table 6. Measures of the mean overtopping volume (Qx) in litres per seconds per metre (l/s/m) during the one-hour simulations as well as maximum volumes (Qx_{max}) in litres per metre (l/m) and the peak water level behind the coastal barrier are provided. For a given mean overtopping discharge, small waves only give small overtopping volumes, whereas large waves may give many cubic metres of overtopping water in one wave and their severity are thus better described by the maximum volumes.

For comparison, the EurOtop mean overtopping estimates were calculated at two locations along Mitchell Street seawall (i.e., T4 and T5). Since wave heights in front of the structures are depth limited due to wave breaking, it is the water level, beach scour level at the toe and wave setup that controls this variable. Structure dimensions were derived from the 2018 LiDAR DEM and post-East Coast Low (event occurred on the 13th July 2020) survey data was used to obtain the bed level at the toe of the structure. A peak period of 12s and shore normal wave direction was assumed for the calculations. For the 2020 to 2060 planning periods the XBeach and EurOtop calculations compare relatively well, however, overtopping volumes for the 2120 scenario are double in the adopted XBeach results which is likely a result of the more detailed wave calculations in the numerical model.

EurOtop (2018) provide guidance on safe mean and maximum overtopping volumes in consideration of impacts to the structure as well as people and infrastructure in the lee, see Table 7. The overtopping volumes presented herein exceed the safe volumes for most locations and planning periods. This suggests that damage to the seawalls may occur during such events and that there is a safety hazard for people behind the structure.

Table 6: Overwash and overtopping discharges (Qx) and peak water level behind coastal barrier from the XBeach modelling and EurOtop calculations (Mitchell St. seawall only).

Profile (see Figure 8)	Crest level (mAHD)	Mean Qx (l/s/m)		Max Qx (l/m)	Max level (mAHD)	Mean Qx (l/s/m)		Max Qx (l/m)	Max level (mAHD)
		EurOtop	XBeach	XBeach	XBeach	EurOtop	XBeach	XBeach	XBeach
		2020				2040			
T1	3.8	-	13	2,536	4.7	-	13	3,131	4.9
T2	4.7	-	4	2,313	5.1	-	4	2,374	5.4
T3	5.7	-	0	1,013	5.9	-	0	518	6.2
T4	5.3	23	17	1,104	5.0	29	27	1,657	5.1
T5	4.4	67	41	3,522	5.2	77	43	3,574	5.6

Profile (see Figure 8)	Crest level (mAHD)	Mean Qx (l/s/m)		Max Qx (l/m)	Max level (mAHD)	Mean Qx (l/s/m)		Max Qx (l/m)	Max level (mAHD)
		EurOtop	XBeach	XBeach	XBeach	EurOtop	XBeach	XBeach	XBeach
T6	6.0	-	4	954	6.3	-	3	741	6.3
T7	4.5	-	89	2,956	4.9	-	159	3,951	5.0
T8	5.5	-	25	1,769	5.2	-	43	1,682	5.4
Cont.		**2060**				**2120**			
T1	3.8	-	21	4,439	5.0	-	34	5,407	5.6
T2	4.7	-	7	2,928	5.4	-	24	3,813	6.2
T3	5.7	-	1	1,208	6.3	-	15	3,422	6.6
T4	5.3	37	51	2,293	5.2	122	280	4,319	5.7
T5	4.4	92	78	4,090	5.6	221	427	5,717	5.8
T6	6.0	-	10	582	6.6	-	60	2,711	6.6
T7	4.5	-	155	3,817	5.0	-	606	5,705	5.2
T8	5.5	-	71	1,394	5.5	-	262	3,927	5.7

Table 7: Overview of safe overtopping volumes provided in EurOtop (2018).

Hazard type and reason	Offshore significant wave height (m)	Mean discharge Qx (l/s per m)	Max volume V_{max} (l per m)
Rubble mound structure (no damage)	>5	1	2,000 to 3,000
Rubble mound structure (rear side designed for wave overtopping)	>5	5-10	10,000 to 20,000
People at seawall (clear view of the sea)	3	0.3	600
	2	1	600
	1	10-20	600
	<0.5	No limit	No limit
Cars on seawall (close behind crest)	3	<5	2,000
	2	10-20	2,000
	1	<75	2,000

4.4.4 Validation

A validation exercise of the hybrid numerical modelling approach and coastal inundation mapping was undertaken for the peak of the East Coast Low wave event on 15th July 2020 at 4PM. Offshore significant wave heights peaked at just under 6m and coincided with a high tide (0.6m AHD at 4.25PM). The wave event was estimated to have a return period of approximately 1-year (i.e. 1-year ARI). Photographs captured during the event by residents as well as anecdotal evidence of inundation extents were available (pers. comms. Prof. Ron Boyd), see Figure 9. Residents reported significant overwash had occurred at Meredith Street and seawater was washed into the most landward (3rd) remaining Hunter Water pond to the north. This anecdotal evidence has been used to validate the coastal inundation mapping approach adopted herein, as shown in Figure 10. The overwash and overtopping areas observed during the event (Meredith Street, Mitchell Street seawall) were well represented in the modelling results while inundation depth and extents are somewhat conservative given the hydraulic modelling assumptions stated in Section 4.5. Coastal inundation at the caravan park was likely overestimated by the model for this event, most likely due to the wave approach experienced differing from the direction adopted herein. However, it does represent a probable scenario for a more northerly storm direction. In consideration of the limitations (see Section 4.5) with simulating the dynamic wave driven coastal inundation processes and datasets available, it was assumed the adopted approach is sufficiently accurate for the purpose of this assessment. However, it is noted that any detailed planning and design of foreshore infrastructure at Stockton requires a more detailed assessment.

Figure 9: Photographs from 15 July 2020 showing (left) wave overtopping at 4:09PM at the northern section of Mitchell Street seawall and (right) overwash at the Hunter Water treatment ponds at 4:44PM (source: Brian Hunt).

Figure 10: Validation of coastal inundation approach against photographs and anecdotal evidence (photograph source: Brian Hunt).

4.4.5 Results

Coastal inundation maps showing the maximum flood extent and depth for the one-hour joint 100-year ARI (or 1% AEP) wave and water level simulations are presented in Section 5 for each planning period. The seaward boundary of the overland inundation modelling is shown in Figure 8 (black diamonds) and does not extend to the seaward end of the coastal barrier. Therefore, any areas between the indicated inundation (blue colours) and the sea can be considered at risk from coastal inundation for the respective planning scenario.

4.5 Limitations

While the results provided herein are suitable for planning purposes and showcase areas at risk and approximate inundation extents, these should be interpreted with consideration of the following limitations:

- Morphological response of the beach during the storm as well as long-term adjustment to sea level rise and recession have not been included herein. Any landward movement of the coastal barrier would also affect the inundation extents and depth. Changes to the nearshore bathymetry due to profile adjustments as well as higher sea levels may change nearshore wave processes that could exacerbate the inundation risk. Conversely, higher sea levels may reduce the wave setup component and counterbalance these effects.
- Stormwater drainage, vegetation and infiltration have not been included in the modelling undertaken herein and would likely reduce the inundation extents and depth presented herein.
- The effects of wind on wave overwash and overtopping were not included. Heavy rainfall, antecedent precipitation and river flooding were also not considered in this study. These factors could exacerbate inundation. Wave forces and momentum of overtopping jets were also not considered herein.
- The accuracy of the Digital Elevation Model (2018 LiDAR, DPIE) used herein is stated as IHO 1B and has a 5x5m horizontal resolution which may not be sufficient to precisely describe coastal barrier elevations and steeper slopes.
- Sensitivity of the overwash/ overtopping rates to input parameters was assessed and suggest that adopting a 14s peak wave period would increase rates by ~15% while varying the wave approach angle by 15 degrees reduced the rates by ~15 to 20%.

5 Coastal inundation maps

Maps showing the maximum extent and depths of the coastal inundation for the respective scenarios are provided in this section. The presented maximum inundation extents and depths are determined for the 2018 LiDAR (DPIE) topography and do not account for physical obstructions by buildings, vegetation or built infrastructure. Drainage and infiltration of seawater are also not included in the results. Therefore, the results are conservative and should be interpreted to identify areas at risk. No inundation risk was identified for the areas north of the map extent and were therefore excluded from the maps.

5.1 Present day (2020)

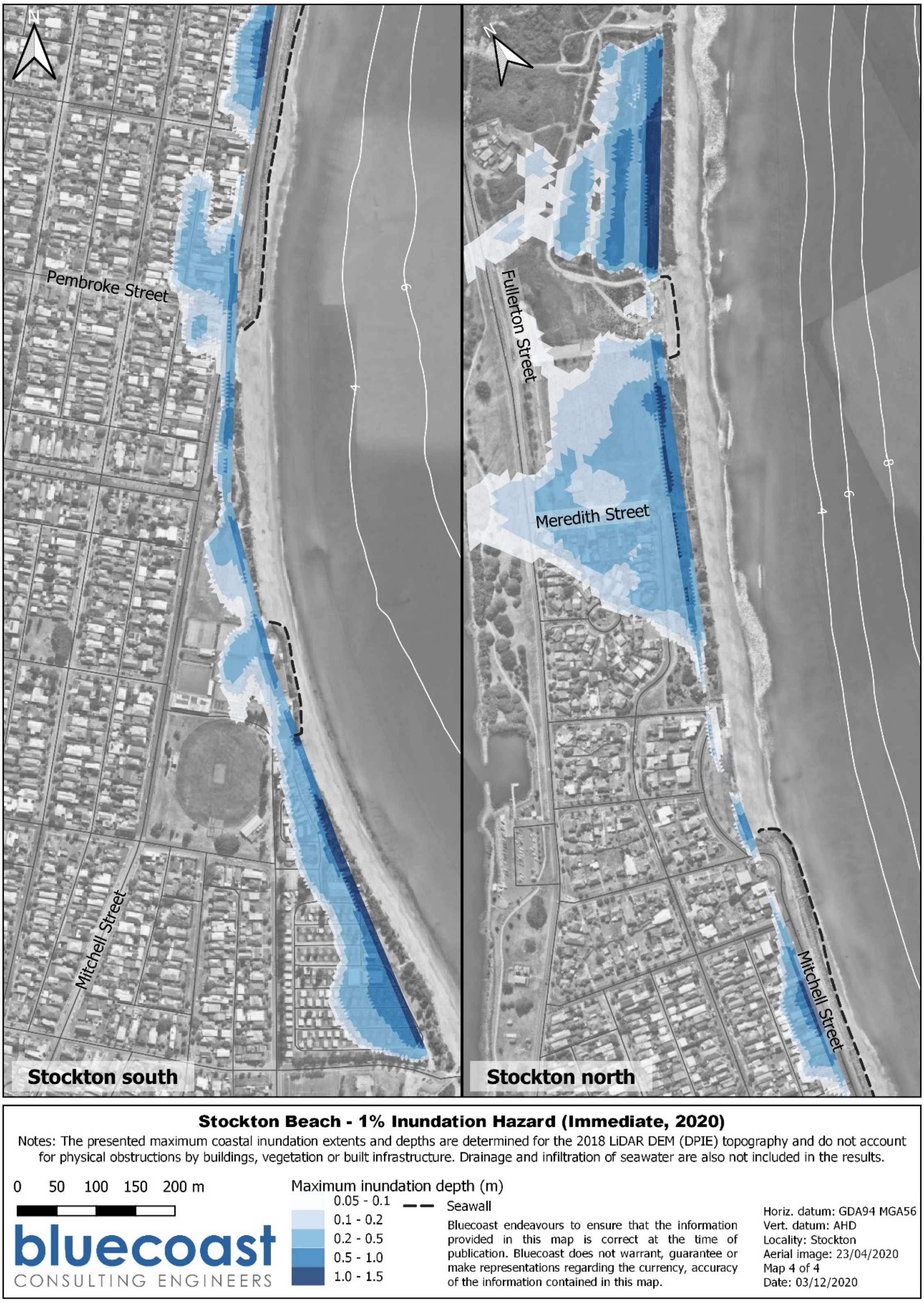

Figure 11: Coastal inundation hazard for 1%AEP in 2020 (immediate).

5.2 2040 planning period

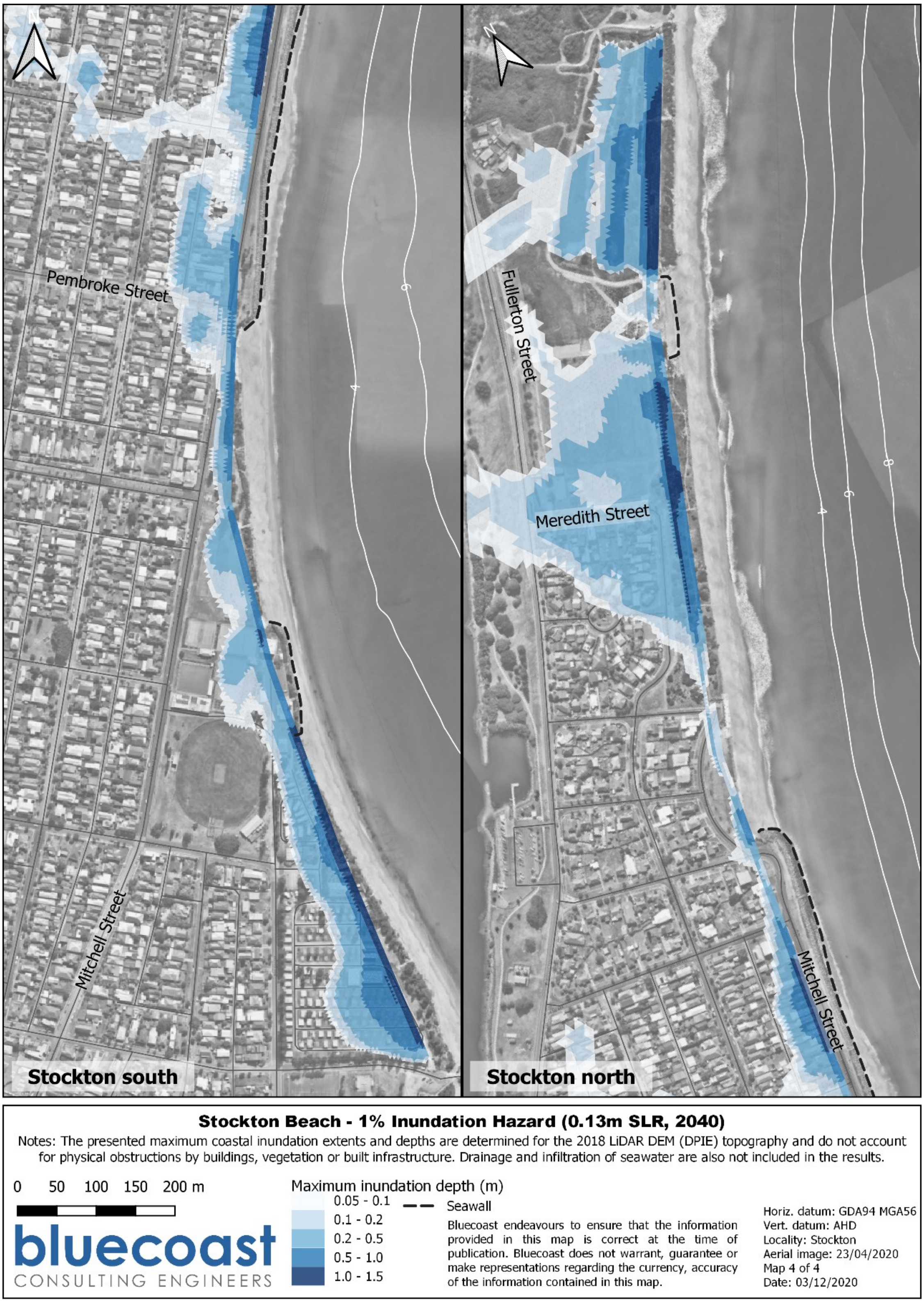

Figure 12: Coastal inundation hazard for 1%AEP in 2040 (0.13m SLR).

5.3 2060 planning period

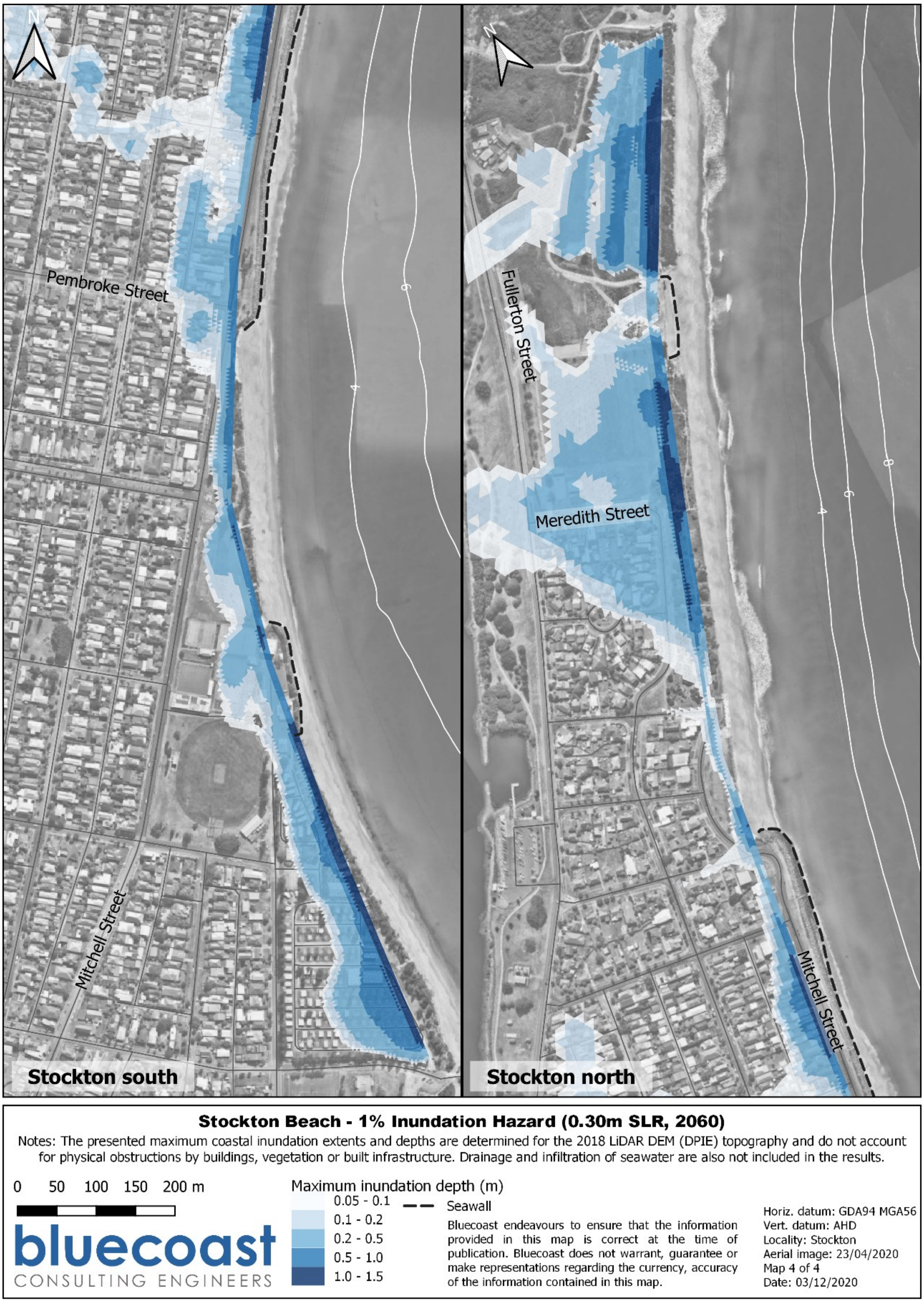

Figure 13: Coastal inundation hazard for 1%AEP in 2060 (0.30m SLR).

5.4 2120 planning period

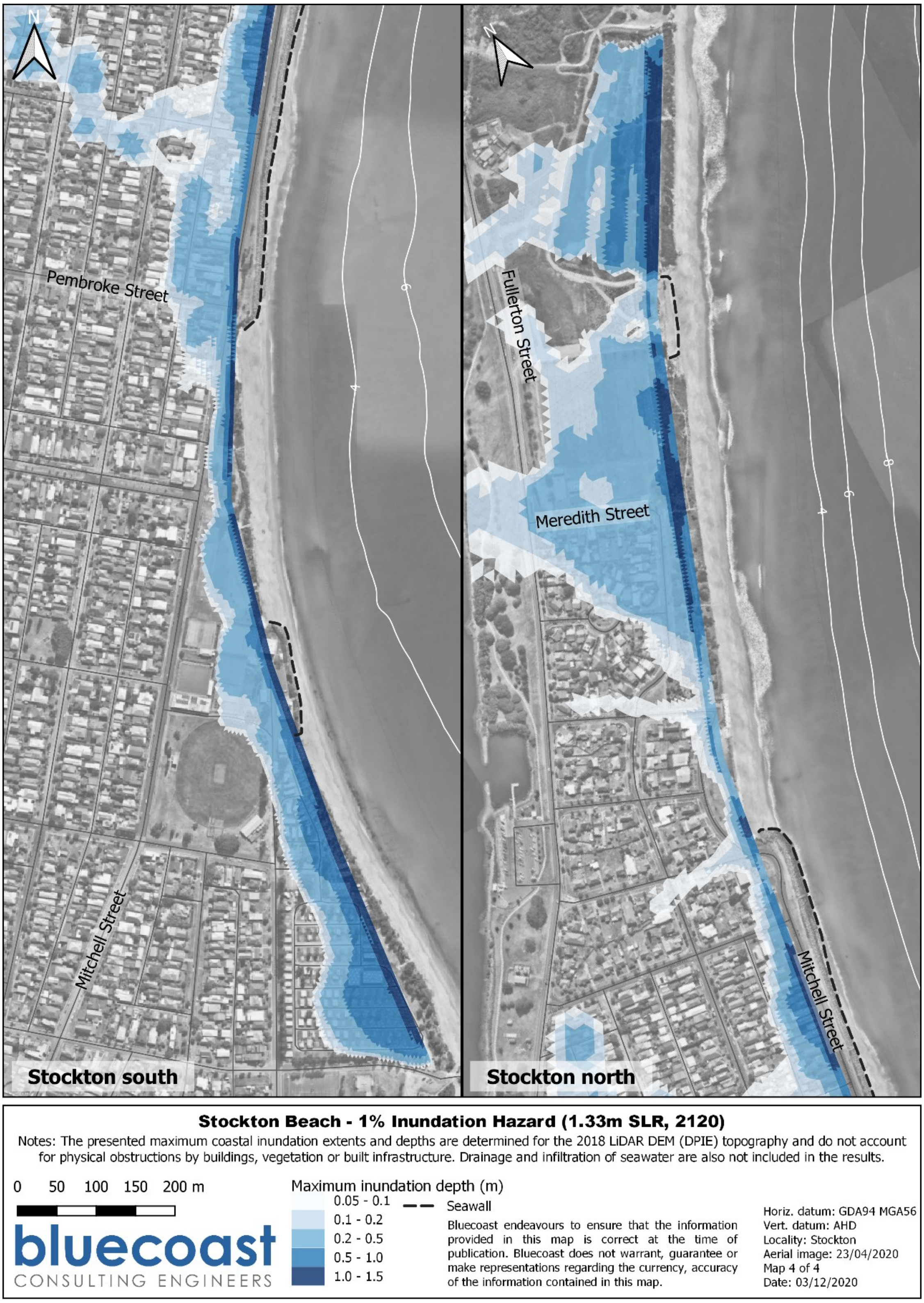

Figure 14: Coastal inundation hazard for 1%AEP in 2120 (1.33m SLR).

6 Summary and discussion

Following on from the preceding coastal erosion hazard assessment for Stockton (Bluecoast, 2002a), a coastal inundation assessment has been undertaken that considers both quasi-static elevated water levels (tide, surge and wave setup) and dynamic, wave driven water levels (wave runup) that leads to overwash and overtopping of coastal barriers. A hybrid numerical modelling approach was developed to avoid the use of the widely adopted 'bathtub' approach. Two state-of-the-art numerical models were used herein, i.e. XBeach (nearshore wave transformation and overwash/overtopping) and Delft3D FM (overland flow and inundation). The adopted approach was validated against photographic and anecdotal evidence of coastal inundation during the East Coast Low on 15th July 2020.

The selection of appropriate hazard conditions for the coastal inundation mapping was derived through comprehensive analysis of the joint probability values for a 100-year ARI (or 1% AEP) likelihood event and adoption of the latest sea level rise projections for the respective planning periods.

Mapping of the coastal inundation hazard identified the following areas:

- Southern Stockton beach (caravan park) was identified to be subject to coastal inundation during present day and future planning periods given the low-lying area extending landward to Pitt Street behind the low coastal sand barrier along this stretch of coast.
- Overtopping of the Surf Life Saving Club seawall was identified for all planning periods, however, the present-day inundation depth is relatively low and overwash predominantly occurs immediately north of the structure.
- The stretch between the SLSC and Mitchell Street seawall experiences relatively low overwash for all planning periods and inundation extents are limited to the foreshore reserve due to the upward sloping topography.
- The southern and northern section of the Mitchell Street seawall are subject to overtopping during all planning periods and the inundation extends to the second row of properties behind Mitchell Street. Inundation occurs along the full length of the structure and extends beyond Dunbar Street for the 2060 and 2120 planning periods.
- Considerable overwash and inundation is shown for the low coastal barrier around Meredith Street and towards the old Hunter Water site for all planning periods extending all the way to the Hunter River on the western side of Stockton peninsula. Inundation flow paths affect most properties between Beeston Road and Meredith Street.

Overall, the identified areas subject to significant coastal inundation for the present-day scenario are limited to the low-lying coastal barriers, while beyond the 2040 planning period most of the Stockton foreshore is affected. The high overwash volumes seen around Meredith Street raises concerns about potential breaching of the Stockton peninsula as seawater flows towards the Hunter River and cuts off Stockton Centre. The overtopping volumes at the seawalls presented herein exceed the safe volumes (EurOtop, 2018) for most locations and planning periods. This suggests that damage to the seawalls may occur during such events and that there is a safety hazard for people behind the structures.

Coastal inundation is not particularly common along the open coast beaches on the NSW coastline. Most open coast shorelines have a dune, constructed from wave run-up, overwash and wind. These are mostly stabilised by vegetation and are rarely overwashed. North of the Hunter Water site (e.g. Fort Wallace), this scenario is observed. The concern for areas south of Fort Wallace is that the erosion has removed the dune and if ongoing erosion occurs this will effectively lower the coastal barrier (due to the downward sloping landward elevation) and result in more frequent overwash. Rising sea levels will further exacerbate this risk.

Furthermore, evidence of crest lowering along the northern and southern sections of Mitchell Street seawall may increase coastal inundation in this area if scouring and lowering of the structure is ongoing. A simplistic view would be to consider a strategy of maintenance, repair and raising of the Mitchells Street seawall but this option and the associated expenditure must be considered holistically with consideration of the deepening and steepening of the southern embayment and the significant downdrift erosion this structure is causing as discussed in Bluecoast (2020a and 2020b).

While the results provided herein are suitable for planning purposes and highlight areas at risk from coastal inundation and approximate inundation extents, these should be interpreted with consideration of the limitations discussed in this technical note. Any detailed planning and design of coastal infrastructure at Stockton requires a more detailed inundation assessment. It is recommended that the performance in protecting against coastal inundation and hazardous wave overtopping is assessed for all measures adopted in subsequent CMPs.

7 Glossary

Annual Exceedance Probability (AEP) – the probability as a percentage at which a given event is likely to occur in one year.

Australia Height Datum (AHD) - the official national vertical datum for Australia.

Average Recurrence Interval (ARI) – the average or expected value of the periods between exceedances of a given intensity event over a given duration.

Beach slope – the gradient at which the beach slopes seaward

Built assets – built infrastructure.

Damage (to seawalls) – defined as any displacement or dislodgment of armour units.

Delft3D FM – a numerical modelling software that can simulate storm surges, tropical cyclones, tsunamis, detailed flows and water levels, waves, sediment transport and morphology, water quality and ecology, and is capable of handling the interactions between these processes.

Digital elevation model (DEM) – gridded elevation data to represent terrain.

Dune ridge – shore-parallel sand ridge that forms part of a dune system.

Elevated still water levels – ocean water level raised due to a storm surge.

Highest Astronomical Tide (HAT) – the highest level which can be predicted to occur under average meteorological conditions.

Infiltration – the process at which water is absorbed into the ground.

Inundation – flooding of land area.

IPCC – Intergovernmental Panel on Climate Change.

Joint probability – the probability of two events occurring at the same time.

LiDAR – Light Detection and Ranging, is a remote sensing method that uses light in the form of a pulsed laser to measure ranges.

Lowest Astronomical Tide (LAT) – the lowest levels which can be predicted to occur under average meteorological conditions.

Mean High Water Neaps (MHWN) – the height of mean high water neaps is the average throughout a year of the heights of two successive high waters during those periods of 24 hours (approximately once a fortnight) when the range of the tide is least.

Mean High Water Springs (MHWS) – the height of mean high water springs is the average throughout a year of the heights of two successive high waters during those periods of 24 hours (approximately once a fortnight) when the range of the tide is greatest.

Mean Low Water Neaps (MLWN) - the height of mean low water neaps is the average throughout a year of the heights of two successive low waters during those periods of 24 hours (approximately once a fortnight) when the range of the tide is least.

Mean Low Water Springs (MLWS) – the height of mean low water springs is the average throughout a year of the heights of two successive low waters during those periods of 24 hours (approximately once a fortnight) when the range of the tide is greatest.

Mean Sea Level (MSL) – the average level of the sea over longer periods of time.

Morphological response – change in beach shape/slope due to an event.

Multivariate copula analysis - used to describe the dependence between random variables.

Natural assets – the natural beach, dunes, and vegetation.

Numerical modelling – computer software modelling used to simulate coastal processes.

Overtopping – the process of water passing over a hard coastal structure such as seawall.

Overwash – the process of water passing over a dune.

RCP – Representative Concentration Pathway is a greenhouse gas concentration trajectory adopted by the IPCC.

Scour – loss of beach/sediment at the toe of a hard structure or dune.

Semi-diurnal tide – two high and two low tides a day.

Significant wave height – the average height of the largest 1/3rd of waves in a given period.

Storm surge – the abnormal rise in sea level during a storm, measured as the height of the water above the normal predicted astronomical tide.

SWASH – numerical model for simulating unsteady, non-hydrostatic, free-surface, rotational flow and transport phenomena in coastal waters as driven by waves, tides, buoyancy and wind forces.

Tidal plane – a plane of reference for elevations, determined from the rise and fall of the tides.

Toe – the 'bottom' or 'front' of a hard structure.

TWL – total water level.

Wave runup - the maximum vertical extent of wave uprush on a beach or structure above the still water level (SWL).

Wave setup - occurs as waves approach the coast and transform over the nearshore beach profile where radiation stresses and ultimately wave breaking force elevated water levels at the shoreline.

XBeach – numerical model for wave propagation, long waves and mean flow, sediment transport and morphological changes of the nearshore area, beaches, dunes and backbarrier during storms.

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