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DHA Fort Wallace Stockton Beach Coastal Engineering Assessment

November 2017

DHA Fort Wallace Stockton Beach Coastal Engineering Assessment

Prepared for:	Department of Housing Australia
Prepared by:	BMT WBM Pty Ltd (Member of the BMT group of companies)

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Synopsis: **This Coastal Hazard Assessment report outlines the potential for coastal erosion, wave overtopping, reduced foundation capacity of dunes, and sand drift to affect the Fort Wallace Planning Proposal by 2100. Measures to mitigate or manage the identified risks by 2100 are also provided.**

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Executive Summary

Defence Housing Australia (DHA) has recently purchased the former Fort Wallace site (Lots 100 &101 DP1152115) covering 31.75 ha on Stockton Beach within the Newcastle local government area (LGA), (see Figure 1). DHA seeks to rezone this site and develop it for a mix of housing for Australian Defence Force (Defence) personnel and the private market. DHA's planning proposal would seek a rezoning of the majority of the site toR2 Low Density Residential. The objectives of the zone are to provide housing within a low density environment and accommodate a diversity of housing forms. In accordance with the precedent set to the south and north of Fort Wallace, the beach portion of the lot would be zoned E3 Environmental Management.

This report provides an assessment of coastal hazards by 2100 that may impact upon the Fort Wallace site, proposed zoning and masterplan prepared by Architectus. Where impacts may occur, this report provides recommended mitigation measures to reduce the risks. Key outcomes of the coastal hazard and mitigation assessment are summarised below.

Risks from Erosion by 2100

Three scenarios for erosion by 2100 were investigated:

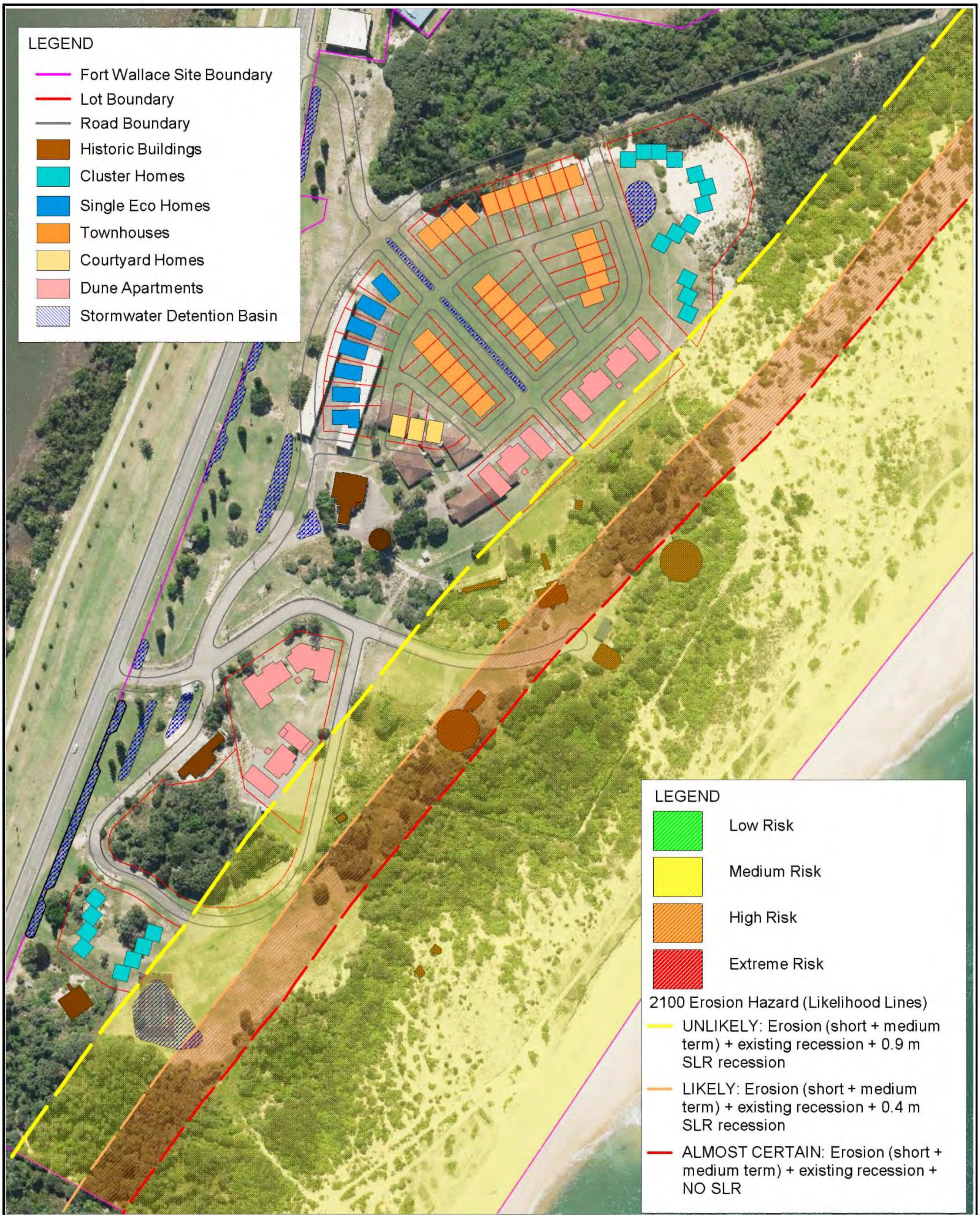
- an 'almost certain' erosion scenario including short and medium term erosion, ongoing recession (due to the Newcastle Harbour breakwaters), but excluding the impacts of sea level rise;
- a 'likely' erosion scenario including short and medium term erosion, ongoing recession, and future recession due to sea level rise of 0.4 m by 2100 (equivalent to the current rate of sea level rise); and
- an 'unlikely' erosion scenario including short and medium term erosion, ongoing recession, and future recession due to sea level rise of 0.9 m by 2100 (equivalent to highest emission scenario along which we are tracking). The 'unlikely' scenario is the typical conservative estimate used for planning purposes in NSW.

To better understand the risk associated with the erosion of land, the following consequence categories were applied to the proposed zones:

- Residential (all densities): major
- Roads, Open Space, Environmental Zones, existing heritage assets: minor

Based upon the combination of the above consequence levels with the erosion hazard scenarios, mapping of potential risk across the proposed zoning was possible, as shown in Figure 1.

As shown in Figure 1, all of land proposed for Low Density Residential is at low risk, located landward of the 2100 'unlikely' erosion hazard. The eastern-most portion of proposed roadway servicing this residential area is also seaward of the 'unlikely' hazard, and found to be at low to medium risk. The existing historical sites, and associated access road and areas of proposed open space are found to be at low to medium risk, being located seaward of the 'unlikely' erosion hazard, although generally landward of the 2100 'almost certain' erosion hazard.



Title:

2100 Erosion Risk Profile for the Fort Wallace Masterplan

Figure: 1

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It must be noted that the coastal erosion hazard estimates are subject to uncertainty, particularly regarding:

- the extent of ongoing recession;
- the response of the shoreline to sea level rise, and
- the potential for mitigation measures such as beach nourishment being implemented on Stockton Beach before 2100 (e.g. by State/Local government to manage the existing risks downdrift of Fort Wallace).

Given this uncertainty, it is possible that the extent of erosion by 2100 is overestimated, and so, the risk to the Fort Wallace proposed zoning is lower than identified through this report.

Reduced Foundation Capacity Hazard

Immediately following a storm erosion event, a near vertical erosion escarpment of substantial height can be left in the dunes or beach ridge. At some time after the erosion event, the escarpment may slump and the slope adjusts to a more stable angle. This slumping may occur suddenly and poses a risk to structures located immediately behind the dune escarpment within this zone of slope adjustment and reduced foundation capacity. The width of the reduced foundation capacity zone is directly dependent on the height of the dunes, with higher dunes resulting in a wider zone.

Caution is required in assessing and applying the dune instability hazard for 2100. The present day height of dunes/land in the region of the 2100 erosion hazard may not accurately represent the actual height of the dunes by that time. Activities including development for residential purposes, community uses, and even dune rehabilitation may lower or heighten the dunes over time. Furthermore, the erosion hazard estimates provide scenarios of potential erosion extents, but there remains uncertainty regarding the exact position of the erosion escarpment in the future, from which the dune instability hazard is calculated.

As the best proxy for the potential region of reduced foundation capacity that may affect the Fort Wallace development, the average, maximum and minimum dune heights along the erosion hazard scenario lines (i.e. ‘almost certain’, ‘likely’ and ‘unlikely’, see Figure 1) were used to calculate the potential region of reduced foundation capacity. Should the erosion escarpment reach a hazard scenario line and dune heights remain at their current level by 2100, the zone of slope adjustment and reduced foundation capacity:

- may average 25 m and range from 15 to 43 m width landward of the 2100 ‘almost certain’ erosion hazard scenario;
- may average 25 m and range from 15 to 41 m width landward of the 2100 ‘likely’ erosion hazard scenario; and
- may average 20 m and range from 11 to 35 m width landward of the ‘unlikely’ erosion hazard scenario.

If erosion were to reach the hazard scenario lines, structures present within these zone widths may be subject to reduced foundation capacity.

Wave Overtopping Hazard

Detailed analysis of wave run up and the subsequent potential for wave overtopping of dune barriers during an extreme storm by 2100 was undertaken. Assuming that existing dune heights along the 2100 erosion hazard scenario lines remain at the same height as at present, the potential for wave overtopping is extremely low, except for along a small section of low lying dune (4 m AHD minimum) on the 2100 ‘unlikely’ erosion hazard line. The risks from wave overtopping at this low lying area may include damage to buildings and footpaths, and engulfment of pedestrians and vehicles, but only in the case where they are located on or immediately adjacent to the dune crest. The site is predominantly composed of sand, therefore it is expected that any flow of water from wave overtopping at this small section of low lying dune will be quickly percolated into the sand, posing no threat to properties or people beyond 10 or 20 m from the dune crest.

Sand Drift Hazard

Dune vegetation on the Fort Wallace site is patchy and contains known weeds such as Bitou Bush. While dune vegetation is variable, sand drift causing ingress and accumulation on private property does not appear to be a significant issue at present.

Sand drift will be effectively managed by rehabilitation (i.e. weed removal and replanting) of the dunes on the site. Maintenance of rehabilitation works will need to be ongoing over time, including after beach erosion and recession events, to continue to provide mitigation of sand drift to adjacent properties. Indeed, proper dune maintenance is considered an important mitigation measure for storm erosion, as it will assist in retaining sand within the dunes to act as a buffer during erosion events.

Risk Mitigation Measures

Dune Rehabilitation to Manage Sand Drift, Short Term Erosion and Wave Overtopping

It is highly recommended that rehabilitation and ongoing maintenance of dunes on the Fort Wallace site be conducted. Properly functioning dune systems provide mitigation of a number of risks (to varying degrees) as follows.

Dune vegetation serves to capture windblown sand from the sub-aerial and aerial beach face. The capture of windblown sand effectively mitigates sand drift into adjacent properties and land.

Because dune vegetation captures and stores sand in the dunes, it is also a mitigation measure for short term storm erosion, by providing a sacrificial buffer of sand that is eroded during such storms. Dune maintenance programs need to accept the loss of dunes during storms from time to time, and support the rebuilding of dunes after such events.

Maintaining dune heights along the seaward boundary of the site of around 6 m AHD effectively nullifies the potential for wave overtopping during an extreme storm. Maintenance of dunes at this height will be largely self-sustaining via rehabilitation and maintenance of native dune vegetation, as dunes naturally tend to build to heights of around 5 m AHD. A dune barrier of 5 m AHD is expected to impede wave overtopping and overwash under most storm scenarios. No further mitigation of wave overtopping is required for the proposed rezoning of the Fort Wallace site.

Coastal Erosion

Residential zones have been kept landward of the ‘unlikely’ 2100 erosion hazard.

These negates the need for implementation of revetment structures to protect at risk properties in the future at Fort Wallace. This is particularly because Stockton Beach is known to be experiencing ongoing recession, and so, revetment structures will be exposed and denuded of sand, with no beach amenity in front or adjacent to the structures. This outcome is already evident at the seawall along Mitchell Street and Stockton Beach.

Potential erosion impacts by 2100 on other proposed land zones on the Fort Wallace site can be accepted, as follows.

- The eastern most section of access road to residential properties found to be at low risk (see Figure 1) can be considered sacrificial, because access to the residential land is also possible via an alternate route.
- Open space areas shown to be at risk from erosion may also be considered sacrificial, as they typically remain functional even where reduced in size, and tend not to contain infrastructure of high financial value.
- A number of heritage assets that already exist on the site are likely to be affected by coastal hazards prior to 2100 (see Figure 1). Please refer to the hazard assessment undertaken by Urbis 2016 for further information on the intended use of and management of heritage items.

Reduced Foundation Capacity

In view of the long timeframes and the high level of uncertainty regarding the occurrence and width of the zone of reduced foundation capacity by 2100, it is recommended that the proposed rezoning proceed at the current time. As all structures are proposed to be sited landward of the ‘unlikely’ erosion hazard, they would not be expected to be subject to reduced foundation capacity risks over this lifespan, and so, foundation piles would not be required.

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1 Introduction

1.1 Purpose of the Planning Proposal

Defence Housing Australia (DHA) has recently purchased two surplus Defence sites at Stockton with the objective of obtaining the necessary planning approvals and developing them for a mix of housing for Australian Defence Force (Defence) personnel and the private market. DHA has an ongoing requirement for additional housing in Newcastle, to cater for Newcastle based Defence members and their families and to replace existing DHA dwellings that do not meet current standards.

One of these sites is the former Fort Wallace site (Lots 100 &101 DP1152115) on Stockton Beach within the Newcastle local government area (LGA). The site covers an area of 31.75 ha, and is currently zoned for SP2 Infrastructure under the Newcastle Local Environment Plan 2012.

DHA are seeking to rezone this site to allow for:

- Low density residential development;
- Potentially a neighbourhood shop and community facilities;
- New streets and open spaces;
- Protection and management of areas of high-value vegetation or environmentally sensitive areas;
- Protection and possible adaptive reuse of the heritage items.

The Planning Proposal will amend the land use / zoning controls, height controls, lot size controls and the local heritage provisions for the site.

This report provides an assessment of coastal hazards by 2100 that may impact upon the Fort Wallace site and proposed rezoning in particular. Where impacts may occur, this report provides recommended mitigation measures to reduce the risks from coastal hazards to the Fort Wallace rezoning proposal. The following coastal hazards are assessed in this report:

- **Erosion**, over the short and medium term, due to long term recession processes, and due to sea level rise in future;
- **Dune Stability and Reduced Foundation Capacity** for buildings in relation to erosion escarpments in dunes;
- **Wave Overtopping**, due to high tides, ocean water levels during storms, and in the future due to sea level rise; and
- **Sand Drift**, whereby natural windborne sand transport from active dunes engulfs nearby properties.

1.2 The Fort Wallace Site

The Fort Wallace site lies on Stockton Beach in NSW around 3.2 km north of Newcastle Harbour entrance, as shown in Figure 1-1. The site lies north of the existing residential development at

Stockton, and between Hunter Water Corporation's (HWC) former Sewage Treatment Works (STW), and the Stockton Centre. The entire site extends to the shoreline of Stockton Beach, however the proposed development footprint, will not extend onto the foredunes or beach. The masterplan layout also retains the existing buildings and features of the former Fort Wallace, which are listed as heritage items (on the Commonwealth register).

Title:

Locality Plan for Fort Wallace

Figure: 1-1

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2 Coastal Setting

2.1 Stockton Beach

Stockton Beach is located at the southern end of the larger embayed section of sandy coast known as Stockton Bight. The northern breakwater of the Hunter River entrance forms the southern end of the beach unit. The southern end of Stockton Beach faces east-north-east. Towards the north, the shoreline curves in a long arc, facing progressively more southwards to culminate at Birubi Point, Anna Bay some 32 km to the north.

The southern 5km or so of Stockton Beach experiences lower waves averaging around 1 m (Short, 2007), as it lies in the wave shadow created by the Newcastle Harbour entrance breakwaters. The surf zone at this end generally displays a single attached sand bar cut by rips, with the sand bar becoming detached towards the north.

Particularly north of the Fort Wallace site, the beach becomes increasingly exposed to wave energy, as it extends beyond the wave shadow created by the Harbour breakwaters and arcs to face into the dominant southerly swell direction. The surf zone is described as high energy, with a well-developed double sand bar system, with both bars cut frequently by rips and separated by a deep wide trough (Short, 2007). In very big seas, the northern end of the beach (Birubi Point) will develop a third outer sand bar (Short, 2007).

In the nearshore zone off Stockton Bight, outcropping of rock reef is not evident in the surfzone, and the beach extends as a long, sandy embayment. The continental shelf is slightly wider through this region particularly out to the 40 m contour, which may have assisted in the onshore supply of sediment to the shoreline. Birubi Point forms a bedrock anchor that has repeatedly trapped northward littoral sediment transport to form Stockton Bight over previous interglacial periods.

2.1.1 Stockton Sand Dunes

The Stockton Sand Dunes are the largest and most active transverse dune system in NSW. The sand dunes extend some 25 km roughly from Fern Bay to Birubi Point in the north, and up to 3 km inland. Sands in some parts of the dune field are believed to pre-date the last two glacial periods (i.e. > 500,000 years old). A key aspect of these active dunes is that they are un-vegetated. This allows for sand to be blown into and northwards along the dunes, thus forming an important part of the coastal sediment transport system. That is, an important portion of the sediment transport occurring along Stockton Beach is actually above the water, on land via these active sand dunes.

2.1.2 The Fort Wallace Site

The Fort Wallace site includes beach frontage on Stockton Beach (Figure 2-1). The site's coastal frontage in cross section includes a region of high, semi-vegetated and hummocky dunes, a low foredune crest, then a fairly wide beach and berm before entering the surf zone. The surf zone fronting the site typically displays a deep trough then single detached bar cut by rips. In the right conditions, the beach can provide decent surfing conditions.

Presently, the back beach and foredunes display a minor erosion escarpment that has slumped somewhat, especially where the dune is unvegetated (Figure 2-2). The erosion escarpment extends along the southern half or more of the site, before disappearing and being replaced by a stable to accreted dune and beach (Figure 2-3). It is possible the erosion escarpment was created during the June 2016 storms. That event arrived from a more north easterly direction, and so more heavily impacted the southern end of Stockton Beach. For this reason, the Fort Wallace site and adjacent beach to the north was barely (if at all) impacted by the June 2016 storms. In general, the site does not presently appear to be greatly affected by ongoing recession due to the harbour breakwaters, unlike the southern part of Stockton Beach (see Section 2.1.4).

The dunes at Fort Wallace range in height from around 5.5 m at the foredune crest, to 10-15 m (and higher) in the hind dunes. Dune vegetation is patchy with weeds such as Bitou Bush clearly evident (Figure 2-1). Bitou Bush will have assisted the creation of hummocks separated by sections of bare sand throughout the dunes.

It is considered likely that during its functioning as Fort Wallace, the site was cleared to allow for placement and clear site from the pillbox and other structures on the site. In this regard, it is difficult to discern if the lack of a well-developed foredune and hind dune system is due to site disturbance, ongoing recession due to the harbour breakwaters (see Section 2.1.4), or a combination of both.

Figure 2-1 View from Fort Wallace Site to North and South, with patchy and hummocked dune vegetation

Figure 2-2 Beach at Fort Wallace (to north and south) showing evidence of erosion and slumping

Figure 2-3 Beach along Northern Half of Fort Wallace, erosion not evident

2.1.3 History of Newcastle Harbour Construction

The history of construction of the breakwaters and dredging activities that have formed the Port of Newcastle entrance are as follows (Umwelt, 2002; DHI, 2006):

- Between 1812 and 1846, the Macquarie Pier was constructed between Newcastle mainland and Nobbys Island (now Nobbys Head);
- Dredging of the Newcastle Harbour entrance commenced in 1859, as the entrance was still hazardous for ships;
- In 1875 the extension of the southern breakwater from Nobbys commenced, and following several storms, was completed in 1891;
- Between 1898 and 1912, the northern breakwater was constructed, measuring nearly 1140 m;
- In 1961, depths across the harbour entrance were around -8 m. To enable safer passage, the harbour entrance was deepened to -11 m between 1962 and 1967;
- A further channel deepening project commenced between 1967 to 1976, to increase depths through the channel to -12.8 m;
- Channel deepening continued between 1977 and 1983 to further deepen the entrance in line with Port expansion activities that continue to the present; and
- At the present time, the navigation channel is maintained at a depth of -18 m, with dredged material typically placed at an offshore disposal site.

2.1.4 History of Recession and Remediation on Stockton Beach

Stockton Beach is known to have experienced ongoing recession, overlain on the natural periods of erosion and accretion. A number of studies have been undertaken over time, confirming that Stockton Beach is experiencing ongoing recession as a result of the cessation of littoral drift past the Newcastle Harbour Breakwaters into the beach. Previous detailed investigations include:

- *Newcastle Coastline Hazards Definition Study* (WBM, 2000)
- *Shifting Sands at Stockton Beach* (Umwelt, 2002);
- *Stockton Beach Coastal Processes Study* (DHI 2006); and
- *Stockton Beach Coastal Processes Study Addendum – Revised Coastal Erosion Hazard Lines 2011* (DHI, 2011).

Northerly littoral drift of up to 30,000 m^3/year has been impeded from passing the Hunter River entrance and supplying Stockton Beach by the construction of the southern then northern breakwaters. Littoral drift past the entrance breakwaters has not been able to re-establish because the Harbour channel is regularly dredged to a depth of 18 m, to allow for the passage of coal and other container ships. Fluvial sand supply from the Hunter River that may also have assisted to supply Stockton Beach has also ceased due to entrance dredging. The result has been ongoing recession of Stockton Beach, occurring as erosion and steepening of the surfzone, reduced beach width and progressive erosion into the back beach dunes and more recently, development.

Recession has previously threatened development in the central section of the beach along Mitchell Street as well as facilities such as the Stockton Beach Surf Life Saving Club (SLSC) house and pavilion, at the southern end of the beach (see Figure 2-4). Four treatment ponds were constructed in the late 1960's on HWC’s Wastewater Treatment Works (adjacent to the Fort Wallace Site). One pond has been lost to erosion and the next most seaward pond is now under threat.

In 1989 in response to the erosion threat, a substantial rock seawall was constructed between Pembroke Street and Stone Street to protect the adjacent section of Mitchell Street and residential properties (see Figure 2-5). A sandbag wall with a design life of 5 years was also constructed in November 1996 to provide interim protection for the Stockton SLSC. The sandbag wall was implemented as a short term solution, however, it is still present and functional some 20 years later today. In June 2011, the sandbag wall was extended at the base of the SLSC towards the north. The sandbag structure was recently exposed during storms in June 2016.

A dune system was formed between the northern breakwater and Pembroke Street, and north of the rock seawall to Meredith Street during the period 1988 to 1991. Severe erosion in the mid-1990s effectively removed these dune reconstruction works. In the late 1990s, a new dune system was constructed south from the SLSC and seaward of the Stockton Caravan Park. Between the SLSC and Mitchell St seawall, a dune system is absent and the general ground level is as low as 4.0m AHD in places (see Figure 2-4). This area was further eroded during the June 2016 storms.

Approximately 130,000 m^3 of sand was dredged from the Harbour entrance in August 2009 and placed off Stockton Beach. The placement event was generally agreed to be a success and represents the first documented nourishment event for Stockton Beach. Over recent years, some small volumes of suitable dredged material (~5,000 m^3 per episode) have been placed at Stockton Beach by the Port’s maintenance dredger. While this is a valuable exercise, it has not fully replicated the lost regional sand supply of up to 30,000 m^3/year into Stockton Beach. As such, recession is expected to be ongoing.

Stockton Beach – July 1999, looking south to SLSC, with clear evidence of recession

Stockton Beach – June 2011, looking south to SLSC, in relatively accreted state

Stockton Beach – July 2016, looking south to SLSC, with recession again evident following storms in June 2016.

Figure 2-4 Stockton Beach Key Area of Recession over time

Mitchell St Seawall – July 1999, with no sand in front of structure and severely affected beach access and amenity.

Mitchell St Seawall – June 2011, with sand naturally accreted onto structure, allowing beach access.

Mitchell St Seawall – July 2016, after recent storms is again eroded of sand, making beach access dangerous.

Figure 2-5 Stockton Beach Mitchell St Seawall and Recession over time

2.2 Coastal Processes

The occurrence of coastal risks such as erosion and inundation occur due to the interaction of different coastal processes with the sediments and structure of a coastline, as described by its geology and geomorphology, outlined for Stockton Beach in Section 2.1.

Coastal drivers operating on coastlines such as Stockton Beach include:

- Waves
- Oceanic water levels
- Sea level rise

These drivers interact to generate:

- Cross-shore sediment transport,
- Longshore sediment transport, and
- Aeolian sediment transport within active dunes.

Depending on these interactions, coastal hazards such as erosion (short term, medium term, recession), wave overtopping and inundation, and sand drift may occur. A brief description of the coastal processes relevant to the hazard assessment of Stockton Beach is provided in Table 2-1.

Table 2-1 Summary of Coastal Processes Relevant to Stockton Beach

Coastal Process	Description	Measured parameter
Waves	**Significant Wave Height** Significant wave height (H_s) varies in response to the different wave generation sources that occur throughout the year, as well as larger scale climate cycles such as the El Nino Southern Oscillation. East coast low cyclones are known to generate the largest waves on the NSW coast.	Average H_s: 1.6 m 100 year Average Recurrence Interval (ARI) 6 hour duration H_s = 8.7 m (based on measured wave data from Sydney)
	Wave Direction Waves on the NSW coast are dominantly south east in origin. Wave direction occur in response to the different wave generation sources and their occurrence during the year, e.g. tropical cyclones occur to the north in summer; east coast low cyclones from May to July that can produce more northerly storms; and mid-latitude cyclones throughout the year that generate the predominant south easterly swell	Average Wave Direction: SE to S, with slight shift towards ESE in summer.
Water levels	**Astronomical Tide** NSW tides are micro-tidal (i.e. <2.0 m range) and semi diurnal (high and low occurs twice a day) with significant diurnal inequalities (the two high and two low tide levels are different in any one day).	Port of Newcastle Highest Astronomical Tide: 1.1 m AHD Lowest Astronomical Tide: -0.9 m AHD
	Elevated water levels Elevated ocean water levels during storms occur due to a combination of: • Astronomical tide • Barometric pressure set up • Wind set up	100 year ARI ocean water level: 1.44 m AHD (DECCW, 2010)
	Wave Set Up Wave set up adds to the elevated water levels at the beach. Wave set up is generated by the breaking of waves, and increases to a maximum at the beach face. A typical measure of wave set up for hazard estimation is 15% of the offshore wave height. A 6 hour duration H_s is typically used, as this is likely to coincide with a high tide.	Wave set up: 1.3 m, (calculated as 15% of the100 year ARI 6 hr duration H_s of 8.7 m)

Coastal Process	Description	Measured parameter
Sediment Transport	**Longshore Sediment Transport** Longshore sediment transport occurs when waves arrive obliquely to the shoreline, generating a current along shore. Depending on the wave direction, transport may be directed upcoast or downcoast. On the NSW coast, the net longshore sediment transport is northerly, due to the predominance of south-easterly waves. The volume of transport also tends to increase towards the north of NSW, as headlands are fewer (and so, there is less interruption of the sediment transport) and sand reserves greater.	Regional longshore sediment transport rate: up to 30,000 m^3/year (based on investigations by various authors including: WBM, 2000; Umwelt, 2002; DHI, 2006)
	Cross-shore sediment transport High waves during storms tend to generate offshore transport of sand eroded from the beach and nearshore. Rip currents are directed offshore, and contribute to beach erosion during storms. During calm conditions, lower waves tend to generate transport of sand back onshore, to help rebuild the beach.	N/A
	Aeolian (Windborne) Sediment transport Aeolian or windborne sediment transport originates from the dry sub-aerial upper beach face and berm and unvegetated incipient dunes and foredunes, supplying sediment to landward foredunes. Aeolian transport is the key builder of foredunes particularly where vegetation enables the windblown sediment to be captured and stabilised.	N/A
Sea Level Rise	**Sea level rise** Sea level rise is occurring at present, and the rate of rise is projected to increase in response to human-induced climate change.	Detailed discussion of sea level rise scenarios investigated for this report is given in Section 2.2.

2.3 Sea Level Rise

2.3.1 Sea Level Rise Measurements to Date

Global mean sea level rose about 1.6 mm/year on average during the 20th Century (CSIRO, 2016a). Since 1992, high quality measurements of sea level rise have been made by satellite altimeters. From 1992 to present, Global Mean Sea Level (GMSL) has risen at a rate of around 3.2 ± 0.4 mm/year (CSIRO, 2016b). The rate of sea level rise over the past 20 years is therefore about double that of the previous century. If the rate of sea level rise were to remain at its present level of 3.2 mm/year, sea level can be expected to be nearly 0.3 m higher than at present by 2100.

Projections for sea level rise of about 0.9 m by 2100 (above 1990 sea level), as given by CSIRO (2015) and IPCC (2014), are based on the rate of sea level rise more than doubling from its present rate of 3.2 mm/year. This is not unreasonable given that the rate of sea level rise has already doubled over the last 20 years. The current rate of rise is also tracking along the rate expected under the highest carbon emission scenario modelled by CSIRO (2015) and IPCC (2014).

2.3.2 Sea Level Rise Projections used in this Assessment

The CSIRO released new regional projections for Australia in 2015, which are the most relevant to this coastal hazard assessment. The CSIRO (2015) suggest a ‘likely’ range for sea level rise of 0.45 to 0.88m by 2090 for the highest emission scenario (along which sea level rise is currently tracking, see Section 2.3.1).

The 2015 CSIRO projections are almost identical to the former *NSW Sea Level Rise Policy Statement 2009* benchmarks of 0.4 m and 0.9 m rise above 1990 mean sea level by 2050 and 2100 respectively. These benchmarks were used by Newcastle City Council in deriving hazard estimates for Stockton Beach (as per the DHI (2011) study). The former benchmarks were based upon the latest reports by the IPCC (2007) and CSIRO (2007) available at that time. The recent IPCC report in 2014 also provides very similar projections to the 2007 IPCC report.

For this study three sea level rise scenarios were considered as shown in Table 2-2, representing:

- no further sea level rise occurs in the future;
- sea level rise remains at its current rate of ~ 3.2 mm/yr to the end of the century; and
- the rate of sea level rise increases as projected for the highest emission scenario by CSIRO (2015), and along which sea level rise has been tracking to date (i.e. the rate of rise doubles over the remainder of this century).

Because the projections from 2007 and 2014/2015 are so similar, the sea level rise scenarios applied are consistent with the projections used by DHI (2011) and Council.

It should be noted that small differences of 1 to 5 cm between exact projections are likely to make no appreciable difference in the position of a hazard line, or level of inundation, particularly at the scale of interest to this study.

Table 2-2 Sea Level Rise Projections used for this assessment

Scenario	SLR Value Adopted	Rational and Reference
No SLR	**0.0 m**	A “no sea level rise” scenario provides a benchmark of coastal risk that is expected to occur regardless of the rate and impact of sea level rise.
SLR at current rate (~3.2 mm/year)	**0.4 m** (above 1990 levels)	This scenario represents current rate of sea level rise of 3.2 mm/year ± 0.4 mm (CSIRO 2016b) prevailing to the end of the century. However, this scenario also represents the lower value estimate given by CSIRO (2015) for the highest emission scenario, of 0.45m by 2090.
SLR at projected rate	**0.9 m** (above 1990 levels)	This scenario represents the upper value given by CSIRO (2015) for the highest emission scenario, of 0.88 m by 2090. As a demonstration of the similarities between previous and current scientific projections, this SLR value is also consistent with the benchmarks previously prescribed by the NSW Government for studies of this kind, including DHI (2011).

3 Coastal Hazard Assessment

3.1 General Provisions

Application of 2100 Timeframe for this Coastal Hazards Assessment

Given the proposed development at Fort Wallace represents a new subdivision, it is typical for local councils (including Newcastle City Council) to apply a 100 year design life to such developments. Therefore, the risk to the subdivision from coastal hazards by 2100 has been investigated. The application of the 2100 hazard extent is particularly important given that Stockton is experiencing ongoing recession (not related to sea level rise).

Use of Existing Hazard Calculations

The coastal hazard definition given in this assessment has relied on existing information in the DHI (2006, 2011) reports because this is the information currently approved and being used by Newcastle City Council for coastal planning purposes.

3.2 Beach Erosion Hazard

3.2.1 Definitions

The following modes of erosion have been included in the definition of the 2100 erosion hazard for the Fort Wallace site on Stockton Beach:

- **Short term erosion**, during a severe storm or storms in close succession (hours to days). Storms involve increased wave heights and ocean water levels (tide, barometric pressure set up, wind set up, wave set up) resulting in waves attacking the beach berm and dunes. The storm waves and water levels generate cross shore (offshore) and longshore sand transport simultaneously, resulting in erosion of the beach, berm and foredune. For example, storms on June 6, 2016 generated significant erosion of the beach and back beach area particularly at the southern end of Stockton Beach (see Figure 2-4).
- **Medium term erosion**, relating to 5-10 year cycles in the wave and water level climates, which are related to large scale climate cycles such as the El Nino Southern Oscillation. For example, there has recently been a shift from El Nino conditions (typically associated with lower storminess and a more dominant southerly wave direction) to La Nina conditions (typically associated with greater storminess and a slight shift in average wave direction towards the east/north). The direction of longshore sediment transport is directly related to the incoming wave direction, and so, slight shifts in wave direction over 5-10 year cycles can have a significant effect on longshore sediment transport direction and volume, and therefore, sand reserves within a beach system.
- **Long term recession**, being the long term, permanent loss of sediment from a beach system, resulting in an ongoing loss of beach and dune width. Stockton Beach has been experiencing recession over the last 100 years or so in relation to the construction of the Newcastle Harbour Breakwaters (commencing in the early 1800s to present, refer Section 3.2.2.2). Beaches such as Stockton that are experiencing long term recession are characterised by a prominent back

beach escarpment which moves landward over time after storm events, rather than recovering fully to the pre-storm position.

- **Future recession due to sea level rise**, where the beach and dune shift upward and landward in response to the rise in sea level. This is commonly represented by the Bruun Rule (Bruun, 1962), as in Figure 3-1 below. The coastline structure in terms of headlands, reefs and artificial structures such as breakwaters and seawalls will also control how recession due to sea level rise occurs, due to the structures' control on longshore sediment transport. While newer modelling techniques are available to assess recession due to sea level rise (e.g. Patterson, 2013, Cowell et al 1992, 1995), it remains accepted industry practise to apply the Bruun Rule (1962) to determine the extent of recession due to sea level rise.

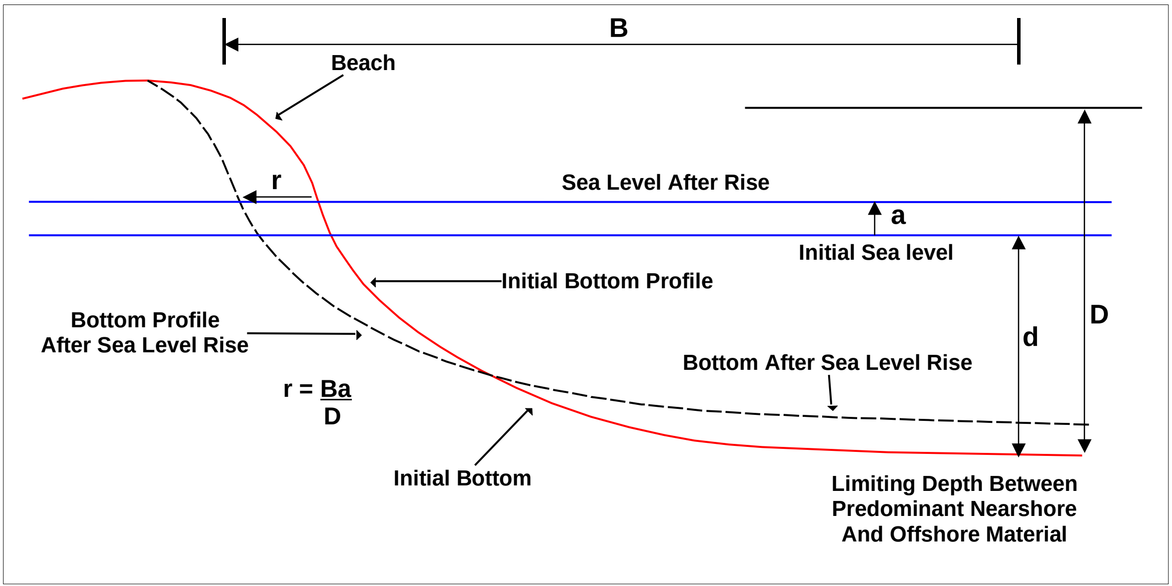


Figure 3-1 Bruun (1962) Concept of Recession due to Sea Level Rise

3.2.2 Calculations

3.2.2.1 Short and Medium Term Erosion

Potential short term erosion for Stockton Beach was analysed by DHI (2006) using a dune erosion model and application of storm conditions from May & June 1974, as well as June 1999 that arrived from the east to east-south-east and so more directly impacted the southern end of Stockton Beach. While the design storm approach can be problematic, 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 Stockton Tourist Park to 17 m at Meredith Street, 22 m at Fort Wallace and 24.5 m at the LGA Boundary, as in Table 3-1. The increase in the extent of storm erosion towards the north reflects the increased exposure of the beach to the pre-dominant south easterly waves experienced on the NSW coast.

Using the photogrammetric data, DHI (2006) also estimated erosion relating to medium term wave climate variability, such as enhanced storminess or more easterly wave direction over a sustained period. DHI (2006) provided a best estimate for medium term erosion of 18 m north of the Mitchell St seawall, which is applicable to the study site, as given in Table 3-1.

Table 3-1 Short and Medium Term Erosion Estimates (adapted from DHI, 2006)

Location	Short term erosion[1]	Medium term erosion
Fort Wallace	22	18
Stockton Centre	24	18
LGA Boundary	25	18

** Erosion has been rounded to the nearest metre, to reflect the uncertainty in erosion estimates (refer Section 3.2.4 also).*

3.2.2.2 Long term Recession

It is well documented that Stockton Beach is experiencing ongoing recession due to the Newcastle Harbour entrance breakwaters (e.g. WBM, 2000, Umwelt 2002, DHI 2006). The breakwaters have cut off the supply of sediment from the southern beaches across the river mouth and into Stockton Beach. The erosion of beaches updrift of river entrance training walls is a well known phenomenon on the NSW coast (e.g. has occurred at Coffs Harbour, Richmond River, Tweed River and others).

Unlike most other places on the NSW coast, the Hunter River entrance and Stockton beach system has not been able to adjust to the construction of the Harbour Breakwaters. Bypassing of the southern breakwater is very likely to be occurring, however, the marine sand is removed by dredging to retain the entrance depth at 18 m to facilitate the passage of coal ships into the Port of Newcastle. Any sediment that in not dredged remains in water depths at or greater than 18 m, which is too deep for significant wave driven currents to form to transport the sediment back onto Stockton Beach (DHI, 2006). Therefore, the loss of up to 30,000 m^3/year of sand into Stockton Beach is, and will continue to be, ongoing.

The pattern of recession varies along Stockton Beach. The northern breakwater acts to shadow the southern end of Stockton Beach from south easterly swells, and a complex pattern of sediment transport is generated towards the south and then captured against the northern breakwater (DHI, 2006). Both the WBM (2000) and Umwelt (2002) studies also identified a slight accretionary trend at the southern end of Stockton Beach. North of this, the recession starts at low rates increasing to its peak of 1.3 m/year loss at the former Sewage Treatment Ponds, before reducing again to around 0.8 m/year loss at Fort Wallace and extending to the LGA Boundary (DHI, 2006).

DHI (2006, 2011) used model results to determine best estimates of shoreline retreat along Stockton Beach, which are reproduced for the study site in Table 3-2. These rates were found to be in good agreement with historical recession rates of 1 to 1.3 m/year along the beach (DHI, 2006).

Periodically, dredged marine sand from the Harbour entrance is placed on Stockton Beach (around 5,000 m^3 per episode, once or twice a year). However, this is insufficient to fully replace the yearly loss to the beach. As such, the recession rates provided by DHI (2006, 2011) have been applied for this assessment.

Table 3-2 Ongoing Recession Rate at Stockton Beach from DHI (2011)

Location	Recession (m/year)
Fort Wallace / Stockton Centre	-0.8
Council Boundary	-0.8

3.2.2.3 Future Recession due to Sea Level Rise

DHI (2011) calculated recession due to sea level rise using the standard Bruun Rule (1962). Long sandy shorelines such as the central portion of Stockton Beach, can reasonably be expected to respond in the uniform, two-dimensional manner described by Bruun (1962), because headlands and reefs are not present and so, sea level rise cannot reduce longshore sediment transport past these structures. However, the southern portion of Stockton Beach is also expected to behave in accordance with the Bruun Rule (1962). The longshore supply into the southern end of Stockton Beach has already been interrupted by the harbour breakwaters (and without recovery due to the ongoing dredging). Sea level rise cannot further reduce longshore transport past the harbour breakwaters. In this case, assessment of recession due to sea level rise with the Bruun Rule (1962) is suitable at Stockton Beach.

DHI (2011) estimated 28 m recession due to a sea level rise of 0.4 m (above 1990 levels) and 68 m for a sea level rise of 0.9 m, as given in Table 3-3 below.

Table 3-3 Future Recession Due to Sea Level Rise (from DHI, 2011)

Sea level rise (above 1990 level)	Recession
0.4 m	28 m
0.9 m	68 m

3.2.3 Erosion Risk Profile for Fort Wallace

3.2.3.1 Coastal Erosion Risk Assessment

According to the Australian Standard Risk Management Principles and Guidelines (AS/NZS ISO 31000:2009) risk is defined as the combination of likelihood and consequence.

For this assessment of coastal erosion risk, the *likelihood* relates to the probable extent of coastal erosion by 2100, as described in Section 3.2.3.2. The *consequence* relates to the potential impact of erosion upon the permissible land uses within the proposed zones of the Fort Wallace planning proposal. The consequence considers the permanency of impact, the type of impact (social, economic, ecological), and the potential resilience of that land use type to erosion, as described in Section 3.2.3.3.

The level of risk is then the combination of likelihood and consequence via a risk matrix. The consequence and likelihood are combined (using GIS processing) to map the potential *level of risk* to proposed land zones on Fort Wallace from coastal erosion by 2100, as discussed and illustrated in Section 3.2.3.4.

3.2.3.2 Likelihood of Coastal Erosion

In order to support the development of risk profiles across the Fort Wallace / Rifle Range site, three scenarios for the erosion hazard by 2100 were investigated, as follows:

- 'Almost certain' erosion by 2100, comprising the addition of short term erosion, medium term erosion, ongoing recession, but no recession due to sea level rise (i.e. a 0.0 m sea level rise was adopted, see Section 2.3.2);
- 'Likely' erosion by 2100, being the addition of short term erosion, medium term erosion, ongoing recession, and recession due to sea level rise of 0.4 m (equivalent to the current rate of sea level rise, see Section 2.3.2) ; and
- 'Unlikely' erosion by 2100 being the addition of short and medium term erosion, ongoing recession, and future recession due to sea level rise of 0.9 m by 2100 (equivalent to highest emission scenario along which we are tracking, see Section 2.3.2).

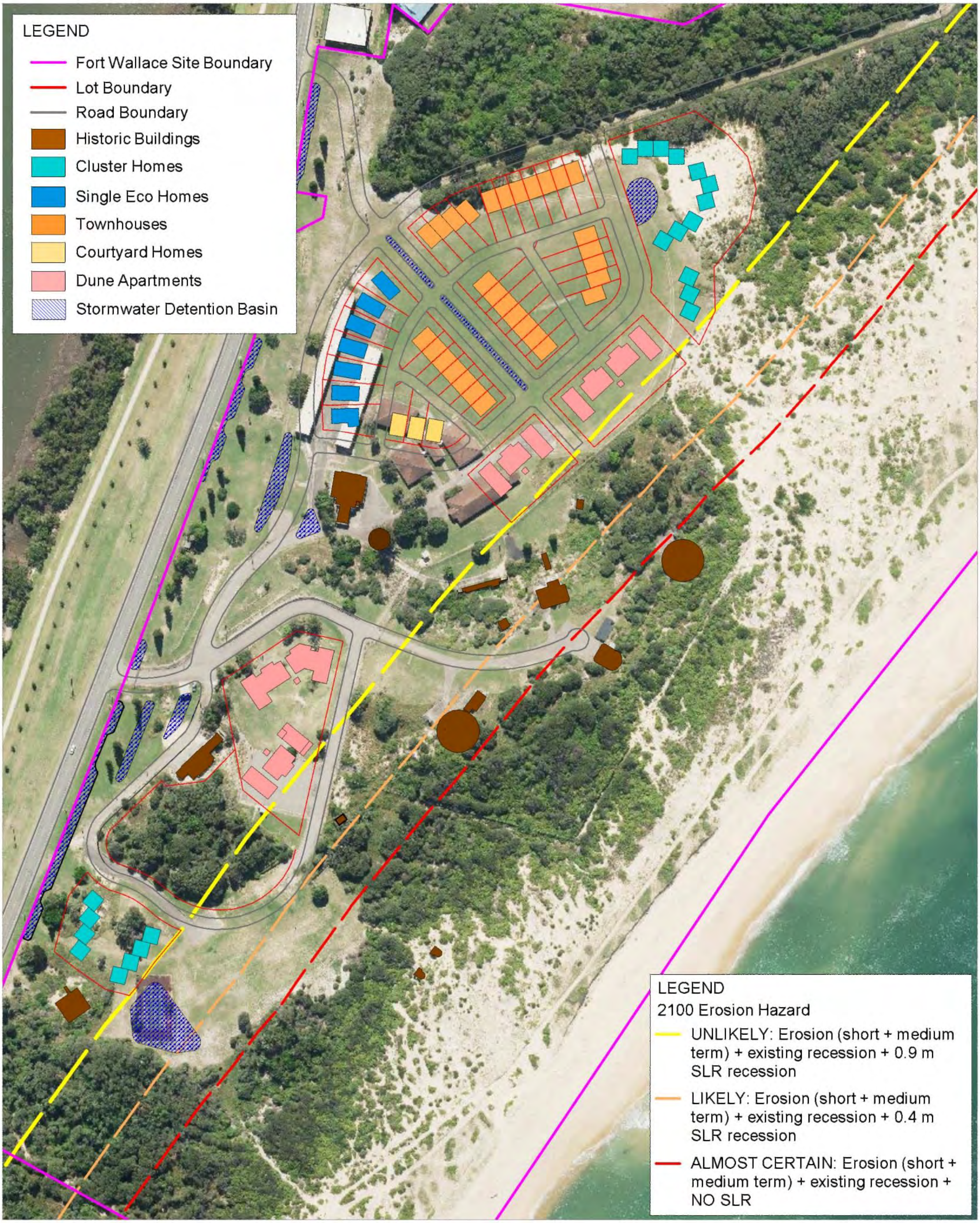
The 'unlikely' scenario represents the conservative hazard estimate that is typically used for planning purposes in NSW. The combination of calculations into the probable erosion extents described above is provided in Table 3-4. The definition of the erosion hazard scenarios in terms of 'likelihood' or a descriptive probability has been used by BMT WBM in numerous other coastal hazard assessments (for example, see BMT WBM, 2015), and is provided in Table 3-5 below.

The erosion hazard scenarios for 2100 have been mapped for Fort Wallace planning proposal zoning (and indicative masterplan layout) in Figure 3-2.

Table 3-4 2100 Erosion Hazard for the Fort Wallace Site

Erosion Likelihood for 2100	Erosion modes included	Calculations[1] for 2100	Total recession distance (fr. 4m AHD beach contour)
Almost Certain	Short term erosion Medium term erosion Ongoing recession NO recession due to sea level rise	22 m 18 m 0.8 m/yr 0 m	112 m
Likely	Short term erosion Medium term erosion Ongoing recession Recession due to 0.4 m sea level rise	22 m 18 m 0.8 m/yr 28 m	140 m
Unlikely	Short term erosion Medium term erosion Ongoing recession Recession due to 0.9 m sea level rise	22 m 18 m 0.8 m/yr 68 m	180 m

1 All calculations sourced from DHI (2006), except recession due to sea level rise sourced from DHI (2011).



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2100 Erosion Hazards for the Fort Wallace Masterplan

Figure: **3-2**

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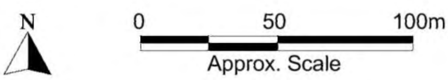

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Table 3-5 Risk Likelihood for Coastal Hazards (100 year timeframe)

Likelihood	Description
Almost Certain	There is a high possibility the event will occur as there is a history of frequent occurrence
Likely	It is likely the event will occur as there is a history of casual occurrence
Unlikely	There is a low possibility that the event will occur, however, there is a history of infrequent and isolated occurrence

3.2.3.3 Consequence of Erosion on Proposed Land Zones

In order to understand the profile of risk from erosion across the proposed land zones in the Fort Wallace Planning Proposal, the potential for erosion to cause adverse impacts within such zones was considered, and is detailed in Table 3-6.

The consequence scale used to derive these consequences is based on that used by BMT WBM for numerous other coastal hazard assessments (for example, see BMT WBM, 2015), as given in Table 3-7 below.

Table 3-6 Potential Consequence of Erosion within Proposed Land Zones

Zone	*Consequence of Erosion*	*Reasoning for Consequence level*
Residential (low, medium or high) *In this case R2 Low Density Residential*	Major	Loss of private residences would have a major social and financial impact on individual owners within the Stockton community.
Roads	Minor	Roads within the Planning proposal are of a local nature, and the use of 'ring' roads allows access to most properties to be maintained, even where erosion of a section of roadway may occur.
Open Space	Minor	Open spaces have limited infrastructure and therefore economic impact, and are generally still usable by the community even if reduced in size by erosion.
Existing Historical Assets	Minor	Historical assets have a high social value to the community, however, they are not habitable structures, nor vital infrastructure. Such structures can be relocated, or otherwise enjoyed until impacts are imminent.
Environmental zones	Minor	Generally, such areas should remain functional even if reduced in size by erosion. Rehabilitation will enhance the resilience of ecological communities, and assist their ability migrate in response to erosion impacts over time.

Table 3-7 Consequence Scale for Coastal Hazards/Issues

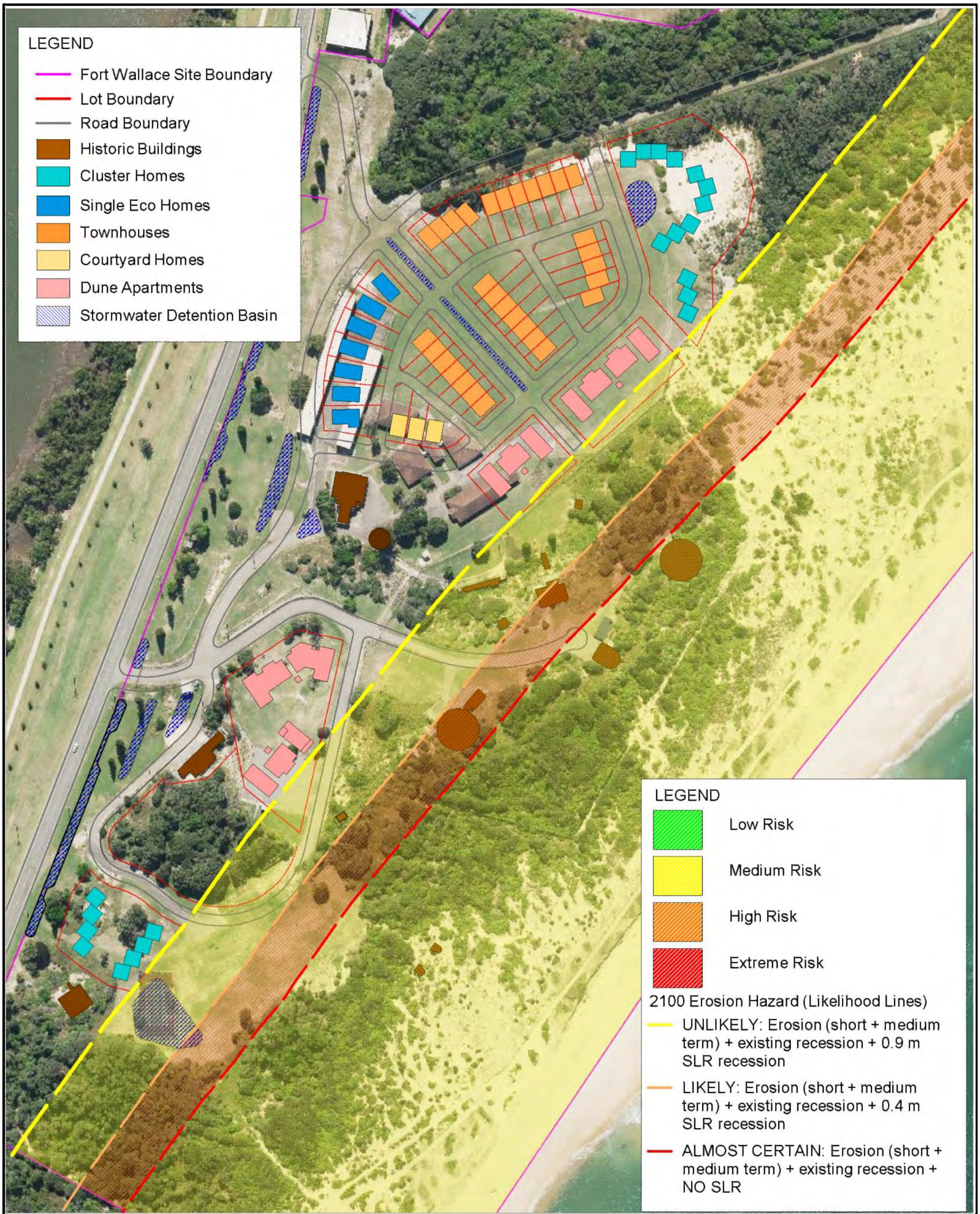
Consequence	Society / Community	Environment	Economy
Major	Major permanent or widespread medium term disruption to community's services, wellbeing, or culture (e.g. 50 % of community affected), or regional loss, or Few, if any, suitable alternative sites exist	Widespread permanent or semi-permanent impact, or widespread pest / weed species proliferation, or semi-permanent loss of entire regionally important habitat. Recovery may take many years, if at all.	Damage to property, infrastructure, or local economy >$2 million
Moderate	Minor long term or major short term (mostly reversible) disruption to services, wellbeing, or culture of the community (e.g., up to 25 % of community affected), or sub-regional loss, or Some suitable alternative sites exist	Significant environmental changes isolated to a localised area, or loss of regionally important habitat in one localised area. Recovery may take several years.	Damage to property, infrastructure, or local economy >$250,000 - $2 million
Minor	Small to medium short term (reversible) disruption to services, wellbeing, finances, or culture of the community (e.g., up to 10 % of community affected), or local loss, or many alternative sites exist	Environmental damage of a magnitude consistent with seasonal variability. Recovery may take one year.	Damage to property, infrastructure, or local economy >$50,000 -$250,000

3.2.3.4 Potential Erosion Risk to Fort Wallace Planning Proposal

The level of risk is the combination of likelihood and consequence via a risk matrix, as derived for this assessment in Table 3-8. The consequence and likelihood were combined using GIS processing to map the potential *level of risk* to proposed land zones on Fort Wallace from coastal erosion by 2100, as shown in Figure 3-3.

Table 3-8 Risk Matrix for Coastal Erosion Assessment

		CONSEQUENCE		
		Minor	**Moderate**	**Major**
LIKELIHOOD	**Almost Certain**	**Medium**	**High**	**Extreme**
	Likely	**Low**	**Medium**	**High**
	Unlikely	**Low**	**Low**	**Medium**



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2100 Erosion Risk Profile for the Fort Wallace Masterplan

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Approx. Scale

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From Figure 3-3, it is evident that:

- The majority of the new proposed residential zones are landward of the 2100 ‘unlikely’ erosion hazard scenario, and therefore considered to be at very low risk.
- A small portion of proposed residential land, and associated roads and open space at the southern end of the site lies seaward of the 2100 ‘unlikely’ erosion scenario, but landward of the ‘likely’ erosion hazard scenario, and is therefore classified to be at medium and low risk by 2100 respectively.
- Existing historical assets and associated access roads and open space associated are generally located seaward of the 2100 ‘unlikely’ hazard scenario, and therefore variously at low to medium risk from erosion by 2100.

3.2.4 Uncertainties in Erosion Hazard estimates

Uncertainty in defining coastal erosion hazards particularly over long timeframes (50 years +) is an inherent feature of all coastal assessments. Uncertainty in coastal hazard estimation arises due to:

- the complexity of the coastal system, and limitations of our understanding of the interactions within this complex system;
- due to this complexity, the requirement for assumptions when replicating the coastal system via modelling or other techniques,
- the uncertainties associated with climate change, particularly the rate and extent of sea level rise over long timeframes; and
- the uncertainties of how the coastal system will respond to sea level rise, particularly as this will be combined with existing recession at Stockton Beach.

With such uncertainties in mind, three scenarios for the occurrence of coastal erosion to the 2100 timeframe were investigated (being ‘almost certain’, ‘likely’ and ‘unlikely’, as noted above), to provide more transparency regarding how erosion estimates are derived and combined.

The key areas of uncertainty in the erosion hazard estimate relating to Stockton Beach are listed then explained below:

- the extent of ongoing recession;
- the response of the shoreline to sea level rise, and
- the potential for mitigation measures such as beach nourishment being implemented on Stockton Beach before 2100 (e.g. by State/Local government to manage the existing risks downdrift of Fort Wallace).

It could be argued that the rate of ongoing recession occurring at the Fort Wallace site is overestimated. The current state of the beach and dunes at the Fort Wallace site are slightly eroded (due to the 2016 storms) to accreted, with a wide beach and berm (see Figure 2-2 and Figure 2-3). The beach state is not typical for a receding beach, but rather is more typical of a stable beach. By comparison, the southern end of Stockton Beach did experience a period of relative accretion as shown in Figure 2-4, however the dunes and beach were not as accreted as is currently evident at Fort Wallace. Fort Wallace does not demonstrate a well-developed foredune and hind dune complex, and this is typical of receding beaches. However, this is equally likely to be due to the use of the site by the Australian Defence Force in the past (and which may have involved clearing for views from the “pillboxes” and other training activities), and then weed infestation, which has destabilised the natural dune hierarchy.

The height and width of the sand dunes on the Fort Wallace site actually represent a substantial store of sand. When the beach recedes into these dunes, the sand will be liberated and can supply the coastal system. The existing substantial stores of sand in the dunes at Fort Wallace in front of the proposed subdivision may assist to reduce the rate of future recession, but have not been taken into account when deriving the erosion hazard estimates. Modelling techniques available to determine future recession either due to historical influences (as in DHI, 2006); or due to sea level rise with the Bruun Rule (as calculated by DHI, 2011), are not currently able to include such sand reserves in their calculation. Indeed, a key argument for avoiding the construction of seawalls on Fort Wallace is because such structures actually lock away the sand reserves, and restrict the mobilisation of this sand into the coastal system, exacerbating erosion updrift.

The Bruun Rule (1962) that was used to estimate recession due to sea level rise is known to have significant limitations (for example, refer Ranasinghe *et al*, 2007). Any one of these limitations may present an error in the sea level rise recession extent used in this coastal hazard assessment. For example, recession calculated with the Bruun Rule (1962) is entirely dependent upon the offshore slope applied. If the bathymetric data is of poor quality or is analysed differently, then a difference in the calculated extent of recession could occur. While the NSW Government has supplied guidance on this matter, selecting the distance/depth offshore from which to measure this slope (called the depth of closure), is an ongoing source of argument and discussion within the coastal science community.

Lastly, Stockton Beach has been subject to many and ongoing investigations by the state and local government regarding methods to ameliorate the existing recession issue. The most recent such study was the Stockton Beach Sand Scoping and Funding Feasibility Study (WorleyParsons, 2011). The WorleyParsons (2011) report identified suitable sediment sources for use as beach nourishment on Stockton Beach. The report recommended: episodic trucking of sand from further north on Stockton Beach to the southern areas affected by recession; continued episodic use of dredged marine sand from Newcastle Harbour on the beach; lobbying of developments within the Port of Newcastle to access marine sand reserves that are liberated during site works; and, while it is currently not politically viable, the dredging and use of sand from offshore (i.e. > 30-40 m water depth) remains a technically and financially viable option.

Given the feasibility of beach nourishment activities described above, it is very possible that both small and large scale nourishment programs may commence on Stockton Beach well before the 2100 timeframe for coastal risks for which this development has been designed for. Such programs will invariably reduce the potential for erosion impacts to the Fort Wallace site.

3.3 Dune Stability and Reduced Foundation Capacity Hazard

3.3.1 Definition

Immediately following a storm erosion event, a near vertical erosion escarpment of substantial height can be left in the dune or beach ridge. At some time after the erosion event, the escarpment may slump, and the slope adjust to a more stable angle. This slumping may occur suddenly, and poses a risk to structures located immediately behind the dune escarpment.

The schema of Nielsen *et al.* (1992) is the accepted method for determining the zone behind a dune escarpment that remains unstable, as follows (see Figure 3-4):

- *Zone of Slope Adjustment:* the area landward of the vertical erosion escarpment crest that may be expected to collapse after the storm event; and
- *Zone of Reduced Foundation Capacity:* the area landward of the zone of slope adjustment that is unstable being in proximity to the storm erosion and dune slumping.

As shown in Figure 3-4, these zones are shaped as a wedge, and so, stable foundation can be reached below the zones. Developments in the immediate vicinity of beaches with the potential to be affected by the zone of reduced foundation capacity may require foundation piles that penetrate to the stable foundation zone (see Figure 3-5).

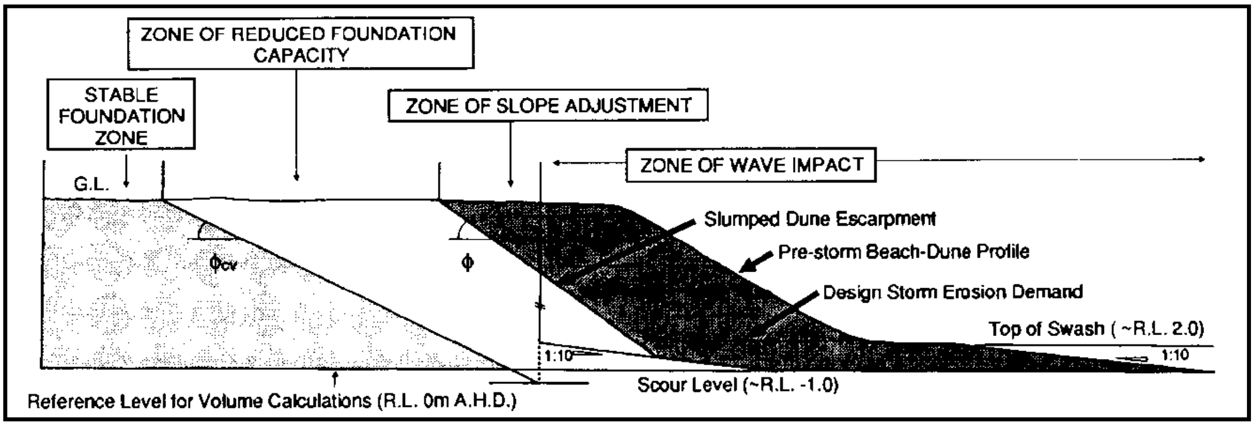


Figure 3-4 Zones of instability after Storm Erosion (From Nielsen *et al.,* (1992)

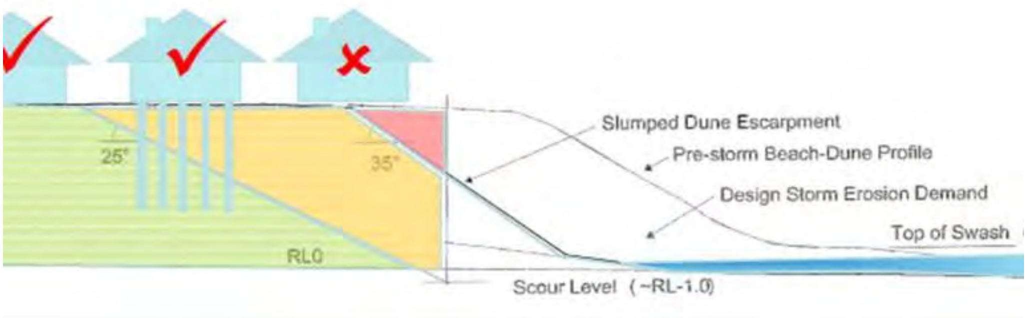


Figure 3-5 Using Foundation Piles to access the Stable Foundation Zone

3.3.2 Calculation

For the purpose of applying the Nielsen *et al.* (1992) schema to beach-scale assessments, it is accepted to assume that the entire dunal system comprises homogeneous sand, which allows an angle of repose of 35° to be applied in the calculation. This is very likely to be a suitable assumption for Stockton Beach given the long geologic history of sand accumulation in Stockton Bight. However, expert geotechnical engineering assessment is required to properly establish the zone and foundation requirements on an individual development basis.

The width of the zone of reduced foundation capacity is also directly dependent upon the height of the dunes. This is problematic where calculations must be made for the presumed position of the erosion escarpment in 2100. The present day height of dunes/land in the region of the 2100 erosion hazard may not accurately represent the actual height of the dunes by that time. Activities including development for residential purposes, community uses, and even dune rehabilitation may lower or heighten the dunes over time.

To provide an indication of the potential zone of reduced foundation capacity behind the 2100 erosion hazard zones, the existing topographic information for dune height has had to be used. Table 3-9 provides the average, maximum and minimum height of dunes along each of the erosion hazard lines fronting the masterplan lot boundary. These dune values have been used to calculate the average and range for the zone of slope adjustment plus zone of reduced foundation capacity that may exist landward of the erosion hazard lines.

Table 3-9 Indicative Zone of Reduced Foundation Capacity Landward of Erosion Hazard Scenarios

Erosion Scenario	Dune Height	Dune Height (m AHD)[1]	Zone of Slope Adjustment (m)[2]	Zone of Reduced Foundation Capacity (m)[2]	Total zone of instability (m)[3]
'Almost certain' erosion hazard	Average	10.5	6.1	18.6	25
	Maximum	19	12.1	30.7	43
	Minimum	6	2.9	12.1	15
'Likely' erosion hazard	Average[4]	10.5	6.1	18.6	25
	Maximum	18	11.4	29.3	41
	Minimum	6	2.9	12.1	15
'Unlikely' erosion hazard	Average	8.5	4.6	15.7	20
	Maximum	15.5	9.6	25.7	35
	Minimum	4	1.4	9.3	11

1 *Dune Heights were calculated along the erosion hazard line fronting the Masterplan Lot Boundary footprint (unless otherwise stated), to best represent conditions at the proposed developments*

2 *Calculated as per Nielsen et al 1992, in Figure 3-4.*

3 *Values rounded to nearest m, to reflect uncertainty and assumptions that affect accuracy of calculation.*

4 *Average dune height fronting the 7 cluster homes only at southern end is also 10 m*

The zone of reduced foundation capacity has not been mapped, because, in addition to these zones being based on present day, not future dune heights, the dunes themselves vary considerably in height.

The assessment of risk has considered the distance of proposed buildings in the masterplan layout from the erosion hazard lines, to determine where properties may potentially be at risk of dune instability, should erosion progress to the estimated level by 2100.

3.3.3 Potential Impacts

The zone of reduced foundation capacity that may be present by 2100 has not been mapped, to avoid presenting a false certainty to these calculations that are derived for a somewhat unknown future scenario.

Should the erosion escarpment reach a hazard scenario line and dune heights remain at their current level by 2100, the zone of slope adjustment and reduced foundation capacity:

- may average 25 m and range from 15 to 43 m width landward of the 2100 'almost certain' erosion hazard scenario;
- may average 25 m and range from 15 to 41 m width landward of the 2100 'likely' erosion hazard scenario; and
- may average 20 m and range from 11 to 35 m width landward of the 'unlikely' erosion hazard scenario.

If erosion were to reach the hazard scenario lines, structures present within these zone widths may be subject to reduced foundation capacity and structural instability.

3.4 Wave Overtopping

3.4.1 Definition

The coastal inundation hazard comprises:

- Elevated ocean water levels, comprising the addition of astronomical tide, barometric pressure set up, wind set up, and wave set up at the shoreline, which may inundate rivers, creeks, lagoons etc. hydraulically connected to the ocean; and
- Wave run up and overtopping of the shoreline, where waves overwash coastal barriers such as dunes and seawalls.

Wave overtopping is the inundation hazard of interest to this assessment, to determine the potential for the overtopping of frontal dunes during storms. The actual height of wave run up does not present a hazard unless the run-up is overtopping coastal barriers at a rate or volume that would cause a significant impact to pedestrians or land and assets behind.

There are no hydraulic connections to the ocean whereby oceanic waters may penetrate to inundate low lying areas on the Fort Wallace site, and so coastal inundation from elevated ocean water levels alone (and which are lower than the wave run up level) were not considered further.

Sea level rise will contribute to elevated ocean water levels and wave run up in the future, and is therefore included in the wave overtopping assessment for 2100.

3.4.2 Calculations

For a coastal protection structure, including a natural dune barrier, wave run-up and subsequent overtopping depends, amongst other things, on:

- hydraulic parameters such as: ocean water level, wave height, wave period, wave direction, water depth; and
- structural parameters such as: the seawall roughness and porosity (random rock armour or smooth concrete surface); slope (sloping, composite, vertical, stepped); and crest levels. Dune sand barriers are considered equivalent to smooth concrete surfaces.

Run-up on a Sandy Beach

The 2% run-up level ($R_{2\%}$) has been derived based on the findings of Nielsen and Hanslow (1991), who indicate:

$$R_{2\%} = 0.58 \times \tan\beta \times \sqrt{H_{0_{RMS}} \times L_{0_{TZ}}} \times \sqrt{ln(50)}$$

Where
β = slope of the beach face (assumed to be 0.10);
$H_{0_{RMS}}$ = deepwater RMS wave height $\approx H_s/\sqrt{2}$;
$L_{0_{TZ}}$ = deepwater wavelength corresponding to zero crossing wave period;
x = exceedence level

The run-up level derived from the above equation is added to the still water level (i.e. the addition of tide, water level anomaly caused by barometric pressure set up and wind set up, plus wave set up), plus sea level rise for 2100 of 0.0 m (almost certain); 0.4 m (likely); and 0.9 m (unlikely).

Wave run up levels for the 2100 are listed in Table 3-10.

Table 3-10 2100 Wave Run Up Hazard, Stockton Beach

Stockton Beach	2100 Wave Run Up Hazard
Almost Certain (no SLR)	5.4 m
Likely (0.4 m SLR)	5.8 m
Unlikely (0.9 m)	6.3 m

Overtopping Rate for a Rock Armoured or Stepped Slope

The present standard for engineering calculation of wave overtopping of various structures is provided by *EurOtop Wave Overtopping of Sea Defences and Related Structures: Assessment Manual* (Pullen *et al,.* 2007) ('the Eurotop Manual').

The mean overtopping discharge is calculated from the relationship provided in Chapter 6 of the Eurotop manual (Pullen *et al.*, 2007).

$$\frac{q}{\sqrt{g \times H_{m0}^3}} = 0.2 \times e^{-2.3 \times \frac{R_C}{H_{m0} \times \gamma_f \times \gamma_\beta}}$$

Where

$q =$ mean overtopping discharge rate (l/s);

$H_{m0} =$ Depth limited spectral significant wave height (m)

$R_c =$ distance of freeboard crest above still water level (m);

$\gamma_f =$ factor for effect of roughness elements (set to 0.60);

$\gamma_\beta =$ factor for effect of roughness elements (set to 1.00, assuming orthogonal wave approach)

The following values were applied in these equations:

- 100 year ARI 6 hour duration wave height (Hs) of 8.7 m;
- 100 year ARI elevated ocean water level of 1.44 m AHD;
- Dune crest height, as measured along the position of the 2100 erosion hazard scenarios (as per Section 3.3.2 also);
- Wave set up calculated from spectral wave modelling (SWAN) at Stockton Beach (using model results from other studies completed by BMT WBM in the Newcastle region, i.e. BMT WBM 2014); and
- Sea level rise of 0.0 m (almost certain); 0.4 m (likely); and 0.9 m (unlikely);
- A nearshore slope out to the 20 m depth contour calculated as -0.008, used in the transformation of waves from offshore to shore.
- The depth limited spectral significant wave height (H_{mo}), which describes the transformation of waves through the breaker zone, was calculated using a graphical method utilising charts derived from the findings of Van der Meer (1990), as recommended in the Eurotop manual; and
- Roughness elements of 1, as natural dune barriers are assumed to behave like smooth concrete for the purpose of the wave overtopping calculation.

Table 3-11 Potential Overtopping Rates for the 2100 Hazard Scenarios

Erosion Scenario	Dune Height	Dune Height (m AHD)	Wave Run Up	Overtopping Rate (l/m/s)
‘Almost certain’ erosion hazard	Average	10.5	5.4 m	0.0
	Maximum	19		0.0
	Minimum	6		0.0
‘Likely’ erosion hazard	Average[4]	10.5	5.8 m	0.0
	Maximum	18		0.0
	Minimum	6		18.5

Erosion Scenario	Dune Height	Dune Height (m AHD)	Wave Run Up	Overtopping Rate (l/m/s)
'Unlikely' erosion hazard	Average	8.5	6.3 m	0.0
	Maximum	15.5		0.0
	Minimum	4		441.4

Table 3-12 Average wave overtopping volume limits resulting in damage (Eurotop, 2007)

At Risk	Average permissible overtopping (l/s/m)
Pedestrian[1]	0.10 to 10
Motor vehicles[2]	0.01 to 50
Damage to paving (landward of the crest)	200
Damage to grasses/turf (landward of the crest)	50
Seawall structure (crest)[3]	200
Buildings and assets[4]	1

Notes:
[1] Assumes that pedestrians have a clear view of the sea and able to tolerate getting wet through to trained staff expecting to get wet. All limits assume non violent, low velocity overtopping.
[2] Lower limits apply to high speed vehicles while upper limits apply to low speed vehicles, pulsating flows at low depths.
[3]Limit for no damage to a well protected crest
[4] Limit for damage, discharge measured at the building or asset

3.4.3 Potential Impacts

The average dune heights currently present along each of the 2100 erosion hazard lines are of sufficient height to protect the proposed development from wave overtopping. For the minimum dune height measured along the 'likely' and 'unlikely' hazard lines, there is potential for wave overtopping, should the dunes be eroded to these hazard lines in the future.

Wave overtopping rates in Table 3-11 have been compared to the guideline overtopping rates given in the Eurotop Manual in Table 3-12. For the minimum dune heights, wave overtopping rates may potentially damage structures and pose a risk to pedestrians or vehicles, should they be located on or immediately adjacent to the dune crest at the time that such overtopping occurs. Given the site is dominantly composed of sand, it can be expected that wave overtopping will be quickly absorbed into the porous sand, rather than continue to flow further landward to create an inundation issue on the site.

Based on the above, and the limited extent of low-lying dunes, the potential for overtopping to cause adverse impact to the proposed development is considered very low. Furthermore, continued maintenance of dune heights at or above 6 m AHD over time, which can generally be achieved through maintenance of appropriate vegetation, will adequately mitigate the potential for overtopping during extreme storm conditions in future.

3.5 Sand Drift

Windborne or Aeolian sediment transport allows the transfer of sand from the sub-aerial beach into the dunes behind. This sand drift is a natural phenomenon, however it can pose a hazard where coastal developments are being overwhelmed by windborne sediment, or significant volumes of sediment are being lost from the active beach system. For example, windblown sand can bury roads, stormwater drains and property located immediately behind an active or poorly vegetated dune system. Sand drift posing a hazard can be initiated by the degeneration or destruction of dune vegetation.

Dune vegetation plays an important role in minimising the detrimental effects of sand drift by acting to trap windblown sand, helping to build up the dune and keep the sand within the active beach system. In fact, the adequate maintenance of dune vegetation also assists to ameliorate other coastal hazards. Dune systems act as reservoirs to supply sand to the active beach during periods of erosion. If sand is lost inland through windborne transport, the volume of sand available to supply the erosion demand is less and therefore the erosion extent will be greater. Similarly, properly functioning dunal vegetation complexes also assist to ameliorate coastal inundation, as the capture of windblown sand helps to build dunes to greater heights, reducing the potential for wave overtopping.

Windborne transport of sand can be an important component of the coastal sediment transport system. This is particularly the case on Stockton Beach north of the Fort Wallace site. The Stockton Bight beach system extends some 32 kilometres to the north east. Aeolian processes are significant within this highly active and vast transgressive dune system. The lack of dune vegetation within this dunal system is highly important for allowing the transgression of sand along Stockton Beach towards Birubi Point and beyond. In this case, a significant portion of the natural northerly sand transport is via the land-based portion of the coastal system. As such, it is vital that this vast active system is and should remain naturally unvegetated.

As noted in Section 2.1.2 (see Figure 2-1), dune vegetation at the Fort Wallace site is present but is patchy and infested with weeds such as Bitou Bush. The patches of bare sand between hummocks created by Bitou Bush would allow for nuisance sand drift into areas behind the beach.

The persistence of dune vegetation here in spite of known pressures such as erosion and weeds suggests that the Fort Wallace site would naturally have good dune vegetation coverage. In this case, the remediation and then ongoing maintenance of adequate native dune vegetation on the Fort Wallace site seaward of the proposed development is recommended. Ongoing maintenance of dune vegetation will also assist to manage other coastal hazards such as erosion and wave overtopping also.

4 Risk Mitigation

4.1 Summary of Potential Coastal Risks by 2100

Based upon the coastal hazard assessment detailed in Chapter 3, the following potential coastal impacts to the Fort Wallace Planning Proposal by 2100 are identified.

- Coastal erosion poses a risk to residential zones proposed seaward of the 2100 'unlikely' coastal erosion hazard scenario, as shown in Figure 3-2.
- Should erosion reach the coastal erosion hazard scenarios by 2100, there may be a zone of reduced foundation capacity immediately landward of the erosion escarpment that will affect structures at that time.
- Should erosion reach the coastal erosion hazard scenarios by 2100, wave overtopping of the coastal dune barrier is not expected to pose a hazard, except at a small portion of low lying dune.
- If dune vegetation is not adequate or maintained seaward of the proposed development, sand drift may pose a hazard.

4.2 Risk Mitigation Measures

4.2.1 Dune Rehabilitation and Maintenance

A program of dune rehabilitation and ongoing maintenance on the Fort Wallace site is highly recommended. All of the identified potential coastal risks to the Fort Wallace site may be ameliorated (to a lesser or greater degree) by the rehabilitation and ongoing maintenance of the dunes on the site. This should include weed removal, replanting with appropriate endemic native species, re-contouring and dune fencing, and ongoing maintenance of the dunes into the future.

The maintenance of dune vegetation at the site reduces the following risks.

- Dune vegetation can capture and retain sand, which acts as a buffer to short term erosion events. It needs to be accepted, however, that dune vegetation will be eroded by storm events from time to time. Ongoing maintenance will assist the dunes to recover and naturally regenerate after storms.
- By capturing sand, dune vegetation aids the growth in height of dunes, which in turn reduces the potential for wave overtopping and overwash into areas behind. Ideally, the foredune height should be maintained at or above 6 m AHD, however properly functioning dunes tend to reach 5 m above the adjacent beach alone. A height of 5 m AHD will protect from wave overtopping during the majority of storm incidences.
- The capturing of sand within dune vegetation also reduces the potential for sand to drift into developed areas behind the beach.

4.2.2 Coastal Erosion

4.2.2.1 Residential Zones

Coastal erosion risk was assessed for the Fort Wallace Planning Proposal for the 2100 timeframe. The conservative (i.e. ‘unlikely’) erosion hazard scenario by 2100 is applied to subdivision proposals in NSW, because the change in land use is expected to remain for more than 100 years (and probably in perpetuity).

At the subdivision stage, the best approach to managing potential erosion is to avoid the risk by siting proposed developments landward of the conservative 2100 ‘unlikely’ erosion hazard. This is the approach that has been used for the majority of the proposed residential zones in the Fort Wallace Planning Proposal. Roads and services associated with residential development should also be avoided within erosion risk areas, unless alternative access can be provided in the future.

It is recommended that all remaining residential zoned land be kept landward of the ‘likely’ erosion hazard zone. Residential land within this zone was assessed to be at medium risk of erosion by 2100 (see Section 3.2.3.4). Generally a medium risk can be tolerated, however, it is recommended that at the development stage, further development controls be undertaken to reduce the risk to residential structures to a low and acceptable level. Such controls are recommended to be included in a development control plan (DCP) or similar for the subdivision.

A review of controls that may be implemented via a DCP for individual developments within the medium risk residential zone is provided in Table 4-1. Based upon this review, the following controls are recommended, for example as “acceptable solutions” in a DCP or similar.

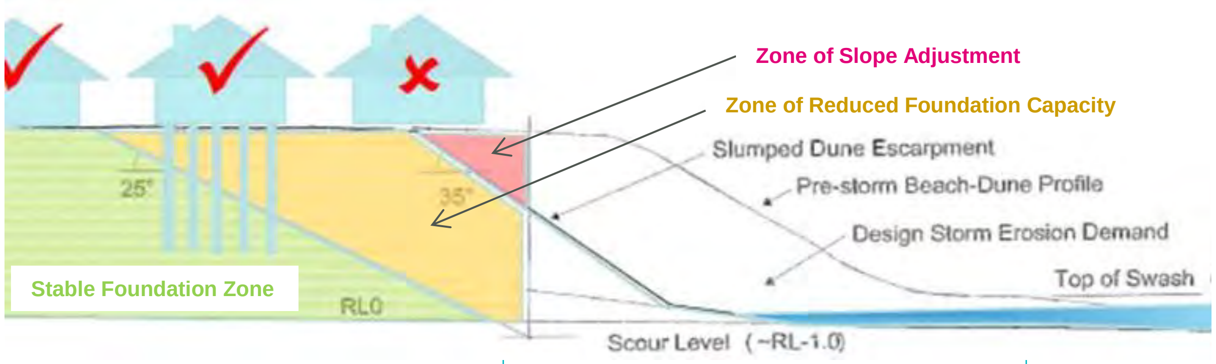
- Siting of buildings landward of the 2100 ‘unlikely’ erosion hazard, in the first instance;
- Where this is not possible, siting of buildings landward of the 2100 ‘likely’ erosion hazard, plus development approval on the condition that if and when an erosion trigger is reached (e.g. when the width of sand seaward of the property ≤ 20 m), the structural stability of the property will be assessed. If found to be unstable, then either:
  - the property is removed or relocated landward into the stable foundation zone;
  - Beach nourishment is undertaken to restore sand reserves fronting the property; and / or
  - Piles are installed below the property into the stable foundation zone.

Implementation of revetment structures to protect at risk properties in the future is strongly discouraged at Fort Wallace. This is particularly because Stockton Beach is known to be experiencing ongoing recession, and so, revetment structures will be exposed and denuded of sand, with no beach amenity in front or adjacent to the structures. This outcome is already evident at the seawall along Mitchell Street and Stockton Beach (see Figure 2-5).

Table 4-1 Risk Mitigation Options for Residential Development within Erosion Risk Areas

Option, ***Ball-park cost***	**Positives**	**Negatives**	**Recommendation for use at Fort Wallace**
Building footprint sited landward of erosion risk area The building footprint is located landward of the 'unlikely' erosion risk area. Cost: dependent on development yield sought for the subdivision.	Avoids the erosion risk. Allows development to proceed without further controls.	May reduce the property yield sought by the developer.	**Yes, recommended**, wherever possible for residential zones
Event-based (conditional) Development Approval. The building is given approval on the condition that when an erosion trigger is met, the property is removed or relocated on site. An example erosion trigger may be a volume of sand measured in front of the property. Cost: planning costs.	Allows land to be developed and used prior to the occurrence of the erosion risk some 50-100 years in the future. *Local councils are also able to issue removal orders for properties found to be at imminent risk, without the prior need for a conditional approval.*	May be difficult to sell properties with a conditional approval.	**Yes, recommended**, for the buildings that cannot be sited landward of the 2100 'unlikely' hazard zone.
Beach nourishment Transporting sand from outside of the coastal system and placing on the beach and / or surf zone, to maintain a sandy beach and protect properties behind. Cost: ~ $1 M to widen beach by 10m for a 200m section of beach (at $50/m^3, being $25 each for purchase and placement). *Note: the use of dredged marine sand from Newcastle Harbour on Stockton Beach is not technically "nourishment", but re-use of sand from the existing coastal system.*	Retains the shoreline in its current position, to maintain the buildings and assets behind the shoreline. Retains a sandy beach for the community. *In the case of Fort Wallace, beach nourishment would not be recommended to occur now, but be required to be implemented in the future when a specific erosion trigger is reached, or an assessment of the property(s) identifies that nourishment is required to restore structural stability.*	Very expensive, due to costs from onshore sand mines plus transport and site costs. *Suitable sand sources at Stockton were identified by WorleyParsons (2011), and may include trucking of sand from further north down to beach sections under threat. At present, the NSW government does not permit mining of sand from offshore sources, however suitable sand does exists offshore of Stockton Beach.*	**Yes, recommended,** for the buildings that cannot be sited landward of the 2100 'unlikely' hazard zone.

Option, *Ball-park cost*	Positives	Negatives	Recommendation for use at Fort Wallace
Foundation piles to stable ground. Installation of deep foundation piles into the 'stable foundation zone'. Cost: ~ $300/m^3 concrete piles, unknown depth or quantity per structure	Provides stability to the property during an erosion event that reaches or exceeds the building footprint. Provides stability to a property located behind an erosion escarpment within the zone of slope adjustment or reduced foundation capacity.	Very expensive outlay, particularly given the long timeframes for the expected erosion impact at Stockton.	**Yes, recommended** for development types expected to have a design life of 80 years or greater (i.e. beyond 2100); and as a future option for buildings that cannot be sited landward of the 2100 'unlikely' hazard zone.



BMT WBM

Option, *Ball-park cost*	Positives	Negatives	Recommendation for use at Fort Wallace
Rock revetment (seawall) Construction of a rock revetment along the seaward boundary of the property(s) (see picture) Cost: ~ $10,000 / linear metre of seawall, plus maintenance costs (which may include beach nourishment). Caution: seawalls are not permissible to be built on an individual property basis, due to their impact on adjacent land (see “negatives”).	Retains the shoreline in its current position, to maintain the buildings and assets behind the shoreline. *In the case of Fort Wallace, the seawall would not be constructed now, but be required to be implemented in the future when a specific erosion trigger is reached, or an assessment of the property(s) identifies that a revetment is required to restore structural stability.*	On receding beaches such as Stockton, the seawall results in a loss of beach and beach amenity in front of the structure (see picture below of Mitchell St seawall). Erosion at the ends of the structure also occurs. Revetments can “lock away” sand reserves that would otherwise be eroded and supply the coastal system. This is particularly so at Fort Wallace given the volume of sand within the existing dunes. Under existing coastal legislation, amelioration of offsite impacts such as erosion in front and at the ends of the structure is required. This typically means ongoing beach nourishment, additional to the cost and maintenance of the seawall structure alone. Given that property owners at Fort Wallace would be the sole beneficiary of the revetment, existing coastal legislation allows the entire cost burden (construction, maintenance and remediation works) to be placed upon these property owners. 	**No, not recommended**, due to the existing recession hazard at Stockton Beach, that would place an unreasonable financial burden on future property owners to build and maintain the structure, including beach nourishment

4.2.2.2 Other Land Zones

Potential erosion impacts on other proposed land zones by 2100 can be accepted, as follows.

- The eastern most section of access road to residential properties found to be at low risk (see Figure 1) can be considered sacrificial, because access to the residential land is also possible via an alternate route.
- Open space areas shown to be at risk from erosion may also be considered sacrificial, as they typically remain functional even where reduced in size, and tend not to contain infrastructure of high financial value.

4.2.2.3 Heritage Assets

A number of heritage assets that already exist on the site are likely to be affected by coastal hazards prior to 2100 (see Figure 3-2). The historical structures are not intended for use as habitable dwellings. It is recommended that the heritage assets on site be utilised and enjoyed until such time as impacts are imminent, which is likely to be many years away. As and when coastal erosion risks threaten the structures, appropriate measures to manage the risks can be investigated and implemented, for example, as follows in order of preference:

(1) **Relocation**: whereby the structure(s) is physically relocated seaward to avoid the erosion risks. This is the preferred option as it enables the heritage asset to be retained, and the beach amenity to be retained because the beach and dune are able naturally progress landward over time.

(2) **Sacrifice**: whereby the structure(s) are removed prior to them becoming a public safety hazard in respect of erosion impacts. This option is recommended second, as it will allow for the beach and dune to migrate landward, maintaining the beach environment, but the heritage item is lost.

(3) **Beach nourishment**: whereby sand is placed along the beach in front of the structure. This option is the third preferred option. Beach nourishment does allow for both the heritage assets and beach amenity to be retained. However it is very costly (at present), and must be continually repeated for the beach and structure to be retained.

Protection works to defend the existing heritage structures are strongly discouraged. Protection structures have significant negative impacts on the beach environment, and also require substantial funds to build and maintain (see Table 4-1).

4.2.3 Reduced Foundation Capacity

In view of the long timeframes and the high level of uncertainty regarding the occurrence and width of the zone of reduced foundation capacity by 2100, it is recommended that the proposed rezoning proceed at the current time. Future development applications for structures should to consider the expected lifespan of the structure, and require foundation piles to mitigate the foundation capacity risk as appropriate. For example, structures with an expected lifespan of 40-50 years sited landward of the ‘unlikely’ erosion hazard would not be expected to be subject to reduced foundation capacity risks over this lifespan, and so, foundation piles would not be required.

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