REPORT

Coffs Harbour Jetty Foreshore State Assessed Planning Proposal - Coastal Risk Management Report

Client: Property and Development NSW

Reference: PA3468-RHD-ZZ-XX-RP-Z-0001

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Glossary

Term	Definition
Annual exceedance probability (AEP)	Is a measure used in risk assessment and statistics to express the likelihood of an event, such as a flood or earthquake, occurring in any given year. For example, a 1% AEP (or 1 in 100-year event) indicates that there is a 1% chance of that event happening in any given year.
Accretion	The build-up of sediments to form land or shoaling in coastal waters or waterways. It may be either natural or artificial. Natural accretion is the build-up of land on the beach, dunes, or in the water by natural processes, such as waves, current and wind. Artificial accretion is a similar build-up of land resulting from built structures such as groynes or breakwaters, or activities such as filling and beach nourishment, or also aggradation.
Average recurrence interval (ARI)	is a statistical term used to estimate the average amount of time between the occurrences of a specific event. It is often used to describe the frequency of such events. For instance, if a particular event has an ARI of 50 years, it means that, on average, that level of flood is expected to happen once every 50 years in a given location.
Beach erosion	Landward movement of the shoreline and/or a reduction in beach volume, usually associated with storm events or a series of events, which occurs within the beach fluctuation zone. Beach erosion occurs due to one or more process drivers; wind, waves, tides, currents, ocean water level, and downslope movement of material due to gravity.
Beach revetment (Seawall)	A type of coastal protection work which protects assets from coastal erosion by armouring the shore with erosion–resistant material. Large rocks/boulders, concrete or other hard materials are used, depending on the specific design requirements.
Breakwater	A man-made structure protecting a shore area, harbour, anchorage or basin from waves.
Coastal Hazard	Any natural or human-made threat or risk that can negatively impact the coastal environment, infrastructure, or communities. These hazards can include events like storms, erosion, sea-level rise, and tsunamis.
Coastal processes	Marine, physical, meteorological and biological activities that interact with the geology and sediments to produce a particular coastal system
Deep trough	Is alow point in the seabed or ocean floor that is located between sandbars or underwater features. It is typically deeper than the surrounding areas and can affect wave patterns and sediment transport.
Design Event	A "design event" is a specific and typically extreme condition or scenario that engineers and designers use as a basis for planning, designing, and evaluating the resilience and safety of structures. It helps them determine the necessary specifications and features to ensure that the structure can withstand and perform effectively under challenging or rare circumstances. Design events are often associated with extreme weather conditions, natural disasters, or other exceptional situations that the structure or system must be prepared to handle.
Design Life	Design life refers to the estimated or intended lifespan of a structure. It represents the period for which the structure is expected to function properly and meet its performance requirements under normal conditions, without the need for major repairs or replacements.
Double sand bar system	A coastal feature characterised by two submerged sandbars that are typically parallel to the shoreline. These sandbars can influence wave and current patterns.
Dune	Large, linear accumulations of sand immediately landward of the beach formed by wind carrying sediment from the beach in a landward direction. Stable sand dunes act as a buffer against wave damage during storms, protecting the land behind from saltwater intrusion, sea spray and strong winds. Coastal dunes also act as a reservoir of sand to replenish and maintain the beach at times of erosion.
Inner transverse bar	Is a submerged sandbar located perpendicular and closer to the shore within the nearshore area of a beach. It can influence wave characteristics and play a role in coastal erosion and sediment movement.
Outer bar	Is a submerged sandbar located farther offshore from the shoreline. It acts as a natural buffer, dissipating the energy of incoming waves before they reach the beach, helping to protect the coast from erosion.

Planning Period	The planning period is the duration of time for which a project, plan, or strategy is designed to be effective and relevant. It represents the time frame during which the intended goals, objectives, and outcomes of the project or plan are expected to be achieved or maintained.
Rips	Powerful and seaward-flowing currents that can occur at beaches. They are typically found in areas where water from breaking waves is funneled back out to sea, creating channels of swift-moving water.
Sediment transport	The process whereby sediment is moved offshore, onshore or along shore by wave, current or wind action.
Shoreline recession	The long-term (decadal plus) net landward movement of the shoreline/mean water line. Occasionally referred to as long-term erosion.
Storm surge	The increase in coastal water levels caused by the barometric and wind set-up effects of storms. Barometric set-up refers to the increase in coastal water levels associated with the lower atmospheric pressure characteristic of storms. Wind set-up refers to the increase in coastal water levels caused by an onshore wind driving water shoreward and piling it up against the coast.
Wave climate	The typical patterns of waves, including their size, frequency, and direction, in a particular coastal area over an extended period of time. It provides information about the prevailing wave conditions at a specific location.

Executive Summary

This executive summary provides a concise overview of the key findings and recommendations from the Coastal Risk Management Report for the Coffs Harbour Jetty Foreshore State Assessed Planning Proposal. The key findings from the vulnerability risk assessment include:

- Any residential and commercial/tourist development as part of the Illustrative Masterplan is outside the Coffs Harbour Coastal Hazard Zone Policy Area.
- The Illustrative Masterplan incorporates coastal hazard considerations, with proposed land use areas and the associated potential new infrastructure types setback from the coastline appropriately. The Illustrative Masterplan is suitable and consistent with coastal planning.
- The existing revetment wall in Jetty Beach Block 3 acts as a long-term defence against erosion and storm surge, if adequately maintained. Therefore, any infrastructure to be placed behind this wall will be protected from erosion.
- Erosion risks are identified for half of the carpark and one sporting court (example infrastructure in the reference scheme) in Jetty Beach Block 3, with increasing risk by 2123, i.e., at the end of the 100-year planning period. Existing rail tracks and commercial/residential buildings landward of this area are indicated to be impacted by the 1% Annual Exceedance Probability erosion line by 2123.
- The proposed land use areas and the associated potential new infrastructure types in Jetty Beach Block 1 and Block 2 are indicated at no erosion risk in the 100-year planning period from 2023.
- Changes to building scale and height within the Marina precinct (within Jetty Beach Block 2) does not affect coastal risk. However, at the development approval stage, building designs will need to consider breakwater overtopping events and ensure mitigation measures for any related coastal inundation of ground-level habitable areas or any below-ground parking areas.
- The proposed land use areas and the associated potential infrastructure types in Boambee North are indicated at no erosion risk if the existing revetment wall is adequately maintained during the 100-year planning period.
- A medium wave overtopping risk during rare storm events exists for the boardwalk in Jetty Beach Block 1, but control measures can be implemented with sufficient warning.
- The Corambirra Point (Deep Sea Fishing), Jetty Hub and Activity Hub & Village Green precincts do not fall within the Coastal Hazard Zone Policy area, therefore are not at risk of current or future coastal erosion.

The report underscores the importance of adopting proactive measures, that will be included in future DA's, to mitigate the potential erosion and overtopping risks above and ensure the long-term resilience of planned infrastructure in the Coffs Harbour Jetty Foreshore Precinct:

- Regular Maintenance: Routine inspections and maintenance of coastal protection structures, including breakwaters and revetment walls, are essential to preserve their effectiveness and safeguard the proposed infrastructure. Any potential overtopping risks will also be addressed at this time.
- Consider extension of revetment wall: To protect proposed sporting courts, car park and existing assets in Jetty Beach Block 3, extending the existing revetment wall is a viable option but not mandated.
- Adaptation to Changing Conditions: Overtopping risks can be mitigated through proper maintenance and adaptation to existing coastal protection structures by incorporating changing ocean conditions.
- Integrated Warning Systems: Implementing robust warning systems for overtopping and erosion risks is essential to mobilize timely control measures and protect infrastructure.

In summary, the Coastal Risk Management assessment has not identified any significant risks or concerns regarding this State Assessed Planning Proposal application. However, should the proposed infrastructure be developed according to the outlined Illustrative Masterplan, it will be imperative to conduct thorough risk assessments and implement proactive mitigation measures to safeguard the resilience and integrity of planned infrastructure within the Coffs Harbour Jetty Foreshore Precinct. All proposed mitigation strategies are deemed viable for this area. These findings and recommendations serve as a valuable guide for informed decision-making in the State Assessed Planning Proposal.

1 Introduction

1.1 Background

Property and Development NSW (PDNSW) is continuing to lead the revitalisation of the Coffs Harbour Jetty Foreshore Precinct (the Precinct) on behalf of the NSW Government. Royal HaskoningDHV (RHDHV) has been engaged by PDNSW to prepare a Coastal Risk Management Report that assesses the coastal vulnerability and associated risks to the proposed Indicative Masterplan.

This Coastal Risk Management Report supports a Planning Justification Report that outlines proposed amendments to the Coffs Harbour Local Environmental Plan (CHLEP) 2013 and will be submitted to the Department of Planning, Housing and Infrastructure (DPHI) as part of a State Assessed Planning Proposal (planning proposal).

As Coffs Harbour continues to grow as a Regional City, the NSW Government and Coffs Harbour City Council have, through various strategic planning exercises, identified four key strategic priorities to reimagine its direction and respond to current and future challenges and opportunities:

- Deliver a regional economy (CHCC LSPS, 2020; CH Economic Development Strategy, 2017) that is diverse, sophisticated and able to retain businesses and skills
- Evolve the tourism offering CHCC LSPS, 2020) with improved attractions, activities and accommodation
- Provide more housing (CHCC LSPS, 2020) in accessible locations, including affordable housing
- Provide better connections between places with more sustainable movement choices (CHRCAP, 2021; CHCC, 2020)

As a large, strategically located and wholly government owned site, the Precinct represents a significant opportunity to deliver on each of these key regional priorities. In this planning proposal, PDNSW seeks to celebrate the unique location, history and culture of the Jetty Foreshore to deliver outcomes for the benefit of the Coffs Harbour community. The revitalisation will be staged and funded, over time, to deliver the shared community vision.

1.1.1 Our Shared Community Vision

Coffs' family playground, a precinct of parks and places, that connects community with Country. The community is and always has been at the heart of creating a thriving regional economy and destination for Coffs Harbour. Shaped with the community, our vision is to ensure The Jetty Foreshore will become a world-class oceanfront precinct through the principles shown in **Figure 1-1**.

Figure 1-1: Vision for the Coffs Harbour Jetty Foreshore

1.1.2 The Precinct

The Precinct, wholly owned by the NSW Government, is strategically significant to the State and to the Coffs Harbour region. The Precinct is located on the traditional lands of the Gumbaynggirr people, in saltwater freshwater Country. It encompasses approximately 62 hectares of foreshore land, 5km east of the Coffs Harbour CBD, located on the Coffs Harbour coast with direct access to the Pacific Ocean. Access is provided on Marina Drive in the north, and Camperdown Street in the south, with Jordan Esplanade bisecting the site north to south. A Precinct map showing existing conditions is provided at **Figure 1-2**.

The west boundary is generally defined by the railway line and Coffs Harbour Railway Station. To the north the Precinct borders a culturally significant site known as “Happy Valley”, which has been returned as freehold land to the Coffs Harbour and District Local Aboriginal Land Council (LALC). Gallows and Boambee Beaches are located to the south of the Precinct, where Littoral Rainforest occurs. Coffs Harbour itself, the Pacific Ocean, Muttonbird Island and South Coffs Island (Corambirra Point) form the eastern boundary.

The Precinct is a popular destination for both locals and tourists offering a variety of attractions and amenities. These include Jetty Beach and extensive parklands with biodiversity value, as well as items of heritage significance such as the Coffs Harbour Jetty and Ferguson’s Cottage, owned by the Coffs Harbour LALC. Further, the Coffs Harbour Fisherman’s Co-op, the Coffs Harbour Yacht Club, weekly Sunday markets, and community hub building (recently delivered by PDNSW) are located within the Precinct. Various public works including breakwater and boat ramp upgrades have been undertaken over recent years to support the marina function.

There are redeveloped and well-maintained parts in the area however, much can be done to enhance the Coffs Harbour Jetty Foreshore Precinct. A large portion of the Precinct is currently gravelled, and a large area of residual railway land is fenced off and inaccessible to the public, as shown in **Figure 1-3**. While gravelled areas provide informal overflow parking, they do not reflect the potential of this foreshore.

Figure 1-2: Coffs Harbour Jetty Foreshore Precinct (Source: SJB)

Figure 1-3: Existing state of the Precinct rail lands and gravelled areas (Source: PDNSW)

1.1.3 The Illustrative Masterplan

The planning proposal is supported by an Illustrative Masterplan (

Figure 1-4) that presents a potential development outcome that could be realised at the Coffs Harbour Jetty Foreshore Precinct – it is not prescriptive nor is it determined. The Illustrative Masterplan builds on the shared vision created via extensive community and stakeholder consultation and provides further detail in relation to land use and development outcomes sought for the Precinct.

The Place Principles shown in **Figure 1-5**, agreed with the community, guided the formation of the Illustrative Masterplan.

The Illustrative Masterplan is broadly organised across six sub-precincts that will each have a distinct character and function. These are identified as:

1. Foreshore Parklands – with improved amenities, proposed new board walk and nature-based playground.
2. The Marina – An active marina revitalised to accommodate local marine based businesses that reflect their regional importance.
3. North Park – Functional open space with recreational courts and formalised parking.
4. Jetty Hub – A hub of residential and tourist accommodation supporting activation, tourism and regional attraction located adjacent to the current Jetty Walkway, with massing capped at 6 storeys stepping down in scale when closer to public areas.
5. Activity Hub and Village Green – An active village green that delivers increased public open space connected to the existing foreshore parklands and may include family-friendly food and beverage, community uses and club houses or facilities to support events. A local business activity zone connected to the rail station.

6. Corambirra Point – A new regional tourist destination on the site of the former Deep Sea Fishing Club site including publicly accessible cafes and restaurants, a function space, activity centre and tourist accommodation.

A precinct map showing the Illustrative Masterplan and the six distinct zones is provided at **Figure 1-6**.

Figure 1-4: Illustrative Masterplan (Source: SJB)

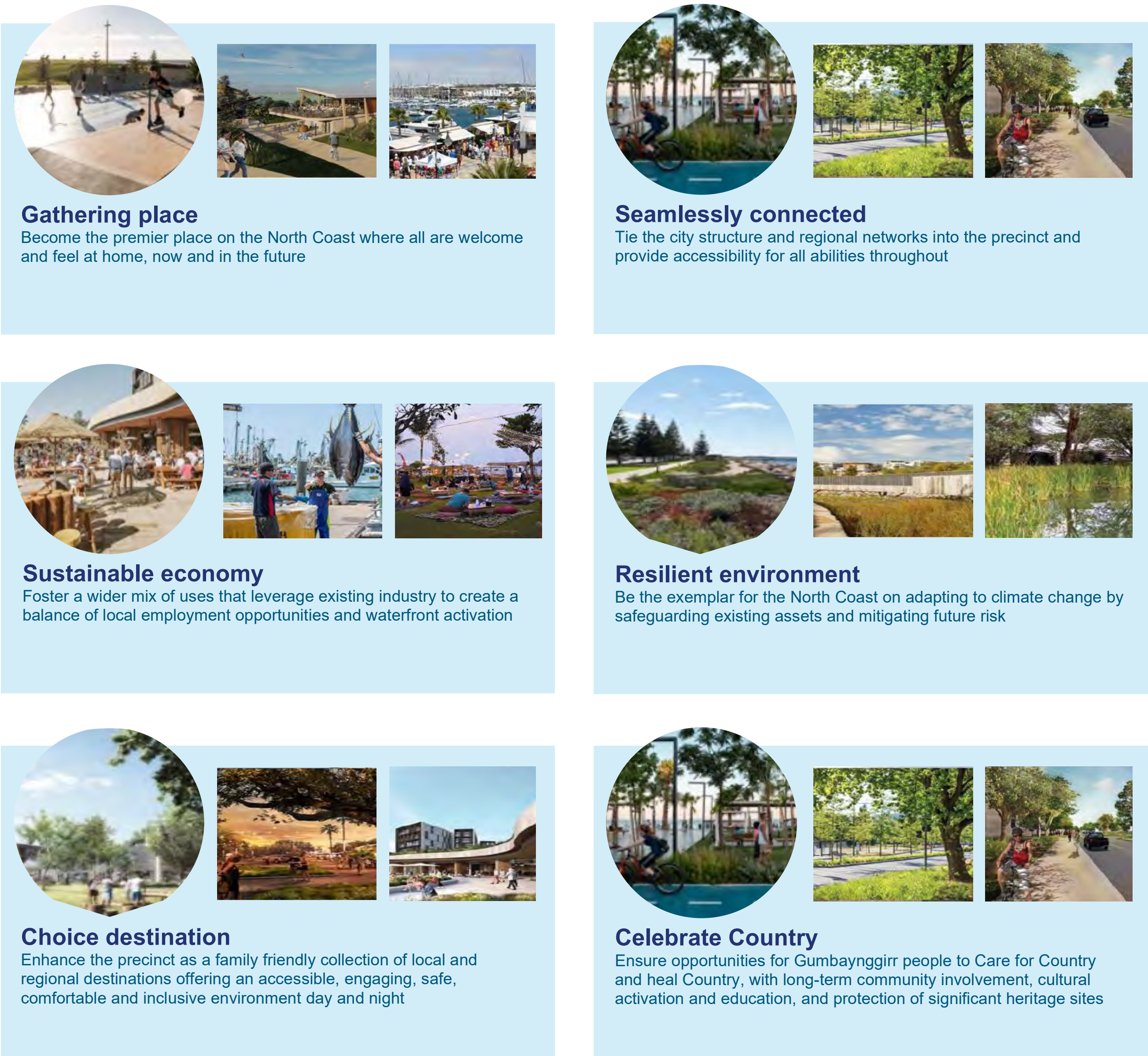

Figure 1-5: Community-led place principles

KEY
Site Boundary

Figure 1-6: Sub-precinct map (Source: SJB)

1.1.4 The Planning Proposal

The master planning of large-scale precincts follows a highly consultative and stepped approach. The current step, which paves the way for the revitalisation of the Coffs Harbour Jetty Foreshore Precinct, is the application for a State Assessed Planning Proposal, which is a legislated process.

PDNSW is lodging a planning proposal with the Department of Planning, Housing and Infrastructure that seeks approval for:

- Changes to permissible land uses
- Changes to permissible maximum building heights
- Planning controls for future State Significant Development Applications including design guidelines and design excellence processes

This Coastal Risk Management Report supports this planning proposal.

1.2 Study Area Zones

The Coffs Harbour Jetty Foreshore Precinct lies within the Coffs Harbour Coastal Hazard Zone Policy area (it is however emphasised that any (residential and commercial/tourist) development as part of the Illustrative Masterplan is outside the Coffs Harbour Coastal Hazard Zone Policy Area) - refer **Figure 1-7**. The Coastal Vulnerability Area Policy (Coffs Harbour City Council (Council), 2022) includes two requirements:

1. A Coastal Risk Management Report (this report) is required for Local Environment Plan Amendments that relate to land that is seaward of the 'unlikely' 2100 Coastal Hazard Line; and
2. A notation is to be placed on all areas within the local government area that are identified within the 100-year Coastal Hazard Zone. This notation states that any new development on the lot will need to address and mitigate the effects of coastal processes, such as erosion and inundation. Furthermore, it emphasizes that the Council mandates that residential and commercial/tourism development must remain resilient against coastal process impacts for a 100-year hazard event and an appropriate planning period duration (however, as outlined above, no residential or commercial/tourism development is proposed inside the Coffs Harbour Coastal Hazard Zone Policy Area by the Illustrative Masterplan).

It's important to note that this planning proposal does not include any form of development but instead nominates an Illustrative Masterplan that will guide future development within the Precinct. Accordingly, the exact timing and form of implementation is uncertain. Therefore, the assessment has considered coastal hazards at the end of three planning periods (2023, 2073, 2123), with a focus on the worst-case scenario based on the 100-year planning period (2123). Should any development be planned for implementation beyond this date, an updated Coastal Risk Management Report will be required.

To complete a contemporary Coastal Risk Management Report, it is considered prudent to undertake a probabilistic Coastal Hazard Assessment (CHA) in line with industry leading practice.

Figure 1-7: Coffs Harbour Coastal Hazard Zone Policy Area (shaded in red) and the Coffs Harbour Jetty Foreshore Precinct boundary (red dash-dot line)

For this assessment, the Precinct has been divided into four areas, as shown by the black regions in

Figure 1-4 and **Figure 1-6**:

- North Boambee Beach;
- Jetty Beach Block 1;
- Jetty Beach Block 2; and,
- Jetty Beach Block 3.

The division of the Precinct is based on the datasets used in this assessment. Profile information, including stereo photogrammetry and LiDAR (light detection and ranging), was obtained from the NSW Beach Profile Database (OEH), which organises the study area into four blocks (**Figure A1-3**).

1.2.1 North Boambee Beach

North Boambee Beach is situated directly south of the anthropogenic connection that forms Coffs Harbour (between natural rock outcrops/island) and spans approximately 200 meters south along Boambee Beach (**Figure 1-8**). The beach consists of fine-grained sand and faces the southeast, receiving the full impact of the predominant wave climate. As a result, it has developed a well-defined double sand bar system. The inner transverse bar exhibits regular rips across its length, while a broad deep trough has formed between the inner and outer bars. Conversely, the outer bar, is generally continuous. Boambee Beach is backed by extensive foredunes, ranging in height from approximately 10 to 20 meters. It's worth noting that sand mining took place in the hind dune ridges during the 1960s and 1970s (BMT, 2011).

The northernmost section of Boambee Beach, located in front of the anthropogenic connection that forms Coffs Harbour, is commonly referred to as Gallows Beach. This particular stretch spans 150 meters and experiences occasional erosion, resulting in the formation of a cobble beach that exposes the underlying bedrock and the land bridge made of rocks. Adjacent to Gallows Beach, there is a gravel and bitumen car park that serves as a facility for recreational use of Gallows Beach (a popular summertime surf beach). Please note that hazard lines were not generated for this specific area due to the unavailability of data. However, the existing rock revetment wall in this location is very important as it acts as a terminal protective barrier against coastal erosion, stabilising the shoreline by preventing the direct impact of waves and currents on the beach (important for this section of the beach as it experiences occasional erosion). The revetment wall also helps safeguard the surrounding infrastructure, including the gravel and bitumen car park, road network and the Coffs Harbour regional boat ramp facility (boat ramp) on the harbourside of this protected area. By reducing the erosive forces of the surf, the revetment wall helps maintain the integrity of these facilities and prevents potential damage.

Boambee Beach has experienced a sustained trend of accretion in response to the construction of Coffs Harbour breakwaters. The harbour has constrained the transport of sediment from Boambee into the harbour and beaches beyond, resulting in accretion on Boambee Beach of approximately +1.82 m per year (**Table A1-1**).

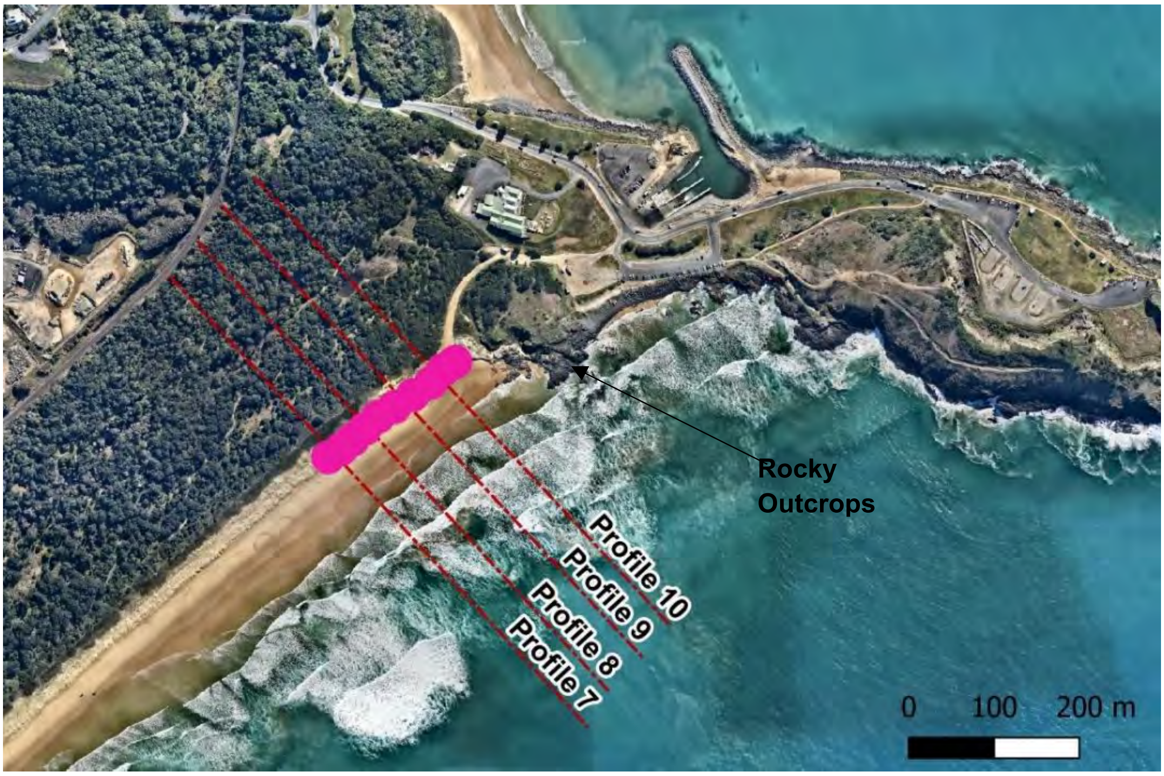

Figure 1-8: North Boambee Beach Coastal Hazard Assessment Area

1.2.2 Jetty Beach Block 1

Jetty Beach Block 1 is situated in the southern part of Jetty Beach, immediately adjacent to the boat ramp, and stretches approximately 550 meters northward (**Figure 1-9**). It is backed by a wide dune system, measuring approximately 80 meters in width, followed by a spacious park and picnic area. Jetty Beach is located within the harbour and enjoys substantial protection from harbour breakwaters and Muttonbird Island. It's essential to mention that the harbour undergoes controlled dredging to ensure navigability. Additionally, the wave height at Jetty Beach rarely exceeds 0.5 meters.

Jetty Beach demonstrates clear evidence of long-term accretion, likely attributed to the construction of the harbour. Sediment that bypasses the eastern breakwater is known to be infilling the harbour at rates ranging from 25,000 to 50,000 cubic meters per year, while also being deposited onto Jetty Beach. Analysis of photogrammetry profiles conducted along Jetty Beach Block 1 has revealed an average long-term shoreline accretion rate of approximately +1.25 meters per year (**Table A1-2**).

Figure 1-9: Jetty Beach Block 1 Coastal Hazard Assessment Area

1.2.3 Jetty Beach Block 2

Jetty Beach Block 2 is situated in the northern part of Jetty Beach, adjacent to the Coffs Harbour Marina, and stretches approximately 320 meters (**Figure 1-10**). It is backed by a robust dune system, measuring approximately 35 meters in width, followed by a spacious park and picnic area. Jetty Beach is located within the harbour and enjoys significant protection from harbour breakwaters and Muttonbird Island. It's important to mention that the harbour undergoes controlled dredging to ensure navigability. Furthermore, the wave height at Jetty Beach rarely exceeds 0.5 meters.

Jetty Beach exhibits clear signs of long-term accretion, most likely attributed to the construction of the harbour. Sediment bypassing the eastern breakwater is known to be infilling the harbour at rates ranging from 25,000 to 50,000 cubic meters per year, while also being deposited onto Jetty Beach. Analysis of photogrammetry Profiles conducted along Jetty Beach Block 2 has revealed an average long-term shoreline accretion rate of approximately +0.39 meters per year (**Table A1-3**).

Figure 1-10: Jetty Beach Block 2 Coastal Hazard Assessment Area

1.2.4 Jetty Beach Block 3

Jetty Beach Block 3, also known as Park Beach South (or North Wall), extends northward from the landward most point of the Coffs Harbour northern breakwater, which connects to Muttonbird Island, and stretches for 250 meters toward the mouth of Coffs Creek (**Figure 1-11**). The northern breakwater extends into a rock revetment wall located immediately behind the southern end of Park Beach South. Between the revetment wall and the water's edge, there's a narrow beach strip that is frequently covered by high tide. At the southern end, there's a car park just inland from the revetment, and a small ramp provides access to the beach.

Jetty Beach Block 3 is characterised by flat open grassland, with recent shrub and tree planting. The waves at this beach are typically small, with an average height of less than 1 meter, thanks to the protection provided by the northern breakwater, Muttonbird Island to the south, and Little Muttonbird Island to the north.

Jetty Beach Block 3 shows signs of shoreline retreat, primarily due to the disruption of the northward movement of sediment along this coastline, mainly influenced by the presence of the harbour breakwaters. An analysis of photogrammetry Profiles conducted along Jetty Beach Block 3 has revealed an average long-term shoreline recession rate of approximately -0.09 meters per year (**Table A1-4**).

The revetment wall, at the southern end of Park Beach South was constructed to safeguard the infrastructure behind the southern corner, near the northern breakwater. Approximately 130 meters of the beach is shielded by this revetment wall. However, the remaining area is vulnerable to coastal erosion. In places where a certified engineered seawall has been built, it provides effective protection from beach erosion (erosion does not extend landward of the revetment), permitting infrastructure to be situated in the landward area behind the wall.

Figure 1-11: Jetty Beach Block 3 Coastal Hazard Assessment Area

1.3 Sand Transport

The open coastline along NSW is subject to a net northward trend in longshore sediment transport, with a regional average longshore transport rate in the order of 75,000 m^3/year at Coffs Harbour. As such, the legacy construction of Coffs Harbour has resulted in profound changes in sediment transport throughout the coastal region over time with steady accretion at the northern end of Boambee Beach, and subsequent recession of Park Beach. The recessionary effect decreases with distance from the harbour, ceasing around the northern end of Moonee Beach (BMT WBM, 2019, **Figure 1-12**).

The infilling of the harbour is also a consequence of the impact on regional sediment transport processes as a result of the harbour's construction. Several studies have estimated the sediment that flows past the eastern breakwater and accumulates in the harbour, with reported rates ranging from approximately 25,000 cubic meters per year (Lord and Van Kerkvoort, 1981) to as high as 50,000 cubic meters per year (Carley *et al.*, 2006). This could be linked to local features (e.g., sediment from shoals offshore of Boambee Beach) or broader climatic forcing (e.g., El Niño / La Niña phases).

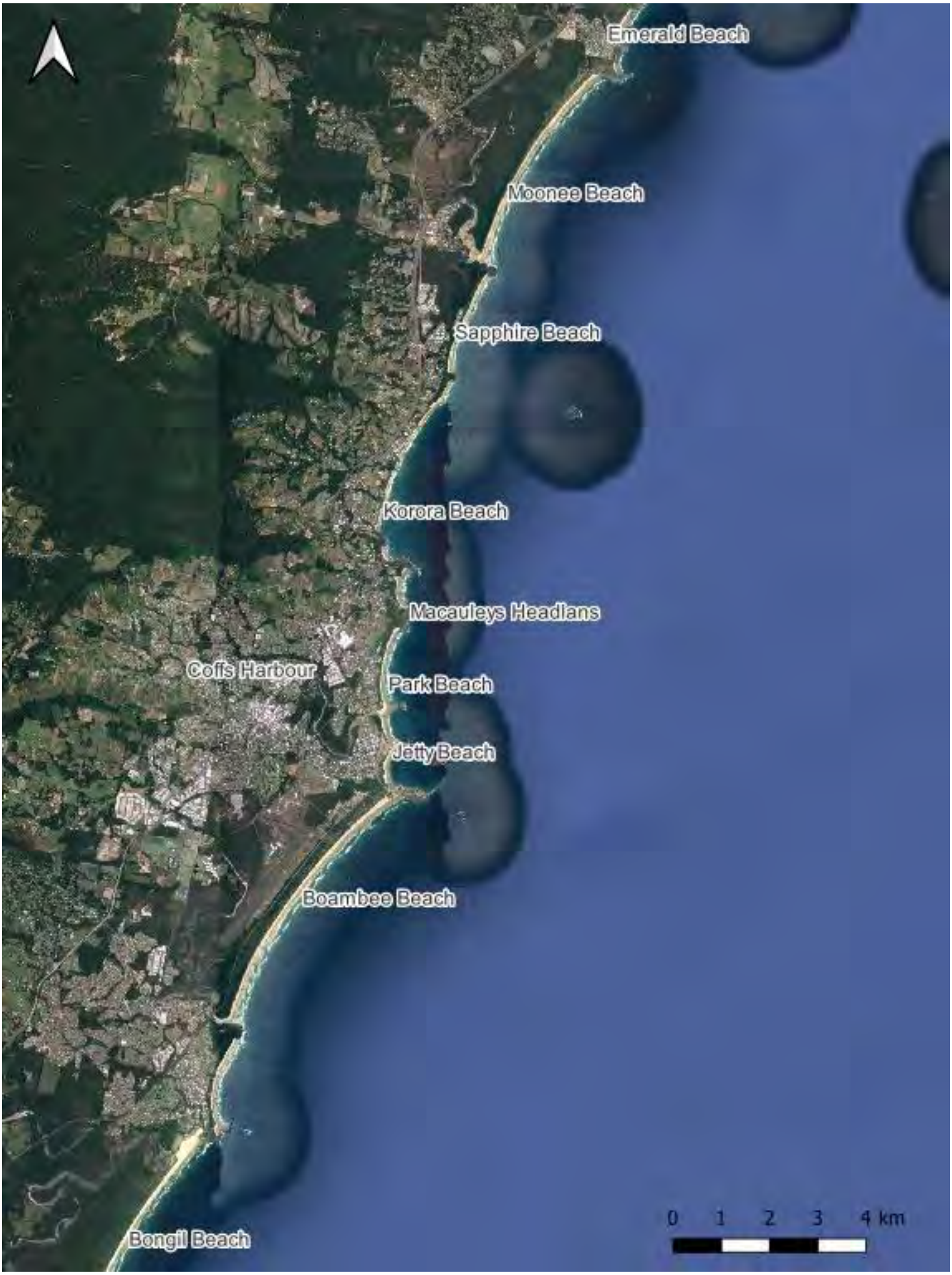

Figure 1-12: Locality plan

2 Methodology to Analyse Vulnerability and Quantify Risk

2.1 Design Philosophy

Figure 2-1 outlines the risk assessment pathway recommended by The National Committee of Coastal and Ocean Engineering of Engineers Australia that should be considered when designing structures where inherent risks exist. This approach has been adopted for the Precinct Illustrative Masterplan coastal hazard vulnerability and risk assessment.

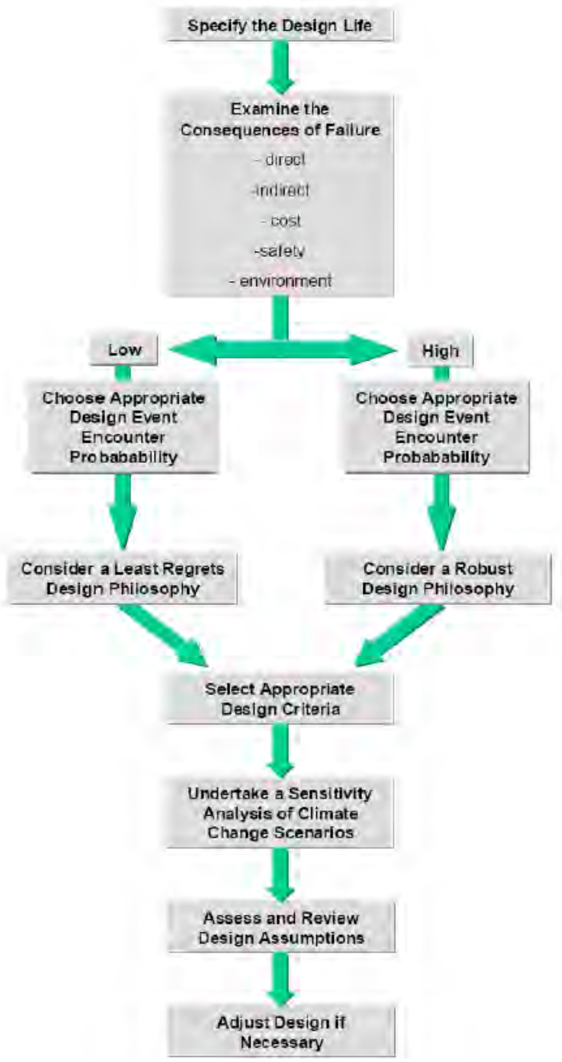

Figure 2-1: Risk-based design flow chart

2.2 Design Life

In specifying design life, the period for which a structure remains fit for its intended purpose, with appropriate maintenance, needs to be considered. The design life of a structure governs the period over which risks are assessed. That is, risks to infrastructure will be determined as being acceptable or not acceptable, based on the risk of damage to the structure at the end of the design life.

The design life of a structure should be related to the typical design life of its components, such as steel, masonry and timber. The design life used in various Australian Standards are as follows:

- In *AS 5100.01, Bridge Design,* the design life is 100 years for a road or rail bridge;
- in *AS 1170.0 - Structural Design Actions - General Principles*, the design life for normal structures (Importance Level 2) is generally taken as 50 years;
- in *AS 4997 - Guidelines for the Design of Maritime Structures*, the design life for temporary works is specified as 5 years or less, small craft facility as 25 years, normal commercial structure as 50 years, and special structures/residential development as 100 years, or more.

In the context of the above, the types and usage functions of the infrastructure being considered herein are most akin to:

- small craft facilities as defined by *AS 4997 - Guidelines for the Design of Maritime Structures.* Typically, these structures are decks, boardwalks, floating walkways/breakwaters, marina harbour master towers and the like, providing access and observation points on relatively sheltered foreshores that will be subject to low frequency extreme metocean conditions;
- normal commercial structures; and,
- residential and tourist accommodation development.

The residential developments outlined in the Illustrative Masterplan are located outside the designated coastal hazard zone policy area (**Figure 1-7**). The proposed infrastructure that will most likely fall within the erosion hazard area will be small craft facilities and normal commercial structures, typically designed with a lifespan of 50 years (50-year design life).

2.3 Design Event

Table 5.4 of *AS 4997* suggests that the design wave events[1] that should be considered are as follows for:

1. "Structures presenting a low degree of hazard to life and property" – 50-year average recurrence interval (ARI);
2. "Normal structures" – 200-year ARI; and,
3. "High property value of high risk to people" – 500-year ARI

Only risk to property is considered herein, not risk to life. In the coastal zone context, risk to life related to development of a structure setback from the beach can be considered acceptably low as:

- Coastal storms (large waves and elevated water levels) are generally foreseeable at least 24 hours in advance, with warnings issued by the Bureau of Meteorology;
- Astronomical tides are a large component of elevated water levels, which can be accurately predicted decades into the future;
- erosion, dangerous wave overtopping and associated coastal inundation would generally be expected to be greatest for a few hours near the peak of the tide;
- the progress of erosion on a beach is visible and perceptible. Generally, it is highly unlikely to proceed undetected and damage development or result in sudden and catastrophic failure;
- it is highly unlikely that a person would be occupying infrastructure and would be unaware (or would not have been made aware) that the infrastructure was at imminent threat from coastal hazards; and
- the State Emergency Service (SES), if mobilised, has powers to warn and evacuate people if required (as does NSW Police).

[1] *AS 4997 notes these should be considered in combination with design water levels not less than mean high water springs*

These factors mean that people would have a very low probability of occupancy and/or loss of life during an actual storm event that could threaten ancillary infrastructure, and hence there is a very low risk to life in such an event.

However, there is still the risk to the infrastructure which is not “low”. Accordingly, the design oceanic storm event recommended is a 100-year average recurrence interval (ARI) event (equivalent to a 1% AEP event). In the context of risk from coastal processes generally, this relates to storm erosion demand or coastal dune overtopping and inundation which can be produced by a storm or a series of closely spaced storms, with varying ARIs with respect to wave heights, wave periods and water level. However, the design event should be considered in the basis of all specific design elements (e.g. structural design to accommodate wave impacts on structures).

2.4 Recognition of Uncertainty

The risk-based design philosophy broadly illustrated by **Figure 2-1**, suggests that sensitivity analysis of climate change scenarios be undertaken. In adopting the risk-based approach, it is important to recognise that regardless of climate change scenarios, future climate cannot be predicted precisely as it is subject to storm variability and longer-term cycles such as the Southern Oscillation Index (El Nino / La Nina), Southern Annular Modulus, Pacific Decadal Oscillation, and Interdecadal Pacific Oscillation (IPO).

Future climate can also not be predicted precisely due to ongoing climate change caused by the enhanced greenhouse effect.

To account for these uncertainties in both existing and future climatology, and in line with the risk based approach in **Figure 2-1**, the approach adopted in this investigation is to determine probabilistically the future shoreline position to define coastal hazard and hence inform decisions about the design of infrastructure within the coastal vulnerability area. Monte Carlo simulation of key design parameters (including sea level rise) represented as a probability density function, allows for tens of thousands of simulations to be analysed to account for uncertainty. More detail on the probabilistic assessment of coastal hazards is provided in **Appendix A**.

2.5 Operational Requirements

Infrastructure in the active beach zone and dune system requires ongoing maintenance to accommodate the harsh coastal environment and varying beach condition. However, the requirement for operational maintenance to maintain infrastructure in an operational condition should be minimised through the design process. Consideration of the required capital expenditure against maintenance expenditure is important when considering the relative benefits of a low maintenance regime.

As part of the design process, consideration should be given to the formulation of a monitoring and maintenance plan that outlines key monitoring requirements of particular infrastructure and triggers for intervention.

3 Vulnerability and Risk Assessment

A risk and vulnerability assessment was undertaken using the information provided in **Appendix A**. The following assessments were completed:

- Erosion hazard risk assessment; and,
- Wave overtopping risk assessment.

The erosion hazard risk assessment used a probabilistic approach, whereby each input variable (underlying recession, recession due to SLR and storm demand) were assigned a single value, which was fed into the Monte-Carlo simulation (refer to **Appendix A1**). With the outputs from the Monte-Carlo simulation, hazard maps (zone of slope adjustment and zone of reduce foundation capacity) and the hazard risk were determined.

The overtopping assessment was based on the following inputs (refer to **Appendix A2**):

- Dune crest height;
- Beach foreshore slope;
- SLR by 2123;
- 100-year ARI storm tide;
- 100-year ARI wave height; and
- 100-year ARI wave period.

An analysis using the above results was applied to the following sites to determine site specific coastal vulnerability risk (**Figure 1-2**):

1. South of Coffs Harbour (North Boambee Beach)
2. Inside Coffs Harbour (Jetty Beach Block 1)
3. Inside Coffs Harbour (Jetty Beach Block 2)
4. North of Coffs Harbour (Jetty Beach Block 3)

3.1 Note on Existing Coastal Erosion Hazard Assessment Methodology

It is noted that the existing Coffs Harbour Coastal Hazard Zone Policy Area as shown in **Figure 1-7** is based on BMT WBM (2011) and represents the ‘unlikely’ 2100 Coastal Hazard Line. All residential and commercial/tourism developments proposed as part of the Illustrative Masterplan are landward of the BMT WBM (2011) ‘unlikely’ 2100 Coastal Hazard Line. However, the (deterministic) assessment methodology and resulting hazard line applied by BMT WBM (2011) is deemed overly conservative and a more contemporary, probabilistic, coastal erosion hazard assessment methodology has been utilised in this study (Coastal Risk Management Report). A separate, comparative assessment of the BMT WBM (2011) methodology and the methodology applied in this report was conducted and the following key take-aways are highlighted:

- BMT WBM (2011) was a broad extent regional assessment, this current study is a site-specific assessment;
- BMT WBM (2011) utilises a deterministic approach in their coastal erosion hazard assessment, whereas this current study applies a probabilistic approach (which is the contemporary accepted industry standard), to incorporate the natural variability in erosion processes and the inherent variability due to the limited understanding or lack of long-term data. Deterministic approaches are typically overly conservative;

- BMT WBM (2011) uses outdated SLR projections for their ‘unlikely’ hazard likelihood zone. This current study uses the latest SLR estimates (IPCC, 2021) and in addition accounts for uncertainty (minimum, modal and maximum trajectories);
- While the Coastal Vulnerability Policy Zone is based on BMT WBM’s (2011) ‘unlikely’ scenario and is more conservative than the hazard lines estimated in this current study, as its comparable 2100 SLR estimate is actually more conservative;
- BMT WBM (2011) uses the ‘unlikely’ beach erosion hazard extent at Coffs Harbour, which this current study after analysis has found to be excessive and not feasible;
- Probabilistic coastal hazard assessments are currently common industry practice, and application of a deterministic approach is rare, if it occurs at all;
- The NSW Government suggests in their Coastal Management Manual (OEH, 2019) the use of detailed coastal erosion hazards studies where ‘new measurements or modelling tools become available that would significantly reduce the uncertainty around, and/or change, previous risk assessment’;
- This current study has access to additional measured data collected between publication of BMT WBM (2011) and the time of writing of this current study. Additional historical data reduces uncertainty in data analyses and increases confidence in the coastal erosion hazard assessment.

3.2 Erosion

A comprehensive analysis of coastal erosion hazard has been conducted for the Precinct, utilising a probabilistic approach. This assessment considers various factors contributing to erosion vulnerability, including underlying recession, recession caused by projected sea level rise, and storm erosion. The evaluation also considers the various zones of influence of storm erosion; the Zone of Wave Impact (ZWI), the Zone of Slope Adjustment (ZSA), the Zone of Reduced Foundation Capacity (ZRFC) and the stable foundation zone, after Nelson *et al*. (1992) (refer **Figure A1**).

A risk assessment (refer to **Appendix A3**) has been undertaken based on the probabilistic coastal hazard assessment (PCHA, **Appendix A1**), which considers the likelihood and consequence of impacts associated with beach erosion on any infrastructure located within the various zones of influence of storm erosion (ZWI, ZSA, ZRFC). **Table 3-1** further describes the zones of erosion and indicates the potential impact on infrastructure located in these zones.

For each zone of erosion impact, the likelihood and consequence were assessed based on the criteria in **Table 3-2** and calculations performed to determine the risk rating (likelihood multiplied by consequence). As a result, the zone with the highest risk was identified among the locations identified by setback distance from the dune vegetation line. Erosion risk has been identified as low, medium, high or extreme (**Table** 3-3).

The erosion risk assessment involved grouping all types of infrastructure together (for example, a building and a boardwalk were treated as having the same consequence) (**Table 3-2**). Additionally, a subsequent assessment was conducted to determine the acceptable risk for different types of infrastructure (however, it is noted again that the Illustrative Masterplan does not have any residential or commercial/tourism development within the Coffs Harbour Coastal Hazard Zone Policy Area). The criterion for acceptable risk, as published in the Australia Geomechanics Society (AGS) is presented below (refer to **Section A3.4**):

- Importance Level 1: Boardwalk, landscaping, carpark and ancillary infrastructure (accept medium risk)
- Importance Level 2: Residential building and community building (accept low risk).

It should be noted that where a revetment wall has been constructed and certified to current engineering standards, erosion would not extend landward of the revetment wall for events up to and including the design storm event.

Table 3-1: Description of hazard zones and potential impact on infrastructure

Zone of Wave Impact (ZWI)	delineates an area where any structure or its foundations would suffer direct wave attack during a severe coastal storm. It is that part of the beach which is seaward of the beach erosion escarpment.	Infrastructure within the ZWI would be either destroyed or severely damaged.
Zone of Slope Adjustment (ZSA)	is delineated to encompass that portion of the seaward face of the beach that would slump to the natural angle of repose of the beach sand following storm erosion.	Infrastructure within the ZSA would be severely damaged.
Zone of Reduced Foundation Capacity (ZRFC)	for building foundations is delineated to take account of the reduced bearing capacity of the sand adjacent to the storm erosion escarpment. Nielsen *et al*. (1992) recommended that structural loads should only be transmitted to soil foundations outside of this zone (i.e. situated landward or founded on piles), as the factor of safety within the zone is less than 1.5 during extreme scour conditions at the face of the escarpment.	Infrastructure within the ZRFC would be at risk of severe damage without immediate or prior (e.g. piled foundations) intervention.
Stable Foundation Zone	This refers to an area where the underlying soil or bedrock is stable and capable of supporting structures and is not at risk of erosion.	Infrastructure within this zone would be at no risk of erosion.

Table 3-2: Likelihood and consequence criteria for erosion risk

Consequence	Erosion Description	Likelihood	Probability (position)	Risk Level
1 Insignificant	Infrastructure located within Stable Foundation Zone	1 Rare	0 to 10	Very Low
2 Minor	Infrastructure located within Stable Foundation Zone	2 Unlikely	10 to 30	Low
3 Moderate	Infrastructure located within Reduced Foundation Capacity	3 Possible	30 to 70	Medium
4 Major	Infrastructure located within Zone of Slope Adjustment	4 Likely	70 to 90	High
5 Catastrophic	Infrastructure located within Zone of Wave Impact	5 Almost Certain	90 to 100	Extreme / High

Table 3-3: Erosion Risk Score Definitions

Erosion Risk Assessment Score	Action Required
Extreme (15 – 25) High (10 – 14)	Unacceptable risk requires immediate attention to eliminate or reduce risk.
Medium (5 – 9)	Control the risks and hazards. If residual risk exists, which are not possible to control, work may proceed provided stakeholder understand the residual risk.
Low (1 – 4)	Acceptable to tolerable risk, work can proceed

3.2.1 North Boambee Beach

Table 3-4, **Table 3-5** and **Table 3-6** present the maximum risk profile for North Boambee Beach for the 2023 (present), 2073 (50 years) and 2123 (100 years) planning periods both seaward and landward of the dune vegetation line.

In the Illustrative Masterplan all the example infrastructure types in the North Boambee Beach section (regional tourist destination, **Section 1.3**) are located behind the existing revetment wall and therefore not at risk of erosion. An erosion risk assessment has still been undertaken (**Figure 3-2**, below) for the area to the south of rocky outcrops (refer **Figure 1-8**), despite there not being any proposed infrastructure in this area. The assessment indicates that if infrastructure was to be constructed in this area it would have a very low risk of erosion impact. If the infrastructure is planned to be at least 30m behind the dune vegetation line, there is no risk of erosion now and 100 years in the future (2123).

Table 3-4: Erosion Hazard Risk at North Boambee Beach for 2023

Distance from Dune Veg Line in metres (positive = seaward, negative = landward)	Maximum Erosion Risk Assessment				
	Consequence	Likelihood	Risk Rating	Description	Zone
-30	N/A	N/A	N/A	N/A	N/A
-20	N/A	N/A	N/A	N/A	N/A
-15	3 (Moderate)	1 (Rare)	3	Low	ZRFC
-10	3 (Moderate)	1 (Rare)	4	Low	ZRFC
-5	3 (Moderate)	1 (Rare)	3	Low	ZRFC
0 (Vegetation Line)	4 (Major)	1 (Rare)	4	Low	ZSA
10	4 (Major)	1 (Rare)	4	Low	ZSA
Note: where a revetment has been constructed, erosion would not extend seaward of the revetment.					

Table 3-5: Erosion Hazard Risk at North Boambee Beach for 2073

Distance from Dune Veg Line in metres (positive = seaward, negative = landward)	Maximum Erosion Risk Assessment				
	Consequence	Likelihood	Risk Rating	Description	Zone
-30	N/A	N/A	N/A	N/A	N/A
-20	3 (Moderate)	1 (Rare)	3	Low	ZRFC
-15	3 (Moderate)	1 (Rare)	3	Low	ZRFC
-10	4 (Major)	1 (Rare)	4	Low	ZSA
-5	4 (Major)	1 (Rare)	4	Low	ZSA
0 (Vegetation Line)	4 (Major)	1 (Rare)	4	Low	ZSA
10	3 (Moderate)	2 (Unlikely)	6	Medium	ZRFC
Note: where a revetment has been constructed, erosion would not extend seaward of the revetment.					

Table 3-6: Erosion Hazard Risk at North Boambee Beach for 2123

Distance from Dune Veg Line in metres (positive = seaward, negative = landward)	Maximum Erosion Risk Assessment				
	Consequence	Likelihood	Risk Rating	Description	Zone
-30	N/A	N/A	N/A	N/A	N/A
-20	3 (Moderate)	1 (Rare)	3	Low	ZRFC
-15	3 (Moderate)	1 (Rare)	3	Low	ZRFC

-10	4 (Major)	1 (Rare)	4	Low	ZSA
-5	4 (Major)	1 (Rare)	4	Low	ZSA
0 (Vegetation Line)	4 (Major)	1 (Rare)	4	Low	ZSA
10	3 (Moderate)	2 (Unlikely)	6	Medium	ZRFC
Note: where a revetment has been constructed, erosion would not extend seaward of the revetment.					

3.2.2 Jetty Beach Block 1

Table 3-7,**Table 3-8** and **Table 3-9** present the maximum risk profile for Jetty Beach Block 1 for the 2023 (present), 2073 (50 years) and 2123 (100 years) planning periods both seaward and landward of the dune vegetation line.

In the Jetty Beach Block 1 area, in the Illustrative Masterplan, the only example infrastructure type within 30 meters landward of the dune vegetation line is a small portion of the boardwalk located to the south (**Figure 3-3**, below). All other infrastructure types in the Illustrative Masterplan are indicated to be positioned well behind the projected 2123 erosion hazard lines.

According to the assessment, the infrastructure type situated 30 meters landward of the dune vegetation line (the boardwalk section) is determined to have a low risk of erosion for the years 2023 (current), 2073 (50 years), and 2123 (100 years). The likelihood of erosion reaching this area is considered rare, indicating that the chances of erosion affecting this specific location will probably never occur or may happen in exceptional circumstances.

If infrastructure was planned to be placed more seaward (for example within 20m landward to the dune vegetation line) by 2073, it would be subjected to a medium risk of erosion. If the infrastructure is categorised as importance level 1, it could be considered appropriate to be constructed in this area as the acceptable risk is medium. However, since there is no infrastructure proposed for this area in the Illustrative Masterplan, the risk of erosion to the infrastructure remains low to non-existent.

Table 3-7: Erosion Hazard Risk at Jetty Beach Block 1 for 2023

Distance from Dune Veg Line in metres (positive = seaward, negative = landward)	Maximum Erosion Risk Assessment				
	Consequence	Likelihood	Risk Rating	Description	Zone
-30	3 (Moderate)	1 (Rare)	3	Low	ZRFC
-20	3 (Moderate)	1 (Rare)	3	Low	ZRFC
-15	4 (Major)	1 (Rare)	4	Low	ZSA
-10	3 (Moderate)	1 (Rare)	4	Low	ZRFC
-5	3 (Moderate)	2 (Unlikely)	6	Medium	ZRFC
0 (Vegetation Line)	3 (Moderate)	2 (Unlikely)	6	Medium	ZRFC
10	3 (Moderate)	3 (Possible)	9	Medium	ZRFC
Note: where a revetment has been constructed, erosion would not extend landward of the revetment.					

Table 3-8: Erosion Hazard Risk at Jetty Beach Block 1 for 2073

Distance from Dune Veg Line in metres (positive = seaward, negative = landward)	Maximum Erosion Risk Assessment				
	Consequence	Likelihood	Risk Rating	Description	Zone

-30	4 (Major)	1 (Rare)	4	Low	ZSA
-20	3 (Moderate)	2 (Unlikely)	6	Medium	ZRFC
-15	3 (Moderate)	2 (Unlikely)	6	Medium	ZRFC
-10	3 (Moderate)	3 (Possible)	9	Medium	ZRFC
-5	3 (Moderate)	3 (Possible)	9	Medium	ZRFC
0 (Vegetation Line)	3 (Moderate)	3 (Possible)	9	Medium	ZRFC
10	4 (Major)	3 (Possible)	12	High	ZSA
Note: where a revetment has been constructed, erosion would not extend landward of the revetment.					

Table 3-9: Erosion Hazard Risk at Jetty Beach Block 1 for 2073

Distance from Dune Veg Line in metres (positive = seaward, negative = landward)	Maximum Erosion Risk Assessment				
	Consequence	Likelihood	Risk Rating	Description	Zone
-30	4 (Major)	1 (Rare)	4	Low	ZSA
-20	3 (Moderate)	2 (Unlikely)	6	Medium	ZRFC
-15	3 (Moderate)	2 (Unlikely)	6	Medium	ZRFC
-10	3 (Moderate)	3 (Possible)	9	Medium	ZRFC
-5	3 (Moderate)	3 (Possible)	9	Medium	ZRFC
0 (Vegetation Line)	3 (Moderate)	3 (Possible)	9	Medium	ZRFC
10	4 (Major)	3 (Possible)	12	High	ZSA
Note: where a revetment has been constructed, erosion would not extend landward of the revetment.					

3.2.3 Jetty Beach Block 2

Table 3-10, **Table 3-11** and **Table 3-12** present the maximum risk profile for Jetty Beach Block 2 for the 2023 (present), 2073 (50 years) and 2123 (100 years) planning periods both seaward and landward of the dune vegetation line.

In the Jetty Beach Block 2 area, in the Illustrative Masterplan, there is no infrastructure type located within 30 meters landward of the dune vegetation line (**Figure 3-4**, below). The community building is located 40 meters landward and all other infrastructure in the Illustrative Masterplan is indicated to be positioned well behind the projected 2123 erosion hazard lines.

According to the erosion hazard assessment, the infrastructure situated 40 meters landward of the dune vegetation line (front edge of the community building) is at no risk of erosion for the years 2023 (current) and 2073 (50 years), which would cover the design life of this structure. By 2123 (100 years) there is only a low risk of erosion and the likelihood of erosion reaching this area is considered rare, indicating that the chances of erosion affecting this specific location will probably never occur or may only happen in exceptional circumstances.

If infrastructure were planned to be placed more seaward (for example within 30m landward to the dune vegetation line) by 2123, it would be subjected to a medium risk of erosion. If the infrastructure type is categorised as importance level 1, it could be considered appropriate to be constructed in this area as the acceptable risk is medium. However, since there is no infrastructure proposed for this area in the Illustrative Masterplan, the risk of erosion to the infrastructure remains low to non-existent.

Table 3-10: Erosion Hazard Risk at Jetty Beach Block 2 for 2023

Distance from Dune Veg Line in metres (positive = seaward, negative = landward)	Maximum Erosion Risk Assessment				
	Consequence	Likelihood	Risk Rating	Description	Zone
-40	N/A	N/A	N/A	N/A	N/A
-30	3 (Moderate)	1 (Rare)	3	Low	ZRFC
-20	3 (Moderate)	1 (Rare)	3	Low	ZRFC
-15	4 (Major)	1 (Rare)	4	Low	ZSA
-10	3 (Moderate)	1 (Rare)	4	Low	ZRFC
-5	3 (Moderate)	2 (Unlikely)	6	Medium	ZRFC
0 (Vegetation Line)	4 (Major)	2 (Unlikely)	8	Medium	ZSA
10	3 (Moderate)	3 (Possible)	9	Medium	ZRFC
Note: where a revetment has been constructed, erosion would not extend landward of the revetment.					

Table 3-11: Erosion Hazard Risk at Jetty Beach Block 2 for 2073

Distance from Dune Veg Line in metres (positive = seaward, negative = landward)	Maximum Erosion Risk Assessment				
	Consequence	Likelihood	Risk Rating	Description	Zone
-40	N/A	N/A	N/A	N/A	N/A
-30	3 (Moderate)	1 (Rare)	3	Low	ZRFC
-20	3 (Moderate)	2 (Unlikely)	6	Medium	ZRFC
-15	3 (Moderate)	3 (Possible)	9	Medium	ZRFC
-10	3 (Moderate)	3 (Possible)	9	Medium	ZRFC
-5	4 (Major)	3 (Possible)	12	High	ZSA
0 (Vegetation Line)	3 (Moderate)	5 (Almost Certain)	15	Extreme	ZRFC
10	4 (Major)	5 (Almost Certain)	20	Extreme	ZSA
Note: where a revetment has been constructed, erosion would not extend landward of the revetment.					

Table 3-12: Erosion Hazard Risk at Jetty Beach Block 2 for 2123

Distance from Dune Veg Line in metres (positive = seaward, negative = landward)	Maximum Erosion Risk Assessment				
	Consequence	Likelihood	Risk Rating	Description	Zone
-40	3 (Moderate)	1 (Rare)	3	Low	ZRFC
-30	4 (Major)	1 (Rare)	4	Low	ZSA
-20	3 (Moderate)	2 (Unlikely)	6	Medium	ZRFC
-15	3 (Moderate)	3 (Possible)	9	Medium	ZRFC
-10	3 (Moderate)	3 (Possible)	9	Medium	ZRFC
-5	4 (Major)	3 (Possible)	12	High	ZSA
0 (Vegetation Line)	3 (Moderate)	5 (Almost Certain)	15	Extreme	ZRFC
10	4 (Major)	5 (Almost Certain)	20	Extreme	ZSA
Note: where a revetment has been constructed, erosion would not extend landward of the revetment.					

3.2.4 Jetty Beach Block 3

Table 3-13, **Table 3-14** and **Table 3-15** present the maximum risk profile for Jetty Beach Block 3 for the 2023 (present), 2073 (50 years) and 2123 (100 years) planning periods landward of the dune vegetation line.

Where a revetment wall has been constructed and meets conventional engineering practice and industry standards, erosion would not extend landward of the revetment. Therefore, the example infrastructure types in the Illustrative Masterplan, located in the area behind the constructed revetment wall (estimated area provided in **Figure 3-1**) are protected from erosion.

Accordingly, the example infrastructure types that will be discussed are those not protected by the revetment wall. Specifically, the sporting court to the north and half of the carpark, are both indicated to be located within 80 meters landward of the dune vegetation line. The sporting court and carpark have been determined to have an importance level of 1, meaning the designated acceptable risk is medium.

Based on the erosion assessment, the carpark is at; no erosion risk in the current year (2023), low risk by 2073 (50 years), and extreme risk by 2123 (100 years). The sporting court is at; low erosion risk for 2023, medium risk by 2073, and extreme risk by 2123. The carpark and sport court have an acceptable level of erosion risk until 2073, indicating that this type of infrastructure is acceptable in this location (
Table 3-3). However, if the infrastructure is intended to endure beyond 2123, the risk increases to extreme, which is not an acceptable risk level, necessitating additional erosion protection measures or mitigation strategies to safeguard both the infrastructure and the safety of individuals.

Table 3-13: Erosion Hazard Risk at Jetty Beach Block 3 for 2023

Distance from Dune Veg Line in metres (positive = seaward, negative = landward)	Maximum Erosion Risk Assessment				
	Consequence	Likelihood	Risk Rating	Description	Zone
-80	N/A	N/A	N/A	N/A	N/A
-60	3 (Moderate)	1 (Rare)	3	Low	ZRFC
-40	4 (Major)	1 (Rare)	4	Low	ZSA
-30	3 (Moderate)	2 (Unlikely)	6	Medium	ZRFC
-20	3 (Moderate)	4 (Likely)	12	High	ZRFC
-10	3 (Moderate)	5 (Almost Certain)	15	Extreme	ZRFC
0 (Vegetation Line/ Revetment)	4 (Major)	5 (Almost Certain)	20	Extreme	ZSA
Note: where a revetment has been constructed, erosion would not extend landward of the revetment.					

Table 3-14: Erosion Hazard Risk at Jetty Beach Block 3 for 2073

Distance from Dune Veg Line in metres (positive = seaward, negative = landward)	Maximum Erosion Risk Assessment				
	Consequence	Likelihood	Risk Rating	Description	Zone
-80	4 (Major)	1 (Rare)	4	Low	ZSA
-60	3 (Moderate)	3 (Possible)	9	Medium	ZRFC
-40	4 (Major)	4 (Likely)	16	Extreme	ZSA
-30	4 (Major)	5 (Almost Certain)	20	Extreme	ZSA

-20	4 (Major)	5 (Almost Certain)	20	Extreme	ZSA
-10	4 (Major)	5 (Almost Certain)	20	Extreme	ZSA
0 (Vegetation Line/ Revetment)	4 (Major)	5 (Almost Certain)	20	Extreme	ZSA
Note: where a revetment has been constructed, erosion would not extend landward of the revetment.					

Table 3-15: Erosion Hazard Risk at Jetty Beach Block 3 for 2123

Distance from Dune Veg Line in metres (positive = seaward, negative = landward)	Maximum Erosion Risk Assessment				
	Consequence	Likelihood	Risk Rating	Description	Zone
-80	3 (Moderate)	5 (Almost Certain)	15	Extreme	ZSRFC
-60	4 (Major)	4 (Likely)	16	Extreme	ZSA
-40	4 (Major)	5 (Almost Certain)	20	Extreme	ZSA
-30	4 (Major)	5 (Almost Certain)	20	Extreme	ZSA
-20	4 (Major)	5 (Almost Certain)	20	Extreme	ZSA
-10	4 (Major)	5 (Almost Certain)	20	Extreme	ZSA
0 (Vegetation Line/ Revetment)	4 (Major)	5 (Almost Certain)	20	Extreme	ZSA
Note: where a revetment has been constructed, erosion would not extend landward of the revetment.					

Figure 3-1: Estimated erosion protection area due to revetment wall

3.3 Erosion Hazard Maps

The probability distribution curves produced as part of the erosion analysis (**Section 3.1**) considered the combined effects of sea level rise, underlying recession and storm demand.

Hazard lines have been determined for the following scenarios (**Appendix B**):

- Position of zone slope adjustment (ZSA) at present (2023);
- Position of zone reduced foundation capacity (ZRFC) at present (2023);
- Position of zone slope adjustment (ZSA) at 50 years (2073);
- Position of zone reduced foundation capacity (ZRFC) at 50 years (2073);
- Position of zone slope adjustment (ZSA) at 100 years (2123); and,
- Position of zone reduced foundation capacity (ZRFC) at 100 years (2123).

Different levels of exceedance are provided, indicating likelihood for input into the assessment of risk, but typically the 1% exceedance level is used to guide decision-making. A 1% exceedance level indicates that there is only a 1% probability that the hazard realised extends further landward than the calculated position indicated by the line. However, it's important to consider that the chosen exceedance level for risk assessment can vary depending on the type of infrastructure. For instance, a residential building where people's safety is a significant concern, the potential damage, injury or loss of life, and cost of reconstruction may warrant the use of a hazard line with a lower probability, as the consequences of the impact of erosion if it reached the infrastructure in question may be catastrophic. On the other hand, a boardwalk might experience less damage, incur lower costs, and pose no safety risk, allowing for a higher probability hazard line to be accepted.

Figure 3-2 to **Figure 3-5** below, illustrates the position of the ZRFC lines in 2123 relative to the infrastructure types in the Illustrative Masterplan for North Boambee Beach, Jetty Beach Block 1, Jetty Beach Block 2 and Jetty Beach Block 3, respectively. Note, where a revetment wall or coastal protection structure has been constructed and certified to engineering standards, erosion would not extend landward of the revetment wall for events up to and including the design storm event (100-year ARI).

Figure 3-2: Zone of Reduced Foundation Capacity at North Boambee Beach for the 2123 planning period overlain on the Illustrative Masterplan

Figure 3-3: Zone of Reduced Foundation Capacity at Jetty Beach Block 1 for the 2123 planning period overlain on the Illustrative Masterplan

Figure 3-4: Zone of Reduced Foundation Capacity at Jetty Beach Block 2 for the 2123 planning period overlain on the Illustrative Masterplan

Figure 3-5: Zone of Reduced Foundation Capacity at Jetty Beach Block 3 for the 2123 planning period overlain on the Illustrative Masterplan

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3.4 Overtopping

In addition to the erosion vulnerability assessment, an assessment of risk associated with wave overtopping has also been undertaken to assess the risk to people and safety (refer to **Appendix A2**) for various planning period.

Mitigation measures can be put in place to reduce the impact of overtopping and are most likely already in place to ensure the risk to life and property is managed appropriately. Measures may include:

- overtopping event forecasting and early warning, and,
- closure of access to at risk infrastructure during overtopping events.

Other mitigation measures could include increasing revetment wall heights for infrastructure potentially located behind coastal structures. The requirements for mitigation of overtopping volumes to acceptable levels for different infrastructure types would be determined during the development application process for specific sites and should be considered during the formal design stage.

3.4.1 North Boambee Beach

Wave overtopping analysis has been undertaken for a sand beach at North Boambee Beach Profile 9 (**Figure 1-8**). Note that overtopping of the existing revetment wall could not be undertaken as there was a lack of data (wall crest height, beach slope etc). The results of the wave overtopping assessment for Profile 9 (dune crest height 7.5m) is presented in **Table 3-16** for the 2023, 2073 and 2123 planning periods.

Table 3-16: Wave overtopping risk for North Boambee Beach Profile 9 2023, 2073 and 2123 planning periods

Section	Elevation and Slope	2023 Wave Overtopping Risk		2073 Wave Overtopping Risk		2123 Wave Overtopping Risk	
		Risk Rating	Description	Risk Rating	Description	Risk Rating	Description
Crest of dune	7.5m AHD dune height, 1V:38H	0	Low	0	Low	0	Low
Note: worst case scenario for a 2, 10, 25, 50 and 100-year ARI event.							

Because of the abundant dune vegetation, there is currently no risk of overtopping, and this will remain true in the future as long as any future infrastructure is built a safe distance away from the dune's base. If there are plans for future development in this area, it is crucial to prioritise the maintenance of this thriving dune system to enhance its resilience against coastal hazards, both now and in the years to come.

3.4.2 Jetty Beach Block 1

Wave overtopping analysis has been undertaken for a sandy beach at Profile 1 and Profile 10 **(Figure 1-9**). In relation to wave overtopping of a sandy beach, three elevations have been assessed; dune crest (4.2 m AHD), dune toe (2.8 m AHD) and the indicative location of example infrastructure types in this area. The results of the wave overtopping assessment for Profile 1 and Profile 10 are presented in **Table 3-17** and
Table *3-18*, respectively, for the 2023, 2073 and 2123 planning periods.

Table 3-17: Wave overtopping risk for Jetty Beach Block 1 Profile 1 2023, 2073 and 2123 planning periods

Section	Elevation and Slope	2023 Wave Overtopping Risk		2073 Wave Overtopping Risk		2123 Wave Overtopping Risk	
		Risk Rating	Description	Risk Rating	Description	Risk Rating	Description
Toe of dune	2.8m AHD dune height, 1V:34H	5	Medium	20	Extreme	25	Extreme
Crest of dune	4.2m AHD dune height, 1V:42H	0	Low	0	Low	4	Low
Proposed Infrastructure	2.9m AHD dune height, 1V:37H	5	Medium	6	Medium	25	Extreme
Note: worst case scenario for a 2, 10, 20, 50 and 100 year ARI event.							

Table 3-18: Wave overtopping risk for Jetty Beach Block 1 Profile 10 2023, 2073 and 2123 planning periods

Section	Elevation and Slope	2023 Wave Overtopping Risk		2073 Wave Overtopping Risk		2123 Wave Overtopping Risk	
		Risk Rating	Description	Risk Rating	Description	Risk Rating	Description
Toe of dune	2.9m AHD dune height, 1V:24H	20	Extreme	25	Extreme	25	Extreme
Crest of dune	3.7m AHD dune height, 1V:433H	0	Low	4	Low	12	High
Proposed Infrastructure	3.7m AHD dune height, 1V:33H	0	Low	4	Low	12	High
Note: worst case scenario for a 2, 10, 20, 50 and 100 year ARI event.							

Overall, the results show that the example infrastructure types in this area are currently at a medium/low risk of overtopping during extreme storm events which will increase to a high/extreme risk (depending on location) by 2123. It should be noted that EurOtop calculations used in the analysis are conservative in nature and do not account for the presence of a healthy vegetated foredune at this site. Vegetation provides roughness which significantly limits wave set-up and the propagation of wave bores into the dune. Maintenance of this healthy vegetated dune system is a key component to ensuring resilience in the face of coastal risks now and in the future.

3.4.3 Jetty Beach Block 2

Wave overtopping analysis has been undertaken for a sandy beach at Profile 2 and Profile 5 (**Figure 1-10**). In relation to wave overtopping of a sand beach, three elevations have been assessed; dune crest (4.2m AHD), dune toe (3.0 m AHD) and the indicative location of example infrastructure types in this area. The results of the wave overtopping assessment for Profile 2 and Profile 5 are presented in **Table 3-19** and **Table 3-20** respectively for the 2023, 2073 and 2123 planning periods.

Table 3-19: Wave overtopping risk for Jetty Beach Block 2 Profile 2 2023, 2073 and 2123 planning periods

Section	Elevation and Slope	2023 Wave Overtopping Risk		2073 Wave Overtopping Risk		2123 Wave Overtopping Risk	
		Risk Rating	Description	Risk Rating	Description	Risk Rating	Description
Toe of dune	3.0m AHD dune height, 1V:22H	20	Extreme	25	Extreme	25	Extreme

Crest of dune	4.2m AHD dune height, 1V:23H	4	Low	5	Medium	12	High
Proposed Infrastructure	4.0m AHD dune height, 1V:26H	4	Low	5	Medium	12	High
Note: worst case scenario for a 2, 10, 20, 50 and 100 year ARI event.							

Table 3-20: Wave overtopping risk for Jetty Beach Block 2 Profile 5 2023, 2073 and 2123 planning periods

Section	Elevation and Slope	2023 Wave Overtopping Risk		2073 Wave Overtopping Risk		2123 Wave Overtopping Risk	
		Risk Rating	Description	Risk Rating	Description	Risk Rating	Description
Toe of dune	2.5m AHD dune height, 1V:31H	20	Extreme	25	Extreme	25	Extreme
Crest of dune	3.6m AHD dune height, 1V:30H	3	Low	5	Medium	20	Extreme
Proposed Infrastructure	3.6m AHD dune height, 1V:30H	3	Low	5	Medium	20	Extreme
Note: worst case scenario for a 2, 10, 20, 50 and 100 year ARI event.							

Overall, the results show that the example infrastructure types in this area are currently at low risk of overtopping during extreme storm events which will increase to a high or extreme risk (depending on location) by 2123. It should be noted that the EurOtop calculations used in the analysis are conservative in nature and do not account for the presence of a healthy vegetated foredune at this site. Vegetation provides roughness which significantly limits wave set-up and the propagation of wave bores into the dune. Maintenance of this healthy vegetated dune system is a key component to ensuring resilience in the face of coastal risks now and in the future.

The assessment above does not factor in the Marina Precinct (**Figure 1-6**) regarding overtopping. The overtopping risk to the Marina Precinct remains unaffected by this planning proposal since the Illustrative Masterplan doesn't alter the current infrastructure type. The primary alteration in this area pertains to the height of the existing infrastructure. There's already an existing risk of overtopping in this area, which is actively managed by closing the breakwater during significant weather events. This risk will necessitate consideration during the detailed design phase for development approval. It might be essential to introduce new mitigation measures in the future.

3.4.4 Jetty Beach Block 3

Wave overtopping analysis has been undertaken for both a rock revetment structure at Profile 1 and a sandy beach at Profile 4 (**Figure 1-11**). In relation to wave overtopping of a sandy beach (Profile 4), two elevations have been assessed; dune crest (8.1m AHD) and dune toe (3.5 m AHD). The results of the wave overtopping assessment for Profile 1 and Profile 4 are presented in **Table 3-21** and **Table 3-22** respectively for the 2023, 2073 and 2123 planning periods.

Table 3-21: Wave overtopping risk for Jetty Beach Block 3 Profile 1 (revetment wall) 2023, 2073 and 2123 planning periods

Section	Crest Height	2023 Wave Overtopping Risk		2073 Wave Overtopping Risk		2123 Wave Overtopping Risk	
		Risk Rating	Description	Risk Rating	Description	Risk Rating	Description

Crest of revetment wall	6.3m AHD crest height	0	Low	3	Low	5	Medium
Note: worst case scenario for a 2, 10, 20, 50 and 100-year ARI event.							

Table 3-22: Wave overtopping risk for Jetty Beach Block 3 Profile 4 (sandy beach) 2023, 2073 and 2123 planning periods

Section	Elevation and Slope	2023 Wave Overtopping Risk		2073 Wave Overtopping Risk		2123 Wave Overtopping Risk	
		Risk Rating	Description	Risk Rating	Description	Risk Rating	Description
Toe of dune	3.5m AHD dune height, 1V:42H	6	Medium	16	Extreme	25	Extreme
Crest of dune	8.1m AHD dune height, 1V:42H	0	Low	0	Low	0	Low
Note: worst case scenario for a 2, 10, 20, 50 and 100-year ARI event.							

The results reveal a minimal risk of wave overtopping in both the 2023 and 2073 climate scenarios for the infrastructure situated behind the existing revetment wall (refer to **Table 3-21**). However, with the elevation of sea levels and the static nature of the revetment crest level, the overtopping risk escalates to a medium level by 2123. All infrastructure types outlined in the Illustrative Masterplan are positioned at least 30 meters away from the revetment wall, ensuring that overtopping will not impact the infrastructure in this vicinity.

The example infrastructure types indicated in the Illustrative Masterplan located to the north of the revetment wall (sport court and half the carpark) are at no risk from overtopping as they are indicated to be located behind the crest of the dune (8.1m high). Maintenance of this healthy vegetated dune system is a key component to ensuring resilience in the face of coastal risks now and in the future.

To ensure resilience against coastal risk, it is also crucial to maintain the existing revetment wall.

3.4.5 Overtopping Hazard Mapping

Risk assessments for wave overtopping and inundation have been undertaken and presented above in risk matrices. The risk assessment was undertaken for infrastructure inside the Coffs Harbour Coastal Hazard Zone Policy Area as depicted in **Figure 1-7**. As outlined previously, any residential and commercial/tourism development proposed in the Illustrative Masterplan is outside this Policy Area. However, given the sandy nature of the profiles and a setback in the order of 100m from the crest of the dune, where overtopping was assessed in **Section 3.4.1** to **Section 3.4.4**, to building developments in the Illustrative Masterplan, overtopping and inundation is likely to be negligible.

3.5 Climate Change

AdaptNSW provides guidance on how the NSW government proposes responding to climate change. Effectively this guidance directs the reader towards the International Panel for Climate Change (IPCC, 2021) documents for a definition of impacts (e.g. sea level rise). The guidance also directs agencies to be proactive, i.e., being prepared to act now to accommodate identified climate change risks before they are realised and present potentially serious (or insurmountable) challenges.

The climate in New South Wales is undergoing noticeable shifts, marked by an increase in the frequency and intensity of extreme weather events, alongside ongoing alterations to long-term weather patterns. The Climate Risk Ready NSW Guide has been developed by the Department of Planning, Industry and Environment (DPIE) with support from NSW Treasury to help NSW Government staff to lead, influence and enable their organisations to better understand their exposure to climate change risks and opportunities, and to develop plans to address them. **Figure 3-6** has been used to evaluate the impact of climate change by analysing various climate variables, assessing potential alterations to these variables, examining the resulting impacts, and evaluating the associated risks.

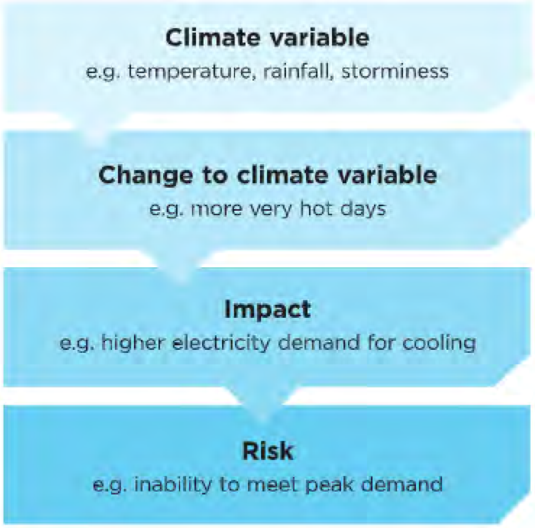

Figure 3-6: Links between climate change and risk (AGO 2006)

3.5.1 Wind

AS1170.02:2021 now integrates a climate change multiplier factor (Mc) to ascertain wind speed in specific regions across Australia. This multiplier factor acknowledges the potential influence of climate change on extreme wind conditions over the typical lifespan of structures designed in accordance with this standard, which typically ranges from 20 to 100 years, extending the applicability of the Mc factor until 2121. The values of Mc are subject to potential adjustments in forthcoming revisions, guided by observed or projected climate trends.

Coffs Harbour is situated between Region A2 and B1 (**Figure 3-7**) and currently has a Mc value of 1.0 (**Figure 3-8**). This indicates no expectation of wind speed changes due to climate change. As this standard embodies best practices within Australia, no adjustments for changes in wind speed resulting from climate change have been incorporated. Thus, based on the current understanding, wind waves (referred to as “local sea”) are not projected to change by 2121 according to the prevailing best practice information at this time.

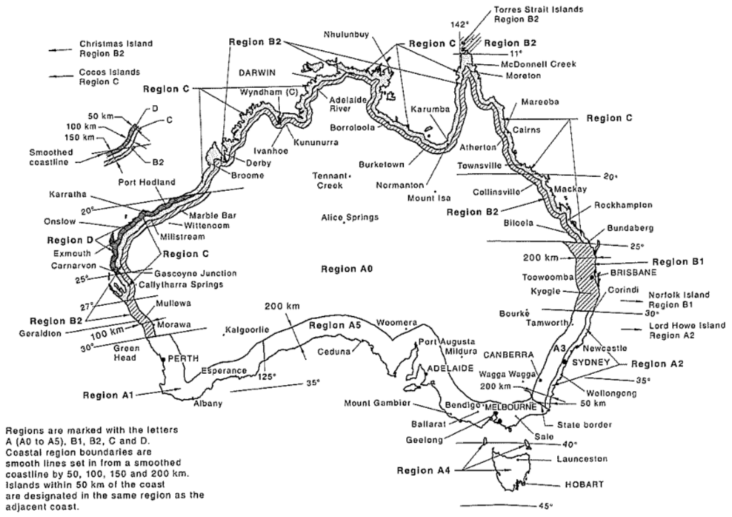

Figure 3.1(A) — Wind regions — Australia

Figure 3-7: Wind regions of Australia (source: Figure 3.1 (A) AS1170.02:2021)

Table 3.3 — Climate change multiplier (M_C)

Region	M_C
A (0 to 5)	1.0
B1	1.0
B2	1.05
C	1.05
D	1.05
NZ (1 to 4)	1.0

Figure 3-8: Climate change multiplier for each wind region (source: Table 3.3 AS1170.02:2021)

3.5.2 Rainfall

Computer-modelled climate projections serve as invaluable tools for government, industry, and communities to prepare for future climate conditions. Spearheaded by the NSW Government, the NSW and Australian Regional Climate Modelling (NARCliM) initiative meticulously generates comprehensive climate projections and data for New South Wales. These projections, predominantly employed across the AdaptNSW website, are based on the rigorously developed NARCliM1.0 projections released in 2014, crafted using scientifically reviewed methodologies and adhering to international best practices.

Within the realm of climate adaptation, AdaptNSW supplies invaluable future rainfall statistics for the broader NSW region, employing a 10km-by-10km grid-based approach to delineate localised impacts. Focusing on the grid encompassing Coffs Harbour, projections indicate a notable increase in annual rainfall. By the year 2040, a 3% rise is anticipated, with a more substantial 14% increase forecasted by 2080 (**Table 3-23**). For context, as of 2024, the long-term average annual rainfall for Coffs Harbour stands at 1680mm, suggesting a potential increase of 240mm annually by 2080.

However, concerning coastal hazard risk, it is important to note that rainfall itself may not directly impact coastal hazards. Instead, the primary concern lies in the implications for drainage and stormwater management systems within the area. As rainfall intensifies, there is an increased likelihood of drainage challenges, flooding and related hazards.

Table 3-23: Potential rainfall impact to Coffs Harbour, due to climate change (Source: AdaptNSW, 2024).

Season	2020 to 2040	2060 to 2080
All year	+3.11 %	+14.34 %
Summer	-0.24 %	+13.90 %
Autumn	+7.90 %	+21.31 %
Winter	-8.96 %	-1.67 %
Spring	+7.85 %	+15.02 %

3.5.3 Temperature

Similar to rainfall projections above, AdaptNSW have also provided information on the effects of climate change to temperature across NSW. When examining the specific area around Coffs Harbour, these projections highlight a significant temperature rise of 0.66°C by 2040 and 1.92°C by 2080 (**Table 3-24**). The implications of such rising temperatures are wide-ranging and may include alterations in weather patterns, such as shifts in rainfall distribution, increased storm frequency and intensity, and changes in seasonal weather conditions. Consequently, a temperature increase of 1.92°C could potentially influence the frequency and intensity of storms. However, it's important to note that the exact extent of these effects remains uncertain due to current limitations in scientific understanding and research. The impact on coastal hazards is not anticipated to be significant and should be limited. The majority of the proposed infrastructure in the Illustrative Masterplan is planned to be situated at a considerable distance from the shoreline and presently lies outside the 2123 0.1% hazard line. This indicates that a minor/moderate increase in storm intensity is unlikely to affect this site at Jetty Beach Block 1 and 2 and North Boambee beach. Although an increase in storm intensity due to potential temperature rise might affect the exposed area in Jetty Beach Block 3, it should not exacerbate the existing erosion risks identified in that area (**Section 3.2.4**).

Table 3-24: Possible impact of climate change on temperatures in Coffs Harbour (Source: AdaptNSW, 2024).

Season	2020 to 2040	2060 to 2080
All year	+0.66 ^{0}C	+1.92 ^{0}C
Summer	+0.84 ^{0}C	+2.06 ^{0}C
Autumn	+0.68 ^{0}C	+1.97 ^{0}C
Winter	+0.51 ^{0}C	+1.79 ^{0}C
Spring	+0.68 ^{0}C	+1.87 ^{0}C

3.5.4 Southern Oscillation Index (SOI)/ Storm Intensity

El Niño and La Niña, collectively known as the El Niño Southern Oscillation (ENSO), play a pivotal role in shaping weather patterns and ocean wave climates, consequently impacting coastal stability. Traditionally, El Niño events, characterized by anomalous sea surface warming in the eastern Pacific, result in reduced storminess and a southerly wave climate in Southeast Australia, while La Niña events exhibit the opposite effects. However, since the 1970s, there has been an increasing occurrence of ENSO events associated with anomalous warming or cooling in the central Pacific Ocean, rather than the eastern Pacific, with climate models suggesting this trend may continue due to climate change related “greenhouse effect warming” (Mortlock, 2016).

Coastlines in Southeast Australia respond to ENSO fluctuations, with observed beach rotations during El Niño and La Niña events. During El Niño, beaches tend to rotate clockwise, while during La Niña, the rotation is anti-clockwise. These rotations are attributed to changes in wave climates associated with different ENSO phases (Mortlock, 2016).

Recent research indicates that changes in the "flavour" of ENSO, particularly toward central Pacific-type events, can significantly alter wave conditions and beach rotations. Central Pacific El Niño events lead to stronger erosion potential at the southern end of embayed beaches, while central Pacific La Niña events result in a sustained anti-clockwise rotation of beaches, exacerbating erosion risks. These findings underscore the importance of considering variability in ENSO climate for coastal risk management in NSW, as they suggest a significant underestimation of coastal vulnerability, particularly for southern sections of embayed beaches (Mortlock, 2016).

Climate change is poised to further impact the behaviour of El Niño and La Niña, potentially worsening coastal hazards in Coffs Harbour and other NSW coastal regions. The heightened frequency or altered characteristics of ENSO events may result in more frequent and intense erosion incidents, necessitating adaptive coastal management strategies to mitigate associated risks (Mortlock, 2016). Although the precise changes in storm frequency and intensity remain uncertain, an anticipated increase in waves, surges, and altered cyclone zones is expected to exacerbate storm damage, particularly erosion (Woodroffe, *et al*., 2012)

While storm demand has been considered in coastal hazard assessments, the potential effects of climate change on storm demand remain unknown due to insufficient scientific research. This uncertainty could pose risks to unprotected areas, such as Jetty Beach Blocks 1, 2, and the northern section of Block 3, highlighting the need for coastal protection measures. Notably, proposed infrastructure (excluding the boardwalk) in Jetty Beach Blocks 1 and 2 is already planned to be located safely away from the erosion hazard line, potentially mitigating impacts. Furthermore, the highly altered (refracted) wave climate within the enclosed harbour area dampens the effect of ENSO related beach rotation and therefore the associated risk of increased erosion. However, the section of coastline north of the revetment wall in Jetty Beach Block 3, including proposed facilities like a carpark and sporting court, faces increased risk due to storm demand and potential effects of ENSO on beach rotation, necessitating future coastal protection works if infrastructure is to be developed in this area.

3.5.5 Waves

Examining the potential ramifications of climate change on Coffs Harbour's wave climate reveals a nuanced interplay between various factors. Recent research underscores that while alterations in wave direction are anticipated, there may not necessarily be a significant shift in actual wave height. Nevertheless, heightened storm intensity could amplify wave height during specific weather events. Despite ongoing research efforts, uncertainties persist, hindering precise risk assessment. A study by Morim *et al*., 2019 (cited in IPCC 2021), indicates a projected decrease in average significant wave height of approximately 0 to 5% for NSW (**Figure 3-9**), along with a potential 0-10% anti-clockwise shift in wave direction (**Figure 3-10**). It's important to note that this information is generalised and based on a global wave model, with specific assessments for NSW lacking. The IPCC 2021 report expresses medium confidence in projections of changes in mean wave climate. However, it does not provide definitive guidance on projected changes in extreme wave conditions due to limited evidence and low confidence in such projections.

Within the harbour itself, the impact of altered wave direction or wave height is projected to be relatively subdued due to the shielding effect provided by existing breakwaters. These structures and the entrance configuration of the harbour moderate the majority of offshore wave energy, mitigating potential disturbances within the harbour’s confines. Conversely, the areas flanking the harbour’s northern and southern reaches are more susceptible to the consequences of a change in wave direction.

Despite this, the indicated master plan for Coffs Harbour appears resilient to potential fluctuations in wave dynamics. The existing protective infrastructure, if diligently maintained and adapted to contemporary climate conditions, is deemed sufficient to safeguard against adverse impacts. Notably, the absence of proposed infrastructure within the vulnerable sections of Boambee North, coupled with the fortification of proposed infrastructure in Jetty Beach Block 3 with an engineered revetment wall, underscores the proactive measures in place to mitigate erosion risks.

In essence, while the prospect of increased wave energy or altered wave direction poses considerations for coastal resilience, diligent maintenance and strategic infrastructure planning are pivotal in safeguarding against erosion risks. As such, the integrity of existing protective structures emerges as a linchpin in ensuring the long-term viability of Coffs Harbour's coastal infrastructure amidst evolving climatic conditions.

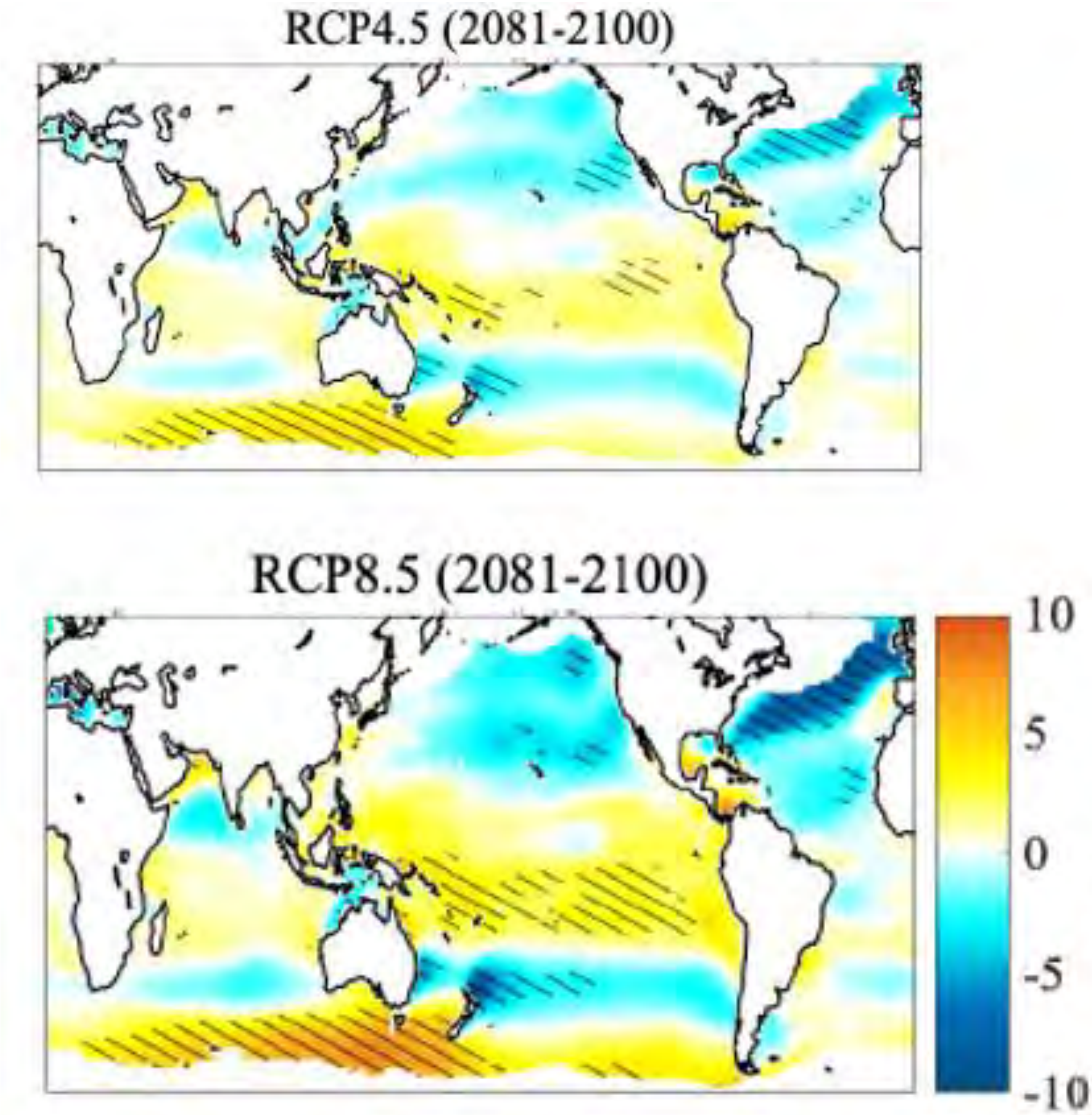

Figure 3-9: Potential changes in average significant wave height due to climate change scenarios RPC4.5 (top) and RCP8.5 (bottom) (Source: Morim et al., 2019)

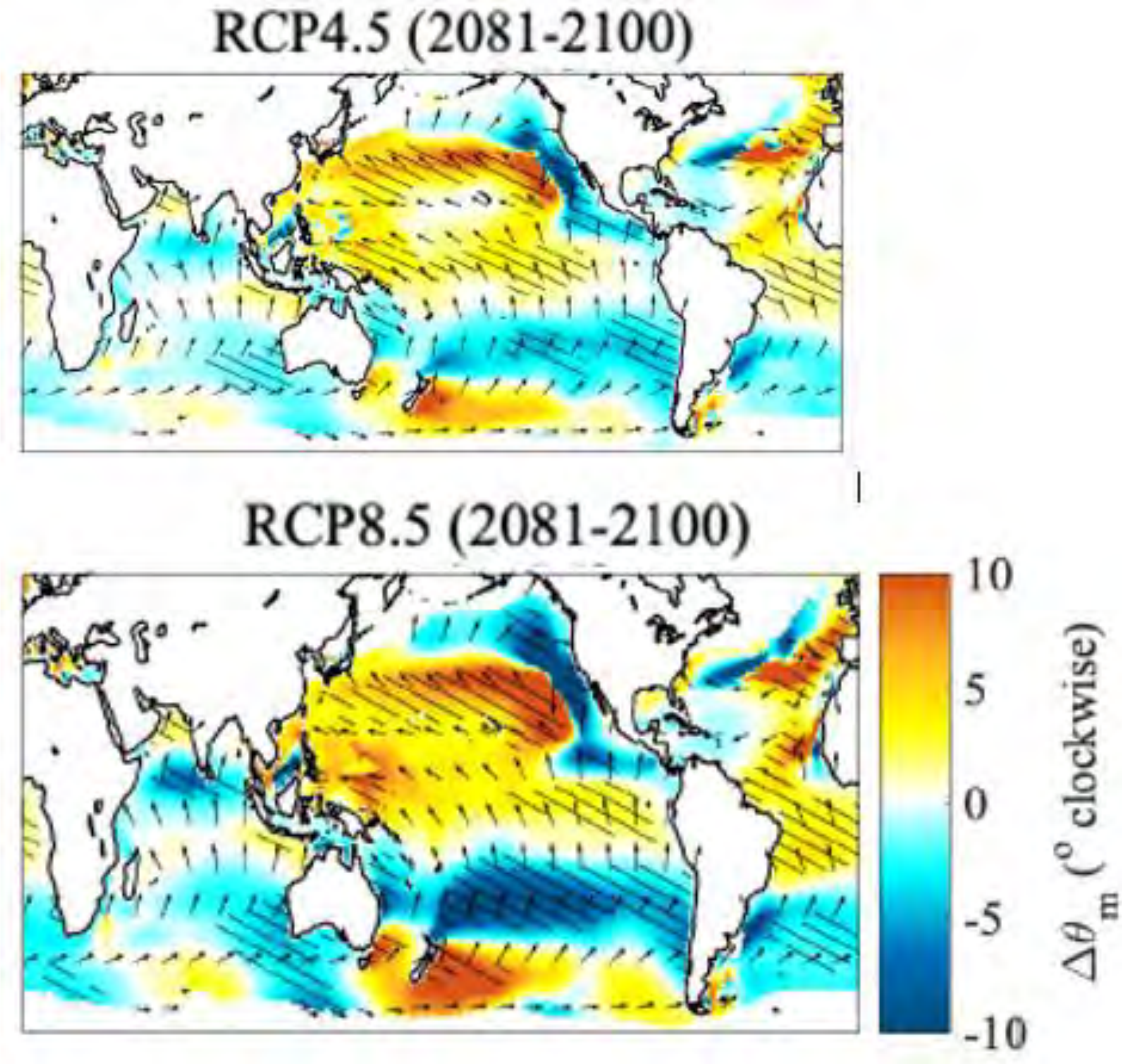

Figure 3-10: Potential changes in average wave direction due to climate change scenarios RPC4.5 (top) and RCP8.5 (bottom) (Source: Morim et al., 2019)

3.5.6 Sea Level Rise

The primary climate change impact relevant to assessing future coastal hazards is sea level rise (SLR), which is the most extensively researched and understood parameter in terms of its impacts on coastal hazards. SLR leads to shoreline recession as the beach profile adjusts to the new coastal water levels. The IPCC 2021 study offers the most up-to-date guidance on changes in sea level rise. If temperatures were to increase by less than 2°C by 2080 (**Section 3.5.3)**, the SSP1-2.6/SSP2-4.5 climate scenario is considered to provide the most likely changes in SLR for Coffs Harbour (**Figure 3-11)**. This scenario indicates a mean SLR of 0.51 meters by 2100.

The impact and risk of sea level rise have already been included in the erosion risk assessment and discussed in detail in **Section 3.1** of this coastal hazard and risk assessment. For further information regarding the specific SLR values utilised in this assessment, refer to **Section A1.2.5** below.

	1.5°C	2.0°C	3.0°C	4.0°C	5.0°C	SSP5-8.5 *Low Confidence*
Closest SSPs	SSP1-2.6	SSP1-2.6/SSP2-4.5	SSP2-4.5/SSP3-7.0	SSP3-7.0	SSP5-8.5	
Total (2050)	0.18 (0.16–0.24) m	0.20 (0.17–0.26) m	0.21 (0.18–0.27) m	0.22 (0.19–0.28) m	0.25 (0.22–0.31) m	0.24 (0.20–0.40) m
Total (2100)	**0.44 (0.34–0.59) m**	**0.51 (0.40–0.69) m**	**0.61 (0.50–0.81) m**	**0.70 (0.58–0.92) m**	**0.81 (0.69–1.05) m**	**0.88 (0.63–1.60) m**
Rate (2040–2060)	4.1 (2.9–5.7) mm yr^{-1}	5.0 (3.7–7.0) mm yr^{-1}	6.0 (4.6–8.1) mm yr^{-1}	6.4 (5.0–8.6) mm yr^{-1}	7.2 (5.7–9.8) mm yr^{-1}	7.9 (5.6–16.1) mm yr^{-1}
Rate (2080–2100)	4.3 (2.6–6.4) mm yr^{-1}	5.5 (3.4–8.4) mm yr^{-1}	7.8 (5.3–11.6) mm yr^{-1}	9.9 (7.1–14.3) mm yr^{-1}	11.7 (8.5–17.0) mm yr^{-1}	15.8 (8.6–30.1) mm yr^{-1}
2000-yr commitment	2 to 3 m	2 to 6 m	4 to 10 m	12 to 16 m	19 to 22 m	
10,000-yr commitment	6 to 7 m	8 to 13 m	10 to 24 m	19 to 33 m	28 to 37 m	

Figure 3-11: SLR projects (Source: IPCC, 2021)

3.5.7 Summary

When considering climate change and its relationship to coastal hazards, sea level rise emerges as the most impactful factor, supported by comprehensive scientific research. This aspect has been incorporated into the erosion hazard assessment discussed previously. However, assessing the risk associated with other potential climate change parameters, such as changes in wave climate and increased storm frequency and intensity, proves challenging due to uncertainties surrounding these variables. Without a clear understanding of how these climate parameters will change, it's difficult to determine their full impact and identify specific risks. Nevertheless, it is anticipated that any impact from alterations in wave climate or storminess in this area may be mitigated to some extent by existing erosion protection structures. By ensuring the maintenance and renewal of these structures, a risk mitigation strategy is already in place to address potential climate change-related risks.

4 Risk Mitigation

In this section, measures that may need to be implemented to mitigate the risk from erosion and overtopping over the 100-year planning period (2123) to acceptable levels based on the example infrastructure types in the Illustrative Masterplan are discussed. The existing revetment walls and breakwaters are valuable assets in protecting against erosion. Regular inspections and maintenance are vital to ensure their continued effectiveness and adherence to contemporary engineering standards over time.

4.1 North Boambee Beach

North Boambee Beach's accretionary nature effectively counters potential recession from sea-level rise over time. Hazard lines mainly account for future storm events, with minimal difference between projections for 2073 and 2123.

With the accretionary nature of the beach and the existing revetment wall, the example infrastructure types in this area in the Illustrative Masterplan will be protected from erosion. A revetment wall is a terminal structure that serves as a robust defence against erosion and storm surge meaning erosion would not extend landward of the revetment wall. Regular condition inspections and maintenance are essential to maintain its integrity and longevity.

While overtopping risk could not be calculated, adequate warning systems can be put in place to mobilise management measures. The overtopping risk will also be effectively mitigated as the revetment wall is maintained and upgraded to maintain contemporary engineering standards over the design life of the structure.

4.2 Jetty Beach Block 1

Similar to North Boambee Beach, Jetty Beach Block 1 exhibits accretionary characteristics and is protected by harbour breakwaters and Muttonbird Island.

In the absence of any alterations to the existing breakwater configuration encircling the harbour, and as long as the rate of sand transportation into the harbour and sand management as part of navigational requirements within the harbour remains consistent, there is no foreseeable erosion risk to the example infrastructure types indicated in the Illustrative Masterplan for the Jetty Beach Block 1 area, both presently and 100 years in the future (2123). Therefore, there is no necessity for additional coastal protection structures or other erosion mitigation measures.

However, it is recommended that the current structures undergo periodic condition inspections and maintenance to ascertain that they have not incurred any damages and continue to meet contemporary engineering practice and industry standards for design, construction and maintenance over the life of the works. This ensures their integrity and longevity over time.

A medium overtopping risk exists, but with the maintenance of the vegetated dune health and appropriate warning systems, management measures (e.g., closure of access to at-risk infrastructure during the event) can be implemented to adequately mitigate this risk.

4.3 Jetty Beach Block 2

This beach section shares the same characteristics as Jetty Beach Block 1, with minimal difference between hazard line projections for 2073 and 2123.

In the absence of any alterations to the existing breakwater configuration encircling the harbour, and as long as the rate of sand transportation into the harbour and sand management as part of navigational requirements within the harbour remains consistent, there is no foreseeable erosion risk to the example infrastructure types indicated in the Illustrative Masterplan for the Jetty Beach Block 2 area, both presently and 100 years in the future (2123). Therefore, there is no necessity for additional coastal protection structures or other erosion mitigation measures.

However, it is recommended that the current structures undergo periodic condition inspections and maintenance to ascertain that they have not incurred any damages and continue to meet contemporary engineering practice and industry standards for design, construction, and maintenance over the life of the works. This ensures their integrity and longevity over time.

There is currently a low risk of overtopping (acceptable to tolerable risk, work can proceed). However, this will increase to a medium and high risk by 2073 and 2123, respectively. With the maintenance of the vegetated dune health and appropriate warning systems, management measures (e.g., closure of access to at-risk infrastructure during the event) can be implemented to adequately mitigate the escalating risks over time.

4.4 Jetty Beach Block 3

If the example infrastructure types of the carpark and sporting court as located on the Illustrative Masterplan are intended to have a design life beyond 2073, then additional erosion protection measures or mitigation strategies will be required to safeguard both the infrastructure and the safety of individuals. An erosion protection option would be to extend the existing revetment wall. By extending the revetment wall, not only will the example infrastructure types (recreational uses) outlined in the Illustrative Masterplan be protected, but the existing development including; rail tracks, stores, and Happy Valley, will also benefit from erosion protection in the future. This extension should be considered outside of the planning proposal given it involves existing dwellings and infrastructure outside of the study area.

To ensure protection against erosion for infrastructure types (existing and potential) located landward of the revetment wall, it is crucial that the existing revetment wall and breakwaters are designed and maintained to contemporary engineering standards and adapt to the changing ocean climate over time. Therefore, it becomes essential to conduct regular condition inspections and maintenance (and potential upgrades) on the current structures. This ensures that they remain undamaged and adhere to contemporary engineering practices and industry standards for design, construction, and maintenance over their design life and potentially beyond. By doing so, the integrity and longevity of these structures are preserved over time.

5 Summary and Recommendations

During the undertaking of investigations to produce this Coastal Risk Management Report, several specific matters were noted. Commentary and recommendations relating to these matters are summarised below in **Table 5-1**.

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Table 5-1: Key design considerations and matters concerning the example infrastructure types in the Illustrative Masterplan, and commentary arising from the PCHA

Key Issue	Boambee North	Jetty Beach Block 1	Jetty Beach Block 2	Jetty Beach Block 3
If future development involves the erection of a building or works, the building or works should be located to avoid or engineered to withstand current and projected coastal hazards for the expected design life of the building or works.	The example infrastructure type in the Illustrative Masterplan (regional tourist destination centre) is located behind an existing revetment wall (**Figure 2**). Therefore, the infrastructure indicated is located to avoid any erosion risks, and this is not an issue for this location. Maintenance of the existing coastal protection structures is essential.	The PCHA shows that majority of the example infrastructure types in the Illustrative Masterplan (**Section 1.1**) are located outside of the erosion zones, both presently and by 2123. Only a small section of indicative boardwalk falls within the 2123 hazard mapping. However, this would be beyond such a structures' design life (if constructed within the next 75 years) and the risk of erosion is very low (indicating that the chances of erosion affecting this specific location will probably never occur or may happen in exceptional circumstances). Therefore, the infrastructure indicated is located to avoid any erosion risks, and this is not an issue for this location. Maintenance of the existing coastal protection structures is recommended.	The PCHA shows that infrastructure types in the Illustrative Masterplan (**Section 1.1**), and existing infrastructure, are located outside of the erosion zones, both presently and by 2123. Therefore, the infrastructure existing and indicated is located to avoid any erosion risks, and this is not an issue for this location. Maintenance of the existing coastal protection structures is recommended.	The PCHA shows that the majority of the example infrastructure types in the Illustrative Masterplan (Section 1.1) are located outside of the erosion zones for the present-day scenario and by 2123 only half the carpark and one of the sport courts falls within the 2123 hazard mapping. To protect the example infrastructure types of the sport court and half of the car park and in future years the existing stores (behind the rail tracks), consideration could be given to extending the seawall approximately 140m to the north (this will also protect the Happy Valley). The other infrastructure indicated is located to avoid any erosion risks. Maintenance of the existing coastal protection structures is essential to provide ongoing mitigation of risk to infrastructure located landward of this engineered structure from erosion.
The proposed development is not likely to alter coastal erosion and recession to the detriment of the natural environment or other land.	As example infrastructure types in the Illustrative Masterplan are not located in the active beach zone, they are not expected to alter coastal erosion or recession processes. Maintenance of the existing coastal protection structures is recommended.	As example infrastructure types in the Illustrative Masterplan are not located in the active beach zone, they are not expected to alter coastal erosion or recession processes. Maintenance of the healthy vegetated dune seaward of the development is recommended.	As example infrastructure types in the Illustrative Masterplan are not located in the active beach zone, they are not expected to alter coastal erosion or recession processes. Maintenance of the healthy vegetated dune seaward of the development is recommended.	As example infrastructure types in the Illustrative Masterplan are not located in the active beach zone, they are not expected to alter coastal erosion or recession processes. Maintenance of the vegetated dune and revetment wall is recommended.
The proposed development is not likely to reduce the public amenity, access to and use of any beach, foreshore, rock platform or headland adjacent to the proposed development.	The example infrastructure types in the Illustrative Masterplan (outlined in Section 1.1) is likely to enhance public amenities in the area. Usage of, and access to, the adjacent coastal areas are likely to remain unchanged or be improved by the future implementation of the Illustrative Masterplan.	The example infrastructure types in the Illustrative Masterplan (outlined in Section 1.1) is likely to enhance public amenities in the area. Usage of, and access to, the adjacent coastal areas are likely to remain unchanged or be improved by the future implementation of the Illustrative Masterplan.	The example infrastructure types in the Illustrative Masterplan (outlined in Section 1.1) is likely to enhance public amenities in the area. Usage of, and access to, the adjacent coastal areas are likely to remain unchanged or be improved by the future implementation of the Illustrative Masterplan.	The example infrastructure types in the Illustrative Masterplan (outlined in **Section 1.1**) is likely to enhance public amenities in the area. Usage of, and access to, the adjacent coastal areas are likely to remain unchanged or be improved by the future implementation of the Illustrative Masterplan.
The proposed development incorporates appropriate measures to manage risk to life and public safety from coastal hazards.	As noted in Section 2.3 (main report), the risk to life and public safety is very low for example infrastructure types in the Illustrative Masterplan. Further data obtained from the PCHA indicates that the chances of erosion or overtopping occurring during the adopted planning period (within 100 years) are unlikely. If there is any overtopping risk, it can be effectively handled through early hazard warnings and the implementation of suitable mitigation strategies.	As noted in Section 2.3 (main report), the risk to life and public safety is considered to be low for example infrastructure types in the Illustrative Masterplan. Further data obtained from the PCHA indicates that the chances of overtopping or inundation happening during the adopted planning period of the structures (if built within 50 years) are unlikely. Furthermore, even in the distant future (2123), inundation is expected to only reach the proposed boardwalk, which can be effectively handled through early hazard warnings and the implementation of suitable mitigation strategies.	As noted in Section 2.3 (main report), the risk to life and public safety is considered to be low for example infrastructure types in the Illustrative Masterplan. Further data obtained from the PCHA indicates that the chances of overtopping or inundation happening during the adopted planning period of the structures are unlikely. Furthermore, even in the distant future (2123), inundation is expected to only reach the existing community building, which can be effectively handled through early hazard warnings and the implementation of suitable mitigation strategies.	As noted in **Section 2.3** (main report), the risk to life and public safety is considered to be low for this development. Further data obtained from the PCHA indicates that the chances of overtopping or inundation happening during the planning period of the structures (if built within 50 years) are unlikely.
Measures are in place to ensure that there are appropriate responses to, and management of, anticipated coastal erosion and recession and current and future coastal hazards.	It is recommended that the current coastal protection structures undergo periodic condition inspections and maintenance to ascertain that they have not incurred any damage and continue to meet contemporary engineering practice and industry standards for design, construction, and maintenance over the life of the works. This ensures their integrity and longevity over time.	While the example infrastructure types in the Illustrative Masterplan are located outside the active beach zone for the design life of the structure (boardwalk), management of the current vegetated foredune into the future will ensure a level of defence against wave runup and overtopping. It is also recommended that the current foreshore protection structures undergo periodic condition inspections and maintenance to ascertain that they have not incurred any damages and continue to meet	While the example infrastructure types in the Illustrative Masterplan are located outside the active beach zone, management of the vegetated foredune into the future will ensure a level of defence against wave runup and overtopping. It is also recommended that the current structures undergo periodic condition inspections and maintenance to ascertain that they have not incurred any damages and continue to meet contemporary engineering practice and industry standards for design, construction,	Management of the current vegetated foredune into the future will ensure a level of defence against wave runup and overtopping. It is also recommended that the current foreshore protection revetment structures undergo periodic condition inspections and maintenance to ascertain that they have not incurred any damages and continue to meet contemporary engineering practice and industry standards for design, construction, and maintenance over the life of

		contemporary engineering practice and industry standards for design, construction, and maintenance over the life of the works. This ensures their integrity and longevity over time.	and maintenance over the life of the works. This ensures their integrity and longevity over time.	the works. This ensures their integrity and longevity over time.
Any protection works deemed necessary and the maintenance thereof over the life of the development are adequately detailed; any protection works are demonstrated to meet contemporary engineering practice and industry standards for design, construction, and maintenance over the life of the works.	No additional coastal protection works are required for this section of beach.	No additional coastal protection works are required for this section of beach.	No additional coastal protection works are required for this section of the beach.	If the example infrastructure types of the carpark and sporting court as located on the Illustrative Masterplan are intended to have a design life beyond 2073, it is recommended that the existing revetment wall be extended. This would protect the sport court and carpark, and in future years the existing rail tracks and stores.

6 Conclusion

The Coastal Risk Management Report for the Coffs Harbour Jetty Foreshore State Assessed Planning Proposal evaluates the vulnerability and risks associated with the potential new infrastructure types associated with the Illustrative Masterplan, should the current planning proposal be approved. The findings of this report will support informed decision-making regarding the location and construction of the potential infrastructure, considering the potential impacts of coastal hazards up to the year 2123.

A probabilistic hazard assessment has been undertaken which accounts for the interaction between the forcing parameters. The probabilistic approach allows each input parameter to randomly vary according to appropriate probability distribution functions. The randomly sampled parameters are repeatedly combined in a process known as Monte Carlo simulation. All outputs from the Monte Carlo simulation are collated to develop a probability curve for shoreline retreat over the planning period for a site. A separate probability curve has been developed for each of the existing Profile lines along the relevant section of coastline.

The investigation found that:

- The Illustrative Masterplan incorporates coastal hazard considerations, with proposed land use areas and the associated potential new infrastructure types setback from the coastline appropriately. The Illustrative Masterplan is suitable and consistent with coastal planning;
- The Corambirra Point (Deep Sea Fishing), Jetty Hub and Activity Hub & Village Green precincts do not fall within the Coastal Hazard Zone Policy area, therefore are not at risk of current or future coastal erosion;
- Erosion risks are identified for half of the carpark and one sporting court (example infrastructure in the reference scheme) in Jetty Beach Block 3, with increasing risk by 2123, i.e., at the end of the 100-year planning period. Existing rail tracks and commercial/residential buildings landward of this area are indicated to be impacted by the 1% Annual Exceedance Probability erosion line by 2123. Any proposed residential and commercial/tourism development as part of the Illustrative Masterplan is outside the existing Coastal Hazard Zone Policy Area;
- This risk could be effectively mitigated through the upgrade and regular maintenance of the existing revetment wall;
- If the carpark and sporting court are of significant importance (noting they are classified as recreational zones only), extending the existing revetment wall by a minimum of 140 meters to the north could be considered to protect these assets from erosion in the future. This extension would not only safeguard the recreational zones outlined in the Illustrative Masterplan but also provide erosion protection to the existing rail tracks, stores, and the Happy Valley site. These extensions should be considered outside of the planning proposal given it relates to existing buildings and infrastructure;
- The proposed land use areas and the associated potential new infrastructure types in Jetty Beach Block 1 and Block 2 are indicated at no erosion risk in the 100-year planning period from 2023;
- Changes to building scale and height within the Marina precinct (within Jetty Beach Block 2) does not affect coastal risk. However, at the development approval stage, building designs will need to consider breakwater overtopping events and ensure mitigation measure for any related coastal inundation of ground level habitable areas, or any below ground parking areas;
- There is a medium overtopping risk to the boardwalk in Jetty Beach Block 1, however as discussed in Section 2.3, this is not likely to occur without sufficient warning to mobilise management measures (e.g. closure of access to at-risk infrastructure during the event); and
- The maintenance of the existing coastal protection structures (breakwaters and revetment walls) is essential to ensuring the infrastructure is protected from erosion now and into the future.

It is essential to consider these findings and recommendations to ensure the long-term resilience and protection of the planned infrastructure in the Coffs Harbour Jetty Foreshore Precinct.

7 References

BMT WBM (2011). Coffs Harbour Coastal Processes and Hazards Definition Study, Final Report, prepared for Coffs Harbour City Council.

BMT WBM (2019). Coffs Harbour Coastal Zone Management Plan, Final Report, prepared for Coffs Harbour City Council, March 2019.

Carley, J.T., Wyllie, S.J., Lord, D.B. and Cox, R. J. (2006). Coastal Processes in the Coffs Harbour Region, Proceedings of the 15th NSW Coastal Conference.

Evans, P. & Hanslow, D. (1996). *Take a Long Line – Risk and Reality in Coastal Hazard Assessment,* Ulladulla: NSW Coastal Conference.

Lord, D.B. and Van Kerkvoort, A. (1981). A Coastal Process Investigation, Coffs Harbour, NSW, Proceedings of the 5th Australian Conference on Coastal and Ocean Engineering, Perth, Institute of Engineers Australia.

Morim, J. *et al*. (2019). Robustness and uncertainties in multivariate wind-wave climate projections, Nature Climate Change **9**, 711–718, doi:10.1038/ s41558-019-0542-5

OEH (2019). NSW Coastal Management Manual Part B: Stage 2 – Determine risks, vulnerabilities and opportunities. 2019 State of NSW and Office of Environment and Heritage

SJB (2023). *Coffs Harbour Foreshore Urban Design Report,* s.l.: Prepared for Property and Development NSW.

Van der Meer, J. W., NWH Allsop, T. Bruce, Julien De Rouck, Andreas Kortenhaus, T. Pullen, H. Schüttrumpf, Peter Troch, and B. Zanuttigh (2018). EurOtop: Manual on Wave Overtopping of Sea Defences and Related Sturctures : An Overtopping Manual Largely Based on European Research, but for Worlwide Application. 3rd ed.

Appendix A – Coastal Hazard and Risk Assessment Methodology

A1 Probabilistic Hazard Line Assessment

A1.1 Methodology

Traditionally, coastal hazard assessments have been undertaken under a deterministic approach, whereby each input variable is assigned a single value (e.g. 'design' storm demand, sea level rise projection, etc. with generally conservative estimates applied). In this study, a probabilistic approach has been adopted which accounts for the interaction between the forcing parameters. In this way, rather than present only a "worst case" scenario, acceptable risk can be considered when examining the predicted erosion extent.

The probabilistic approach allows each input parameter to randomly vary according to appropriate probability distribution functions. The randomly sampled parameters are repeatedly combined in a process known as Monte Carlo simulation. All outputs from the Monte Carlo simulation are collated to develop a probability curve for shoreline retreat over the planning period for a site. A separate probability curve has been developed for each of the existing transect lines along the relevant section of coastline. Shoreline retreat has been examined considering a 100-year design life for any structure.

The three key input parameters to the probabilistic analysis are:

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

The methodology for the probabilistic approach is set out in **Figure A1** below. Some general points are noted below:

- where an input parameter can vary randomly but has a distribution that is not fully known, a triangular distribution is typically assigned for the parameter. The triangular distribution is defined by a minimal value, a maximum value, and a peak/modal value (most likely or best estimate value). The peak/modal value does not need to be equidistant between the minimum and maximum values hence a skewness can be assigned to the probability distribution. The triangular distribution is depicted in **Figure A1**;
- recession due to sea level rise is estimated based on application of the Bruun rule, which requires an estimate of the magnitude of sea level rise and the inverse of the average beach slope extending to the depth of closure. For the Monte Carlo simulations, both of these parameters (sea level rise and inverse beach slope) are defined by separate triangular probability distributions;
- in the case of sea level rise, the minimum, maximum and modal values in successive years over a given planning period are set so that they follow a specified trajectory, e.g. an International Panel for Climate Change (IPCC) concentration pathway, hence random sea level rise trajectories are generated in the Monte Carlo simulations in the case of sea level rise;
- the total long-term recession at each year is calculated by summing the separate Monte Carlo results for underlying recession and for recession due to sea level rise for that year;
- in the case of storm demand, annual exceedance probabilities (AEP values) of storm demand are randomly sampled in each year of the planning period and then converted to a volume using empirical relationships. So-called 'low demand' values for storm demand are adopted;

- storm demand volume is then converted to a setback distance using the methodology outlined in Nielsen (1992), allowing separate determination of Zone of Slope Adjustment (ZSA) and Zone of Reduced Foundation Capacity (ZRFC);
- the total setback for each zone (ZSA, ZRFC) is calculated by adding the storm demand setback to the combined long-term recession, randomly, on a year-by-year basis;
- calculations are performed for each beach Profile along a section of shoreline of interest (Profiles generally established by a photogrammetric analysis); and
- it is assumed that the beach has recovered from the storm-driven erosion that occurs in a year at the beginning of the subsequent year[2].

A1.2 Coastal Hazard Line Components

A1.2.1 Introduction

The following sections set out the proposed values for the key parameters to adopt in the probabilistic analysis. Consideration of the proposed values has been based on relevant background documents, photogrammetric data (refer **Figure A1**) covering the period 1973 to 2022, as well as the experience of RHDHV. In addition to a nominated pre-storm beach Profile and planning period, the key parameters for input to the probabilistic analysis are:

- underlying recession;
- recession due to sea level rise (includes projected amount of sea level rise and Bruun slope factor); and
- storm demand.

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

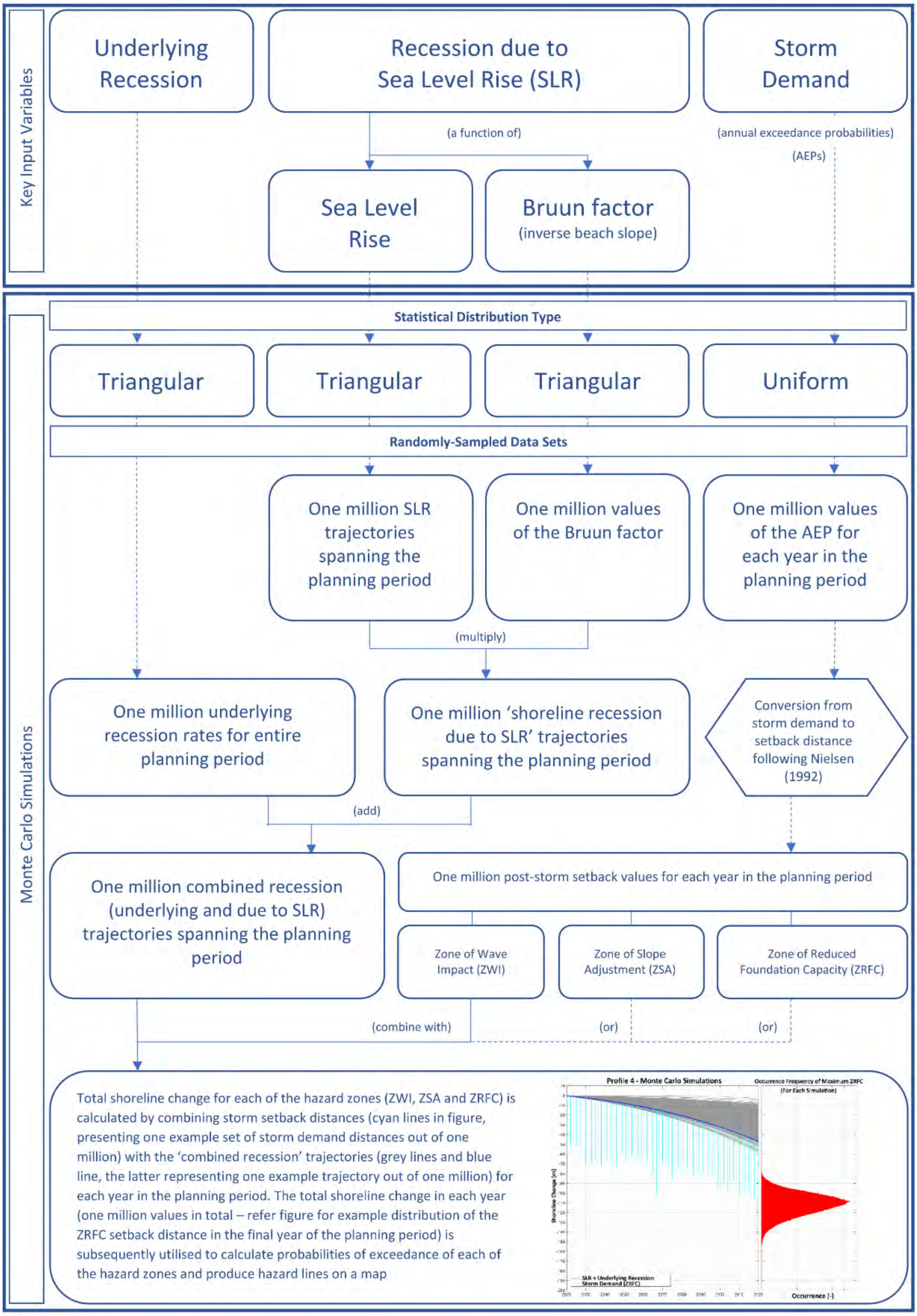

Figure A1-1: Flow chart for the probabilistic assessment of coastal hazard

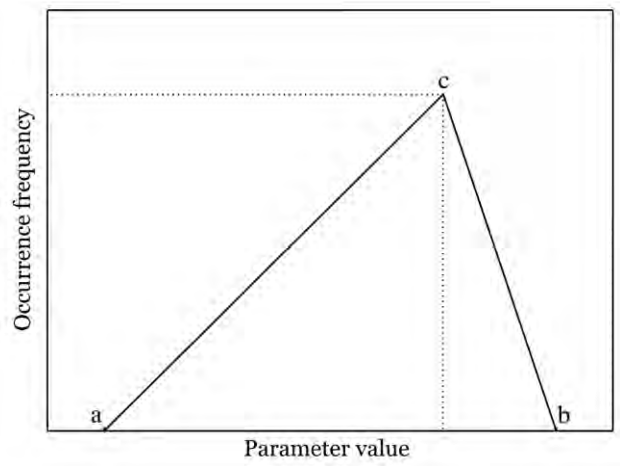

Figure A1-2: The probability density function of a triangular distribution

Figure A1-3: Available photogrammetric data at the project site

A1.2.2 Pre-Storm Beach Profile

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

In selecting the pre-storm Profile, the aim should be to adopt a relatively accreted beach Profile, typically referred to by RHDHV as an 'average beach full' Profile, as the high storm demands selected in hazard assessments can only be realised in practice if accreted Profiles exist (as noted in **Footnote 2**, in the situation of eroded Profiles there are typically large quantities of sand in offshore bars which dissipate wave energy giving lower storm demands). The selected pre-storm Profile should also, ideally, be a 'real' and recent Profile (not synthesized).

Figure A1 to **Figure A1** shows beach Profiles available from the NSW Beach Profile Database at Boambee North Block 4 Profile 9 (just south of Coffs Harbour), Jetty Beach Block 2 Profile 3 (inside Coffs Harbour) and Jetty Beach Block 3 Profile 2 (just north of Coffs Harbour) between 2013 and 2022. The locations of these nominated Profiles are shown in **Figure A1**. The trends evident in **Figure A1** to **Figure A1** are generally representative of the beach Profiles adjacent to these nominated Profiles.

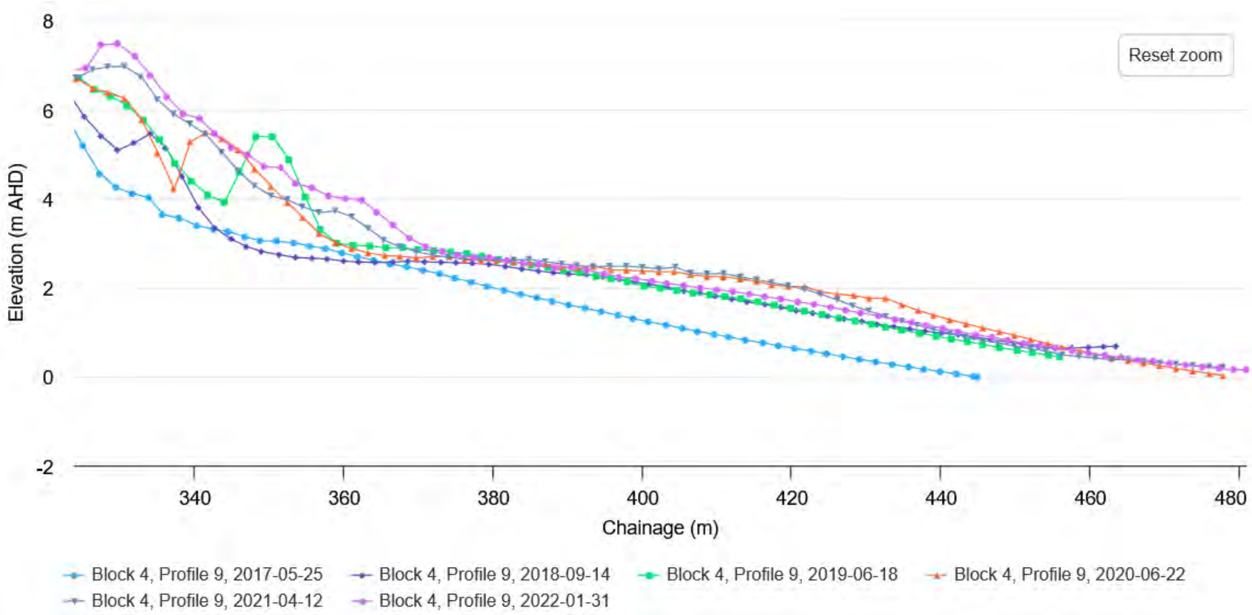

Figure A1-4: Beach Profiles at Block 4 Profile 9 for the period 2013-2023 (south of Coffs Harbour)

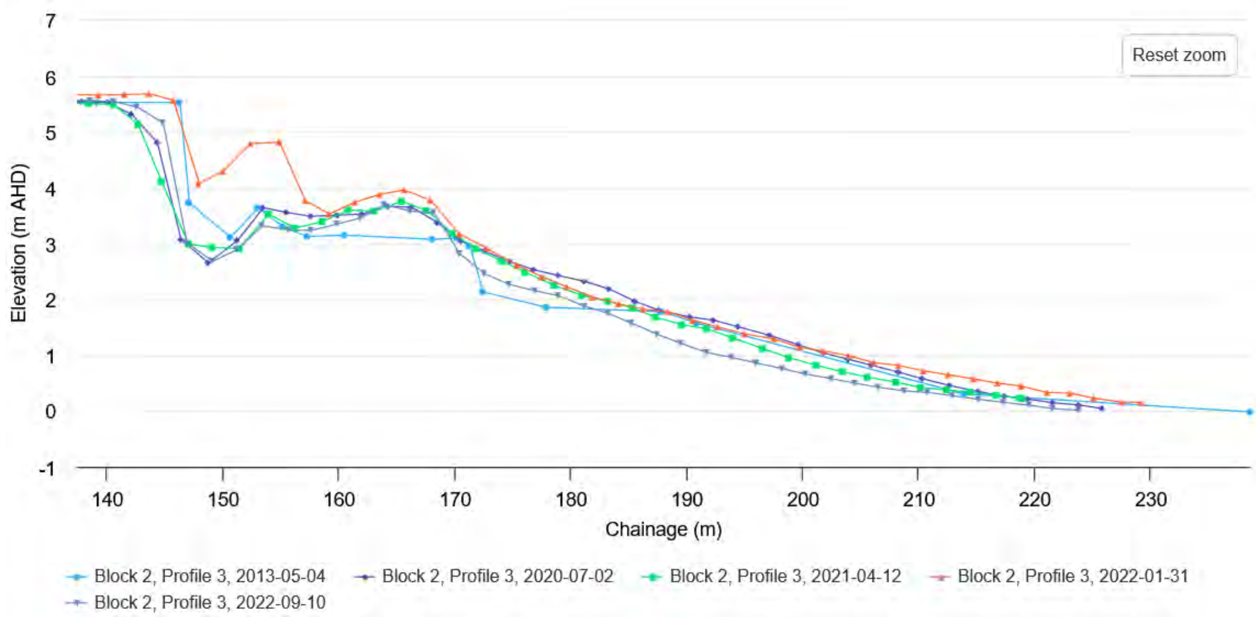

Figure A1-5: Beach Profiles at Block 2 Profile 3 for the period 2013-2023 (inside Coffs Harbour)

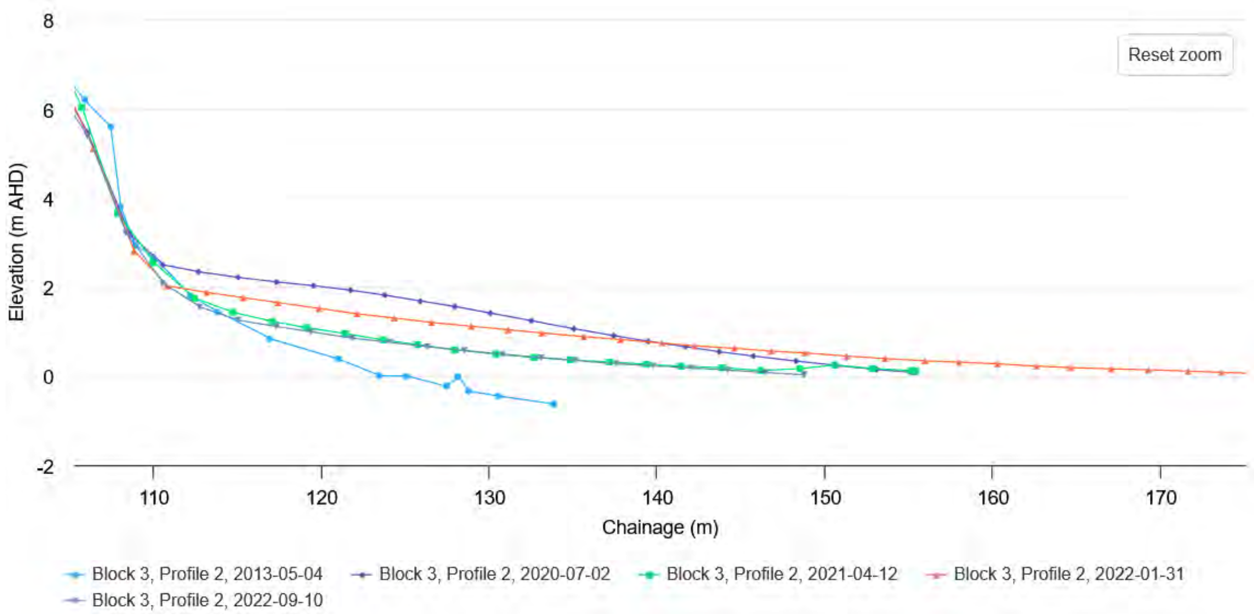

Figure A1-6: Beach Profiles at Block 3 Profile 2 for the period 2013-2023 (north of Coffs Harbour)

When assessing the beach Profiles between the 2 m and 3 m AHD elevation contours (where some variation exists), it appears the (31 January) 2022 Profile would best qualify as an ‘average-beach full’ Profile (as mentioned above) across all beach Profiles. It is also the second-most recent survey. Hence the (31 January) 2022 Profile has been adopted for the probabilistic coastal hazard assessment.

A1.2.3 Planning Period

As outlined in **Section 2.2**, the coastal hazard is to be determined at year 2123. Hence, an approximately 100-year planning period is adopted for assessment of coastal hazard. It is also possible to determine the hazard at any intermediate date. In terms of the actual development of the land, the accepted typical life of building structures would also need to be considered.

A1.2.4 Underlying Recession

Underlying or long-term shoreline recession rates are typically estimated by analysis of a photogrammetry dataset for a sufficiently long time period. Rates of shoreline movement (for each beach Profile) of the frontal dune for an appropriate elevation contour position(s) are derived by linear regression (refer the examples in **Figure A1** to **Figure A1**).

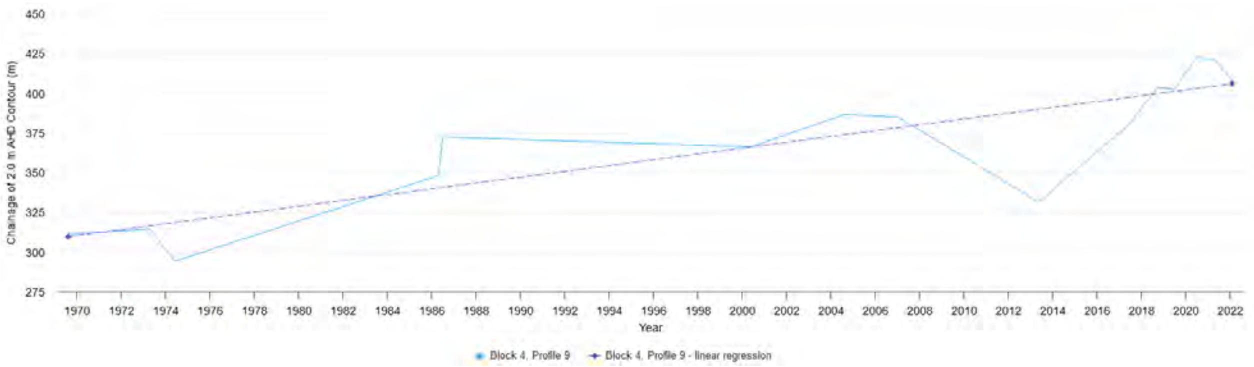

Figure A1-7: Beach contour time-series (Boambee North - Block 4 - Profile 9)

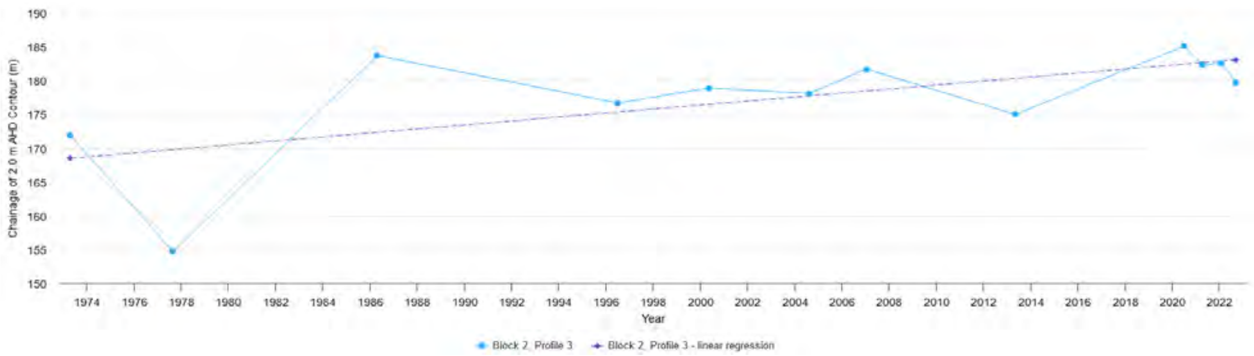

Figure A1-8: Beach contour time-series (Jetty Beach - Block 2 - Profile 3)

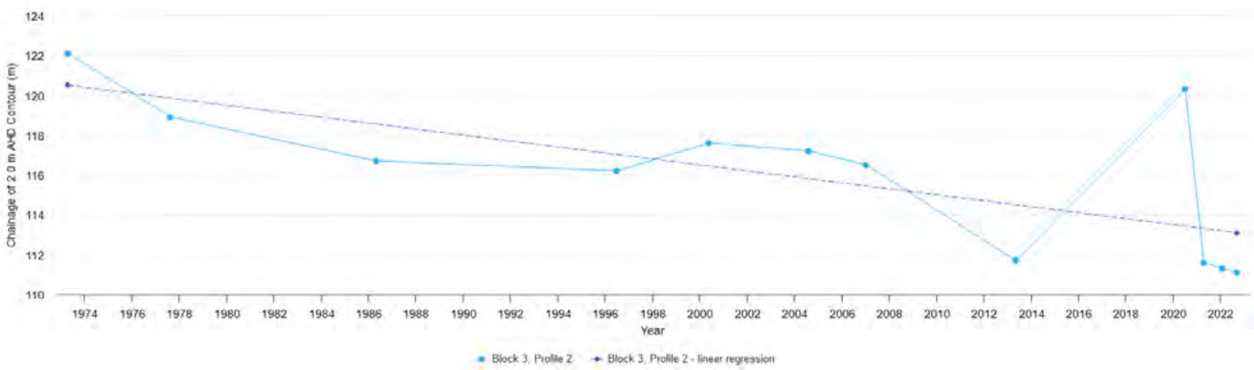

Figure A1-9: Beach contour time-series (Jetty Beach - Block 3 - Profile 2)

Alternatively, or in addition, rates of shoreline movement may be determined by assessment of volumetric change (for each beach Profile) above 0 m AHD derived by linear regression. Underlying shoreline recession rates typically vary spatially (within a beach compartment) and temporally (depending on the analysis period considered). In all cases the interpretation of underlying recession needs to be developed in the framework of a strong coastal processes understanding. A triangular probability distribution, as a rough approximation of a random variable with unknown distribution, is used to generate a set of random underlying recession values (refer **Figure A1** and **Section A1.1**).

Generally, a complete dataset provides greater confidence in statistical values, rather than utilising a subset. However, in estimating underlying recession rates at the project site, the photogrammetric dataset spanning approximately 1970 to present day (comprising 12 or more survey dates - depending on the block in question) has been utilised, omitting the (what RHDHV considers to be) spurious 1942 survey data. As outlined in section 2.5.5 of BMT WBM (2011), mining has been undertaken in the general coastline area of Coffs Harbour in the past. However, Profiles in the harbour precinct appear not to have been affected. **Table A1-1** to **Table A1-4** present the results of the updated underlying recession rates calculations (noting that positive underlying recession rates indicate progradation), which have been adopted for the probabilistic coastal hazard assessment. To this end the project site was divided into four separate areas (with different long-term beach behaviour due to location and/or beach orientation):

- South of Coffs Harbour (Boambee North – Block 4);
- Inside Coffs Harbour (Jetty Beach – Block 1);
- Inside Coffs Harbour (Jetty Beach – Block 2); and
- North of Coffs Harbour (Jetty Beach – Block 3).

Table A1-1: Adopted underlying recession rates – Boambee North, Block 4 (1969 and onward) - south of Coffs Harbour

Beach Section	Linear Regression Slope (m/year)
Boambee North - Block 4, Profile 7	+1.84
Boambee North - Block 4, Profile 8	+1.76
Boambee North - Block 4, Profile 9	+1.83
Boambee North - Block 4, Profile 10	+1.84
Lower Estimate (m/year)	+1.77
Best Estimate (m/year)	+1.82
Upper Estimate (m/year)	+1.84

Table A1-2: Adopted underlying recession rates – Jetty Beach, Block 1 (1973 and onward) - inside Coffs Harbour

Beach Section	Linear Regression Slope (m/year)
Jetty Beach - Block 1, Profile 1	+2.00
Jetty Beach - Block 1, Profile 2	+1.63
Jetty Beach - Block 1, Profile 3	+1.96
Jetty Beach - Block 1, Profile 4	+1.50
Jetty Beach - Block 1, Profile 5	+1.19
Jetty Beach - Block 1, Profile 6	+1.12
Jetty Beach - Block 1, Profile 7	+0.88
Jetty Beach - Block 1, Profile 8	+0.54
Jetty Beach - Block 1, Profile 9	+0.63
Jetty Beach - Block 1, Profile 10	+1.06
Lower Estimate (m/year)	+0.58
Best Estimate (m/year)	+1.25
Upper Estimate (m/year)	+1.98

Table A1-3: Adopted underlying recession rates – Jetty Beach, Block 2 (1973 and onward) - inside Coffs Harbour

Beach Section	Linear Regression Slope (m/year)
Jetty Beach - Block 2, Profile 1	+0.90
Jetty Beach - Block 2, Profile 2	+0.53
Jetty Beach - Block 2, Profile 3	+0.30
Jetty Beach - Block 2, Profile 4	-0.02
Jetty Beach - Block 2, Profile 5	+0.24
Jetty Beach - Block 2, Profile 6	+0.40
Lower Estimate (m/year)	+0.05
Best Estimate (m/year)	+0.39
Upper Estimate (m/year)	+0.81

Table A1-4: Adopted underlying recession rates – Jetty Beach, Block 3 (1973 and onward) - north of Coffs Harbour

Beach Section	Linear Regression Slope (m/year)
Jetty Beach - Block 3, Profile 1	-0.08
Jetty Beach - Block 3, Profile 2	-0.15
Jetty Beach - Block 3, Profile 3	-0.12
Jetty Beach - Block 3, Profile 4	+0.01
Lower Estimate (m/year)	-0.15
Best Estimate (m/year)	-0.09
Upper Estimate (m/year)	+0.00

A1.2.5 Recession due to Sea Level Rise

A1.2.5.1 Introduction

Sea level rise (SLR) may result in shoreline recession due to re-adjustment of the beach Profile to the new coastal water levels. IPCC (2021) provides global mean sea level projections and Bruun (1962; 1983) has proposed a methodology to estimate shoreline recession due to SLR, the so-called Bruun Rule. The Bruun Rule is based on the concept that SLR will lead to erosion of the upper shoreface, followed by re-establishment of the original equilibrium Profile. This Profile is re-established by shifting it landward and upward.

Similar to underlying recession (refer **Section A1.2.4**), there is uncertainty around the distribution of both of these parameters, i.e., the values for SLR and for the Bruun factor. As such, for the Monte Carlo simulations, both of these parameters are defined by separate triangular probability distributions and minimum, maximum and peak/modal SLR and Bruun factor values are required.

A1.2.5.2 Sea Level Rise

The key climate change impact of relevance to the assessment of future coastal hazards is sea level rise. Sea level rise projections investigated by BMT WBM (2011) utilised SLR planning benchmarks of 0.4 m by 2050 and 0.9 m by 2100 above the 1990 mean sea level. This is consistent with the former NSW Government’s Sea Level Rise Policy Statement (DECCW, 2009), with the two benchmarks allowing for consideration of SLR over different timeframes. These levels were based upon the IPCC (2007) and

CSIRO (2007) reports current at that time. SLR projections from the IPCC (2014) report are consistent with these levels and were considered a suitable basis for the Coffs Harbour CZMP (BMT WBM, 2019).

However, it should be noted that DECCW (2009) is no longer NSW government policy. Furthermore, advice was provided by the NSW Government in April 2014 that Councils are to obtain expert advice in using a range of sea level rise projections as well as document the methodology and approach applied.

The latest global mean SLR projections are provided in IPCC (2021), which is the Technical Summary for the Sixth Assessment Report (AR6) that was progressively released by IPCC through 2021 and 2022.

IPCC (2021) provides global mean sea level projections for five (5) Shared Socioeconomic Pathways (SSPs). Each SSP comprises a narrative of future socioeconomic development used to generate scenarios of energy use, air pollution control, land use, and greenhouse gas emissions to which Representative Concentration Pathways (RCPs) are applied to achieve an approximate radiative forcing level at the end of the 21st century. The SSPs considered in IPCC (2021) are indicated on **Figure A1** and include:

- SSP1–1.9 - Very Low emissions scenario;
- SSP1–2.6 - Low emissions scenario;
- SSP2–4.5 - Intermediate emissions scenario;
- SSP3–7.0 - High emissions scenario; and,
- SSP5–8.5 - Very High emissions scenario.

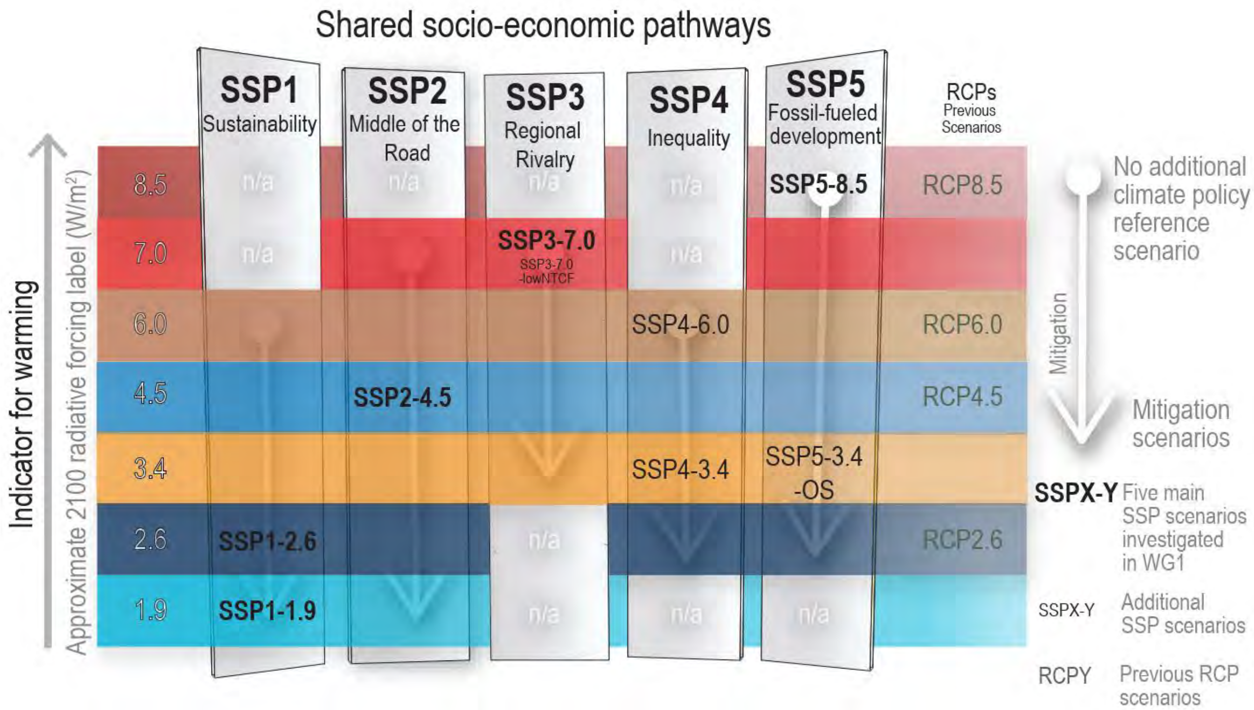

Figure A1-10: Shared socio-economic pathways (source: IPCC (2021) figure 1, page 232)

For each SSP scenario, IPCC (2021) provides SLR projections for future years up to 2150 comprising median values along with a likely range (medium confidence)[3].

[3] *The 'likely' range is associated with the 17th to 83rd percentile range for each SSP. IPCC (2021) also report low confidence projections for the SSP5-8.5 scenario, which includes a 'very likely' upper bound projection, i.e. 5th to 95th percentile range.*

Global plots of percentage deviation from the global SLR are provided in IPCC (2013) and indicate that the local variation along the east coast of Australia is up to 10% higher than the global trend. IPCC global SLR projections, with adjustment of +10% to account for local variation in SLR relative to the global mean, have been adopted, for example, by Eurobodalla Shire Council, Shoalhaven City Council, Wollongong Council, Shellharbour Council and Sutherland Shire Council. This approach is described in several recent probabilistic assessments of coastal hazards carried out by RHDHV (RHDHV, 2019; 2020a; 2020b).

Global SLR projections including local adjustments, based on the IPCC studies referenced above, are available on the NASA Sea Level Change Portal (NASA, 2023), which have been adopted for the present study as summarised in **Table A1-5**.

Table A1-5: Adopted sea level rise allowances above 2022 baseline (adjusted from IPCC, 2021)

Planning Period (year)	Minimum Trajectory SSP1-1.9 (lower)	Modal Trajectory SSP3-7.0 (median)	Maximum Trajectory SSP5-8.5 (upper)
2022	0.00	0.00	0.00
2030	0.02	0.04	0.06
2040	0.04	0.10	0.16
2050	0.07	0.17	0.28
2060	0.10	0.24	0.42
2070	0.12	0.34	0.60
2080	0.14	0.44	0.79
2090	0.16	0.55	1.01
2100	0.16	0.68	1.26

The following is noted:

- The ‘upper’ and ‘lower’ trajectories correspond with the 17th and 83rd percentile values (respectively) that constitute the ‘likely’ range of projections. While a wider range of values is statistically possible, consideration of the ‘likely’ range projections is considered to be reasonable for the purpose of this assessment because they only include processes that can be projected skilfully with at least medium confidence (based on agreement and evidence) (IPCC, 2021). For example, the ‘likely’ range projections do not include ice-sheet-related processes that are characterised by deep uncertainty;
- Sensitivity testing will be undertaken to assess the influence of alternative SLR projections on the probabilistic model results. This will include consideration of low confidence projections provided in IPCC (2021);
- The adoption of SSP1–1.9 (lower) and SSP5–8.5 (upper) for the minimum and maximum trajectories respectively represents a wide range of SLR projections but is considered to be reasonable given IPCC (2021) noted that all SSPs are plausible;
- Adoption of the ‘median’ value within SSP3–7.0 as the peak/modal trajectory is potentially conservative but is considered appropriate; and
- In each case the projections have been ‘normalised’ to a zero SLR value at the start of the planning period of 2022.

A1.2.5.3 Bruun Factor

Bruun (1962) proposed a methodology to estimate shoreline recession due to sea level rise, the so-called Bruun Rule. It can be described by the following equation:

$$R = \frac{S \times B}{h + d_c} \tag{1}$$

where R is the recession (m), S is the long-term sea level rise (m), h is the berm height above the initial mean sea level (m), d_c is the depth of closure of the Profile relative to the initial mean sea level (m), and B is the cross-shore width of the active beach Profile, that is the cross-shore distance from the initial berm crest to the depth of closure (m).

This equation is a mathematical expression that the recession due to sea level rise is equal to the sea level rise multiplied by the average inverse slope of the active beach Profile, with the variables as illustrated in **Figure A1**.

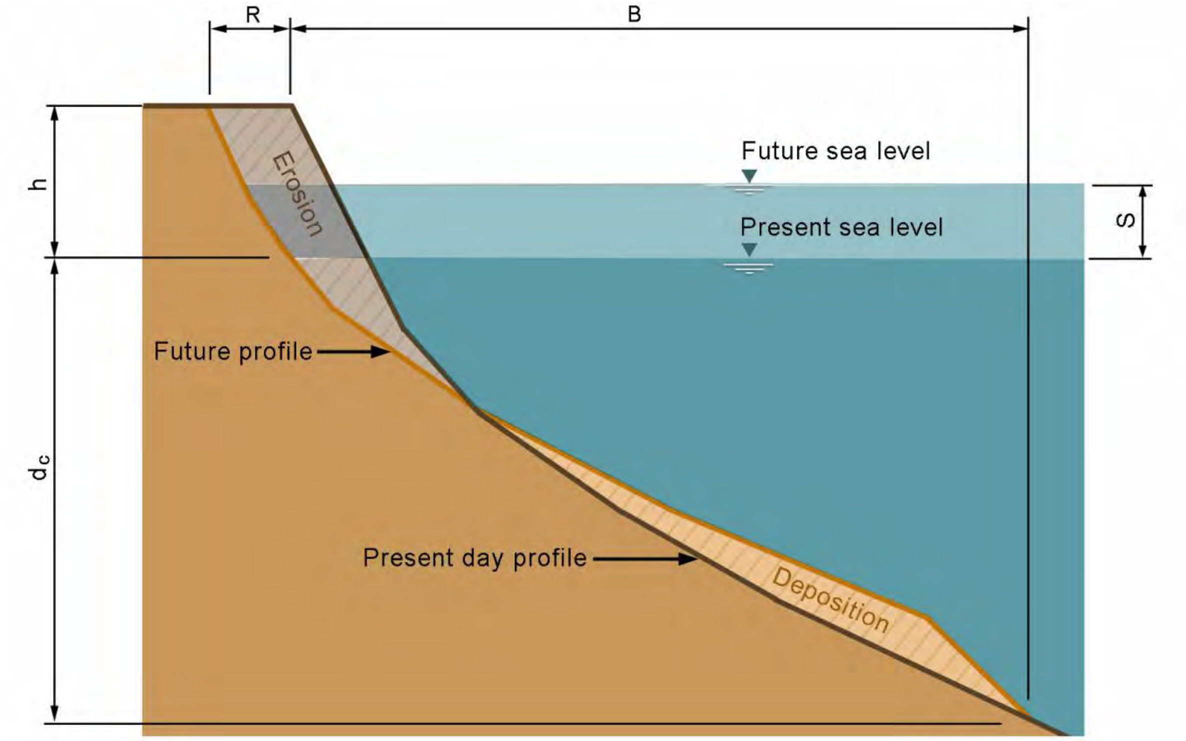

Figure A1-11: Illustration of variables in the Bruun Rule

Equation 1 can be simplified in the following way:

$$R = S \times BF \tag{2}$$

Whereby the recession becomes a function of the sea level rise and the Bruun Factor (BF) which encompasses the geometry of the beach ($B/(h + d_c)$). For this study the BF for this section of coastline would be determined using the 31 January 2022 beach Profile, as discussed in **Section A1.2.2**.

The depth of closure, defined by Bruun (1962) as "the outer limit for the nearshore littoral drift and exchange zone of littoral material between the shore and the offshore bottom area", has been estimated using analytical methods based on wave characteristics and sediment grain size characteristics.

For methods based on wave characteristics, Hallermeier (1981, 1983) defined three Profile zones, namely the littoral zone, shoal or buffer zone[4], and offshore zone. This thus defined two closure depths (defined to be relative to the mean low water level), namely:

- an "inner" (closer to shore) closure depth at the seaward limit of the littoral zone, termed d_l by Hallermeier (1981) and d_s by Hallermeier (1983), and d_{inner} herein; and
- an "outer" or "lower" (further from shore) closure depth at the seaward limit of the shoal/buffer zone, termed d_i by Hallermeier (1981) and d_o by Hallermeier (1983), and d_{outer} herein.

From Hallermeier (1981):

$$d_{inner} = 2.28H_e - 68.5\left(\frac{H_e^2}{gT_e^2}\right) \tag{3}$$

where H_e is the effective significant wave height exceeded for 12 hours per year (that is, the significant wave height with a probability of exceedance of 0.137%), and T_e is the corresponding significant wave period. For practical purposes it is assumed by Rijkswaterstaat (1987) that the d_{outer} can be calculated as follows:

$$d_{outer} = 2d_{inner} \tag{4}$$

Similar to the underlying recession calculations, the effective significant wave height was calculated for three different areas:

- Open coast beaches (Jetty Beach Block 3 and Boambee North, north and south of Coffs Harbour, respectively);
- Inside Coffs Harbour (Jetty Beach – Block 1); and
- Inside Coffs Harbour (Jetty Beach – Block 2).

For the open coast beaches, based on measured Coffs Harbour offshore wave data as analysed by RHDHV for this project, H_e was estimated to be 4.99m (offshore wave height) and the equivalent T_e 12.5s. When applied to equation 3, this results in an inner closure depth of about -10.8m relative to AHD (10.3 m below Mean Low Water (MLW) at -0.53 m AHD (BMT WBM, 2011). The outer closure depth is then approximately 20.5m below MLW or -21.1mAHD. For the estimation of the effective significant wave height inside Coffs Harbour reference is made to RHDHV (2021). A concise summary is provided below.

Physical modelling for Coffs Harbour undertaken by MHL in (2015) and (2020) tested wave transmission through the harbour, with a focus on governing conditions at the Coff Harbour boat ramp and basin (near output location 5 – refer **Figure A1**). Testing of 100-year return period offshore wave heights resulted in a transmission coefficient of 0.19 at output location 5 (five) in front of Jetty Beach Block 1 in approximately 5m water depth. Based on the 'open coast' effective significant wave height of 4.99m (refer above), the estimated H_e for Jetty Beach Block 1 is then 0.19 * 4.99m ≈ 0.95m with a corresponding T_e of 14.0s (refer RHDHV, 2021). This results in an inner and outer closure depth of -2.7mAHD and -4.8mAHD, respectively.

For output location 3 (three) in front of Jetty Beach Block 2, a transmission coefficient of 0.175 was found (refer RHDHV, 2021). Similar to the above, the estimated H_e for Jetty Beach Block 2 is then 0.175 * 4.99m

[4] *Shoal zone in Hallermeier (1981) and buffer zone in Hallermeier (1983)*

$\approx$ 0.87m with a corresponding T_e of 14.0s. This results in an inner and outer closure depth of -2.5mAHD and -4.4mAHD, respectively.

Construction of the beach slope according to the Bruun Rule and calculation of the Bruun factor for the four areas identified in **Section A1.2.4** is presented in **Table A1-6** to **Table A1-9** and **Figure A1** to **Figure A1** (example Profiles).

Table A1-6: Calculated minimum and maximum Bruun factors (Boambee North Block 4)

Profile	Minimum Bruun factor (inner depth)	Maximum Bruun factor (outer depth)
Boambee North - Block 4, Profile 7	38	52
Boambee North - Block 4, Profile 8	39	51
Boambee North - Block 4, Profile 9	38	50
Boambee North - Block 4, Profile 10	42	52
Mean (rounded)	39	51

Table A1-7: Calculated minimum and maximum Bruun factors (Jetty Beach Block 1)

Location	Minimum* Bruun factor (inner depth)	Maximum Bruun factor (outer depth)
Jetty Beach - Block 1, Profile 1	29	33
Jetty Beach - Block 1, Profile 2	26	25
Jetty Beach - Block 1, Profile 3	28	25
Jetty Beach - Block 1, Profile 4	23	22
Jetty Beach - Block 1, Profile 5	22	21
Jetty Beach - Block 1, Profile 6	22	21
Jetty Beach - Block 1, Profile 7	23	21
Jetty Beach - Block 1, Profile 8	28	24
Jetty Beach - Block 1, Profile 9	27	24
Jetty Beach - Block 1, Profile 10	23	21
Mean (rounded)	25	24

* *The minimum Bruun factor may be slightly greater than the maximum Bruun factor due to the shape of the lower shore face*

Table A1-8: Calculated minimum and maximum Bruun factors (Jetty Beach Block 2)

Profile	Minimum* Bruun factor (inner depth)	Maximum Bruun factor (outer depth)
Jetty Beach - Block 2, Profile 1	24	22
Jetty Beach - Block 2, Profile 2	22	20
Jetty Beach - Block 2, Profile 3	20	19
Jetty Beach - Block 2, Profile 4	24	22
Jetty Beach - Block 2, Profile 5	26	24
Jetty Beach - Block 2, Profile 6	29	26
Mean (rounded)	24	22

* *The minimum Bruun factor may be slightly greater than the maximum Bruun factor due to the shape of the lower shore face*

Table A1-9: Calculated minimum and maximum Bruun factors (Jetty Beach Block 3 (north of the harbour))

Profile	Minimum Bruun factor (inner depth)	Maximum Bruun factor (outer depth)
Jetty Beach - Block 3, Profile 1	43	72
Jetty Beach - Block 3, Profile 2	42	70
Jetty Beach - Block 3, Profile 3	41	67
Jetty Beach - Block 3, Profile 4	42	75
Mean (rounded)	42	71

Based on the above, the adopted minimum, mode and maximum Bruun factor values for the four areas are presented in **Table A1-10**. For the locations inside Coffs Harbour, minimum and maximum Bruun factors are set by applying variations of -5 to +5 to the best estimate factor, to allow for the uncertainties involved in determining projected future sea level rise impacts on the shoreline.

Table A1-10: Adopted minimum, mode and maximum Bruun factors

Profile	Minimum	Mode	Maximum
Boambee North - Block 4	39	45	51
Jetty Beach - Block 1	20	25	30
Jetty Beach - Block 2	18	23	27
Jetty Beach - Block 3 (north of the harbour)	42	57	71

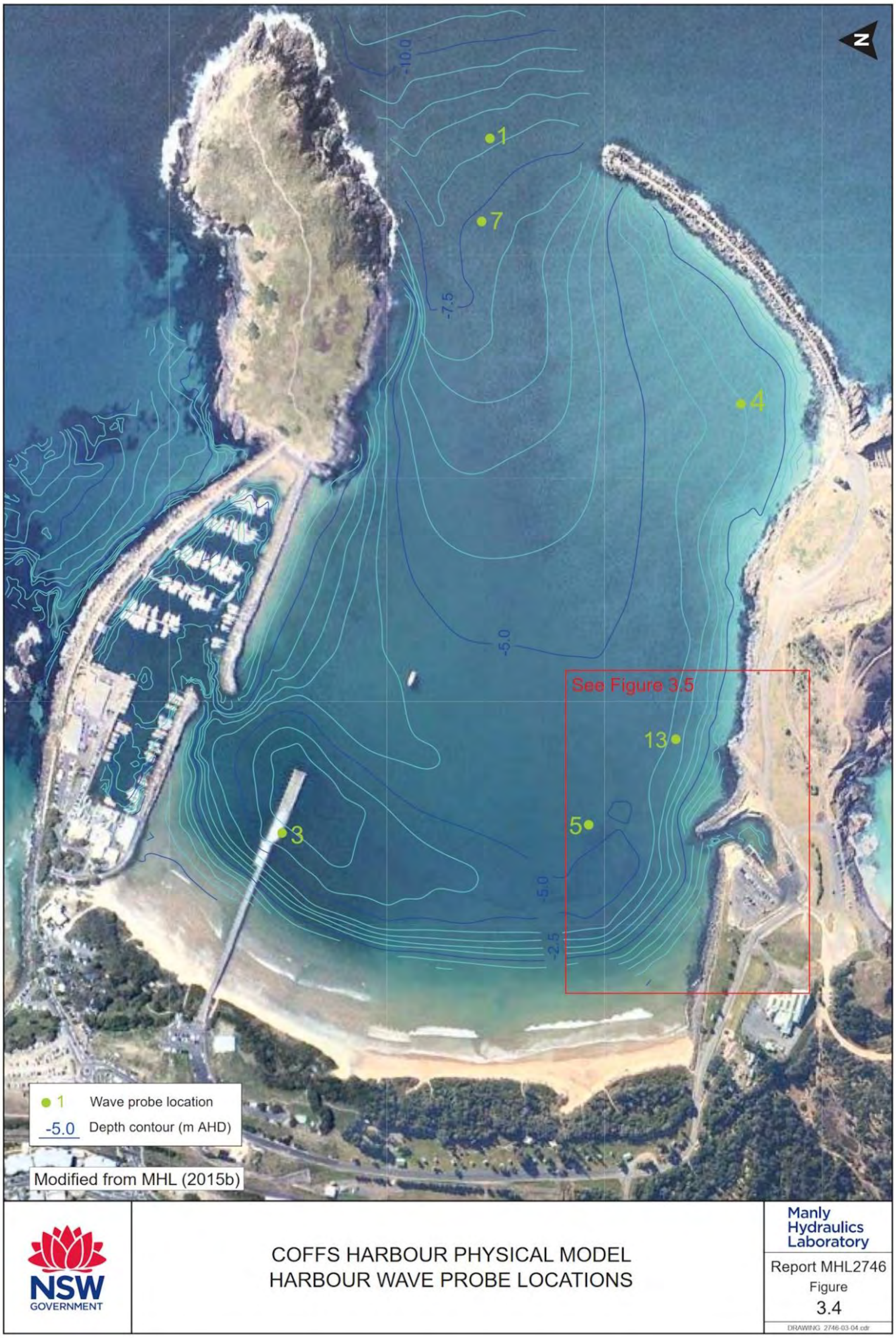

Figure A1-12: Coffs Harbour physical modelling output locations (source: MHL (2020) figure 3.4)

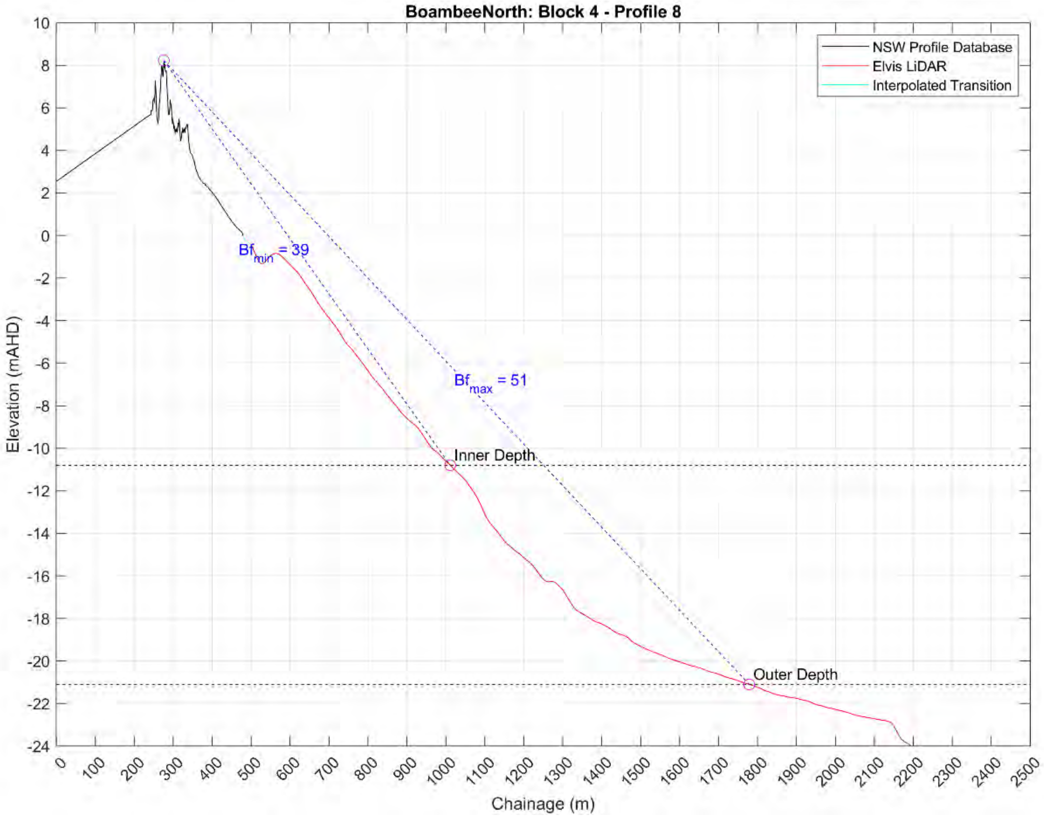

Figure A1-13: Example Bruun factor calculation for Boambee North Block 4 - Profile 8

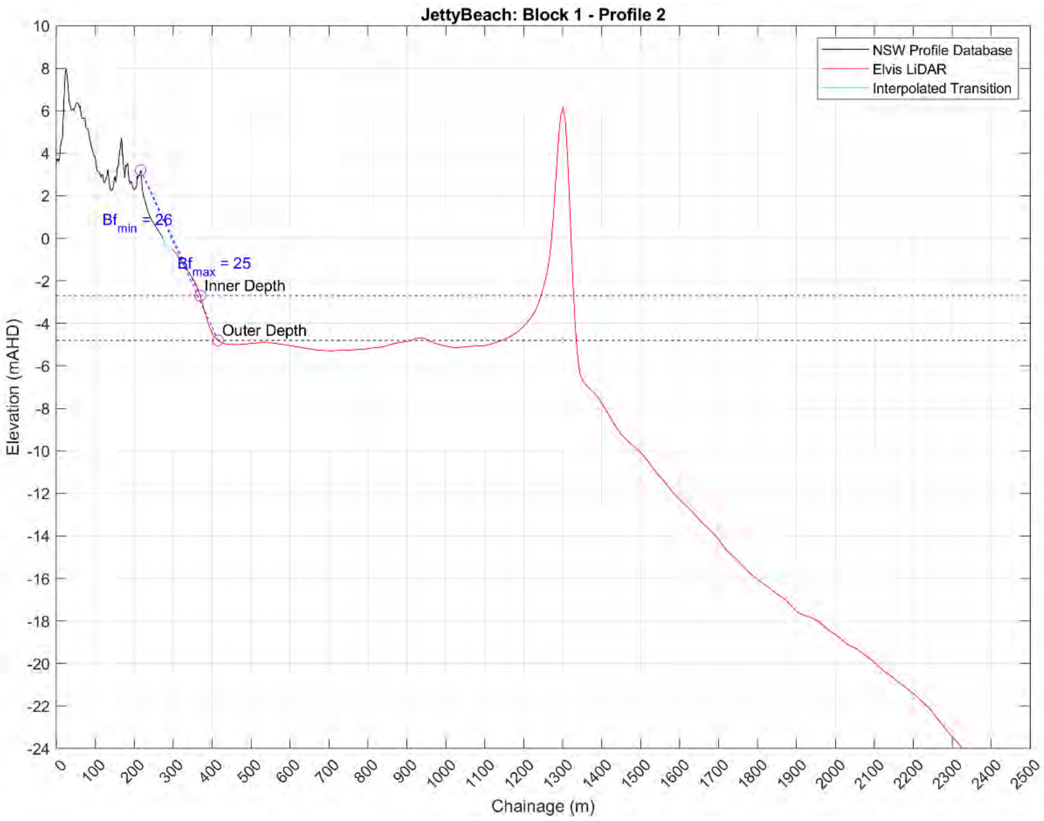

Figure A1-14: Example Bruun factor calculation for Jetty Beach Block 1 - Profile 2

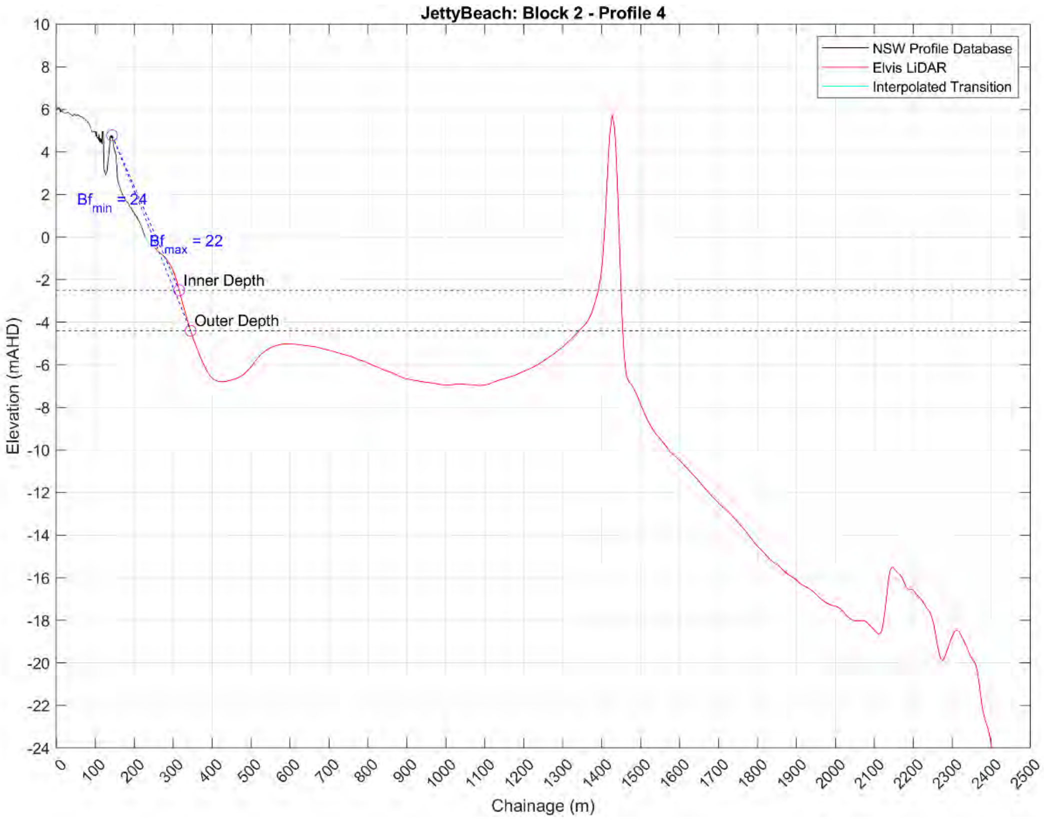

Figure A1-15: Example Bruun factor calculation for Jetty Beach Block 2 - Profile 4

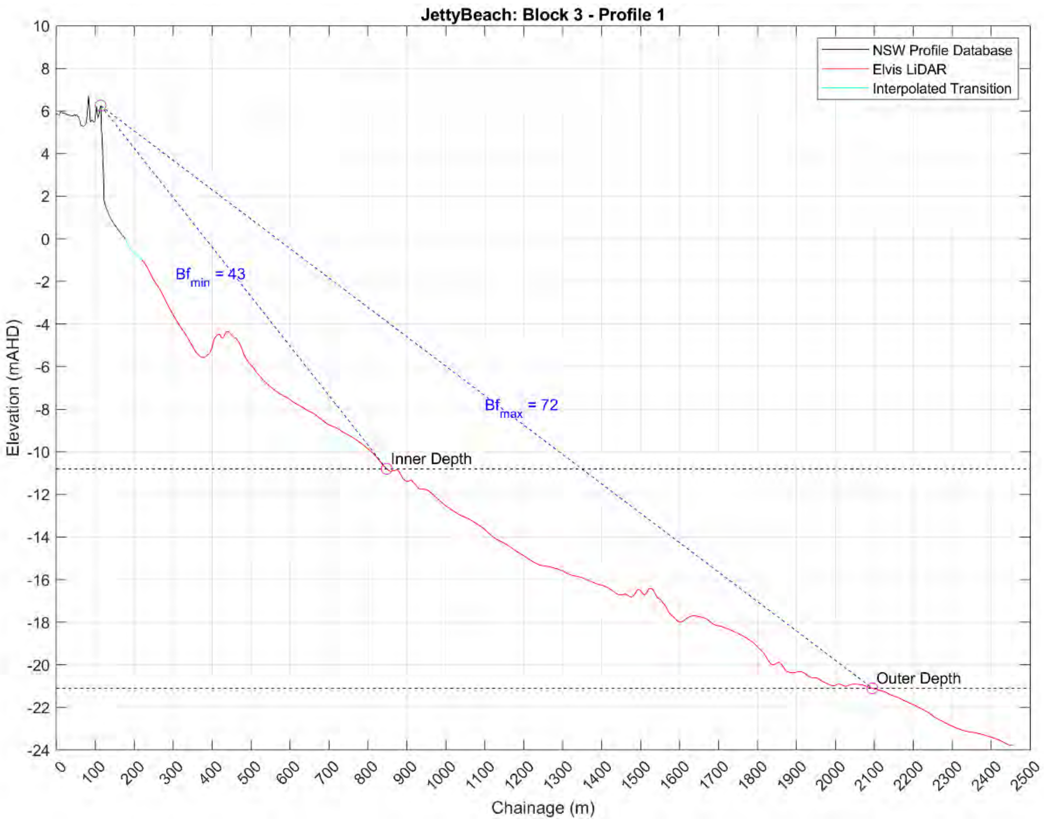

Figure A1-16: Example Bruun factor calculation for Jetty Beach Block 3 - Profile 1

A1.2.6 Storm Demand

A1.2.6.1 Introduction

During storms, large waves and elevated water levels can cause severe erosion to sandy beaches. Storm demand represents the subaerial volume of sand removed from a beach (defined herein as the volume lost above 0m AHD) that could be expected due to a severe storm or from a series of closely spaced storms. Coffs Harbour is impacted by East Coast Low (ECL) and Tropical Cyclone (TC) storm events which generate large waves and storm surge causing beach erosion.

Nielsen *et al*. (1992) has delineated various coastline hazard zones as discussed below and depicted in **Figure A1**, assuming an entirely sandy (erodible) subsurface.

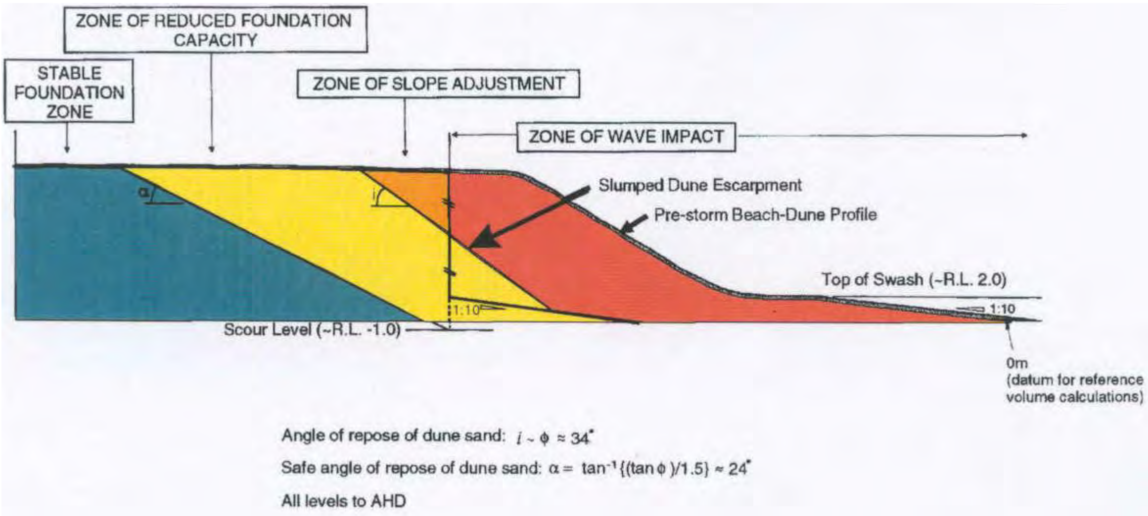

Figure A1-17: Schematic representation of coastline hazard zones (after Nielsen et al. (1992))

The *Zone of Wave Impact* (ZWI) delineates an area where any structure or its foundations would suffer direct wave attack during a severe coastal storm. It is that part of the beach which is seaward of the beach erosion escarpment.

A *Zone of Slope Adjustment* (ZSA) is delineated to encompass that portion of the seaward face of the beach that would slump to the natural angle of repose of the beach sand following storm erosion.

A *Zone of Reduced Foundation Capacity* (ZRFC) for building foundations is delineated to take account of the reduced bearing capacity of the sand adjacent to the storm erosion escarpment. Nielsen *et al*. (1992) recommended that structural loads should only be transmitted to soil foundations outside of this zone (i.e. situated landward or founded on piles), as the factor of safety within the zone is less than 1.5 during extreme scour conditions at the face of the escarpment.

In the method of Nielsen *et al*. (1992), a φ value (natural angle of repose of sand, also known as the friction angle) of 33° would be adopted. Kinsela and Hanslow (2013) have suggested that a risk averse approach would be to consider a range of φ values between 30° and 35°. However, it is noted that (for example) for an 6m AHD dune elevation, the difference in ZSA position over this φ range is only 0.5m, with lower φ values giving further landward positions. That is, the φ value has a relatively insignificant effect on hazard definition, with effects in the order of 1m in magnitude and not of significance for this study. Therefore, no allowance would be made for variability in φ values.

A1.2.6.2 Storm Demand for Coffs Harbour

A comprehensive storm erosion demand analysis in terms of volume (m^3) per metre beach has not been previously undertaken for the Coffs Harbour coastline. BMT WBM (2011) adopted 'almost certain' and 'unlikely' erosion extents in metres (at the 2m AHD contour), for the beach erosion hazard in the Coffs Harbour Local Government Area (LGA) for the immediate timeframe – refer **Figure A1**. However, no site-specific assessment was undertaken by BMT WBM (2011).

Beach	Erosion [1] (m)		Recession		Notes
	Almost certain [2]	Unlikely [3]	Present	By 2100 with 0.9 m SLR (from S to N)	
North	50	120	Stable	30 to 15 m	Erosion values from Bongil adopted as no photogrammetric data, beaches are similar size and orientation.
Bongil	50	120	Stable	75 to 20 m	
Sawtell	15	50	Stable	50 to 15 m	
Boambee	50	120	+ 3.5 m/yr	60 to 20 m	Erosion values from Bongil adopted due to accretionary trend, beaches are similar size and orientation.
Jetty (Coffs Harbour)	15	50	+ 1.3 m/yr	40 m	Beach erosion applied from 2 m AHD contour due to low dunes.
South Park	15	50	Stable	115 m	Recession due to harbour has now stabilised. Erosion values from Sawtell adopted due to historical recession, beaches are similar size and orientation.
Park	15	50	-0.9 m/yr	115 to 50 m	Erosion values from Sawtell adopted due to historical recession, beaches are similar size and orientation.
Diggers	15	50	- 1.0 m/yr	150 to 110 m	Erosion values from Sawtell adopted due to historical recession, beaches are similar size and orientation.
Charlesworth Bay	40	75	Stable	40 m	Stable due to gravel sediments. Beach erosion applied from 2 m AHD contour due to low dunes. Erosion values from Sawtell adopted due to historical recession, beaches are similar size and orientation.
Korora	15	50	-0.4 m/yr	35 to 70 m	Erosion values from Sawtell adopted due to historical recession, beaches are similar size and orientation.
Hills	15	50	-0.2 m/yr	65 to 45 m	Erosion values from Sawtell adopted due to historical recession, beaches are similar size and orientation.
Campbells	15	50	Stable	30 to 75 m	Historical recession of 20-30 m which has now stabilised. Erosion values from Sawtell adopted due to historical recession, beaches are similar size and orientation.

Figure A1-18: Erosion and recession values adopted for beaches in the Coffs Harbour LGA (source: BMT WBM, 2019)

The beach erosion extents for Boambee North Block 4 were in fact taken from Bongil beach, an open coast beach approximately 10 km south, which was considered to be similar in terms of accretionary trend and beach size and orientation.

Similarly, the beach erosion extents for Jetty Beach Block 1 and Block 2, significantly protected by the harbour construction, and Jetty Beach Block 3 (South Park Beach) were from Sawtell beach (refer **Figure A1**), an open coast beach approximately seven km south of the harbour, which was considered to be similar in terms of stored sediment volume in the beach and dune (Jetty Beach Block 1 and 2) and historical recession and beach size and orientation (Jetty Beach Block 3 or South Park Beach).

RHDHV have converted these erosion extents, adopted by BMT WBM (2011), to an equivalent storm demand for the nominated Profiles (refer **Figure A1**) based on the zone of slope adjustment (ZSA) as defined by Nielsen (1992). Results for the same four areas as defined in **Section A1.2.4** are presented in **Table A1-11** to **Table A1-14**, and visualised for an example Profile in **Figure A1** to **Figure A1** (example Profiles).

Table A1-11: Equivalent storm demand volumes (m^3/m) based on the 'almost certain' and 'unlikely' storm erosion extents (BMT WBM, 2011, 2019) – Boambee North Block 4

Profile	'Average Measured Erosion' (15m) ('almost certain')*	'Maximum Measured Erosion' (50m) ('unlikely')*
Boambee North - Block 4, Profile 7	196	528
Boambee North - Block 4, Profile 8	187	546
Boambee North - Block 4, Profile 9	192	577
Boambee North - Block 4, Profile 10	181	511
Mean (rounded)	189	541

* BMT WBM (2019)

Table A1-12: Equivalent storm demand volumes (m^3/m) based on the 'almost certain' and 'unlikely' storm erosion extents (BMT WBM, 2011, 2019) – Jetty Beach Block 1

Profile	'Average Measured Erosion' (15m) ('almost certain')	'Maximum Measured Erosion' (50m) ('unlikely')
Jetty Beach - Block 1, Profile 1	70	177
Jetty Beach - Block 1, Profile 2	63	160
Jetty Beach - Block 1, Profile 3	67	159
Jetty Beach - Block 1, Profile 4	54	151
Jetty Beach - Block 1, Profile 5	49	153
Jetty Beach - Block 1, Profile 6	45	148
Jetty Beach - Block 1, Profile 7	58	164
Jetty Beach - Block 1, Profile 8	94	189
Jetty Beach - Block 1, Profile 9	72	169
Jetty Beach - Block 1, Profile 10	61	155
Mean (rounded)	63	163

Table A1-13: Equivalent storm demand volumes (m^3/m) based on the 'almost certain' and 'unlikely' storm erosion extents (BMT WBM, 2011, 2019) – Jetty Beach Block 2

Profile	'Average Measured Erosion' (15m) ('almost certain')	'Maximum Measured Erosion' (50m) ('unlikely')
Jetty Beach - Block 2, Profile 1	57	158
Jetty Beach - Block 2, Profile 2	54	166
Jetty Beach - Block 2, Profile 3	66	230
Jetty Beach - Block 2, Profile 4	82	220
Jetty Beach - Block 2, Profile 5	81	185
Jetty Beach - Block 2, Profile 6	72	185
Mean (rounded)	69	191

Table A1-14: Equivalent storm demand volumes (m^3/m) based on the 'almost certain' and 'unlikely' storm erosion extents (BMT WBM, 2011, 2019) – Jetty Beach Block 1 (South Park Beach)

Profile	'Average Measured Erosion' (15m) ('almost certain')	'Maximum Measured Erosion' (50m) ('unlikely')
Jetty Beach - Block 3, Profile 1	95	296
Jetty Beach - Block 3, Profile 2	114	314
Jetty Beach - Block 3, Profile 3	83	289
Jetty Beach - Block 3, Profile 4	60	306
Mean (rounded)	88	301

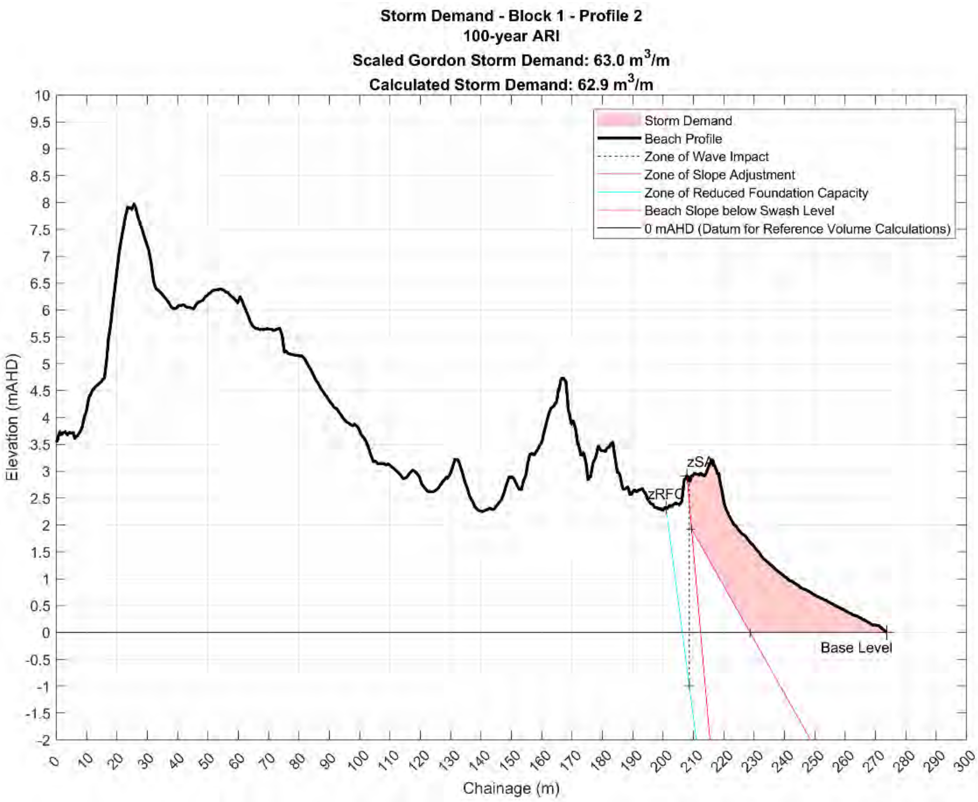

Figure A1-19: Storm demand volume for a 100-year ARI storm event (Jetty Beach Block 1 Profile 2)

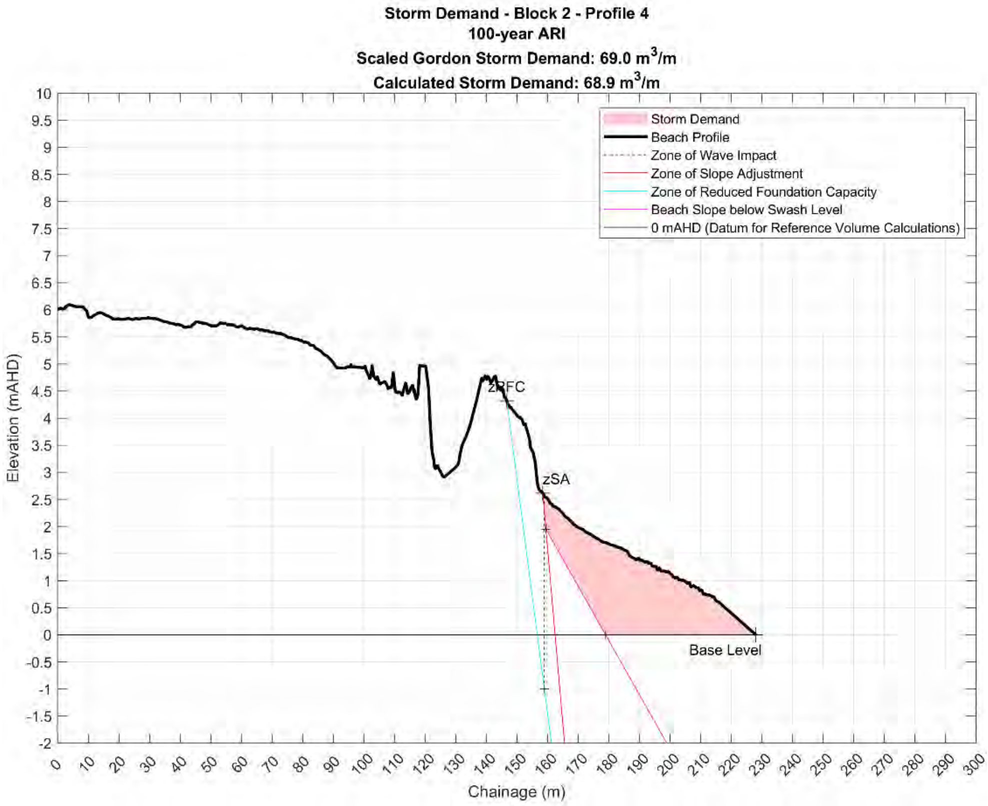

Figure A1-20: Storm demand volume for a 100-year ARI storm event (Jetty Beach Block 2 Profile 4)

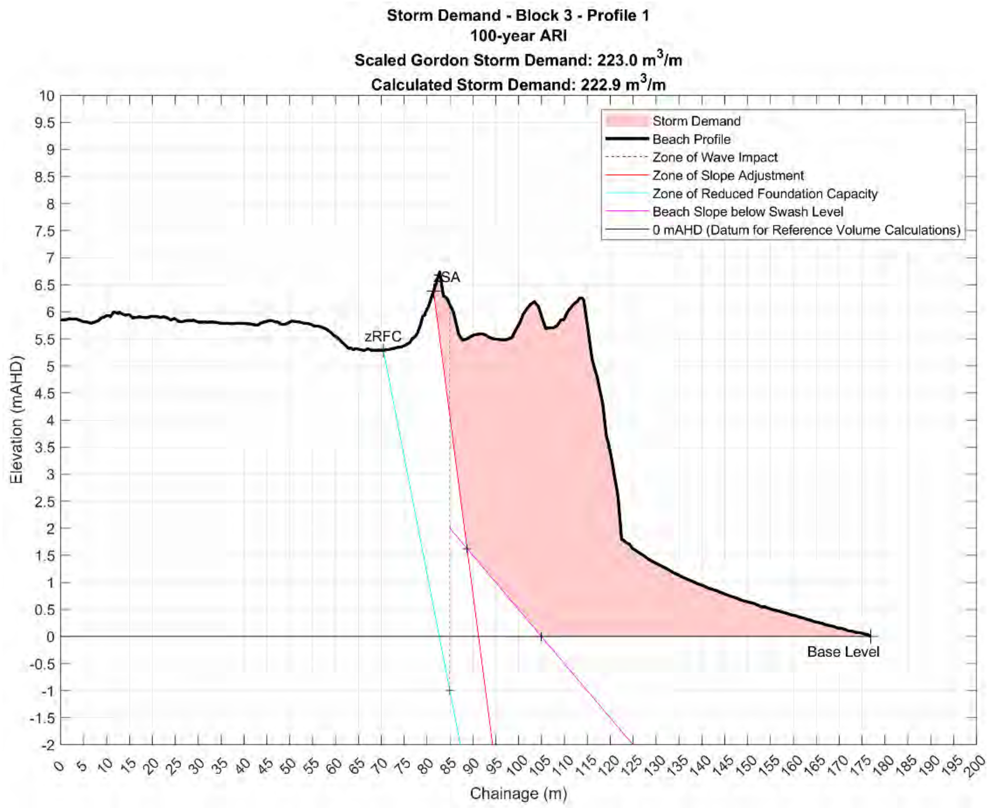

Figure A1-21: Storm demand volume for a 100-year ARI storm event (Jetty Beach Block 3 Profile 1)

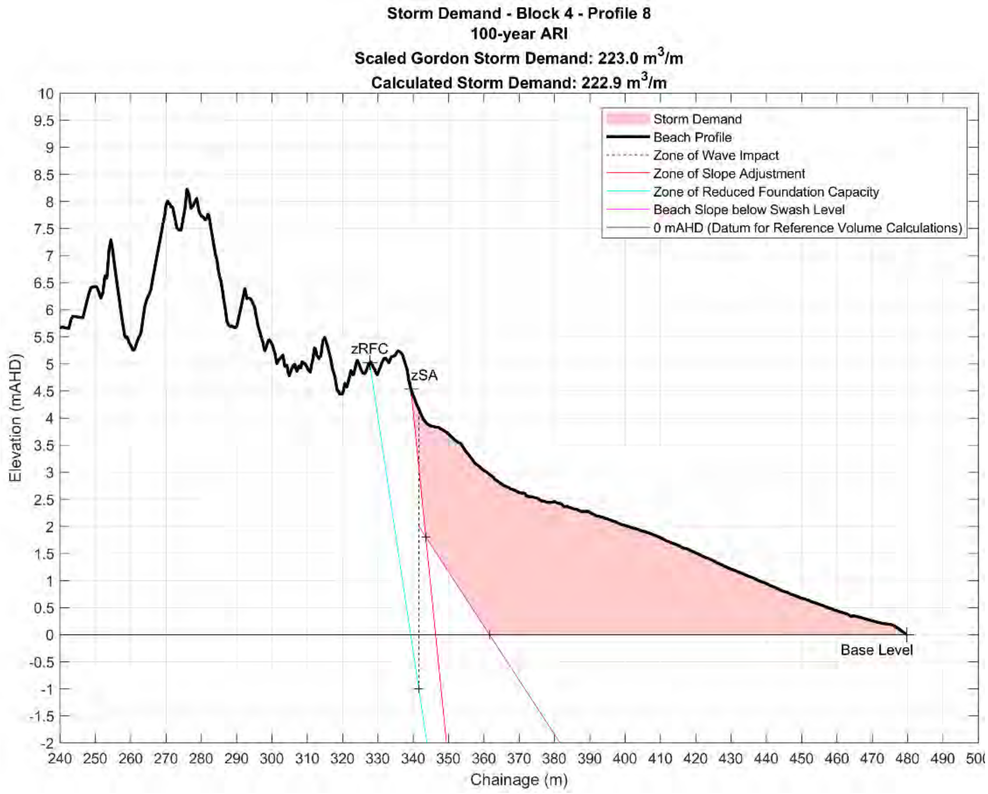

Figure A1-22: Storm demand volume for a 100-year ARI storm event (Boambee North Block 4 Profile 8)

It is proposed that the relationship developed by Gordon (1987) be adopted for estimation of storm demand values for a range of recurrence intervals. The storm demand values outlined in Gorgon's (1987) data remain best practice. This information is derived from storms in the 1970s, representing a 100-year ARI event. Ths intensity of event has not been surpassed in its extremity, thus remaining accurate and relevant to this day.

Based on measurements at open coast NSW beaches, Gordon (1987) derived relationships between storm demand and average recurrence interval, in both 'high demand' (at rip heads) and 'low demand' (away from rip heads) areas. The relationship between storm demand and the logarithm of ARI could be considered linear (Gordon, 1987).

It was estimated by Gordon (1987) that the storm demand above 0m AHD was about 140m^3/m for the 100-year ARI event for exposed NSW beaches away from rip heads. However, the harbour provides significant protection to Jetty Beach Block 1 and 2 and wave energy is significantly lower. The above calculated average equivalent storm demand volumes of 163 and 191m^3/m for the 50m erosion extent (BMT WBM, 2011, 2019) at sheltered Jetty Beach Block 1 and Block 2, respectively (refer **Table A1-12** and **Table A1-13**), are significantly larger than the storm demand of 140m^3/m estimated by Gordon (1987) for exposed beaches (away from rip heads). Accordingly, these values are not considered feasible for this location.

Based on the above, a storm demand volume of 63 and 69m^3/m were adopted ('low' demand - refer above), equivalent to the 15m storm erosion extent (BMT WBM, 2011; 2019). These values are considered to be a conservative design storm demand in this location, based on the relative wave energy that can penetrate the harbour during a representative 100-year ARI storm.

In regard to Boambee North Block 4 and Jetty Beach Block 3, the calculated average equivalent storm demand volumes for the 50m erosion extent (BMT WBM, 2011, 2019) are 541 and 301m^3/m, respectively. It was estimated by Gordon (1987) that the storm demand above 0m AHD for exposed NSW beaches at rip heads was about 220m^3/m for the 100-year ARI event. RHDHV considers this a typical if not conservative 100-year ARI storm demand value for the NSW open coast. The equivalent storm demand volumes for the 50m extent as outlined above are excessive in comparison to the typical expected 100-year ARI storm demand volume; the equivalent storm demand at Boambee North is more than double the 'Gordon' value and significantly higher at Jetty Beach Block 3 (South Park Beach). While the presence of Coffs Harbour provides significant sheltering from the dominant southeast storm direction at the latter location, the beach is still vulnerable to significant erosion due to swell from an easterly-north-easterly direction (for e.g. cyclones). RHDHV therefore propose to use the Gordon 100-year ARI storm demand volume of 223m^3/m at both Boambee North Block 4 and Jetty Beach Block 3.

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A2 Overtopping Assessment

Overtopping of a rock structure or sandy beach can be determined using the EurOtop Manual on wave overtopping of sea defence and related structures (EurOtop, van der meer, 2018). The following overtopping scenarios were considered for each location (locations as defined in **Section A1.2.4)**:

- Overtopping of dune crest
- Overtopping revetment wall (where a revetment wall structure has been constructed)

Design overtopping of a rock structure with a steep slope and design overtopping for sandy beaches were determined using the following equations respectively:

$$\frac{q}{\sqrt{g \times H_{m0}^3}} = 0.1035 \times \exp\left(-1.35 \frac{R_c}{\gamma_f \times \gamma_\beta \times H_{m0}}\right)^{1.3}$$ Equation 6.6, EurOtop 2018

$$\frac{q}{\sqrt{g \times H_{m0}^3}} = \frac{0.026}{\sqrt{tan\alpha}} \times \gamma_b \times \xi_{m-1,0} \times \exp\left(-2.5 \frac{R_c}{\gamma_v \times \gamma_b \times \gamma_f \times \gamma_\beta \times \xi_{m-1,0} \times H_{m0}}\right)^{1.3}$$ Equation 5.12, EurOtop 2018

Where:

q = mean overtopping discharge ($m^3/s/m$)
H_{mo}= wave height (m)
g= acceleration due to gravity (9.81 m/s^2)
$tan\alpha$= foreshore slope
R_c = Crest freeboard (m)
γ_v= influence factor for a vertical wall on the slope (1 no wall at top of beach)
γ_b= influence factor for a berm (1 assume no berm)
γ_f= influence factor for the permeability and roughness of or on the slope:

- 0.55: 2 layers, impermeable core for rock structure
- 1: smooth impermeable surface for overtopping of dune crest

γ_B= influence factor for oblique wave attack (1 assume 90^0 waves)
$\xi_{m-1,0}$= breaker parameter

The design life of a seawall has been determined to be 25 years (refer to **Section 2.1**). However, the planning period for this study is 100-years. Therefore, the SLR value adopted for the overtopping analysis was a 2123 SSP3-7.0 (medium) SLR of 0.7m (refer to **Section A1.2.5** and **Table A1-5**). The 100-year ARI water level data (**Section A2.1**) and wave height data (**Section A2.2**) was obtained from the Coastal Processes and Hazards Definition study undertaken by BMT WBM in 2011.

The inputs used for each beach location (as defined in **Section A1.2.4)** to calculate overtopping are presented in **Table A2-1**.

Table A2-1: EurOtop Inputs

Location	Dune Crest (m AHD)	Beach Slope (1:x)	SLR 2073 (m)	SLR 2123 (m)	100-year ARI (tide + surge only)	100-year ARI Wave Height (m)	100-year ARI Wave Period (s)
Boambee North – B4 – Profile 9	7.5	38	0.35	0.7	1.49	5.60	14
Jetty Beach – B1 – Profile 6	3.0	29	0.35	0.7	1.49	1.45	14
Jetty Beach – B2 – Profile 6	3.5	29	0.35	07	1.49	1.45	14
Jetty Beach – B3 – Profile 1	6.3	43	0.35	0.7	1.49	5.60	14

A2.1 Water Levels

Still water levels corresponding to the 1% AEP (equivalent to the 100-year return period) and 50% AEP (equivalent to the 20-year return period) event were assessed using the NSW Extreme Ocean Water Levels assessment for the Coffs Harbour station (MHL, 2018). The extreme water level values excluding wave effects for the current scenario are shown below in **Table A2-2.**

Table A2-2: Extreme water levels adopted for this study based on MHL (2018)

Water level scenario	Still Water Level (m AHD)
40% AEP (2 year ARI)	1.37
10% AEP (10 year ARI)	1.4
5% AEP (20 year ARI)	1.43
2% AEP (50 year ARI)	1.45
1% AEP (100 year ARI)	6.49

A2.2 Wave Height

Wave conditions at the study site for a various AEP events have been determined looking at the offshore conditions given in the Coastal Processes and Hazards Definition study (BMT WBM, 2011), and transmission coefficients estimated using existing physical modelling of Coffs Harbour and collected nearshore wave data. A transmission coefficient of 0.175 has been adopted based on the available information (RHDHV,2021). **Table A2-3** shows the offshore and nearshore (at the Jetty) significant wave heights for various present day AEP events. Wave period was taken as 14 seconds (BMT WBM, 2011) and the wave direction assumed to be shore normal in the nearshore.

Table A2-3: Extreme significant wave heights adopted for this study based on BMT WBM (2011)

Wave Height Scenario	Offshore significant wave height (m)	Open Coast Nearshore significant wave height (m)	Jetty Nearshore significant wave height (m)
40% AEP (2 year ARI)	5.60	4.10	1.00
10% AEP (10 year ARI)	6.70	4.80	1.20
5% AEP (20 year ARI)	7.10	5.30	1.25
2% AEP (50 year ARI)	7.80	5.60	1.37
1% AEP (100 year ARI)	8.20	5.90	1.45

A3 Risk Assessment

The probabilistic hazard assessment indicates the likelihood of infrastructure constructed landward of the "dune vegetation line" of being impacted on by coastal erosion processes during design life (i.e. 100-years, refer **Section 2.2**). Depending on the location of this infrastructure there is a varying likelihood of reduced foundation capacity, or complete undermining of infrastructure during a coastal storm event that occurs during that time.

Two approaches are available to design infrastructure in the coastal vulnerability area, which are:

1. design a structure to withstand the event (if the structure, or par thereof, located is seaward of the zone of reduced foundation capacity, this would require deep piled foundations); or
2. design (and accept the risk of) a structure that is sacrificial in the event, which would require shallow foundations at relatively less expense.

Piling of infrastructure, particularly linear infrastructure such as pathways, is a significant expense which may not be justifiable relative to the facility provided. This may be reason to assess and review the design assumptions and adjust designs as necessary in the context of the risk-based design philosophy (**Figure 2-1**).

The risk assessment would be undertaken on the assumption that the structures would be founded on shallow foundations.

By virtue of the fact that this investigation is considering infrastructure in some areas of the Precinct that will be (or already is) constructed without the protection of terminal seawall coastal protection, in the active beach erosion zone (i.e. coastal vulnerability area), there are inherent risks. These risks will be realised in the following ways:

- impact of coastal processes on proposed infrastructure;
- impact of the infrastructure on coastal processes;
- constructability issues, e.g. access for plant and equipment, temporary protection from tides and waves (e.g., sand bund), existence of obstructions for any piled structure (buried rock).

The location of infrastructure varying distances landward of the dune vegetation line will determine the level of risk of impact from/on coastal processes that the infrastructure is subject to. Accordingly, the spatial definition of risk within the effected zone is necessary to inform decision making.

A3.1 Defining Acceptable Risk

Risk may refer to anyone of a number of items, including:

- people and safety;
- infrastructure;
- environment;
- reputation;
- socio-cultural; and,
- cost and economics.

The project focusses on risk to:

- people and safety (overtopping); and,
- infrastructure (erosion).

The *Safe Design of Structures Code of Practice* (Safe Work Australia, 2018) and the *How to manage work health and safety risks Code of Practice* (Safe Work Australia, 2018) outlines the steps required to undertake a risk assessment. The process is known as risk management and involves the following steps:

1. Identify hazards – find out what could cause harm.
2. Assess risks, if necessary – understand the nature of the harm that could be caused by the hazard, how serious the harm could be and the likelihood of it happening. This step may not be necessary if you are dealing with a known risk with known controls.
3. Control risks – implement the most effective control measure that is reasonably practicable in the circumstances and ensure it remains effective over time.
4. Review hazards and control measures to ensure they are working as planned.

The risk management process is shown graphically in **Figure A3-1**. The risk assessment for the Coffs Harbour Jetty Foreshore Precinct beaches would comprise Step 1 and Step 2. The risk associated with a particular hazard is the combination of:

- the probability (or likelihood) of the hazard occurring; and,
- the consequence of the hazard.

The two primary hazards would be erosion and overtopping.

A risk matrix is presented in Australian Geomechanics Society (AGS) procedures for landslide risk management, AGS (2007a, b), and the Beach Management Manual (Second Edition) (CIRIA, 2010). A risk matrix, based on AGS (2007a, b), is shown in **Figure A3-2**.

AGS (2007a, 2007b) defined “acceptable risk” as follows:

> “A risk for which, for the purposes of life or work, we are prepared to accept as it is with no regard to its management. Society does not generally consider expenditure in further reducing such risks justifiable”.

A key aspect of the AGS (2007a, b) approach is that they defined the acceptable level of risk for new development as being “low” risk (or lesser, that is “very low”). This was based on review of the limited literature available, extensive discussion amongst the AGS Working Group, and consideration of the annualised cost of damage to property. AGS (2007a, b) concluded that:

> “most informed home owners are likely to be risk averse as a result of appreciation of the consequences at a family or personal level, almost regardless of the likelihood of the event. This risk aversion suggests that Low Risk to Property is an appropriate recommendation for acceptable risk to the regulator for domestic dwellings which are of Importance Level 2 (as defined in the BCA [Building Code of Australia])”.

Note that AGS (2007a, b) considered that the acceptable risk level was “low” for structures of both:

- Importance Level 2 (such as low-rise residential construction); and
- Importance Level 3 (such as buildings and facilities where more than 300 people can congregate in one area, schools of greater than 250 people, health care facilities with a capacity of 50 or more residents, power generating facilities, water treatment and wastewater treatment facilities.

For structures of Importance Level 4 (such as buildings and facilities designated as essential facilities or with special post-disaster functions, medical emergency or surgery facilities, emergency service facilities (fire, rescue, police etc.), the designated acceptable risk level was “very low”.

However, for structures of Importance Level 1 (such as minor temporary facilities), the designated acceptable risk level was “medium”.

For the purposes of this report on infrastructure, an importance Level of 2 and 3 is assumed. Accordingly, **low risk** is therefore considered acceptable.

Figure A3-1: Risk Management Process

Likelihood	Consequence				
	5 Catastrophic	4 Major	3 Moderate	2 Minor	1 Insignificant
5 Almost Certain	E25	E20	E15	H10	M5
4 Likely	E20	E16	H12	M8	L4
3 Possible	E15	H12	M9	M6	L3
2 Unlikely	H10	M8	M6	L4	VL2
1 Rare	M5	L4	L3	VL2	VL1
0 Exceptionally Rare	VL0	VL0	VL0	VL0	VL0

Risk Assessment Scores	Action Required
Extreme (20-25) High (10-20)	Unacceptable risk requires immediate attention to eliminate or reduce risk.
Medium (5-9)	Control the risks and hazards. If residual risk exists, which are not possible to control, work may proceed provided stakeholders understand the residual risk.
Low (1-4)	Acceptable to tolerable risk, work can proceed.

Figure A3-2: Risk Matrix, based on AGS (2007a, b). Required actions may vary, depending on the Client and the hazard

A3.2 Likelihood

The likelihood of a risk occurring depends on various factors such as the nature of the risk, the mitigation measures in place, and the overall context of the situation. Assessing the likelihood of a risk accurately is crucial for effective risk management and decision-making. A typical description of likelihood is presented in **Table A3-1**.

For erosion risk, the likelihood is based off the probabilistic approach described in **Section A1.1**, whereas overtopping likelihood calculations used a quantitative approach which is recommended to determine the likelihood of an event occurring.

Table A3-1: Likelihood table.

Likelihood	Description
5 Almost Certain	Could happen at any time under normal circumstances. Is expected to occur at regular intervals.
4 Likely	Probably will occur under normal circumstances. Has occurred several times in the past on similar projects.
3 Possible	Possibility it will occur under normal circumstances. Has occurred a few times in the past on similar projects.
2 Unlikely	Could happen but unlikely under normal circumstances. Has occurred once in the past on a similar project.
1 Rare	Will probably never occur. May happen in exceptional circumstances.

A3.3 Consequence

The consequences of a risk can vary greatly depending on the nature and severity of the risk event. Understanding the potential consequences allows for better risk planning and mitigation strategies to minimize potential negative impacts. A typical description of likelihood is presented in **Table A3-2** for people and safety and infrastructure.

Table A3-2: Consequence table.

Consequence	Description
5 Catastrophic	People and Safety – potential death. Infrastructure – structure(s) completely destroyed and/or large-scale damage requiring major engineering works for stabilisation. Could cause at least one adjacent property major consequence damage.
4 Major	People and Safety – potential permanent or long-term disability or illness requiring urgent medical attention and hospital admission. Infrastructure – extensive damage to most of structure, and/or extending beyond site boundaries requiring significant stabilisation works. Could cause at least one adjacent property medium consequence damage.
3 Moderate	People and Safety – potential temporary disability or illness requiring medical attention. Infrastructure – moderate damage to some of structure, and/or significant part of site requiring large stabilisation works. Could cause at least one adjacent property minor consequence damage.
2 Minor	People and Safety – minor injury requiring first aid. Infrastructure – limited damage to part of structure, and/or part of site requiring some reinstatement stabilisation works.
1 Insignificant	People and Safety – negligible injury or discomfort. Nor medical treatment or measurable physical effects. Infrastructure – negligible damage possibly requiring minor repairs and negligible financial loss.

It is recommended that the consequence is linked to a parameter that can be readily calculated, rather than a qualitative descriptor, which can be ambiguous. The risk to infrastructure is link to erosion descriptors after Nielsen (1992) while the risk to safety would be linked to overtopping volumes.

In the coastal zone context, risk to people and safety related to development of infrastructure and setback from the beach can be acceptably low as outlined in **Section 2.3**. People would have a very low probability of occupancy and/or loss of life during an actual storm event that could threaten infrastructure, and hence there is a low risk to life in such an event.

A3.4 Erosion Risk Assessment

The hazard line mapping produces lines showing the probability that erosion will be exceeded in 2023, 2073 and 2123. For example, the 95% hazard line (purple) has a 95% change of occurring (almost certain) where a 0.1% line (red) has only a 0.1% of occurring (rare). The probabilities of exceedance are then assigned to a likelihood as per **Table A3-3**. The consequence of the risk to infrastructure is linked to the erosion descriptors delineated by Nielsen (1992, **Section A1.2.6.1**). For the three planning periods (2023, 2073 and 2123) the erosion risk rating was determined based on the criteria in **Table A3-3**.

Table A3-3: Consequence and likelihood criteria for erosion risk

Consequence	Erosion Description	Likelihood	Probability (position)	Risk Level
1 Insignificant	Infrastructure located within Stable Foundation Zone	1 Rare	0 to 10	Very Low
2 Minor	Infrastructure located within Stable Foundation Zone	2 Unlikely	10 to 30	Low
3 Moderate	Infrastructure located within Reduced Foundation Capacity	3 Possible	30 to 70	Medium
4 Major	Infrastructure located within Zone of Slope Adjustment	4 Likely	70 to 90	High
5 Catastrophic	Infrastructure located within Zone of Wave Impact	5 Almost Certain	90 to 100	Extreme / High

A3.4.1 Alignment/Location

To reduce the likelihood of undermining or reduced foundation capacity of infrastructure it is recommended that it is located, or in the case of linear infrastructure aligned, such that the seaward extent is minimised. Intuitively, the likelihood reduces the further landward infrastructure is located. The hazard assessment defines this further by calculating the probabilities of occurrences of the landward extents of the Zone of Slope Adjustment and Zone of Reduced Foundation Capacity. This allows risk management decisions regarding infrastructure to be made based on defined probabilities of event occurrence.

A3.4.2 Overtopping Risk

Overtopping volumes have been calculated for the following ARI events:

- 2-year ARI (40% AEP)
- 10-year ARI (10% AEP)
- 20-year ARI (5% AEP)
- 50-year ARI (2% AEP)
- 100-year ARI (1% AEP)

For overtopping likelihood, the probability that a particular storm event will be exceeded within a particular design life is given by:

$$Probability\ over\ design\ life = 1 - (1 - \mathrm{AEP})^{design\ life}$$

Where *AEP* is the annual exceedance probability (e.g., 1% for the 100-year ARI).

Table A3-4 outlines the probability that different ARI events will be exceeded within varying design lives. The probabilities are then assigned a likelihood value. The consequence of the risk to overtopping is linked to critical overtopping discharges and volumes are outlined in The Rock Manual (CIRIA, 2008) and EurOtopII (van der meer, 2018). The critical values have then been applied to consequence categories.

For the three planning periods (2023, 2073 and 2123) the overtopping risk rating was determined based on the criteria in **Table A3-5** (consequence multiplied by likelihood).

The design life for a revetment wall is 25 years, therefore the probability of different ARI events occurring over design life will be based off 25 years for all the planning periods.

In some cases when considering the management of overtopping, access to infrastructure is closed temporarily due to overtopping risks where considered extreme, e.g. Coffs Northern Breakwater, Shelly Beach esplanade (Manly). Management action recommendations would be developed if this sort of extreme overtopping is expected based on modelling results. Many Councils close paths, accessways and public spaces until the beach can be restored, often accelerated by beach scraping. Lifeguards can be a special case and particular post storm access arrangements may need to be considered for them.

Table A3-4: Probability of different ARI events occurring over design life.

Design Life	Probability of ARI event occurring at least one (%)				
	2	10	20	50	100
1	50%	10%	5%	2%	1%
25	100.0%	92.8%	72.3%	39.7%	22.2%
50	100.0%	99.5%	92.3%	63.6%	39.5%
100	100.0%	100.0%	99.4%	86.7%	63.4%

Table A3-5: Consequence and likelihood criteria for overtopping risk

Consequence	Discharge range, q ($m^3/s/m$)	Likelihood	Probability of ARI event occurring at least one (%)
1 Insignificant	0 to 0.00003	1 Rare	0 to 10
2 Minor	0.00003 to 0.00007	2 Unlikely	10 to 30
3 Moderate	0.00007 to 0.0001	3 Possible	30 to 70
4 Major	0.0001 to 0.001	4 Likely	70 to 90
5 Catastrophic	0.001 to 1	5 Almost Certain	90 to 100

Note: q = mean overtopping discharge (m^3/s per m length in accordance with The Rock Manual (CIRIA, 2010))

A3.4.3 Recommended Detailed Analysis Approach

While the preliminary and generic analysis presented above provides a coarse overview of potential overtopping risks, it is recommended that further investigations for the design of any specific infrastructure employ numerical modelling to estimate overtopping. Overtopping calculations based on the EurOtop calculations provide conservative estimates of overtopping based on a fixed Profile. However, in reality the Profile will be dynamic during storm conditions. As a result of this, it is recommended that a numerical model such as XBeach (McCall et al., 2014; Roelvink et al., 2009) or CoastalFOAM be applied to the problem to calculate overtopping rates based on a more realistic mid-storm Profile.

A4 References

AGS (2007a). Guideline for Landslide Susceptibility, Hazard and Risk Zoning for Land Use Planning. Australian Geomechanics Society, Australian Geomechanics Vol42 No1 March 2007.

AGS (2007b). Practise Note Guidelines for Landslide Risk Management 2007. Australian Geomechanics Society, Australian Geomechanics Vol42 No1 March 2007.

BMT WBM (2011). Coffs Harbour Coastal Processes and Hazards Definition Study, Final Report, prepared for Coffs Harbour City Council.

BMT WBM (2019). Coffs Harbour Coastal Zone Management Plan, Final Report, prepared for Coffs Harbour City Council, March 2019.

Bruun, P. M. (1962). Sea Level Rise as a Cause of Shore Erosion. Journal of the Waterways and Harbours Division, ASCE, Vol 88 No. WW1, February.

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

CIRIA (2010). The Rock Manual- The use of rock in hydraulic engineering. 2nd ed.

CSIRO (2007). Climate Change in Australia - Technical Report 2007. CSIRO Marine and Atmospheric Research and Bureau of Meteorology, Melbourne, VIC, Australia.

DECCW (2009). NSW Sea Level Rise Policy Statement. Department of Environment, Climate Change and Water, Sydney

Gordon, A.D. (1987). ‘Beach Fluctuation and Shoreline Change’. 8th Australasian Conference on Coastal and Ocean Engineering, Launceston, Tasmania.

Hallermeier, R. J. (1981). A Profile zonation for seasonal sand beaches from wave climate. Coastal Eng., Vol. 4, pp 253-277.

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

Intergovernmental Panel on Climate Change [IPCC] (2007). Climate Change 2007: Synthesis Report, Intergovernmental Panel on Climate Change key findings and uncertainties contained in the Working Group contributions to the Fourth Assessment Report.

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

Intergovernmental Panel on Climate Change [IPCC] (2021). Ocean, Cryosphere and Sea Level Change. In *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* [Masson-Delmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, and B. Zhou (eds.)].

Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 1211–1362, doi:10.1017/9781009157896.011.

Kinsela, M.A and Hanslow, D.J. (2013). Coastal Erosion Risk Assessment in New South Wales: Limitations and Potential Future Directions. Prepared for the Natural Disasters Resilience Program.

McCall, R.T., Masselink,G., Poate, T.G., Roelvink, J.A., Almeida, L.P., Davidson, M., Russell, P.E. (2014). Modelling storm hydrodynamics on gravel beaches with XBeach-G. Coastal Engineer Volume 91, 231-250. https://doi.org/10.1016/j.coastaleng.2014.06.007

MHL (2015). Coffs Harbour Boat Ramp Basin Extension Final Design. Prepared for Coffs Harbour City Council.

MHL (2020). Coffs Harbour Physical Model Boat Ramp Basin and Breakwater Testing. Prepared for Department of Planning, Industry and Environment – Crown Lands.

NASA (2023). Sea Level Projection Tool, accessed 19 June 2007. < https://sealevel.nasa.gov/ipcc-ar6 sea-level-projection-tool>.

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

RHDHV (2019). Mollymook Beach Cost Benefit and Distributional Analysis – Coastal Hazard Assessment, for Origin Capital Group, September 2020.

RHDHV (2020a). North Wollongong Beach Cost Benefit and Distributional Analysis Coastal Hazard Assessment. Prepared for Origin Capital Group, March 2020.

RHDHV (2020b). Warilla Beach Cost Benefit and Distributional Analysis Coastal Hazard Assessment. Prepared for Marsden Jacob, April 2020.

RHDHV (2021). Coffs Jetty Community Building Coastal Risk Management Report. Prepared for Property NSW, August 2021. PA2831-RHD-ZZ-XX-RP-Z-0001, S0/P01.01.

Rijkswaterstaat (1987). Manual on Artificial Beach Nourishment, document prepared by the Netherlands Department of Public Works (Rijkswaterstaat), August, ISBN 9021260786.

Roelvink, D., Reniers, A., Van Dongeren, A., Van Thiel De Vries, J., McCall, R., Lescinski, J. (2009). Modelling storm impacts on beaches, dunes and barrier islands. Coastal Engineering 56, 1133–1152. https://doi.org/10.1016/j.coastaleng.2009.08.006

van der Meer, J. W., NWH Allsop, T. Bruce, Julien De Rouck, Andreas Kortenhaus, T. Pullen, H. Schüttrumpf, Peter Troch, and B. Zanuttigh. 2018. EurOtop: Manual on Wave Overtopping of Sea Defences and Related Sturctures : An Overtopping Manual Largely Based on European Research, but for Worlwide Application. 3rd ed.

Appendix B – Coastal Hazard Maps

B1 Boambee North Hazard Maps

This appendix presents the annual exceedance probability erosion hazard lines for Boambee North area. The following hazard lines have been modelled:

- The coastal hazard (ZSA) at present year (2023): **Figure B1-1**;
- The coastal hazard (ZSA) at 50 years (2073): **Figure B1-2**;
- The coastal hazard (ZSA) at 100 years (2123): **Figure B1-3**;
- The coastal hazard (ZRFC) at present year (2023): **Figure B1-4**;
- The coastal hazard (ZRFC) at 50 years (2073): **Figure B1-5**; and,
- The coastal hazard (ZRFC) at 100 years (2123): **Figure B1-6**.

Figure B1-1: Zone of Slope Adjustment at Boambee North (2023)

Figure B1-2: Zone of Zone of Slope Adjustment at Boambee North (2073)

Figure B1-3: Zone of Slope Adjustment at Boambee North (2123)

Figure B1-4: Zone of Reduced Foundation Capacity at Boambee North (2023)

Figure B1-5: Zone of Reduced Foundation Capacity at Boambee North (2073)

Figure B1-6: Zone of Reduced Foundation Capacity at Boambee North (2123)

B2 Jetty Beach Block 1 Hazard Maps

This appendix presents the annual exceedance probability erosion hazard lines for Jetty Beach Block 1 area. The following hazard lines have been modelled:

- The coastal hazard (ZSA) at present year (2023): **Figure B2-1**;
- The coastal hazard (ZSA) at 50 years (2073): **Figure B2-2**;
- The coastal hazard (ZSA) at 100 years (2123): **Figure B2-3**;
- The coastal hazard (ZRFC) at present year (2023): **Figure B2-4**;
- The coastal hazard (ZRFC) at 50 years (2073): **Figure B2-5**; and,
- The coastal hazard (ZRFC) at 100 years (2123): **Figure B2-6**.

Figure B2-1: Zone of Slope Adjustment at Jetty Beach Block 1 (2023)

Figure B2-2: Zone of Slope Adjustment at Jetty Beach Block 1 (2073)

Figure B2-3: Zone of Slope Adjustment at Jetty Beach Block 1 (2123)

Figure B2-4: Zone of Reduced Foundation Capacity at Jetty Beach Block 1 (2023)

Figure B2-5: Zone of Reduced Foundation Capacity at Jetty Beach Block 1 (2073)

Figure B2-6: Zone of Reduced Foundation Capacity at Jetty Beach Block 1 (2123)

B3 Jetty Beach Block 2 Hazard Maps

This appendix presents the annual exceedance probability erosion hazard lines for Jetty Beach Block 2 area. The following hazard lines have been modelled:

- The coastal hazard (ZSA) at present year (2023): **Figure B3-1**;
- The coastal hazard (ZSA) at 50 years (2073): **Figure B3-2**;
- The coastal hazard (ZSA) at 100 years (2123): **Figure B3-3**;
- The coastal hazard (ZRFC) at present year (2023): **Figure B3-4**;
- The coastal hazard (ZRFC) at 50 years (2073): **Figure B3-5**; and,
- The coastal hazard (ZRFC) at 100 years (2123): **Figure B3-6**.

Figure B3-1: Zone of Slope Adjustment at Jetty Beach Block 2 (2023)

Figure B3-2: Zone of Slope Adjustment at Jetty Beach Block 2 (2073)

Figure B3-3: Zone of Slope Adjustment at Jetty Beach Block 2 (2123)

Figure B3-4: Zone of Reduced Foundation Capacity at Jetty Beach Block 2 (2023)

Figure B3-5: Zone of Reduced Foundation Capacity at Jetty Beach Block 2 (2073)

Figure B3-6: Zone of Reduced Foundation Capacity at Jetty Beach Block 2 (2123)

B4 Jetty Beach Block 3 Hazard Maps

This appendix presents the annual exceedance probability erosion hazard lines for Jetty Beach Block 3 area. The following hazard lines have been modelled:

- The coastal hazard (ZSA) at present year (2023): **Figure B4-1**;
- The coastal hazard (ZSA) at 50 years (2073): **Figure B4-2**;
- The coastal hazard (ZSA) at 100 years (2123): **Figure B4-3**;
- The coastal hazard (ZRFC) at present year (2023): **Figure B4-4**;
- The coastal hazard (ZRFC) at 50 years (2073): **Figure B4-5**; and,
- The coastal hazard (ZRFC) at 100 years (2123): **Figure B4-6**.

Figure B4-1: Zone of Slope Adjustment at Jetty Beach Block 3 (2023)

Figure B4-2: Zone of Slope Adjustment at Jetty Beach Block 3 (2073)

Figure B4-3: Zone of Slope Adjustment at Jetty Beach Block 3 (2123)

Figure B4-4: Zone of Reduced Foundation Capacity at Jetty Beach Block 3 (2023)

Figure B4-5: Zone of Reduced Foundation Capacity at Jetty Beach Block 3 (2073)

Figure B4-6: Zone of Reduced Foundation Capacity at Jetty Beach Block 3 (2123)