Sunshine Coast Council

Shoreline Erosion Management Plan 2025-2035

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Acknowledgements

JBPacific acknowledges the traditional custodians of the lands and seas where we work. We pay our respects to Elders past, present, and emerging.

Reference document

This document should be cited as follows:
'Sunshine Coast Council Shoreline Erosion Management Plan 2025-2035 – Volume 1'.

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Abbreviations

AEP	Annual Exceedance Probability
AHD	Australian Height Datum
ARI	Average Return Interval
EVA	Extreme Value Analysis
CHAI	Coastal Hazard Adaptation Infrastructure
CHAS	Coastal Hazard Adaptation Strategy
DEM	Digital Elevation Model
GPD	Generalised Pareto Distribution
HAT	Highest Astronomical Tide
HCMP	Healthy Coast Management Plan
IPCC	Intergovernmental Panel on Climate Change
LAT	Lowest Astronomical Tide
LGA	Local Government Area
MDA	Maximum Dissimilarity Algorithm
MHWN	Mean High Water Neap
MHWS	Mean High Water Spring
MLWN	Mean Low Water Neap
MLWS	Mean Low Water Spring
MSL	Mean Sea Level
MSQ	Maritime Safety Queensland
RBF	Radial Basis Function
SCC	Sunshine Coast Council
SSP	Shared Socio-economic Pathway
SEMP	Shoreline Erosion Management Plan
PSM	Permanent Service Marker
TC	Tropical Cyclone
WRB	Wave Rider Buoy

1. Introduction

The Sunshine Coast local government area has approximately 60 kilometres of coastline, stretching north from Bribie Island and the Pumicestone Passage to Coolum Beach. This Shoreline Erosion Management Plan (SEMP) fits within Council's strategic policy and planning framework for coastal zone management. Within this framework, the SEMP is the primary plan relating to Councils management of coastal erosion impacts to Council controlled assets and public infrastructure. It sits alongside a number of other coastal planning documents including the Healthy Coast Management Plan, Coastal Hazard Adaptation Strategy, and the forthcoming Coastal Hazard Adaptation Infrastructure projects for Golden Beach, and Maroochydore/Mooloolaba. The SEMP presents a coordinated, regionally consistent, and prioritised plan to address shoreline erosion issues throughout the Sunshine Coast for a ten-year period spanning 2025 to 2035. It builds on the management actions undertaken during the previous SEMP that spanned 2014 to 2024.

This Volume (1) of the SEMP presents the background information for erosion management in the Sunshine Coast. It includes Councils coastal management framework, an overview of coastal processes, a review of progress from last SEMP, new modelling of extreme wave conditions, a review of sand sourcing requirements, a compendium of coastal management options, and information gained through community consultation.

In addition to the introductory section, this report includes the following sections:

- Section 2: Coastal management framework
- Section 3: Coastal processes
- Section 4: Progress from last SEMP
- Section 5: Extreme coastal conditions
- Section 6: Sand sourcing
- Section 7: Compendium of coastal management options
- Section 8: Community consultation

Figure 1-1: Coastal protection works at Mooloolaba (SCC)

Figure 1-2: Location Map

2. Coastal management framework

2.1 Definition and purpose of the SEMP

Over the last decade, coastal erosion management has been guided by a SEMP that spanned 2014 to 2024. The preparation of a revised SEMP spanning 2025 to 2035 has allowed its definition and purpose to be reviewed in relation to the Council's latest coastal management framework. Given the expanded number of coastal planning documents now available, specifically the Healthy Coast Management Plan (HCMP), Coastal Hazard Adaptation Strategy (CHAS), and forthcoming Coastal Hazard Adaptation Infrastructure (CHAI) projects there is the opportunity for the SEMP to have greater differentiation as an operationally focussed plan to address coastal erosion. The role of the SEMP is therefore to ***review, appraise, select, and plan for management actions to address existing and emerging coastal erosion issues from 2025 to 2035***. The objectives of the SEMP are to:

- Be the primary plan relating to Councils management of coastal erosion at Council controlled assets and public infrastructure; and
- To offer a coordinated, regionally consistent and prioritised approach to address shoreline erosion issues for Council controlled assets and public infrastructure across the entire Sunshine Coast; and
- To integrate within other plans for the long-term coordination of all coastal hazards (the CHAS) and the long-term management of the coastline to recreational uses, community values, the natural environment and processes, and liveability (the HCMP).

The development of a ten-year plan within the SEMP will require an adaptive pathways approach. This allows current erosion issues to be addressed, however keeps options open and avoids commitments to areas where ongoing erosion problems are not realised. Rather than specifying timeframes for engineering interventions, the Plan incorporates trigger levels to help identify when actions need to be considered. This allows Council to plan for, prioritise, and stagger investment when it is needed. For areas where coastal erosion issues do not evolve, it will allow Council to delay actions and follow a new strategy that may change over time.

2.2 Coastal management framework

The SEMP sits within Council's strategic policy and planning framework under the Corporate Plan, Environment and Liveability Strategy, and Coastal Management (Public Lands) Policy. This framework is illustrated in Figure 2-1.

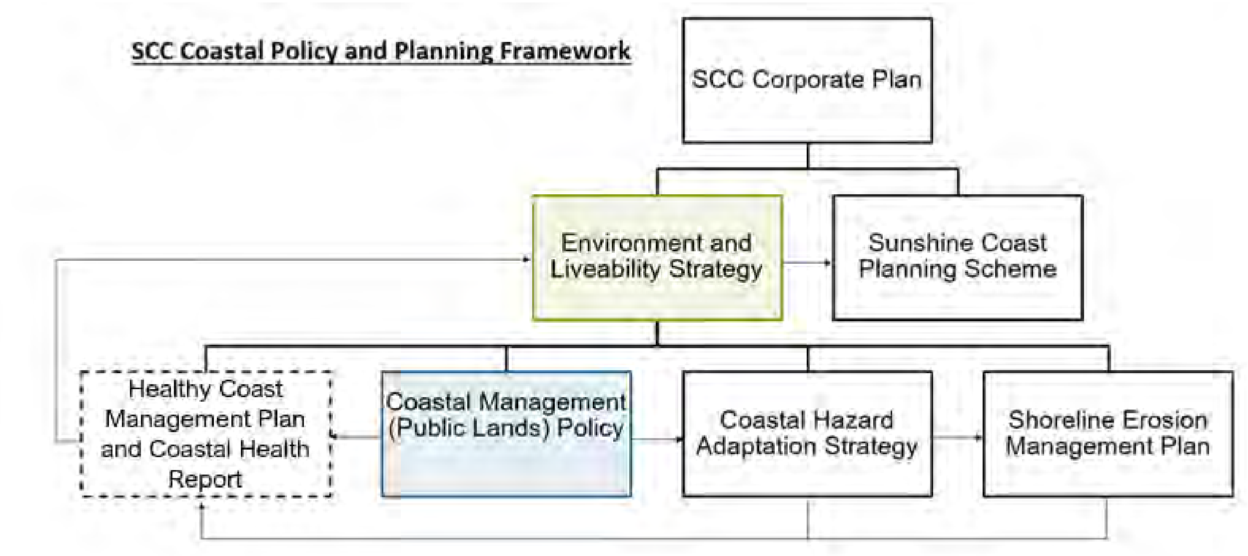

Figure 2-1: SCC Coastal Policy Framework

Other important documents exist within Councils coastal framework which should be read in conjunction with the SEMP. These present the wide range of background information available for the coastline and Councils management approach. These include:

- Healthy Coast Management Plan (HCMP) and Coastal Health Report (HCR): The HCMP is a wider-reaching plan than the SEMP, which considers not only coastal hazards but also recreational uses, community values, the natural environment and processes, and liveability of the broader region. Management actions have been developed in consideration of beach and coastal systems, its level of modification, demand level, environmental values, liveability values, significant assets, and Councils management priorities, including the SEMP, CHAS, Environmental Management Priorities, Liveability Management Priorities, and Economic and Built Asset Management Priorities.
- Coastal Hazard Adaptation Strategy (2021): Councils Coastal Hazard Adaptation Strategy (CHAS) has been released through the 'Our Resilient Coast. Our Future' program. This is a long-term strategy which extends to a 2100 planning horizon, which helps to manage the impacts of coastal hazards. It considered a range of coastal hazards, including coastal erosion, short or long-term seawater inundation of land due to storm surges, and expanding tidal areas due to sea level rise. This strategy is a regional risk assessment and change management initiative to better prepare council and the community to proactively respond to, and mitigate (and where required, adapt to) risks associated with coastal hazards.
- Coastal Hazard Adaptation Infrastructure (CHAI): CHAI projects seek to identify and assess suitable infrastructure options to mitigate the impact of coastal hazards on the public realm. They focus on beach units/locations identified in the Coastal Hazard Adaptation Strategy (CHAS, 2021) as requiring adaptation pathways. CHAI project outcomes include identification of short-term interim solutions, with a primary focus on long-term solutions that can implemented for future planning horizons.
- SEMP (2014-2024): The previous SEMP presented a ten-year management plan that spanned 2014 to 2024. It focused on erosion issues observed at the time of writing, as well as short to medium term potential erosion sites that were located within mapped erosion zones. This mapping was based on a defined storm event. Management actions were developed across four zones and 28 Beach Units, with actions ranging from monitoring programmes to new seawalls.

- **Bribie Island Breakthrough Action Plan (2014).** This action plan has been in place since 2014 and was used to prepare the Golden Beach foreshore for a breakthrough of the island. Actions undertaken as a result of the plan includes sand renourishment via annual dredging, ongoing monitoring, and infrastructure upgrades. The breakthrough occurred in January 2022.

2.3 Alignment with the United Nations Sustainable Development Goals

Other important documents exist within Councils coastal framework which should be read in conjunction with the SEMP. These present the wide range of background information available for the coastline and Councils management approach. These include:

- UNSDG 9 - Industry Innovation and Infrastructure
  The actions of this plan will result in quality, reliable, sustainable and resilient coastal infrastructure that will support economic development and the existing and future safe community use of the coast, with a focus on equitable access for all.
- UNSDG 11 - Sustainable Cities and Communities
  Outcomes of the Shoreline Erosion Management plan endeavour to make the coast inclusive, safe, resilient, and sustainable, protecting areas of high cultural, environmental, and social value.
- UNSDG 13 - Climate Action
  This document aspires to build, and strengthen the resilience and adaptive capacity of, coastal infrastructure and management of the coastline in the face of climate-related hazards and natural disasters, specifically sea level rise and storm tide inundation.
- UNSDG 14 - Life Below Water
  The actions and outcomes of the Shoreline Erosion Management Plan aim as much as possible to minimise interference with existing coastal processes in order to sustainably manage and protect marine and coastal ecosystems, avoiding significant adverse impacts, and where possible assisting in coastal ecosystem restoration through the inclusion of nature-based adaptation options in order to achieve healthy and productive oceans.

Figure 2-2: United Nations Sustainable Development Goals

3. Coastal processes

3.1 Introduction

The coastal processes for the Sunshine Coast have been presented within various scientific and engineering-related studies, plans and reports. Those most relevant to the SEMP are listed below, which have been summarised in the following sections.

- The Coastal Processes Study for the Sunshine Coast (2013) includes a range of information on the geological setting, long-term trends, erosion prone areas and historic beach profiles (BMT 2013).[1]
- The Draft Sunshine Coast Storm Tide Study (JBP, 2024)[2] has updated earlier reports on extreme sea levels, surges and storm tides.
- The CHAS and reports under Councils '*Our Resilient Coast. Our Future*' program updated information on coastal hazards during 2020 and 2021, including maps showing coastal erosion, coastal inundation and expanding tidal areas due to sea level rise. The CHAS provides a high-level plan for the future management of coastal hazards through until 2100. An initial phase involved identifying regionally focused priority areas and a five-year action plan that extends between 2021/22 to 2025/26.
- A range of monitoring data that is becoming available following the Bribie Island Breakthrough in January 2022.
- New research has been conducted on headland bypassing around Noosa Headland, which presents additional information on how sand is transported north and leaves the Sunshine Coast region.

3.2 Coastal setting

The Sunshine Coast spans approximately 60 km of open shoreline. The defining natural features include the coastal plains, dunes, open beaches, rocky shores, estuaries, nearshore marine waters, reefs, and coastal lagoons. The shoreline extends from Coolum Beach in the north to Bribie Island in the south.

The management of coastal erosion requires an understanding of sediment movement. This is a complicated process, affected by several wave, hydrodynamic, and morphologic processes. These collectively lead to different longshore, cross shore, and suspended sediment processes, as shown in Figure 3-1. For any beach, it is also important to consider how any local engineered structures will interact with these processes, such as seawalls.

1 BMT (2013) Sunshine Coast Regional Council Coastal Processes Study for the Sunshine Coast

2 JBP (2024) Draft Sunshine Coast Storm Tide Study, January 2024, Document reference: 2022s1141-JBAP-00-00-RP-MO-0001-S3-P03-Storm Tide Study_DRAFT.pdf

- Longshore sediment transport occurs when waves arrive at oblique (diagonal to the coast) angles to the coast. Breaking waves cause sediment to become suspended in the water column and flow parallel to the coastline.
- Cross-shore sediment transport occurs through offshore and onshore movement of sediment across the beach profile. During storm conditions, sand is removed from the frontal dunes and deposited into the nearshore. During seasonal calm periods this lost material can be gradually restored along the beach and dune systems by waves and onshore wind.

Sediment can also be transported within estuaries due to waterway flows and tidal currents. Tidal exchange regularly moves sand into an estuary which is able to form flood tide shoals within the mouth, with outgoing tides able to shift sand back into the open coastline where it can settle as an ebb tide shoal. During flood events, large sediment deposits can be transported downstream to resettle within the estuary and can be redistributed along the coast through longshore sediment transport. This process can be a primary source of sediment material for coastal beaches.

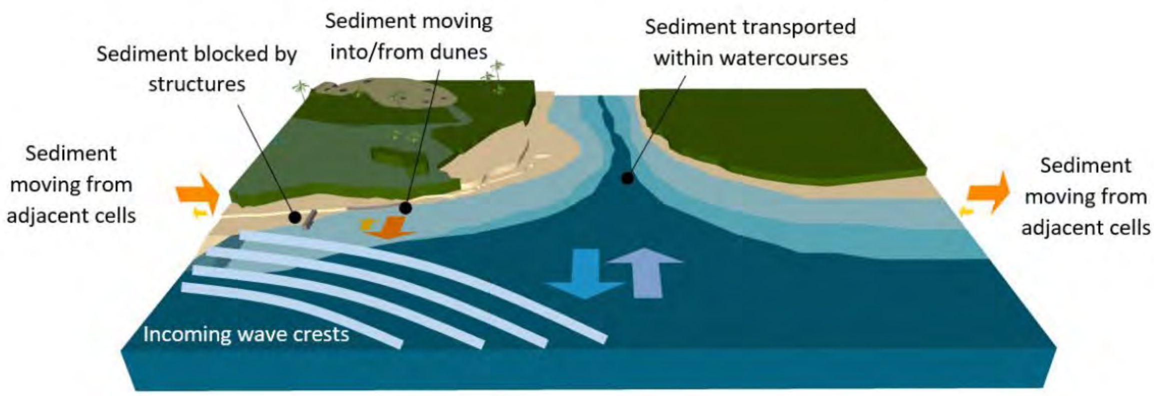

Figure 3-1: Drivers of Coastal Sediment

The way in which sand is transported through longshore, cross shore, or suspended processes is controlled by tide, storm surge, and waves processes.

- Astronomical tide: This is the regular periodic variation in water levels due to the gravitational effects of the moon and sun, which can be predicted with generally very high accuracy at any point in time (past and present) if sufficient measurements are available. The highest expected tide level at any location is termed the Highest Astronomical Tide (HAT) and occurs once every 18.6-year period.
- Storm surge: This is the combined result of the severe atmospheric pressure gradients and wind shear stress of the storm acting on the underlying ocean. The storm surge is a long period “wave” capable of sustaining above-normal water levels over several hours or even days. The wave travels with and ahead of the storm and may be amplified as it progresses into shallow waters or is confined by coastal features. The magnitude of the surge is affected by several factors such as storm intensity, size, speed, and angle of approach to the coast and the coastal bathymetry.
- Wind-driven waves: Winds blowing across a water surface apply a shear stress which is converted to wave energy. The height (and energy) of a wave train is directly related to the speed of the blowing wind, the linear distance of water over which the wind is applied, and the duration that the wind is blowing. Within estuaries, the distance and duration of wind stress, and hence the size of waves, is limited by the size of the estuary.

- Wave setup: As waves break, they create a localised effect to increase the water level, known as breaking wave setup. It predominately occurs at a sloping beach or structure and becomes less significant within river mouths or protected low-lying mangrove or swampy lands.
- Wave runup and overtopping: If broken waves reach the shoreline any residual energy may intermittently run up and down the beach face, known as wave runup. This can cause swash zone transport, as sand grains are shifted along the beach face. The vertical elevation the waves and swash zone transport may reach will be dependent on the slope of the shoreline, the porosity, vegetation and the coastal (wave and sea) conditions.

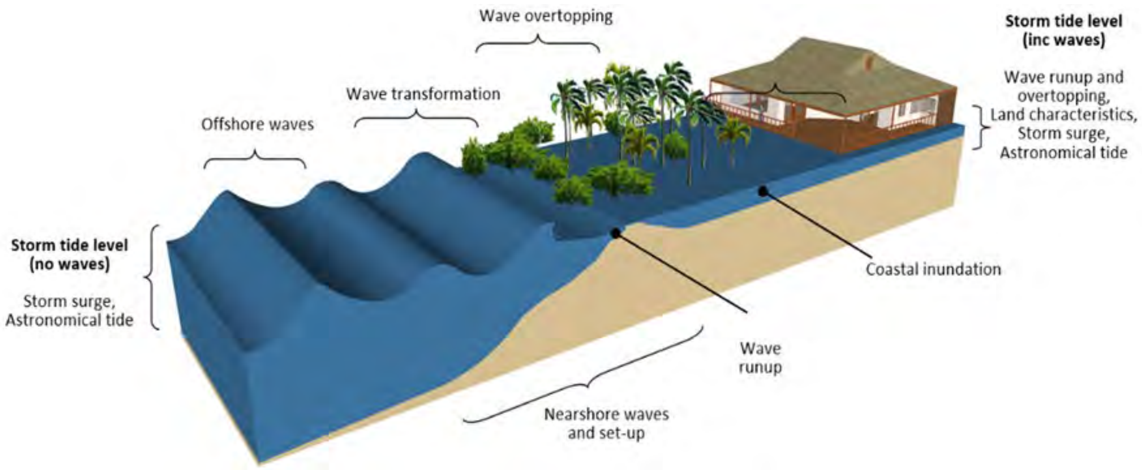

Figure 3-2: Drivers of Coastal Risk

3.2.1 Coastline evolution

On a geological timescale the Sunshine Coast has experienced moderate change. Over the last 120,000 years large variations in sea level have influenced the evolution of the coastline.

Approximately 120,000 years ago sea levels were 1-3m higher than present. Since this time the sea level varied due to numerous glacial cycles. The lowest sea level, 120m below the present level, is believed to have occurred approximately 18,000 years ago.

Major sea level change occurred between 18,000 and 6,500 years ago. During this period the sea rose to its present level.

Since the "stillstand", 6500 years ago, sea levels have remained approximately at their present level. Along the Sunshine Coast however, the continued evolution and reshaping of the shoreline has occurred in response to gradients in littoral drift.

The present coastline is not static. Most of the flat areas behind the present coastline are formed by sediments deposited during the previous high sea level (about 120,000 years ago). During the high sea period the coastline was further to the west and the headlands of Noosa, Coolum and Point Cartwright were islands. Low barrier sand spits formed between these islands (present headlands), and shallow tidal deltas accumulated behind them. Inland from these tidal deltas were extensive bays of open water backed by mangroves, estuaries and mud flats, which over time gradually filled with muds and sands. The glacial period that followed caused a major drop in sea level (approximately 120m vertically), resulting in the eastern migration of the shoreline.

Between 18,000 and 6,500 years ago the sea level rose again, approximately reaching its present level. In response to the rising sea, the shoreline moved landward submerging the former coastal plain. During this transgression, the existing older Pleistocene alluvial and coastal sediments were reworked at the shoreface and, in part, transported onshore. Riedel and Byrne (1979)[3] suggest the northern end of Pumicestone Passage, as we know it today, formed during the early Holocene period (approximately 10,000 years ago). Before this time the rivers had scoured deeper, narrower channels and were depositing fluvial sediments east of the present shoreline. As the sea level rose, the rivers were drowned, and sediments began depositing within what is now the Pumicestone Passage area. The rising seas reworked the old offshore delta deposits, pushing beach sands onto the eastern side of Bribie Island. Sediment samples indicate the northern end of Bribie Island developed to its present position approximately 4,000 years ago. Since the standstill, anecdotal evidence suggests the coastline north of Currimundi has experienced a persistent trend of erosion. This is indicated by the present widespread exposure of humic sandstone (coffee rock) along the coast within the study area (Jones 1992).[4] Erosion north of Currimundi is the result of littoral drift gradients occurring north of the Caloundra Headland. Based on sediment samples, Jones identifies Caloundra Headland as the littoral drift divide, with longshore transport directed away from the headland to both the north and south. North of this location the littoral drift of sediment slowly increases leading to a low rate of coastal recession. These low recession rates are attributed to the shallow, wide offshore inner shelf bathymetry, causing incoming waves to refract, becoming almost shore parallel and resulting in only weak longshore currents.

3.2.2 Sand supply

The Sunshine Coast falls within the Australian Coastal Sediment Compartment central east region, where coastal processes and landforms are linked together (Thom 2015).[5] However, it is largely disconnected from the prevailing northerly transport of sand along the Australian east coast that supplies Holocene sands to the Gold Coast, Minjerribah (Stradbroke Island), Mulgumpin (Moreton Island) and further north to K'gari (Fraser Island). The sediment compartment boundaries act as natural barriers to sediment transport, enabling the coastline to act as a semi-closed system. Splitting at Caloundra Head, the Sunshine Coast spans two sub-compartments:

To the north is compartment QLD05.01.05. This area is typically exposed open coast beaches extending from Noosa Head to Caloundra. They are east facing, with headland-tied wave dominated sandy beaches.

In the south is the Bribie Island compartment QLD05.01.06. Whilst experiencing the same coastal processes, Bribie Island’s eastern coastline extends over 30 km, from its current northern entrance to the Pumicestone Passage to its southeastern tip at Skirmish Point. It offers a continuous, curving sandy beach composed of well-sorted fine quartz sand. The beach is part of a low regressive Holocene barrier that is backed by the meandering, tide dominated Pumicestone Passage.

Both compartments are influenced by their dominant southerly swell, which have low to moderate south-east seas (south-east wind-waves). Other climatic drivers include the El Nino Southern Oscillation (driving sea-level variability, tropical cyclone frequency, beach erosion/accretion cycles); and the Madden-Julian Oscillation (driving weather patterns including monsoons and tropical cyclones).

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3 Riedel & Byrne (1979) estuarine and tidal study proposed canal development Caloundra, Queensland.

4 Jones, MR (1992), Quaternary Evolution of the Woorim-Point Cartwright Coastline, Volumes 1 & 2, Department of Minerals and Energy, Marine and Coastal Investigations Project Report MA49/2

5 Thom, B., 2015: Coastal Compartments Project Summary for Policy Makers. Accessed 5 May 2016.

The beaches around Caloundra Head (e.g., Shelly Beach) have appeared to be based on beach material from local sources and comprise of a relative high portion of calcareous material (i.e., shell grit). These beaches are considered as pocket beaches with finite sand resources.

Historically, some fluvial sediment has been supplied from Bells Creek, Lamerough Canal, Currimundi Lake, Mooloolah River, and Maroochy River catchments, which consists mostly of fine sandy material. However, these rivers are not considered to supply a significant amount of sand to the beach system.

Available Longshore Sediment Transport (LST) estimates are mostly a decade old and represent an information gap to be addressed in future years. The wave-driven longshore sediment transport along the Sunshine Coast was calculated over a 12-year period (1997-2008) in the previous SEMP (2014-2024), which confirmed the net northerly transport for the majority of the coast. This begins at zero net transport at Caloundra Headland (i.e., at the littoral drift divide), with a northerly transport then increasing progressively along the northern coastline. The predicted average net LST from the 2013 study estimates the LST for Buddina Beach is around 5,600 m^3/yr, and at Mooloolaba Beach (Mooloolaba Surf Club) and Maroochydore Beach (Maroochy Surf Club) it increases to approximately 6,100 m^3/yr and 7,400 m^3/yr respectively. These rates reflect estimated transport potentials only, with the actual sand transport rate typically expected to be restricted by the availability of sand and therefore less than previously estimated. However, given the frequency and volumes of beach nourishment undertaken by Council in recent years (of the order 50,000 m^3/yr), it can also be suggested that larger LST rates may be present along the coast than previously estimated.

Table 3-1: Potential LST rate estimates (BMT 2013)

Location	Mean Net LST (m^3 / year)
Currimundi	3,700 (north)
Buddina	5,600 (north)
Mooloolaba Surf Club	6,100 (north)
Maroochydore Surf Club	7,400 (north)
Mudjimba	8,300 (north)
Yaroomba	11,400 (north)
Peregian Beach	17,900 (north)
Sunshine Beach (Noosa Region)	23,300 (north)

3.2.3 Recent changes in Bribie Island

In January 2022, a coastal storm event caused a breakthrough of a narrow section of northern Bribie Island, opposite Golden Beach. This occurred due to the erosion caused by unusually high tides and large waves associated with ex-Tropical Cyclone (TC) Seth. In the following months, this breakthrough widened to become the new northern outlet of the Pumicestone Passage.

Analysis of the breakthrough and resulting water level changes was reported by Metters et al. (2023).[6] Figure 3-3 shows satellite images captured of the breakthrough, based on data available through Sentinel Hub (2023). The figure shows:

A. pre breakthrough December 2021
B. breakthrough January 2022
C. breakthrough September 2022,
D. breakthrough April 2023.

Analysis of tide gauges in 2023 already showed an increase in the tidal range of 0.4m to 0.5m with a fall in the mean low water level of -0.21m, and an increase in the mean high-water level of 0.23m. Southward of the breakthrough, the change in tidal range decreased from 0.57m to 0.06m over the historic tidal range. The increase in observed tides reflect conditions that more closely align with the open coast. A similar trend is expected with storm tide levels, which are now anticipated to be more representative of open coast levels. This northern section of Pumicestone Passage remains an evolving coast and estuarine environment, with ongoing changes expected over the life of the SEMP.

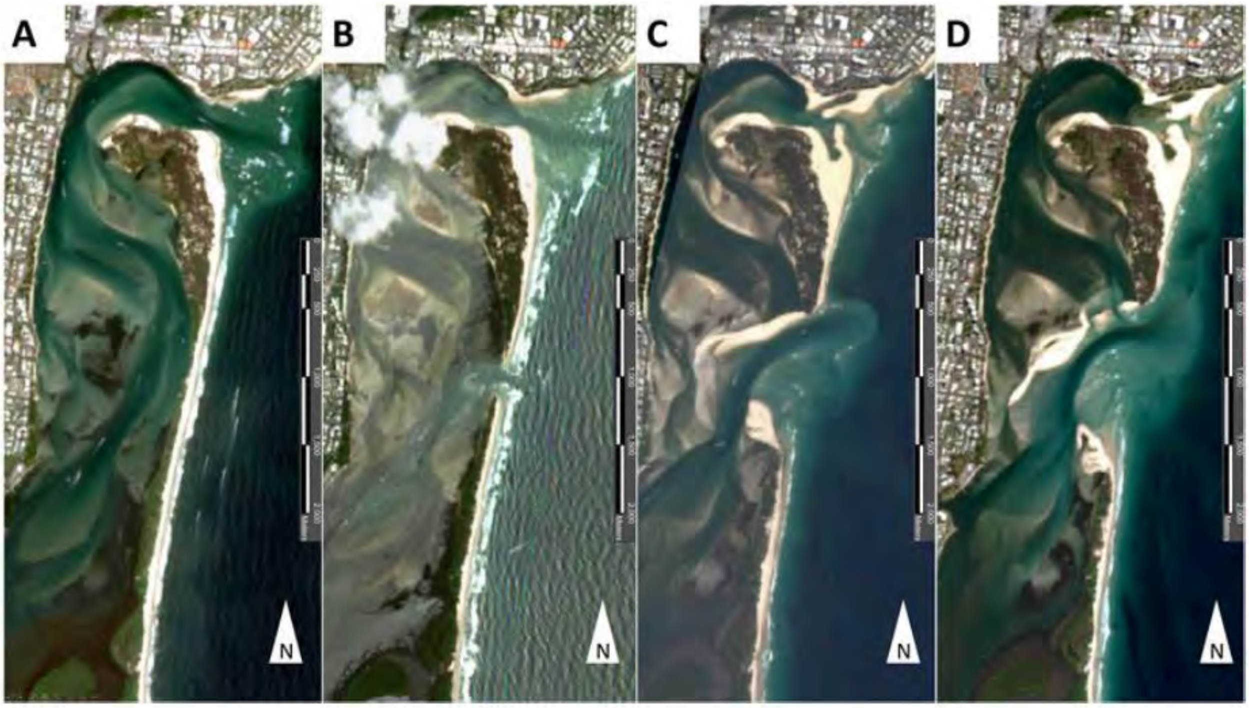

Figure 3-3: Satellite images showing the development of the breakthrough (Metters et al. 2023)

6 Metters, D., Ryan, D. & Daniels, R. (2023) "Change in bathymetry and tidal dynamics after the Bribie Island breakthrough", Queensland Government Hydraulics Laboratory. Proceedings of the Australasian Coasts & Ports 2023 Conference – Sunshine Coast, 15-18 August 2023.

3.2.4 Extreme storms

Beach levels fluctuate in response to tides, storm surges, and wave conditions. Long-term beach profile data has been collected through the Coastal Observation Program - Engineering (COPE) between 1971–1996, which shows the variability in the Sunshine Coast beaches (see historic Mooloolaba profiles in Figure 3-4).

During storms, beach levels can change suddenly due to coastal erosion. The region has experienced a range of historic erosion events captured through survey and photographs, with the most recent erosion observed following TC Oswald in 2013. Post-event photos at Mooloolaba are shown in Figure 3-5, which shows over 2m of vertical erosion where sand levels dropped to around -0.6mAHD. Greater erosion events have been recorded historically and are available on the Sunshine Coast Libraries website (SCLibraries 2023).[7] Figure 3-6 to Figure 3-8 show images captured at Kings beach and Maroochydore, which include:

- Kings Beach from the Pavilion car park after Cyclone Daisy, Caloundra, February 1972
- Kings Beach showing erosion following heavy storms, 1959
- Kings Beach showing extensive erosion to the beach after cyclone damage, 1945
- Maroochy SLSC after extreme conditions, 1957.

These images show the extreme erosion experienced in the 1940s (ex-TC Daisy), 50s, and 70s (TC Beth). Approximate scaling from the photographs indicates the erosion scarp at Kings Beach may have measured around 4-5m vertically, which eroded the beach from under any shallow building foundations.

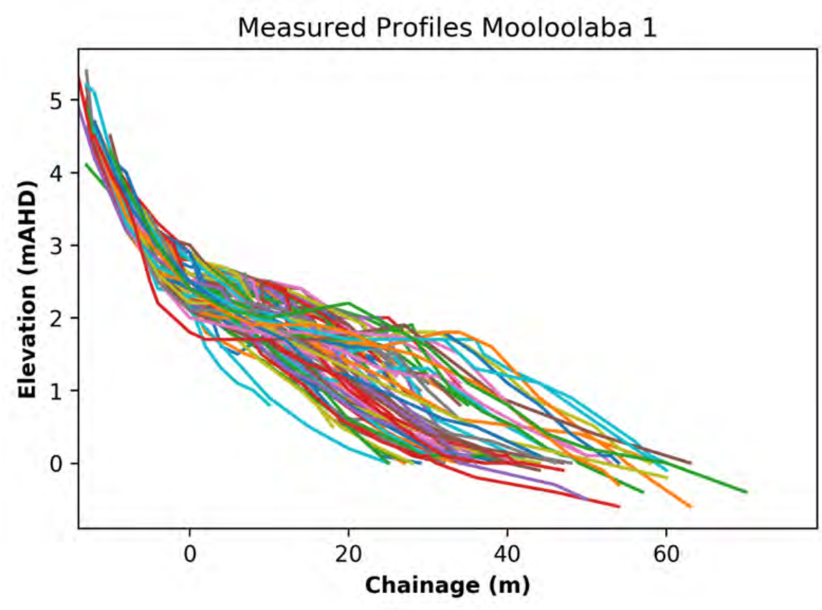

Figure 3-4: Measure beach level fluctuation at Mooloolaba from the COPE programme

7 SCLibraries (2023) " https://sunshinecoast.spydus.com/cgi-bin/spydus.exe/MSGTRN/WPAC/HOME

Figure 3-5: Mooloolaba Beach following TC Oswald

Figure 3-6: Kings Beach from the Pavilion car park after Cyclone Daisy, Caloundra, February 1972

Figure 3-7: Erosion at Metropolitan Caloundra Surf Life Savers Club, Kings Beach, Caloundra, 1950

Figure 3-8: Kings Beach showing erosion following heavy storms, 1959

Figure 3-9: Maroochy SLSC after extreme conditions, 1957

3.2.5 ICOLLS

Many of the smaller Sunshine Coast creeks act as Intermittently Closed and Open Lake or Lagoons (ICOLLs) and have their own unique erosion challenges. This includes Stumers Creek (Figure 3-10), Currimundi Lake, Coondibah and Tooway. The dynamic nature of an ICOLL entrance is determined by the interactions between the opposing forces of catchment and ocean processes on the movement and accumulation of sand at the flood-tide delta, entrance berm, and nearshore (DPIE, 2021).[8] An ICOLL will begin to fill with water if the berm level increases, which creates a dam-like barrier across the watercourse. The barrier can increase in height, driven by wave action which can overtop the barrier, depositing sediment on top and over the original berm level (Hine, 1979),[9] (Strahler, 1966).[10] When closed, an ICOLL can become disconnected from the ocean tides and act as a lake. Here, water levels can rise due to overtopped wave water or from catchment runoff. If water levels rise higher than the berm level, they can initiate a breach, where the entrance can suddenly scour out as the lake empties, which can cause erosion around the mouth. After a breach, the typically small tidal prism is usually insufficient to maintain an open entrance and the mouth begins to close again.

Figure 3-10: Aerial picture of Stumers Creek ICOLL during a closed period

8 DPIE (2021) Form and function of NSW intermittently closed and open lakes and lagoons. State of NSW and Department of Planning, Industry and Environment. ISBN 978-1-922558-52-7.

9 Hine, A.C., 1979. Mechanics of berm development and resulting beach growth along a barrier spit complex. Sedimentology 26, 333–351.

10 Strahler, A.N., 1966. Tidal cycle of changes on an equilibrium beach. Journal of Geology 74, 247–268.

3.3 Coastal processes gaps

The information presented in this section has been based on various pieces of literature and reports prepared over the last decade or more. The development of the original SEMP (2014) used the Coastal Processes Study for the Sunshine Coast (2013),[11] which was the key source of information during its development. A review of its suitability for ongoing coastal erosion management has been undertaken to identify recommendations for new research.

The Coastal Processes Study (2013) includes information from previous research, historical photography, beach and offshore profile surveys, offshore bathymetry surveys, metocean conditions (tide, storm tide, waves, hydrodynamics), Longshore Sediment Transport, Erosion Prone Areas, and climate change assumptions. A wide range of this data and analysis remains relevant for the revised SEMP which will span 2025 to 2035, including the geological setting, long-term trends, and historic beach profile review. However, as new information has become available our understanding of several coastal processes has now changed, which will require future updates to remain relevant.

- Tides:
  - The Coastal Processes Study (2013) quotes outdated tidal regimes based on Maritime Safety Queensland 2010 estimates for the open coast. In Pumicestone Passage the entire tidal regime has now changed due to the new entrance breakthrough.
  - Recommendation: The latest Maritime Safety Queensland (MSQ) tidal planes should be used for all coastal planning along the open coast and established estuaries. Ongoing monitoring and review of tides in Pumicestone Passage should be undertaken, which are evolving following the breakthrough.
- Storm tides:
  - The Coastal Processes Study (2013) presents storm tide information from the 'Maroochy Shire Storm Tide Study' (Connell Wagner, 2005), the 'Joint Probability Assessment – Storm Tide and Freshwater Flooding – Caloundra City Council' (Aurecon, 2008) and the Queensland-wide tropical cyclone study of Hardy et al. (2004), which is now superseded.
  - Recommendation: All new coastal engineering is to use extreme sea levels published within the Sunshine Coast Storm Tide Study Revision (JBP 2024)[12] and any revision to the planning scheme, once adopted
- Waves:
  - The Coastal Processes Study (2013) uses a wave model to convert offshore extreme waves to a mid-shore location at approximately -20m AHD seaward of each beach unit. New offshore data is now available, which should be included in any analysis.
  - Outcome: A new extreme wave study has been completed as part of this project. All extreme wave conditions should be based on those presented in this SEMP and relevant appendices.

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11 BMT WBM (2013) Coastal Processes Study for the Sunshine Coast.

12 JBP (2024) Draft Sunshine Coast Storm Tide Study, January 2024, Document reference: 2022s1141-JBAP-00-00-RP-MO-0001-S3-P03-Storm Tide Study_DRAFT.pdf.

- Coastal sediment processes:
  - Since the completion of the Coastal Processes Study (2013) several large-scale changes have occurred (e.g., the Bribie Island Breakthrough) in addition to a range of new data now being available through records and remote sensing. An updated, wholistic sediment transport study is recommended for the region to support new coastal management.
  - Recommendations: Until a new regional sediment transport study is completed, any coastal development should include a site-specific review of coastal processes to support any engineering or planning work.

4. Progress from last SEMP

The SEMP (2025 to 2035) builds on the erosion management work undertaken during the lifetime of the previous SEMP, which spanned from 2014 to 2024. Over the ten-year SEMP period, a number of significant actions have been completed, which can be used to measure its level of completion, to understand which actions were postponed or not required during its implementation timeline. Remaining actions have then been reviewed to consider their transfer into the new SEMP.

Figure 4-1: Renewal of the Maroochy Groyne Field

4.1 Coastal management activity review: identification of outstanding items

Actions have been reviewed from the previous SEMP (2014-2024). These actions have been prepared under different beach unit definitions than those adopted in this updated document. The previous SEMP progress can be summarised in four zones and 28 Units:

- Zone 1: Coolum to Mudjimba, Units 1-5
- Zone 2: Mudjimba to Point Cartwright, Units 6 to 13
- Zone 3: Point Cartwright to Caloundra Headland, Units 14 to 20
- Zone 4: Caloundra Headland to Southern Boundary, Units 21 to 28.

A three-level scoring system was used where:

- Score 1 - Action was not started or was not considered suitable to be progressed.
- Score 2 - Action was commenced or is currently in progress.
- Score 3 - Action has been completed.

The number of actions in each zone ranged from 5 to 16, with the most proposed actions in Zones 2 (Mudjimba to Point Cartwright) and 3 (Point Cartwright to Caloundra Headland). However, the greatest number of actions were completed in Zone 4 (Caloundra Headland to Southern Boundary), potentially linked with the urgency of undertaking anticipatory actions for the Bribie Island Breakthrough.

Table 4-1: Status of actions from previous SEMP (2014 to 2024)

Level of completion	Zone 1	Zone 2	Zone 3	Zone 4
Number of actions in previous SEMP (2014 to 2024)	5	16	15	12
Score 1 - Action was not started or was not considered suitable to be progressed.	3	3	1	0
Score 2 - Action was commenced or is currently in progress	1	11	11	10
Score 3 - Action has been completed	1	2	3	2
Percentage of actions in Score 2 or 3 (underway or completed)	40%	81%	93%	100%

Overall, the previous SEMP proposed 48 priority actions that were anticipated to be scheduled between 2014 to 2024. The SEMP planning framework allowed Council discretion prior to implementing any actions, which has meant not all actions were required if erosion problems did not persist. Of the 48 actions:

- 8 actions have been completed.
- 33 were commenced or are currently in progress,
- 7 actions were not started or were not considered suitable to be progressed.

The location and scale of key coastal projects delivered between 2014-24 are shown in Table 4-2 Several key projects and lessons learned are summarised in the following sections.

In addition, a range of LGA-wide actions exist within the previous SEMP, that can be applied at any location. These are reviewed in Figure 4-2, which indicate they are either underway or completed.

Table 4-2: SEMP LGA Wide Actions

Summary of Priority Actions from SEMP1	SEMP Actions Level of Completion**:
Develop dunal education campaign & key signage	2 (commenced, ongoing)
General beach management and erosion management at beach accesses and bathing reserves	3 (complete)
Monitoring of shoreline and beaches	3 (complete)
Sand sourcing study for nourishment purposes	3 (complete)

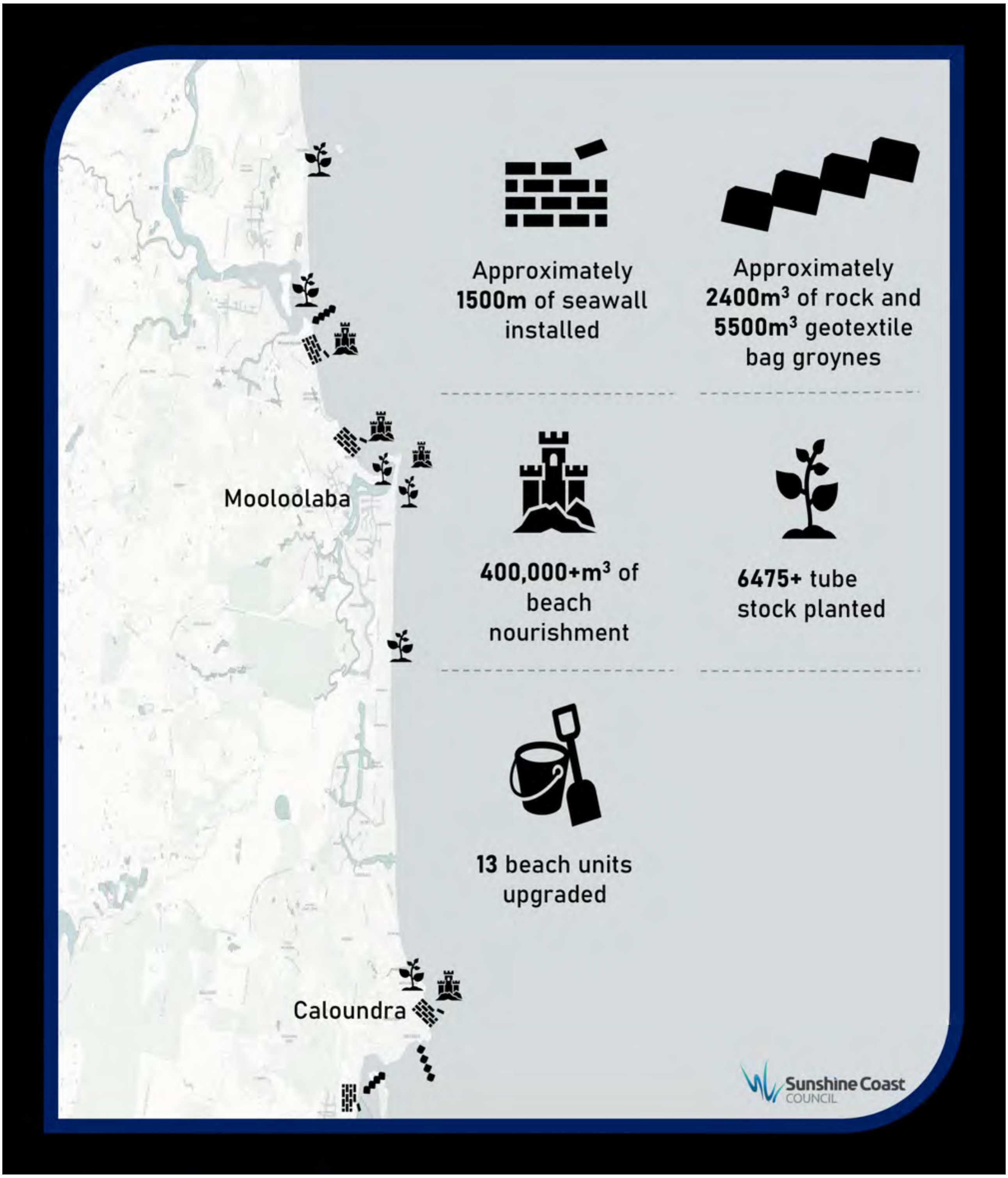

Figure 4-2: Summary of SEMP actions between 2014 to 2024

4.2 Coastal management project review: management challenges and recommendations

A number of major projects have been completed during the previous SEMP (2014 to 2024), which are listed below. Several key projects have been reviewed and are presented in the following subsections.

Major projects include:

- Beach nourishment at Golden Beach, Mooloolaba Bay Beach and Alex-Maroochydore Beach (and smaller-scale works at other locations).
- Maroochy River entrance groynes stabilisation/rebuild.
- Extension and remediation of the Kings Beach groyne.
- Mooloolaba Foreshore Revitalisation.
- Estuary shoreline stabilisation works.
- Whole of System Permit for Currimundi Lake entrance management.
- Golden Beach and Bribie Island Breakthrough Planning documents; including options, designs, approvals and investment planning.
- Maroochydore Beach buried seawall proactive approvals.
- Mooloolaba buried geotextile wall.
- Ongoing shoreline monitoring programme.

Figure 4-3: Projects reviewed: clockwise from top left: Maroochy groynes, Mooloolaba seawall, Buried Seawall concept, nearshore nourishment trial

4.2.1 Maroochy groynes reconstruction

Geosynthetic Sand Containers (GSC) have been used to stabilise the Maroochy River mouth for over 20 years. They are one of the earliest GSC groyne fields constructed on the open coast in Australia. Initial design, testing and construction was performed between 1997 and 2003 by the then Maroochy Shire Council, which used 2.5 m^3 GSC units to construct four groynes. During their lifetime, damage included bag movement and GSC loss linked to subsidence, deflation, and sand loss, which required their renewal between 2020 and 2022.

New bag shapes, sizes, and ways to interlock units were evaluated to increase stability and longevity for the GSC renewal. Testing was undertaken at the Water Research Laboratory, with larger 5.0 m^3 units with an alternating layer orientation selected as the preferred design. Manufacturer and contractor testing developed a new GSC unit to closely match physical testing, which required a new filling, lifting and placement procedure, with the final bag volume reaching 4.5 m^3 and weighing 8t. Renewal works using the 8t GSCs began on two groynes in June 2020. The groyne field was completed in 2022, and a seawall constructed using 2.5 m^3 GSCs between the groynes. To assist in upholding the erosion buffer 50,000 m^3 of sand was pumped from the lower Maroochy River to Maroochydore beach (Hall Contracting, 2023).[13.]

Figure 4-4: Maroochy Groynes image (left)[14] shows the first reconstruction in 2020. Right shows an aerial image post construction (JBP, 2023)

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[13] Maroochy Groyne Renewal Project, Hall Contracting Accessed 10/03/2023 https://www.hallcontracting.com.au/projects/government/maroochy-groyne-renewal-project

14 Rising to the Challenge (2020). Hall Contracting. Accessed 14/02/2023 https://www.hallcontracting.com.au/uploads/HALL_yearbook_2020_FINAL_ELECTRONIC.pdf

Challenges during planning

The key challenges during the planning stage included:

- Planning for GSCs require the identification of a sand source to fill the bags. When used as an erosion control, GSCs are typically positioned on a beach experiencing a sediment deficit. In these circumstances, sand from the beach cannot be used to fill the bags. Whilst initial planning had considered sand could be reused from the existing (aging) bags when they were being decommissioned/emptied, additional filling needs meant additional planning requirements for a 'top up' sand source.
- Planning for the seawall renewal. It was identified that the seawall was not originally listed in the original planning approvals. This required the legacy structure to be added into the new approvals.

Challenges during construction

The use of the new 8t bags required a new filling, lifting and placement procedure. Progressive inspections throughout the groyne construction showed the new bag design and construction approach to be successful, with periodic bag weight measurements, bag placement and crest alignment meeting specification.

However, immediately after construction a range of new processes were experienced at the most southern groyne that caused new scour holes and sliding of the lower units, up to 1.2m laterally. This created voids within the structure, allowing further movement of upper layers. This movement stabilised in the initial months after construction.

Other challenges included:

- Delays due to the COVID-19 global pandemic.
- Due to limited space, 50% of the community car park was closed to the public during construction to allow site offices, plant access and stockpile zones.
- A scour hole developed at the head of a groyne. Minor redesign was needed which implemented an extra scour bag to prevent further damage to the structure.
- Public safety during construction was challenging because the project area was large, open and one of the most popular recreational spots in the SCC region.
- Challenges in the integrating of an erosion mitigation project within a high-profile urban setting. Many of the lessons learned from this project have now been incorporated into standard practice, including the addition of placemaking within high profile erosion design projects and prolonged community consultation.

Recommendations and lessons learned

- Prior to the renewal of any aging structure, the planning approvals should be reviewed to consider any differences between the approved designs and the in-situ structure. This should review the footprint, size, shape, form, and materials of the structure, and if they differ from original plans or approvals.
- The reconstruction of the Maroochy Groynes using 8t GSC units is a first in Australia. The development of very-large GSC units has allowed the groynes to better withstand open-coast conditions. They can now be used to develop more accurate maintenance costs for GSCs when used in the open-coast to support future cost-benefit analysis between geotextile and rock groynes in a similar wave climate.

- The reconstruction project has identified the design challenges inherent within groyne fields, as opposed to individual groynes. Any future groyne field projects will need to have a greater focus on the design of the most 'updrift' groyne, including changes to the head design, configuration of the roundhead, and the need for coincident sand nourishment during construction.
- During the redesign project the need for long-term beach profile data that extends into the nearshore was recognised. This would allow new information to be recorded, such as the position of channels and nearshore gutters.

Figure 4-5: Maroochy Groynes - 8t GSC unit filling and lifting procedure (JBP 2021)

4.2.2 Mooloolaba Foreshore Seawall (north parkland wall)

The Mooloolaba Foreshore Seawall is part of the Mooloolaba Foreshore Revitalisation Stage 1 Project, completed in June 2022. The seawall component of the project is a sloped rock revetment spanning 295m, which replaced an informal rubble structure. It has a 1 in 50-year design standard and uses 1.5t rock armour due to the adjacent rock shelf initiating a depth-limitation on waves. The wider project includes a boardwalk with viewing platforms, two new beach access points, a new adventure playground, public toilets, and a comprehensive revegetation plan including 120 new trees and 10,000 new plants. This project aimed to increase the foreshore resilience to major weather events, increase public beachfront parkland by 40% and provide new community spaces, enhanced family facilities, and accessible amenities.

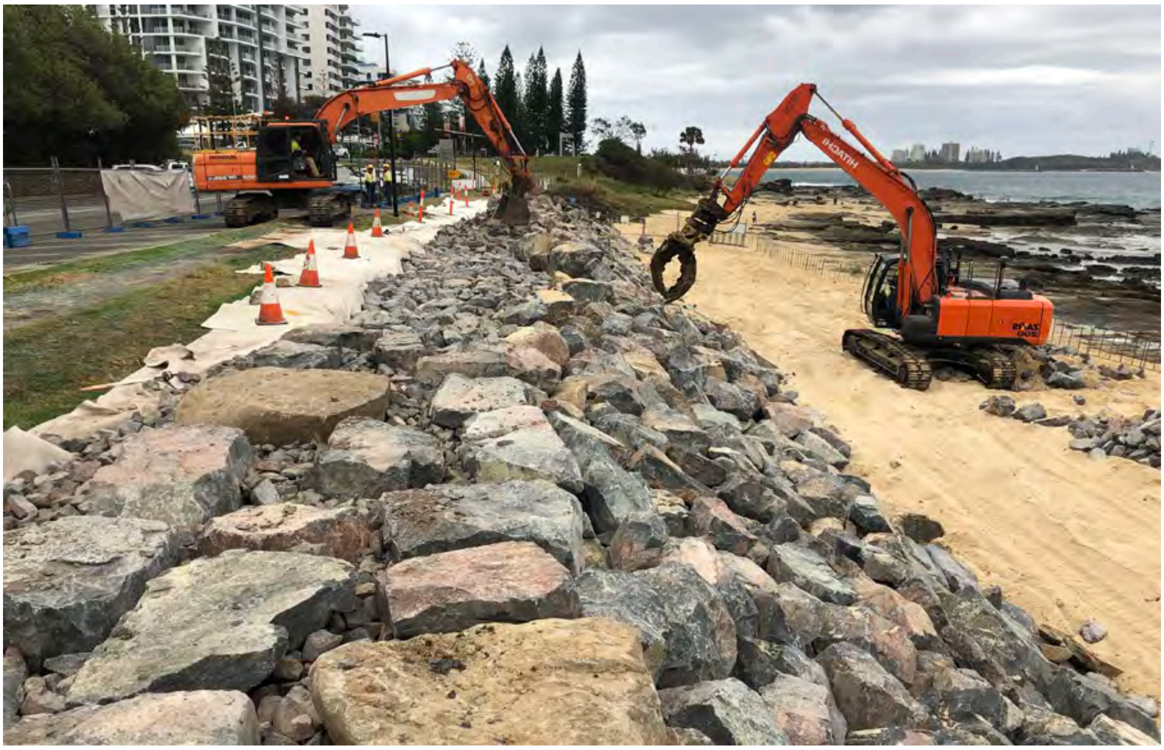

Figure 4-6: Mooloolaba Foreshore seawall during construction

Challenges during planning

- Design changes were made from the initial 'L' wall capping detail to concrete infill to reduce costs.
- Sourcing suitably sized rock in large quantities was a challenge. Special blasts and setups were required at the quarry in addition to specialised trucks with modified beds to transport the large amount of armour rock.
- The site staging area was shared with contractors doing associated works and could become congested.
- Planning for holiday periods and public safety in order to keep the beach area clear of pedestrians.

Challenges during construction

- Erosion of the site during a storm event left very low levels of sand, limiting the ability for excavators to track over the rock shelf.

- Managing the build through summer school holidays and keeping approximately 70 carparks open posed a big challenge for public safety with five body trucks delivering rock every few hours.
- Loss of vegetation (invasive plant Singapore Daisy and non-native palm trees) left the public with a perception that Council didn't plan to revegetate the area.

Figure 4-7: Mooloolaba northern parkland seawall (top)[15]

Recommendations and lessons learned

Following completion, the project was reviewed to develop a list of lessons-learned for the future development of the 'Stage 2 - Central Meeting Place' project. Recommendations relating were made for ongoing research to understand the benefits and challenges in using new materials for coastal works. This should then be incorporated into Council's standards and asset owner requirements. New technology and materials are continuously emerging, which may change the way marine grade stainless steel and aluminium are specified or may allow the incorporation of materials such as Glass Fibre Reinforced Plastic within structural elements. is to be used throughout this project for built structures.

4.2.3 Maroochydore beach nearshore nourishment trial

Sand nourishment is a common management approach within the Sunshine Coast, with sand transported using dredgers, pipelines, or trucks. A trial project was undertaken at Maroochydore beach in November 2022, which distributed sand into the nearshore area through a process called 'rainbowing' or 'bottom dumping', which was placed from a vessel around 300m offshore. The sand is then able to act as a buffer to storms and may be redistributed back onto the beach through waves, current, and tide action. The

15 Sunshine Coast News (2021) "A plan to transform Mooloolaba's foreshore has hit a rock wall". Picture by Warren Lynam. Accessed on 09 March from: https://www.sunshinecoastnews.com.au/2021/02/24/mooloolaba-foreshore-revitalisation-project/.

purpose of the trial was to understand if the process could be viable for placing larger quantities of sand in the future and to understand community views on the technique.

Sand was dredged from the Spitfire Channel using a Trailing Suction Hopper Dredge (TSHD). The maximum dredge depth was 25m, with a hopper capacity of 2,900 m^3. Throughout the trial, approximately 50,000 m^3 was nourished, resulting in a unit rate of $15/$m^3$ (i.e., the cost to deliver and place a cubic metre of sand).

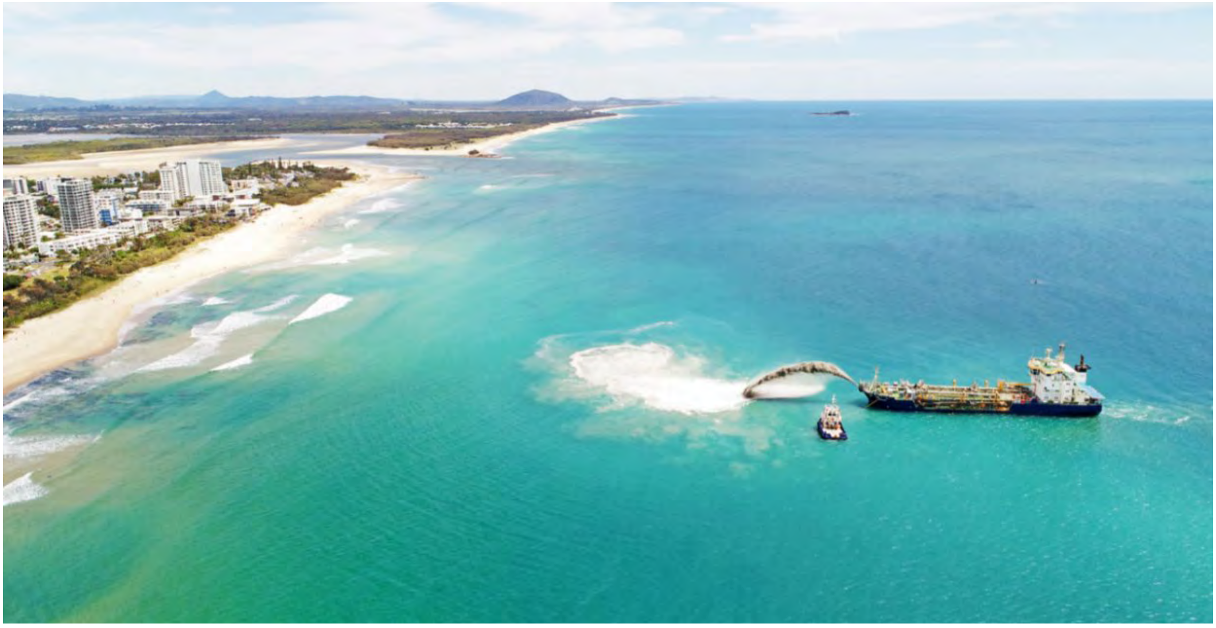

Figure 4-8: Sand being rainbowed out of the dredge during the Maroochydore Nearshore Nourishment Trial (SCC, 2022)[16]

Challenges during planning

Planning for the project required consideration of various planning, environmental, and social factors. An existing, approved, sand source was used to minimise the planning requirements, which consequently only required a placement permit. The placement permit was relatively easy to obtain, though it included conditions regarding reef monitoring.

The approval for the works required the establishment of an exclusion zone around reefs and other benthic habitats. Following approval, the council conducted ecological surveys to track changes in the marine environment over a three-year period.

The trial was conducted away from shorebird resting areas to minimize disturbances and impacts. The dredging operation deposited sand in the nearshore zone off Maroochydore Beach, deliberately avoiding the mouth of the Maroochy River, a known habitat for shorebirds.

16 SCC (2022) "Maroochydore nearshore beach nourishment trial". Accessed on 10 March 2023 from: https://www.sunshinecoast.qld.gov.au/Council/Planning-and-Projects/Infrastructure-Projects/Maroochydore-Nearshore-Beach-Nourishment-Trial.

Nourishment activities required the use of an approved sand source, with Spitfire Channel being the closest suitable location. Due to the distance between the nourishment site and the channel, each trip required seven hours to complete. (i.e., the time taken for a round trip from Spitfire Channel to Maroochydore site for off-loading).

Challenges during the trial

Widespread flooding delayed the project, due to the contracted dredger being needed for remedial dredging efforts. This caused a cascading delay, resulting in the projects start date being pushed to late 2020.

When in operation, the TSHD collected sand from the Spitfire Channel, Moreton Bay, which was transported to Maroochydore Beach for release. This caused long turnaround times due to the sand source being four hours away. Due to the rainbowing method, community safety needed to be a priority, and exclusion zones were established when the dredge was operating in area.

Recommendations and lessons learned

Reviews on the nearshore benefits and impacts of the nourishment campaign are ongoing, with current monitoring including:

- The impacts on marine plants and the reef with divers.
- The sand movement over time with hydrographic surveys.
- The impacts to surf amenity through the University of the Sunshine Coast.
- Community sentiment on the technique.

Despite the delays and troubles, the trial was considered successful. With the different nourishment approach (and an economy of scale) delivering sand nourishment costs around half of typical small dredge/pipeline projects. Further savings could be expected if new approved dredge sites were identified closer to the deposition site. The need to use an approved dredge site far from the project site was a major contributor to nourishment costs, and meant the dredge worked 7 days a week, 24 hours per day.

4.2.4 Alexandra Headland to Maroochydore Future Buried Seawall

All coastal protection structures require planning approvals and permits before they are constructed. However, often the planning process can take up to 12 months to complete, meaning a delay to construction. At Alexandra Headland, a future buried seawall has been designed and proactive planning permissions gained, which will allow future construction to occur without delay.

Planning commenced in 2011 to design the seawall to a concept level and gain state approvals. A staged management approach was developed which includes sand renourishment, dune revegetation and protection, and limiting beach access points. In the longer term, a seawall has been planned to provide ongoing protection, which has been designed as a buried structure beneath the dunes (see Figure 4-9). It has been split into three sections, with two responsible government agencies. The Department of Transport and Main Roads (DTMR) is responsible for sections one and two, and SCC is responsible for section three.

There is no timeframe proposed for the construction of the buried seawall, with previous sand renourishment maintaining the beach. Approval has been granted for the construction, which is linked to a trigger to initiate actions. The trigger has been set on a distance between assets and the coastline, which requires the toe of the frontal dune to be reduced to 15m from the road boundary at Okinja Road following an erosion event. The use of the 15m trigger width is to allow space for the construction logistics of the buried seawall.

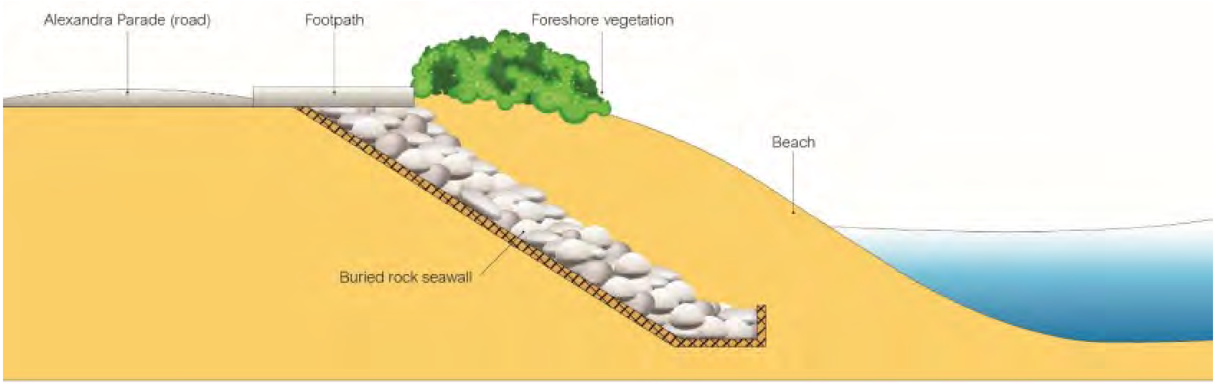

Figure 4-9: Concept for the buried seawall (SCC 2021)[17]

Challenges during planning

In October 2015, approval was given for the buried seawall (OPW14/0656). The approval does not permit the start of any works, which is based on the erosion trigger, however it does allow both DTMR and Council to act quickly if the buried seawall is required with a consistent design and construction methodology. Challenges during approvals included:

- Concept drawings were required to be submitted to support the application. However, with no expected construction date these may require changes if extreme conditions worsen.
- The seawall required coordination between two land managers - DTMR and SCC
- The development approval lasts for a limited timeframe; in this case 35 years.

Recommendations and lessons learned

Whilst planning approval has already been gained, community consultation will be important prior to any construction works. This project demonstrates a new approach to minimise planning delays, gaining proactive permissions, and using a trigger-based approach to initiate works. Whilst this scheme uses a trigger based on a linear width of beach, future triggers may consider available beach volume. This would account for different beach heights; for example, a 16m wide beach at a low elevation may have less protection than a 14m wide beach with tall dunes. An additional consideration for similar projects that involve early planning is that a design review may be required closer to the time of construction to consider new information on sediment transport, extreme wave height or storm tide levels.

17 SCC (2021) "Alexandra Headland to Maroochydore Future Buried Seawall - Factsheet" Accessed on 10 March 2023 from: https://assets-us-01.kc-usercontent.com/c631baf8-1b46-001f-580c-d0001b68b4a8/9dd75e24-4f12-499d-b813-e552b23720d9/2FEB36B0-ADA0-4DB5-9C21-B42F82686E3F

5. Extreme coastal conditions

5.1 Introduction

Extreme coastal conditions are referenced within this Section to support ongoing erosion management actions. These conditions are based on those published in 2023 and 2024 during the development of the SEMP, and whilst they are considered suitable for the design of erosion protection options throughout its ten-year implementation period, care should be taken to use any updated information available (e.g., updated tide tables).

5.2 Tides

Tidal plane information has been sourced from the 2023 Queensland Tide Tables[18] for the open coastline and are shown in Table 5-1 for Mooloolaba. Adjustments to these levels may be required if erosion management actions are being planned in areas upstream, where tidal range may be reduced.

The tidal regime in Pumicestone Passage is evolving due to the Bribie Island breakthrough in early 2022. Here, the tidal regime is shifting to becoming more indicative of an open coast location. Erosion design work within the Pumicestone Passage is required to seek the latest tidal data from MSQ as it becomes available.

Table 5-1: Tidal planes for Mooloolaba (MSQ 2013)

Tide level	2023 (mAHD)	2100 (mAHD)*
HAT	1.20	2.00
MHWS	0.69	1.49
MHWN	0.37	1.17
MSL	0.00	0.80
MLWN	-0.38	0.42
MLWS	-0.73	0.07
PSM37055	4.71	-
AHD	0.00	-
LAT	-1.01	-0.21
* 2100 levels based on SSP5 Climate change scenario, 0.8m SLR		

5.3 Storm tides

Storm tide information for the Sunshine Coast is to be taken directly from the Sunshine Coast Storm Tide Review (2023). This presents updated storm tide levels for coastal creeks, however, retains the open coast levels from the previous Sunshine Coast Storm Tide Study (Aurecon 2013).

18 Available from: Maritime Safety Queensland (MSQ) 2023, https://www.msq.qld.gov.au/tides/tidal-planes

5.4 Sea level rise

The previous SEMP uses climate change and sea level assumptions from the Queensland Coastal Plan (2011), which adopted a sea level rise projection of 0.8m by 2100 (relative to the 1990 mean sea level). At the time, this value was based on the upper range of projections published by the Intergovernmental Panel on Climate Change (IPCC) within their Fourth Assessment Report (IPCC, 2007). Since this assessment, the IPCC has released the Sixth Assessment Report (AR6), which includes a range of Shared Social Economic Pathways (SSP) that account for different emissions scenarios (IPCC, 2021).[19]

The use of a general sea level rise projection of 0.8m by 2100 continues to have widespread use in Queensland for high level planning. However, a move towards probabilistic sea level rise projections is recommended, as presented within the Intergovernmental Panel on Climate Change (IPCC) within their sixth Assessment Report (AR6). In particular the SSP5-8.5 scenario is recommended by the IPCC for high profile or high-risk projects. This is a high reference scenario that assumes no additional climate policy is adopted through governments. Increasingly, end of life planning will project beyond 2100, and should follow a risk-based design approach where multiple sea level scenarios are considered. Figure 5-1 shows the projected sea level rise under SSP5-8.5 relative to a 1995-2014 baseline, which presents different probabilities. In 2100 the 50th percentile (median) sea level estimate is +0.77m above 1995-2014 levels, however estimates range between +0.50m to 1.31m (5th to 95th percentiles).

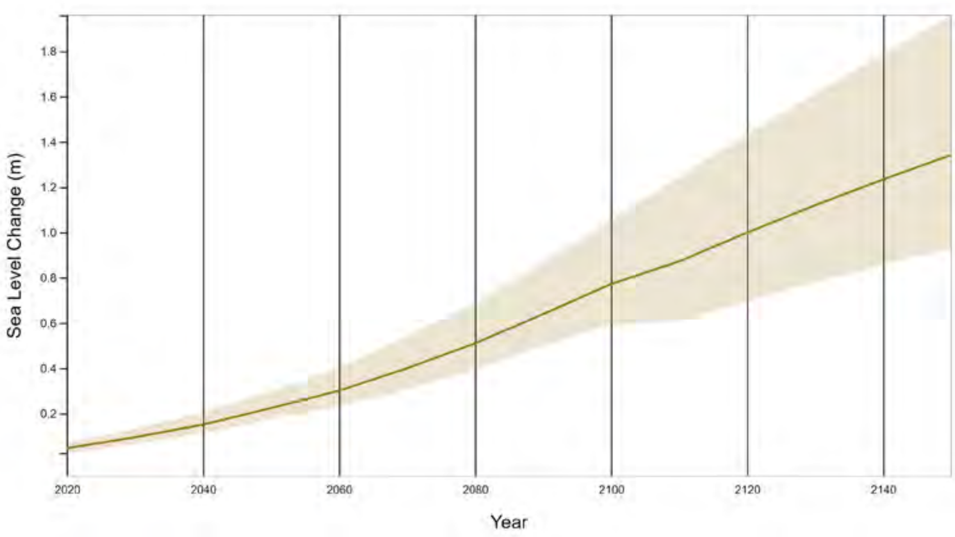

Figure 5-1: Projected Sea Level Rise under SSP5-8.5 – relative to 1995-2014 baseline (IPCC 6AR)

19 IPCC, 2021: Technical Summary. 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. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 147–286, doi:10.1017/9781009157896.003.]

5.5 Offshore waves

A new extreme wave assessment has been completed for this SEMP, with extreme 'midshore' waves now available at a 10m depth contour for each beach unit. A full description of this work is included in Appendix A and summarised here.

Extreme value analysis (EVA) was conducted for offshore wave data at the Brisbane Wave Rider Buoy (WRB), for use in wave modelling conditions. A generalised pareto distribution (GPD) has been applied to the wave record to model the distribution of the largest waves that exceed a certain threshold. A peak over threshold (POT) method has been used to isolate wave events exceeding the threshold height. Figure 5-2 shows the fitting of the GPD function to wave data and estimation of extreme wave heights at Brisbane WRB. The estimated offshore wave conditions are shown in Table 5-2, indicating a 1% Annual Exceedance Probability (AEP)/100-year Average Recurrence Interval (ARI) significant wave height approaching 8m.

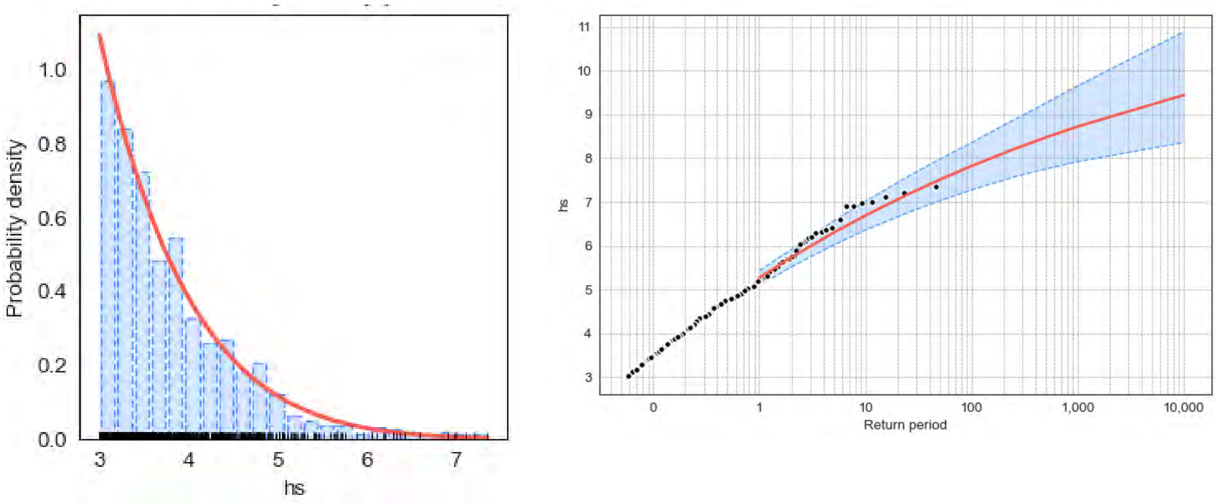

Figure 5-2 Left: GPD fit to wave heights above 3.0m and Right: GPD estimation of extreme wave height, for Brisbane WRB

Table 5-2: Extreme wave height return periods for Brisbane WRB

ARI (yrs)	Hs (m)
2	5.74
5	6.30
10	6.69
20	7.10
50	7.51
100	7.82

5.6 Midshore waves

Midshore (-10m depth contour) extreme wave conditions have been estimated for each beach unit. A probabilistic approach has been used to establish a 10,000-year wave simulation, representing a range of potential wave conditions for each nearshore location. The following methodology has been used to derive these conditions:

1. Metocean data collation: Historical offshore wave data is collated for the Brisbane WRB.
2. Data declustering: The historical data series is declustered into discrete events.
3. Data simulation: The declustered data is used to produce a large 10,000-year set of potential offshore conditions.
4. Data sampling: A subset of 200 representative events is sampled from the large dataset.
5. Wave modelling: The 200 representative events are applied as wave model boundary conditions, with results extracted in the nearshore at each coastal unit.
6. Midshore wave emulation: An emulator is used to translate the remainder of the large set of wave conditions to the midshore.

Following the translation of 10,000-years of wave conditions, extreme value analysis was conducted for each beach unit. Table 5-3 shows extreme midshore wave heights for each coastal unit. A complete summary of extreme wave conditions for all units has been included in Appendix A Table 9-7. This includes a future 2100 scenario where a "worst-case" scenario has been assessed for the northern section of Pumicestone Passage assuming a complete loss of Bribie Island north and the development of open coast bathymetric conditions from Pelican Waters to Caloundra.

5.7 Waves at the beach/toe of structures

The extreme waves provided in Table 5-3 have been estimated at the -10m depth contour as they approach the beach unit. Table 5-4 shows extreme waves estimated for the future 2100 'worst case' scenario at Pumicestone Passage for unit E3 to E6. Depending on the intended use, these may require transformation and consideration of breaking as they then approach the shoreline. For example:

- Many wave runup calculations require offshore 'deepwater' conditions. Whilst the -10m contour is not exactly a deepwater environment, these conditions have the advantage of offering differentiation between beach units due to their orientation and headlands.
- Sediment transport modelling/calculations typically use wave conditions seaward of the breaker zone, in -5 to -10m water depth.
- Structural calculations require waves to be calculated closer to the shoreline.

In order to estimate very nearshore conditions, additional wave transformation modelling or calculations are required. This may include the following:

- Further transformation using a numerical model, particular for high risk or high-profile locations. This may be a 2D spectral wave model or a transect using a 1D spectral wave model such as SWAN, or other wave group resolving models such as XBeach. This will allow local bathymetry, reefs, and structures to be included in detail. Care will need to be given to selecting an appropriate nearshore bathymetry for the simulations which will depend on the use. For example, for an extreme wave study the bathymetry may need to be altered to reflect eroded conditions.
- For low-risk projects and areas protected by significant rock shelfs, analytical depth limited calculations could be used. Preference would be given to calculations that consider bed slope, wave period and wave steepness, in addition to wave height and water depth.

Table 5-3: Present day midshore extreme wave heights (-10m depth contour)

Beach name	Unit	10%AEP Hs (m)	2% AEP Hs (m)	1% AEP Hs (m)
Coolum Beach	O1	4.65	5.16	5.31
Stumers Creek	L1	4.59	5.06	5.20
Point Perry to Point Arkwright	H1	4.61	5.17	5.35
Yaroomba Beach	O2	4.59	5.20	5.39
Mount Coolum Beach	O3	4.22	4.84	5.06
Marcoola Beach	O4	4.39	4.97	5.16
Mudjimba Beach	O5	3.25	3.67	3.85
Twin Waters Beach	O6	4.42	4.93	5.07
Maroochy River Estuary	E1	4.52	5.00	5.16
Maroochydore Beach	O7	4.28	4.80	4.96
Alexandra Headland Beach	O8	4.08	4.58	4.73
Alexandra Headland	H2	3.84	4.40	4.59
Mooloolaba Beach	O9	3.49	4.00	4.18
Point Cartwright	H3	4.32	4.63	4.72
Buddina Beach	O10	4.33	4.97	5.19
Mooloolah River Estuary	E2	3.35	3.83	4.02
Warana Beach	O11	4.34	5.00	5.25
Bokarina Beach	O12	4.39	5.00	5.20
Wurtulla Beach	O13	4.44	4.69	4.73
Currimundi Creek	L2	3.89	4.36	4.53
Currimundi Beach	O14	3.92	4.49	4.67
Coondibah Creek	L3	4.14	4.65	4.82
Dicky Beach	O15	4.30	4.77	4.92
Bunbubah Creek	L4	4.35	4.86	5.03
Tooway Creek	L5	4.42	4.94	5.13
Moffat Beach	O16	4.42	4.86	5.01
Moffat Headland	H4	4.44	4.94	5.06
Shelly Beach	O17	4.34	4.84	4.98
Caloundra Headland	H5	3.48	3.74	3.83
Kings Beach	O18	3.33	3.51	3.57

Beach name	Unit	10%AEP Hs (m)	2% AEP Hs (m)	1% AEP Hs (m)
Happy Valley	O19	3.71	4.04	4.13
Bribie Island Beach	O20	2.95	3.27	3.39

Table 5-4: Future 2100 nearshore extreme wave heights for Pumicestone Passage

Beach name	Unit	10%AEP Hs (m)	2%AEP Hs (m)	1%AEP Hs (m)
Pumicestone Passage - Bulcock Beach to North Street	E3	1.35	1.51	1.59
Pumicestone Passage – North Street to Jellicoe Street	E4	2.62	2.90	2.98
Pumicestone Passage - Jellicoe Street to Onslow Street	E5	2.87	3.21	3.32
Pumicestone Passage - Onslow Street to Lamerough Canal	E6	2.90	3.19	3.27

6. Sand Sourcing

The use of sand nourishment as an erosion mitigation approach is widespread along the Sunshine Coast. This has a range of social and economic benefits and is an approach aligned with Nature-Based Solutions. Several beaches will require increased volumes of sand nourishment over the lifetime of the SEMP, which may require expansion of existing permits and approvals. In addition, there is a growing interest in establishing an offshore sand source, which has been reviewed and the next steps recommended.

6.1 Existing Permits (estuarine)

A range of permits exist for sand extraction in the Maroochy River, Mooloolah River, Golden Beach and various canal systems.

6.1.2 Maroochy River

Permits EA0000800 (issued 3 August 2020) provides large scale dredging from the river mouth:

- ERA 16 - Extraction and Screening 1: Dredging, in a year, the following quantity of material (c) more than 100,000t but not more than 1,000,000t (62,500 to 625,000 m^3): Adjacent to Lot 2 on AP22145
- ERA 16 - Extraction and Screening 1: Dredging, in a year, the following quantity of material (c) more than 100,000t but not more than 1,000,000t (62,500 to 625,000 m^3): Adjacent to Lot 39 on AP22145
- ERA 16 - Extraction and Screening 1: Dredging, in a year, the following quantity of material (c) more than 100,000t but not more than 1,000,000t (62,500 to 625,000 m^3): Adjacent to Lot 1 on CP862576

The permitted volumes are considered to exceed existing operational nourishment requirements for Maroochydore Beach (50,000 m^3/yr) and those over the SEMP lifetime which are expected to increase by 10-20%. The sand volume within the lower Maroochy River appears sustainable, with any sand dredged from the system placed on the 'updrift beach', which is then naturally pushed back towards the estuary mouth through longshore sediment transport.

Permit EPPR00870913 (effective on 23 August 2018):

- ERA 16 - Extraction and Screening 1(b) - Dredging, in a year, the following quantity of material - more than 10,000t but not more than 100,000t: Location at Lot 721 on CG5072.

  Placement of the sand was approved at the western side of Chambers Island.

6.1.3 Mooloolah River

Nourishment of Mooloolaba Beach is undertaken using a combination of DTMRs existing extraction permit and smaller Council-held permits, with sand then shifted using a permanent pipeline and nourished by Council who holds a placement permit for Mooloolah Beach.

Permit EPPR02005514 (previously EPPR00730013 and SPDE00269110):

- ERA 16 - Extraction and Screening 1: Dredging, in a year, the following quantity of material (b) more than 10,000t but not more than 100,000t/year from Mooloolaba Boat Harbour (Lot 1 on SP14293) and Coral Sea offshore area.
- ERA 16 - Extraction and Screening 1: Dredging, in a year, the following quantity of material (b) more than 10,000t but not more than 100,000t (6,250 to 62,500 m^3): Mooloolah River entrance and nearshore (Adjacent to Lot 1 and 2 on SP143293).

- ERA 16 - Extraction and Screening 1: Dredging, in a year, the following quantity of material (b) more than 1,000t but not more than 10,000t (625 to 6,250 m^3): Between Mooloolah Island and Outrigger Park, adjacent to Lot 709 on SP157254.

  Mooloolah River Entrance – Mooloolaba Dredge and Disposal Areas Approval Drawing BN- 15-49-1A dated 7.5.10 allows the placement of dredge material nearshore adjacent to and parallel to Mooloolaba Beach between the Rock wall Mooloolaba and west up to Urunga Esplanade to the west.

In 2023 a nourishment campaign placed 15,000 m^3 of sand along the beach to the Surf Life Saving tower. Operational estimates consider this volume may need to be repeated annually, and even increased to 30,000 m^3 in the SEMP lifetime. Whilst this is within the permitted volumes, it primarily relies on the DTMR dredging permit, with the smaller Council permits not holding sufficient volume. It is recommended that Council gains their own dredging permit for the Mooloolah River entrance to support ongoing nourishment requirements.

6.1.4 Golden Beach (northern areas)

Nourishment of the northern Golden Beach area is undertaken using a dredging permit that allows extraction from within the channel and placement on the estuary banks.

Permit EPPR00188713 (previously IPDE00381806A11, issued on 26 July 2006):

- ERA 16 - Extraction and Screening 1(a) - Dredging, in a year, the following quantity of material – 1,000t to 10,000t. Dredging material from the bed of any waters using plant or equipment having a design capacity of not more than 5,000 t per year (3,120 m^3). This covers Golden Beach, Caloundra and within the Pumicestone Passage Navigation and Access Channels north of approximately Jellicoe Street.

This volume is expected to be exceeded during the lifetime of the SEMP. A revised permit is recommended with an increase in dredging and placement volume.

6.1.5 Golden Beach (southern areas)

Nourishment of the southern Golden Beach area is undertaken using a dredging permit that allows some variability within annual dredged volumes.

Permit EPPR03441315 (15 Dec 2015)

- ERA 16 - Extraction and Screening 16-(1b) Dredging >10,000t but <100,000t yr (6,250 to 62,500 m^3): Preferred sand dredging area within Pumicestone Passage offshore of approximately Lamerough Canal and Roy Street. Additional sand dredging area spanning approximately Jellicoe Street to Bells Creek inlet.

Reference OPW12-0018 (21 April 2017):

- Development Permit for Operational Works, for Prescribed Tidal Works – Dredging and Beach Nourishment Works, allowing more flexibility to Permit EPPR03441315. This incorporates seagrass buffers within the current dredge footprint, flexibility in annual maximum extraction and nourishment volumes. Initially 10,000 m^3/yr is permitted. Once triggers are met, this can increase to 40,000 m^3 in a single given year, however this is capped at 100,000 m^3 over the ten-year approval period.

The current permit allows for dredging within Pumicestone Passage and placement along the foreshore at Golden Beach. The requirement to shift from the 10,000 m^3/yr volume to 40,000 m^3 is based on the triggers presented in the Bribie Island Breakthrough Plan (BMT WBM, 2015). The expectation is that the expanded volume of 40,000 m^3 will only be used once through a larger scale 'capital' nourishment campaign, with a return then to 5,000 m^3/yr for annual maintenance. The required triggers are:

1. Material required for beach nourishment exceeds the existing permitted volume of 10,000 m^3/year;
2. An unstainable volume of sand is required for ongoing beach nourishment; and/or
3. An observed increase to the mean high water springs level and/or mean sea level greater than 0.2m. *NOTE: This has been met due to the recent breakthrough, which has caused an increase in mean high-water level of 0.23 metres (see Section 5).*

6.1.6 Various Canals

Dredge material from canals is not expected to be suitable for beach nourishment. Various canal dredging permits are presented below for reference, however they have not been considered in detail for an open coast source of sand. Dredging from the Maroochy Waters canal is the source of nourishment activities along Picnic Point and eastern sections of Bradman Avenue. The permitted extraction volumes are controlled by the level of sedimentation within the canal in relation to the design canal depth, with dredging only permitted when the channel is shoaled above this level.

Permit EPPR00187013 (27 September 2016):

- ERA 16 - Extraction and Screening 16-(1a) Dredging >1,000t but <10,000t yr (625 to 6,250 m^3): Mooloolah River in the Minyama and Buddina Canal System
- ERA 16 - Extraction and Screening 16-(1b) Dredging >10,000t but <100,000t yr (6,250 to 62,500 m^3): Buddina and Minyama Canal System
- ERA 16 - Extraction and Screening 16-(1b) Dredging >10,000t but <100,000t yr (6,250 to 62,500 m^3): Canal System found in the Maroochy and Mooloolah River (Maroochy River - Maroochy Waters and Riverbreeze Canal Estate, Mooloolah River - Emerald Estate, Mayes, Tuckers Creek, Hideaway Waters, Baronga Broadwater and Mundoora Broadwater Canal).

  The dredged material is approved to be places along the foreshore of the east of Chambers Island, either side of the canal from Maroochy Waters.

Permit EA0000851 (19 June 2017):

- ERA 16 - Extraction and Screening1(a) - Dredging, in a year, the following quantity of material - 1000t to 10,000t: Mooloolah River at Lot 709 Nicklin Way, Minyama (Canal System).

Permit EA0001226 (10 April 2018):

- ERA 16 - Extraction and Screening 1(a) - Dredging, in a year, the following quantity of material - 1000t to 10,000t: Coongarra Esplanade, Wurtulla (Lot 30 on W93214), Buderium Street, Currimundi (lot 708 on CG3862), Oceanic Drive, Warana (Lot 715 on CG4006).
- ERA 16 - Extraction and Screening 1(b) - Dredging, in a year, the following quantity of material - more than 10,000t but not more than 100,000t: Coongarra Esplanade, Wurtulla (Lot 30 on W93214), Buderium Street, Currimundi (lot 708 on CG3862), Oceanic Drive, Warana (Lot 715 on CG4006).

  Placement of dredge material is to be in accordance with the approved Currimundi Lake Adaptive Sande Management Plan, which allows material to be placements in identified locations through the Currimundi Lake and adjoining canal system and along Ballinger Beach.

6.2 Current dredging volumes and future placement needs

Around 100,000 m^3 of sand is used annually for nourishment along the Sunshine Coast beaches. In the future this is expected to increase by 10-20% as greater sand volumes are needed. The priorities for expanded dredging or placement permits should be:

- Mooloolaba dredge source
- Northern Golden Beach dredge and placement permits
- Southern Golden Beach dredge and placement permits (linked to existing triggers).

6.3 Next steps in establishing an offshore sand source

Nearshore sand placement was trialled at Maroochydore Beach in November 2022. This used sand sourced from the Spitfire Channel under approval 2201-27063 SDA (21 April 2022) which allowed up to 100,000 m^3 of sand to be dredged and placed over a temporary marine plant disturbance area of 3,780 m^2 along Maroochydore beach. It was considered an efficient, cost-effective approach to sourcing sand and is a promising approach to provide greater volumes than existing estuarine locations due to the larger dredge capacities. In the future this approach for nourishment may be used for Mooloolaba and Maroochydore Beaches, and potentially smaller beaches if placement methods allow.

Identifying any local offshore sand source has been recommended in the Sand Sourcing Study (BMT WBM 2016). This would allow future nearshore nourishment campaigns similar to the Mooloolaba trial. The Sand Sourcing Study identified three options for sand sourcing to assist with beach nourishment. These included:

- Estuarine reserves (Maroochy River Mouth and Northern Pumicestone Passage).
- Purchasing and transporting commercially extracted marine sand (from Moreton Bay).
- Identification and allocation of an offshore reserve.

Whilst there is potentially a large quantity of sand available in offshore reserves, the cost associated with its access may be prohibitive, and consequently other sand sources have been used to date. However, this option has been reinvestigated to understand the next steps in understanding its viability.

6.3.1 Legislative framework

Offshore sand extraction is likely to have an onerous approvals process and would only be feasible if large volumes were required. Whilst being investigated by other states (Stockton Beach, Newcastle (NSW), Adelaide 'Living Beaches' (SA), Port Beach, Fremantle (WA)), any offshore sources for the Sunshine Coast will be located adjacent to the Moreton Bay Marine Park and subject to environment approval.

Offshore dredging in Queensland is subject to the following legislation and associated regulations:

Commonwealth

- *Aboriginal and Torres Strait Islander Heritage Protection Act 1984*
- *Environment Protection and Biodiversity Act 1999*
- *Native Title Act 1993*
- *Protection of Movable Cultural Heritage Act 1986*.

State

- *Aboriginal Cultural Heritage Act 2003*
- *Coastal Protection and Management Act 1995*

- *Environmental Protection Act 1994*
- *Environmental Protection (Sea Dumping) Act 1981*
- *Fisheries Act 1994*
- *Land Act 1994*
- *Local Government Act 2009*
- *Marine Parks Act 2004*
- *Marine Parks (Moreton Bay) Zoning Plan 2019*
- *Marine Park Regulation 2017*
- *Nature Conservation Act 1992*
- *Planning Act 2016*
- *Planning Regulation 2017*
- *Queensland Heritage Act 1992*
- *State Development and Public Works Organisation Act 1971*
- *Torres Strait Islander Cultural Heritage Act 2003*
- *Vegetation Management Act 1999*.

6.3.2 Approvals required

To facilitate the offshore dredging for beach nourishment purpose, Council will require approvals, permits and resource allocations pursuant to those Acts mentioned above, in conjunction with those existing approvals for placement (i.e., beach nourishment) of sand.

For projects that are:

- Complex approval requirements, involving local, state and federal governments.
- Significant environmental effects.
- Strategic significance to the locality, region or state, including for the infrastructure, economic and social benefits, capital investment or employment opportunities it may provide.
- Significant infrastructure requirements.

Council may wish to seek for the offshore dredging project to be declared a 'coordinated project' under the *State Development and Public Works Organisation Act 1971*. To meet the criteria for a 'coordinated project' will be subject to the volume of sand proposed to be extracted and the environmental impact. Based on similar projects undertake on the Gold Coast, we understand that this project would not be supported by the Coordinated General as a 'coordinated project'.

Therefore, the approval pathway for an offshore dredging project in the Sunshine Coast is as follows:

1. Determine if the proposed activity is deemed a 'controlled action' pursuant to the *Environment Protection and Biodiversity Act 1999* (EPBC Act). This involves an assessment of the proposed

activity against the provisions of the *Significant Impact Guidelines 1.1 - Matters of National Environmental Significance*.[20]

2. Identify to the relevant triggers at a commonwealth, state and local level (environmental triggers, planning provisions etc.).
3. Confirm owners' consent and resource allocations required.
4. Identify the relevant State codes and applicable approvals required (i.e., tidal works, removal of marine plants).
5. Identify if the works will be located in a designated marine park, in this instance, it will be the Moreton Bay Marine Park.
6. Identify development/works which are assessable under the Sunshine Coast Planning Scheme and the applicable approvals to be obtained.
7. Once the above is determined, meeting with the relevant commonwealth, state and local agencies is pertinent to confirm the approvals, permits, consents and allocations required to facilitate the project.

The approvals required to facilitate offshore dredging as detailed below, noting that this is not an exhaustive list and is subject to the legislation at the time.

Table 6-1: Approvals required for offshore dredging

Approvals required	Legislation	Approving agency
Approval under sections 130(1) and 133 of the EPBC Act for a controlled action (EPBC Act Approval)[21]	*Environment Protection and Biodiversity Act 1999*	Department of Climate Change, Energy, Environment and Water (DCCEEW)
Owners consent (for development application lodgement and to undertake works)	*Land Act 1994*	Department of Resources Relevant landholders (i.e., Council, private)
Development permit for operational work for tidal works	*Planning Act 2016* *Planning Regulation 2017* *Coastal Protection and Management Act 1995*	Department of Environment, Science and Innovation
Development permit for a material change of use of an Environmentally Relevant Activity (ERA) for:[22] - ERA 16(1)(d) – extractive and screening activities – dredging	*Planning Act 2016* *Planning Regulation 2017* *Environmental Protection Act 1994*	Department of Environment, Science and Innovation

[20] https://www.dcceew.gov.au/environment/epbc/publications/significant-impact-guidelines-11-matters-national-environmental-significance
[21] If the proposed activity is confirmed that it will not have a significant impact on matters of national significance, then an EPBC Act approval is not required.
[22] The quantities will be subject to the volume material required to fulfill Council beach nourish program.

Approvals required	Legislation	Approving agency
more than 1,000,000 tonnes of material in a year [23] - ERA 16(3)(c) – extractive and screening activities – screening more than 1,000,000 tonnes of material in a year.	*Environmental Protection Regulation 2008*	
Environmental authority to undertake a prescribed Environmentally Relevant Activity – ERA 16 (1)(d) and ERA 16 (3)(c)	*Environmental Protection Act 1994* *Environmental Protection Regulation 2008*	Department of Environment, Science and Innovation
Allocation notice to take quarry material – removal of quarry material from land under State tidal water [24] [25]	*Coastal Protection and Management Act 1995* *Coastal Protection and Management Regulation 2017*	Department of Environment, Science and Innovation
Registration as a suitable operator for the carrying out of an Environmentally Relevant Activity (ERA 16(1))	*Environmental Protection Act 1994* *Environmental Protection Regulation 2008*	Department of Environment, Science and Innovation
Marine Park Permit for dredging in a Moreton Bay Marine Park	*Marine Parks (Moreton Bay) Zoning Plan 2019* *Marine Parks Act 2004* *Marine Park Regulation 2017*	Department of Environment, Science and Innovation
Development Permit for operational work for the removal, destruction or damage of marine plants	*Planning Act 2016* *Planning Regulation 2017* *Fisheries Act 1994*	Department of Agriculture and Fisheries
Approval to damage vegetation on State coastal land	*Coastal Protection and Management Act 1995*	Department of Environment, Science and Innovation
Permit to Occupy (State Land)[26]	*Land Act 1994*	Department of Resources

[23] ERA 16(1)(d) is also listed as a concurrence ERA requiring development approval under the *Planning Act 2016* from the local government.
[24] An allocation of quarry material may not be required where material is to be removed from one location to another within tidal water. However, you may need a development permit, environmental authority or a marine park permit. Seek guidance and advice from a qualified professional or the Department of Environment, Science and Innovation.
[25] Allocation to remove quarry material from land under State tidal water applies to capital dredging associated with some form of tidal works (e.g., beach nourishment). Removal can involve taking the material for sale, reclamation, fill above the high watermark, removing the material for dewatering, or another environmental purpose on land.
[26] Required for beach access for placement of dredged material.

Approvals required	Legislation	Approving agency
Approvals for development assessable under the Planning Scheme	*Planning Act 2016* *Planning Regulation 2017*	Local Government (Sunshine Coast Council)

This is not an exhaustive list, and the relevant agencies should be consulted prior to undertaking planning and works. [27]

The above applications and request for consent will be required to be supported by relevant technical assessments, reports and plans. These may include, but not limited to, and at the discretion of the relevant agency at the time of lodgement:

- Dredging management plan – clearly outlining the dredge and placement areas, allocation area required, volumes, dredging operations (extraction practices and transportation).
- Coastal process and water quality assessment and management.
- Marine geology assessment – assessment of the existing conditions (geology and soils).
- Environmental impact assessment – identifying the existing environment and the impact of the activity, and how this will be mitigated and managed.
- Traffic management – identifying if the proposed offshore activity will impact on current use and operations within the water (shipping, recreational use), and if so, how will this be mitigated and managed.
- Impact assessment – understanding the impact of the activity on indigenous and non- indigenous cultural heritage, social and visual impacts.

6.3.2 Other consideration

Cultural heritage & native title considerations

The occurrence of indigenous cultural heritage objects and artefacts being located offshore are low; however, the process involved in consulting the registered Aboriginal Parties and providing native title notification will be provided to ensure that all legislative obligations relating to cultural heritage and native title are complied with. Additionally, a review of the current registers will be undertaken to identify any existing claims, notices or agreements (i.e., Indigenous Land Use Agreements) that may be, or are required to be, in place.

Socio-economic considerations

The use of the sand sourcing locations and the beach nourishment project areas may impact their use by the general population. As such, a review of the potential social and economic impacts will be undertaken. These may include, but are not limited to, Recreational and commercial boat users,

[27] Pursuant to the *Environment Protection (Sea Dumping) Act 1981*, a Sea Dumping Permit is not required in this instance as the dredged material will be disposed of on land (i.e., the beach); however, where material is to be dumped at sea, a Sea Dumping Permit is required. Please refer to the National Assessment Guidelines for Dredging (Australian Government, 2009).

Recreational and commercial fishery operators and amenity and recreational use values of the local beaches.

The timing of the works will have an impact on these considerations, as such, avoiding peak times would be recommended (i.e., school holidays, Christmas, etc.).

Landowner's consent

Pursuant to the *Planning Act 2016* and the *Land Act 1994*, landowner's consent is required to allow works to occur on private and/or State-owned land, regardless, if the works are deemed to be Exempt, Accepted or Assessable development.

Consent from the Department of Resources (the State) is required where the works are to occur in tidal water for land owned by the State or is intrusted to Council. This consent is required to be obtained to also accompany any development application and for Accepted development/Excluded works, prior to works being undertaken.

An application is required to be lodged with the Department of Resources seeking the consent of which take between 6-8 weeks.

Approvals pathway and timing

An Environmental Impact Statement (EIS) may be required for offshore sand extraction, whether that be a requirement under the EPBC Act or the *Environmental Protection Act 1994*, can have a significant impact on the time and cost associated with the approval process; however, can be managed through appropriate prior preparation and pre-lodgement meetings with the relevant agencies.

7. Compendium of coastal management options

7.1 Introduction

This Section provides information on erosion management options; including available resources, existing structures used along the Sunshine Coast, a proposed 'standard design' for a rock revetment, and how nature-based solutions (NbS) can be incorporated into erosion management.

7.2 Available Resources

Coastal protection refers to a range of measures taken to prevent or mitigate the impacts of natural hazards, such as erosion, flooding, and storm surges, on the coastlines. These hazards can cause significant damage to coastal communities, including loss of infrastructure, property damage, and in severe cases, loss of life. Coastal protection measures are designed to reduce the risk of these hazards and protect the coastal environment and communities from their negative impacts.

Coastal protection can take various forms, including the construction of artificial structures, such as seawalls, groynes, and breakwaters, as well as beach nourishment and dune restoration. These measures are designed to dissipate wave energy, reduce erosion, and prevent flooding. Additionally, coastal protection can also involve the implementation of policies and strategies, such as land use planning, zoning regulations, and the creation of protected areas, that aim to reduce the exposure of coastal communities to natural hazards.

A range of existing resources have been developed throughout Australia that can provide background information on coastal protection options. This includes guidance developed at a national or state level, or guidelines developed for specific options, such as fish friendly designs or nature-based solutions. This section summarises several references, which can be used to provide additional background information.

National Level:

- CoastAdapt coastal management options resources.
- State based resources:
- QLD Compendium of Coastal Hazard Adaptation Options.
- NSW coastal manual.
- NSW Environmentally Friendly Seawalls Guideline.

7.2.1 CoastAdapt coastal management options resources

CoastAdapt (www.coastadapt.com.au/) is a tool developed by the National Climate Change Adaptation Research Facility (NCCARF), commissioned by the Australian Government through the (then) Department of the Environment. It includes a suite of online resources to support coastal decision-makers and managers in Australia, to understand their risks from climate change and sea-level rise, and to take action to address those risks.

CoastAdapt presents a pathways approach framework, based on the principle that coastal protection and adaptation should be a continuous and iterative process that requires flexibility between planning and implementation. It introduces the concept of a trigger threshold for actions - for example soft mitigation measures could be used until a criterion is exceeded that triggers a hard structure. The threshold could be the available volume of sand in the profile or the beach width. The key advantages of the pathways approach are:

- It buys time to plan and reduces the pressure of making decisions now.

- It reduces uncertainty by using events not time as decision points.
- Its flexibility enables the plan to reflect local circumstances.
- It keeps options open until there is more information, funding or support for options.
- It allows for learning along the adaptation journey.

The CoastAdapt tool contains information and guidance on a wide range of subject areas, including adaptation options. Specific to this project are:

- Planning options
- Engineering options
- Environmental options
- Social, community and educational options.

Figure 7-1: CoastAdapt guidance sheets for coastal options

7.2.2 QLD Compendium of Coastal Hazard Adaptation Options[28]

The Compendium of Coastal Hazard Adaptation Options is one of the technical resources made available for the QCoast$_{2100}$ CHAS program. The document provides technical descriptions of adaptation options and provides advice on how best to adapt to current and future coastal hazards. It presents a multi-criteria analysis of each option against climate uncertainty, social, environmental, political, and economic components. Originally developed in 2012, many of the concepts throughout the compendium remain valid, however planning and cost information is considered out of date.

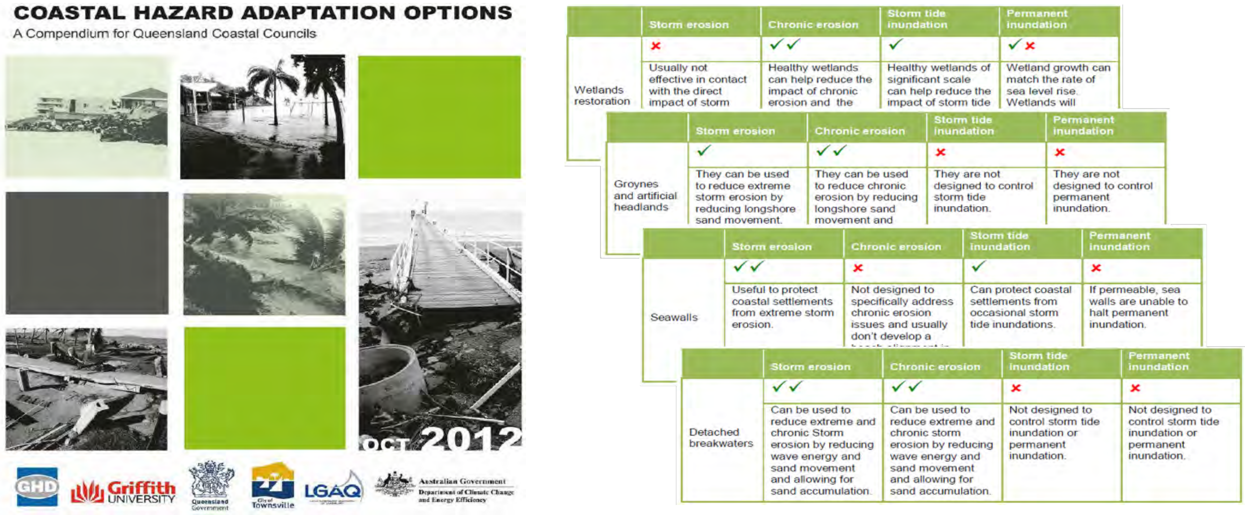

Figure 7-2: Coastal Hazard Adaptation Options - A compendium for Queensland Councils

7.2.3 NSW Coastal Management Manual[29]

The New South Wales (NSW) Coastal Management Manual provides guidance for local governments to implement a Coastal Management Program (CMP); which is the NSW equivalent to a SEMP. Part B (Stage 3 – Identify and evaluate options) of the manual includes guidance on identifying coastal management options, with different strategic approaches proposed to address different levels of risk. It includes five broad categories:

- Alert – includes coastal management actions that seek to 'watch and wait' such as monitoring change and setting thresholds, low regret responses and research to improve knowledge.
- Avoid future impact – includes recommending proactive land use planning and encouraging new development only in locations of low-risk.
- Active intervention – coastal management actions that seek to protect assets or accommodate change in any of the coastal management areas, while maintaining current systems and values.

28 GU CCZM (2012) "Coastal Hazard Adaptation Options - A Compendium for Queensland Coastal Councils", prepared by the Griffith University Centre for Coastal Management and GHD Pty Ltd. Accessed on 18 April 2023 from: https://www.townsville.qld.gov.au/__data/assets/pdf_file/0015/10725/Coastal_Hazard_Adaptation_Options.pdf.

29 NSW Coastal Management Manual (2018), Prepared by the Department of Planning and Environment. Accessed 30th May 2023 from: https://www.environment.nsw.gov.au/topics/water/coasts/coastal-management/manual.

- Planning for change – includes coastal management actions that seek to facilitate habitat migration and transformative changes to natural systems. For built areas, this includes planning to relocate or redevelop assets to consider the dynamic and ambulatory nature of the shoreline. It may be timed to commence as opportunities arise or when thresholds of exposure, impact and risk are exceeded.
- Emergency response – coastal management actions to address emergency situations.

7.2.4 NSW Environmentally Friendly Seawalls Guideline[30]

This guideline was developed to support improved environmental value of seawalls and seawall-lined foreshores in estuaries. It was published by the State of NSW, Sydney Metropolitan Catchment Management Authority and Office of Environment and Heritage first in 2009 and again reprinted with updated details May 2012, and remains an important guideline for fish-friendly seawall design. This document provides illustrations of the environmental consequences of building traditional seawalls, which differ from natural estuarine foreshores. It provides information on the steps involved in designing, approving, building, or upgrading seawalls in estuaries with a range of options to improve the environmental value of seawalls and seawall-lined foreshores. Recommendations are made on techniques to improve the environmental value of seawalls; either existing or new, and establishing estuarine vegetation such as mangroves directly in front of seawalls. Other options include the inclusion of native riparian vegetation buffers landward of the seawall, providing artificial reef habitat immediately in front of seawalls, and the inclusion of a variation of textures and form on the seawall surface. The guidelines aim to maximise the use of native riparian and estuarine vegetation, and both habitat diversity and complexity.

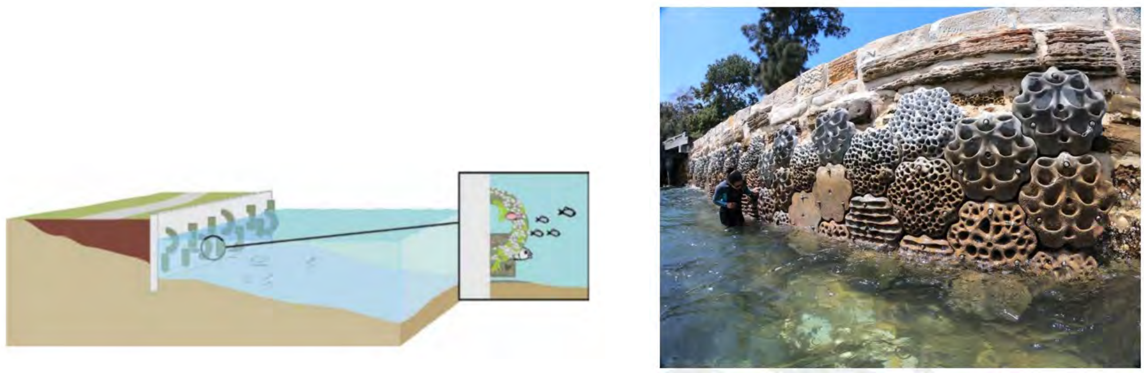

Figure 7-3: Seawall with living shoreline panels (left: © Daniel Wiecek, OEH. Right ReefDesignLab)[31]

30 OEH (2012) "Environmentally Friendly Seawalls - A guide to improving the environmental value of seawalls and seawall-lined foreshores in estuaries". NSW Office of Environment and Heritage. Accessed 18 April 2023 from: https://www.environment.nsw.gov.au/research-and-publications/publications-search/environmentally-friendly-seawalls

31 Right Image: ReefDesignLab (2022) "Living Seawalls". Produced by Reef design lab & Sydney Institute of Marine Science. Accessed on 14 April from: https://www.reefdesignlab.com/living-seawalls

7.3 Existing erosion control structures used along the Sunshine Coast

Coastal erosion protection structures are designed to mitigate the forces of wave energy on a shoreline. These structures are strategically placed along coastlines to dissipate wave energy, control sediment transport, and prevent the gradual loss of coastal land and infrastructure. A range of erosion control structures exist within the Sunshine Coast LGA which are summarised in this section. They include:

- Vertical seawalls within the Maroochy Estuary.
- Seawall/revetment at Moffat Beach.
- Proposed terraced revetment at Mooloolaba.
- Geotextile Sand Container (GSC) revetment at Maroochy Estuary.
- Coastal groynes along the Pumicestone Passage.

Vertical seawalls within the Maroochy Estuary

Traditionally a seawall is a vertical or near vertical structure, constructed from material such as concrete, masonry, or grout materials. It has the benefit of a small footprint when compared to sloped structures. Its disadvantages are the requirements for structural and geotechnical input into their design to ensure the wall does not overturn and their increased risk of toe erosion. The design life of a seawall can exceed 50-years.

Many examples of vertical seawalls exist within the Maroochy Estuary which can be templates for future designs. Conceptual designs in Figure 7-4 show a typical segmental concrete wall with a footprint as narrow as 2m. Figure 7-5 shows examples within the Maroochy River with the standard design used near Bradman Avenue.

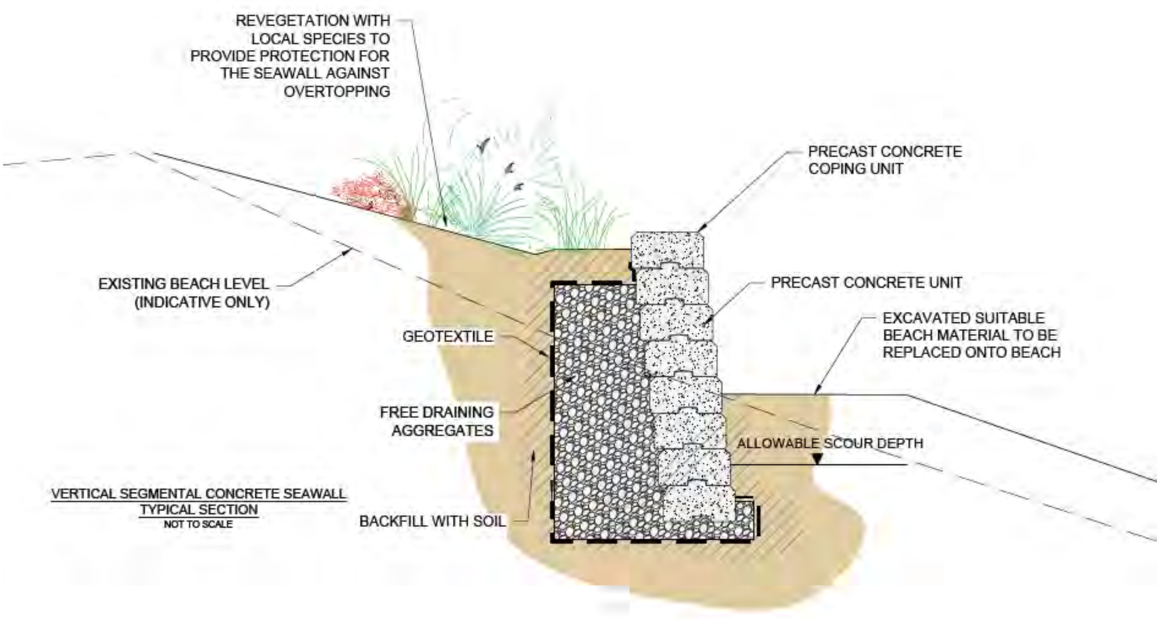

Figure 7-4: Typical segmental concrete seawall cross section

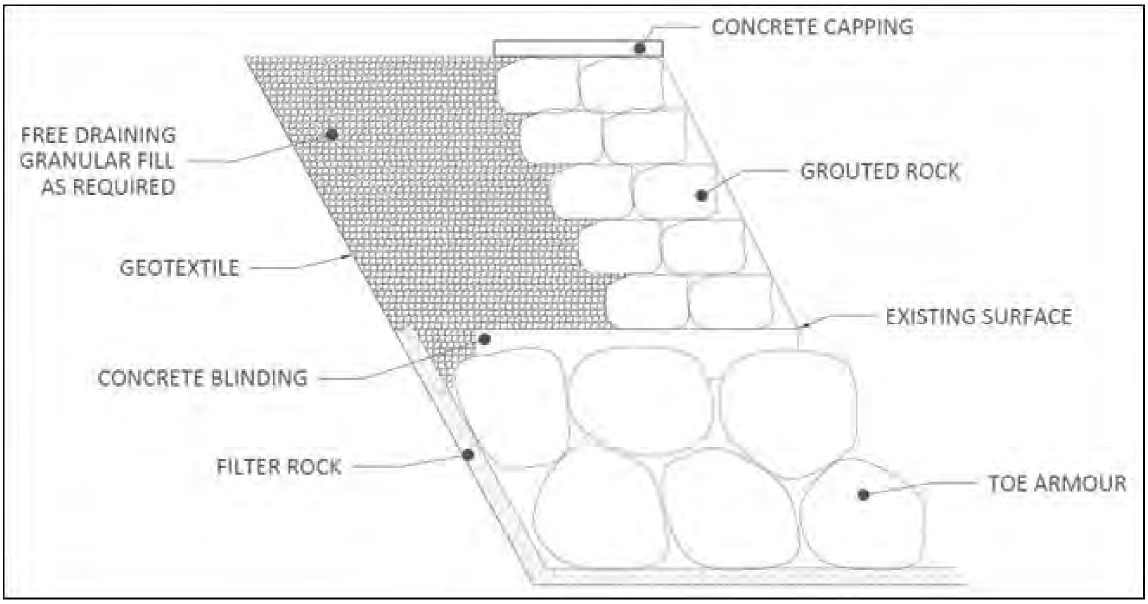

Figure 7-5: Vertical seawall example and standard design in the Maroochy Estuary

7.3.2 Rock revetment

A rock revetment is a sloped coastal defence made by layers of interlocked rock. It is typically constructed as multiple layers beginning with a geofabric material, a small rock underlayer, and a double layer of primary armour. The advantages of a rock revetment include their effectiveness in dissipating wave energy, they have a relatively simple construction method and are considered semi-flexible; meaning they can move during extreme storms and will accommodate scour without failing. Their disadvantages are the space required to fit the wide footprint and low aesthetic values.

Rock revetments are common throughout the Sunshine Coast with examples in estuaries and along the open coast. They typically have long design lives of 50 years and can be cost efficient where quality rock exists, and the site is accessible for construction plant. Conceptual designs in Figure 7-6 show a typical rock revetment design. Figure 7-7 shows an example of a revetment at Dicky Beach with an example standard design used near Kings Beach in Caloundra.

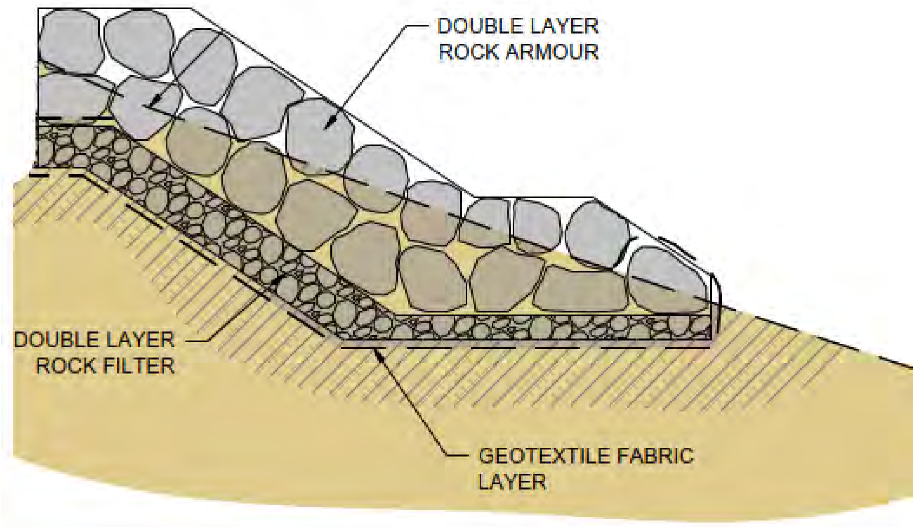

Figure 7-6: Typical rock revetment cross section

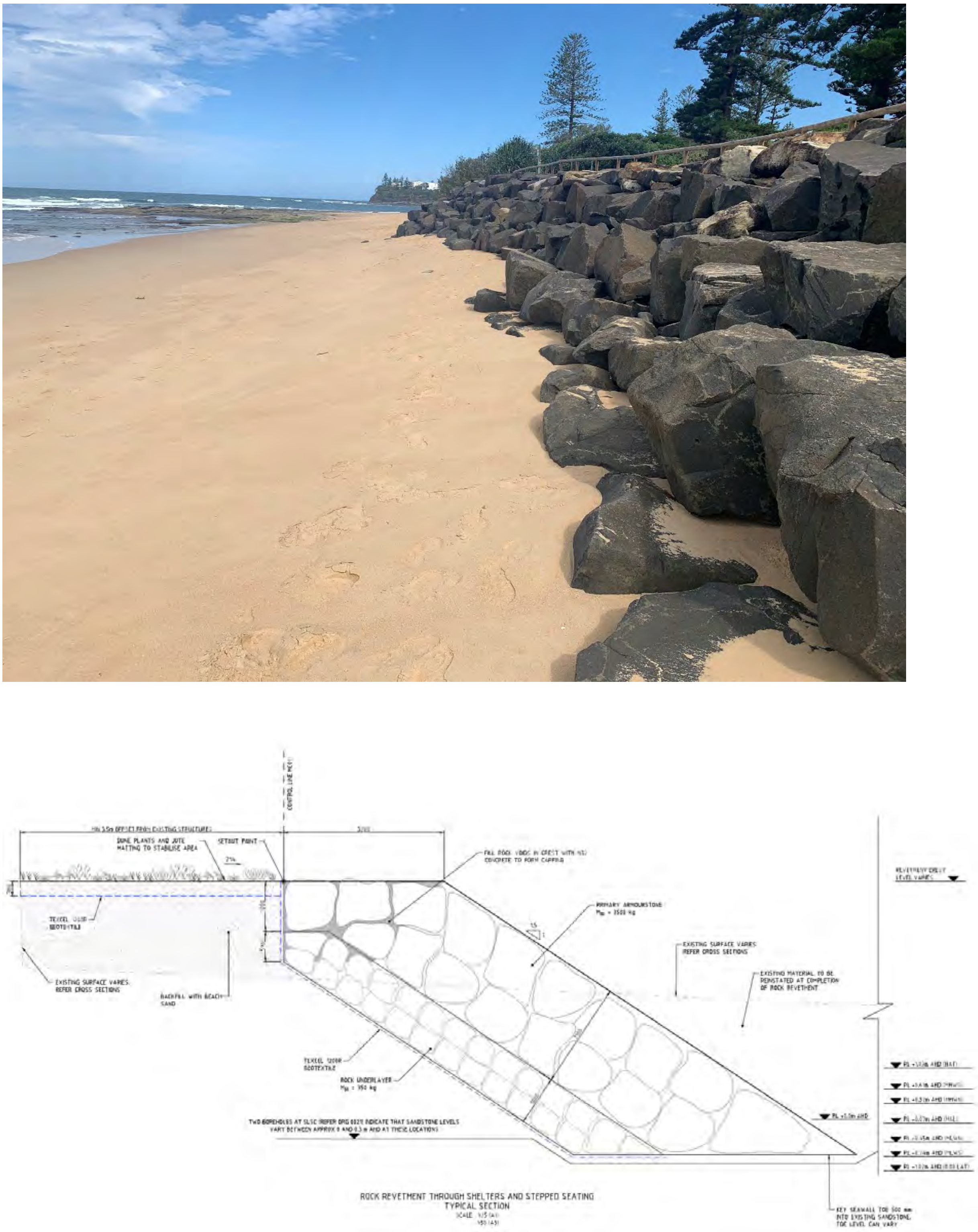

Figure 7-7: Rock revetment example at lower Neill Street, Dicky Beach (JBP 2023) and proposed design for future rock revetment at Kings Beach (SMEC detailed design 2021)

7.3.3 Terraced revetment at Mooloolaba

A terraced revetment is a stepped coastal defence. It consists of a series of horizontal or nearly horizontal steps or platforms built into the slope or embankment, typically using materials such as concrete, stone, or timber. The advantages of a terraced revetment are that they can be incorporated into high amenity areas given their terraces can be used by the public for access and seating. Their disadvantages are their wide footprint, high design requirements (structural and geotechnical inputs are required) and higher costs. Conceptual designs in Figure 7-8 show a typical terraced revetment design. Figure 7-9 shows the terraced revetment concept designs for Mooloolaba.

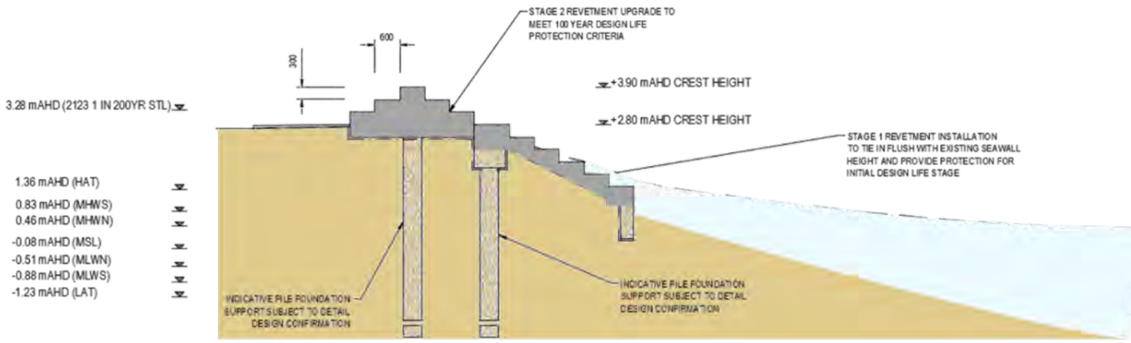

Figure 7-8: Typical terraced revetment cross section

Figure 7-9: Example terraced revetment concept design for Mooloolaba Central Meeting Precinct (Concept Blue) Source: (SCC, 2023)[32]

32 SCC (2023) "Mooloolaba Foreshore Revitalisation Project - Central Meeting Place. Compare the Concepts". Accessed on 14 April 2024 from:

7.3.4 Geotextile Sand Container (GSC) revetment

A Geotextile Sand Container (GSC) revetment is a sloped coastal defence made of layered sandbag units. It is typically constructed in multiple layers beginning with a geofabric material, and a double layer of GSCs. The size of the GSC unit varies based on the nearshore wave climate, but typically includes:

- $0.75m^3$ units, which are in use in northern Queensland in areas protected from large waves (e.g., Lacinda Groynes, Shire of Hinchinbrook)
- $2.5m^3$ units, which are used throughout Queensland (e.g., majority of the Sunshine Coast GSCs, Noosa, Fraser Coast, Whitsunday Region, Muskers Beach in Hinchinbrook Shire, Midge Point in Mackay Region)
- $4.5m^3$ units, which are now being tested for areas exposed to the open coastline, such as at the Maroochy Groynes.

GSC seawalls are popular for their amenity in areas with high public interaction. Although not specifically designed for public access, they are typically utilised in the public realm for seating and access. They have been installed at Maroochydore and a buried GSC seawall is located at Mooloolaba.

GSC units are vulnerable to vandalism and are not suited to high energy environments (i.e., on the open coastline). GSCs rely on the layers below to support themselves, therefore when a unit in the lower layers is damaged, the integrity of the structure is compromised. With a smooth surface, GSC seawalls also tend to experience more severe scour issues than porous rock structures, which suggests additional consideration to toe design and maintenance works. An expected design working life is approximately 15 to 20 years when fully exposed to UV, with ongoing repairs and major remediation works required towards the end of its design life, generally involving disposal of bags and reuse of fill material. Due to this, GSC seawalls work best when they are buried for most of their life as they are less exposed to vandalism and UV. These buried GSC seawalls act as a last line of defence in extreme events and are likely to last up to 50 years. The break down of the artificial fabric has not been fully understood, therefore its impact on the environment, including the possibility of releasing fibre or plastic into ocean, is still being researched. Care should be taken when considering a GSC structure.

Conceptual designs in Figure 7-10 show a typical GSC revetment design. Figure 7-5 shows examples at Maroochydore with the standard design used between the groynes.

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https://haveyoursay.sunshinecoast.qld.gov.au/mooloolaba-foreshore-revitalisation-project-central-meeting-place/compare-concepts

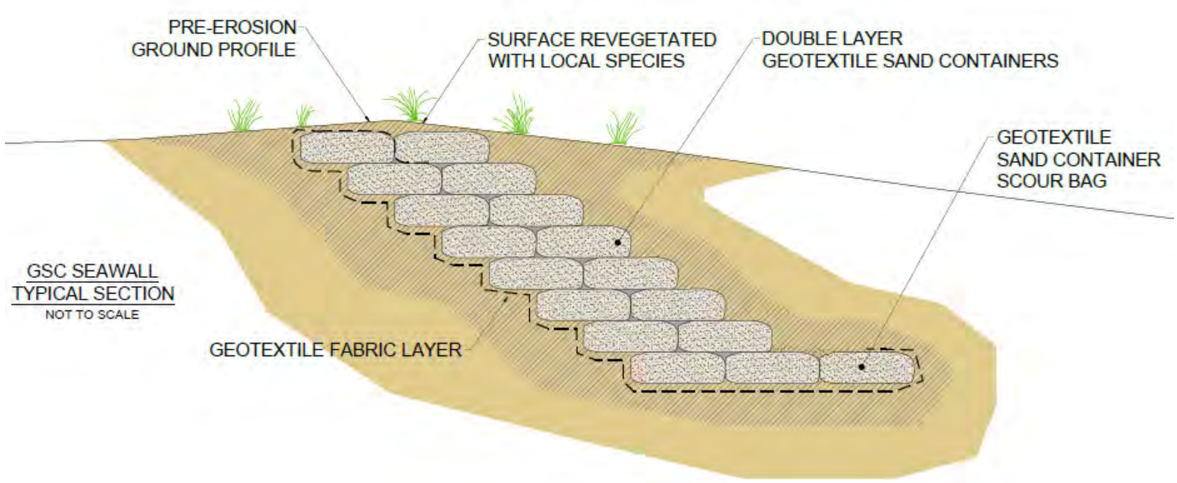

Figure 7-10: Typical GSC revetment cross section

Figure 7-11: Mooloolaba GSC seawall (SCC)

7.3.5 Groynes

Groyne structures are effective in areas of high sediment transportation, where they are designed and constructed to retain sediment in a coastal compartment, and often define the compartment itself. They are usually aligned perpendicular to the dominant transport direction, or to the coastline. Alternatively, they are also found at channel outlets, to reduce maintenance requirements on dredging. Carefully designed groynes will have local impact to the compartment and neighbouring land, but such designs can be intensive in numerical modelling and physical tests. Catastrophic outcomes can come from overly lengthy groynes starving the downstream area, creating erosion issues elsewhere.

Groynes can be comprised of several materials including GSC (Maroochy, Golden Beach) rock (Kings Beach, Golden Beach) or other options such as concrete units. In the case of rock armour, the main layer of rock units typically overlays a geotextile layer and core material, however some groyne structures are comprised entirely of rock armour. Costs increase when materials are transported, particularly over long distances, which needs to be considered for any project on islands or in a rural area.

Conceptual designs for a typical GSC groyne cross section are shown in Figure 7-12. Figure 7-13 shows examples of rock groynes at Golden Beach with the standard design used when upgrading the historic GSC groynes to rock materials.

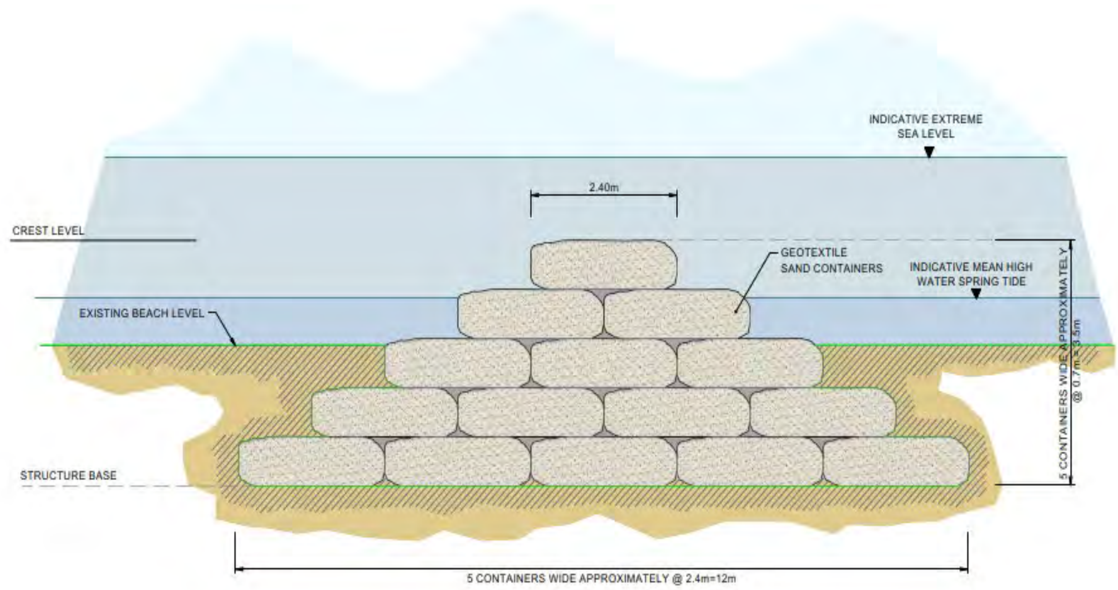

Figure 7-12: Typical GSC groyne cross section design

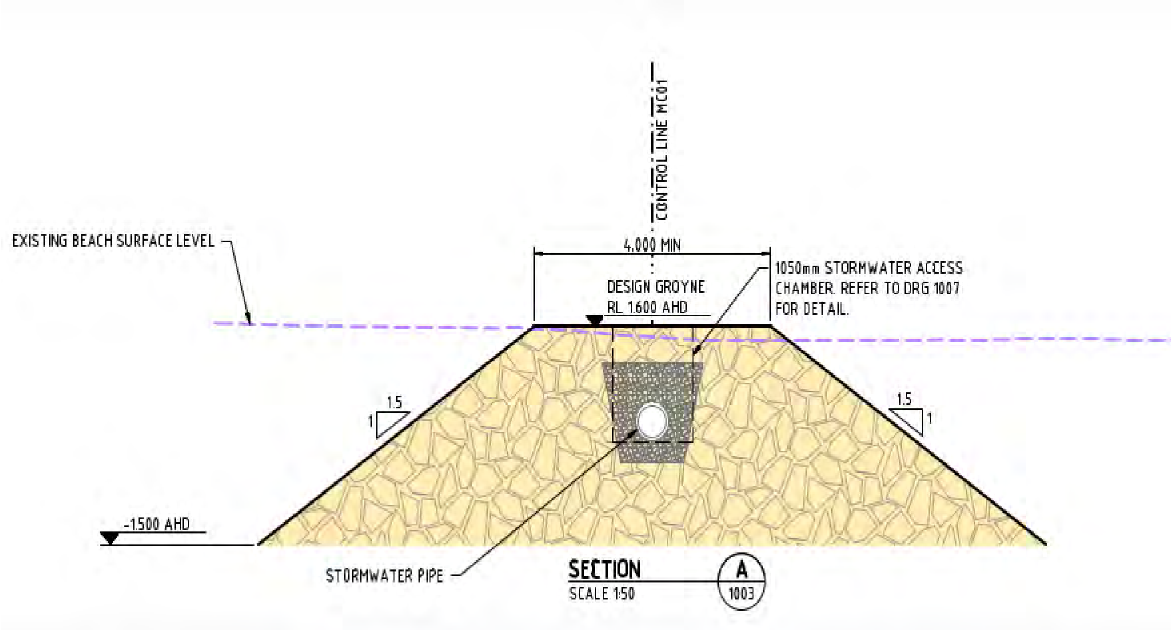

Figure 7-13: Rock groyne example and standard design for Golden Beach (SMEC detailed design 2020)

7.2 Nature based solutions (NbS) for erosion management

Ecosystem-based mitigation strategies are rapidly gaining interest to mitigate the adverse effects of erosion. Within the Sunshine Coast region, they are expected to be used to build resilience against erosion, to help strengthen natural systems, and ultimately prolong the need for the construction of hard defences. The key components of a Nature Based erosion management option is the natural vegetation that can capture and bind sediment and dissipate erosive forces such as waves and currents. Along the coastline this will include the establishment of a healthy dune and beach system, and in many estuarine areas can include mangroves and macrophytes.

7.4.1 Benefits of dune vegetation

Dune vegetation has significant environmental, social, and economic value. Revegetation of dune areas that have been blown out or lost vegetation cover would increase the value of the dune system. New growth will help stabilisation by trapping windblown sand, roots will help prevent erosion by wind and waves, and pioneer plant species can extend beyond the dune toe, allowing it to advance seaward. This will lessen impacts of a storm event but there is still potential for major losses during severe storms. In Queensland, there have been several studies conducted on dune vegetation. The list of benefits that vegetation has on mitigating coastal erosion are:

- Sand stabilisation: Dune vegetation can stabilize sand particles and prevent them from being easily displaced by wind and water, which helps to stabilize the dunes and prevent sand erosion.[33]
- Windbreaks: Vegetation can reduce wind velocity, by creating wind shelter that slows the wind and reduces the erosion effect. Vegetation can also reduce sand transport and erosion by intercepting and trapping blowing sand.
- Erosion control: Dune vegetation can reduce the impact of storm surges and prevent sediment loss during high tide events, leading to less erosion and a more stable shoreline.[34]
- Habitat for wildlife: Dune vegetation provides habitats for a variety of wildlife species, including birds, reptiles, and mammals, which helps to maintain biodiversity and ecosystem health.[35]
- Carbon sequestration: Dune vegetation can act as a carbon sink, sequestering carbon dioxide from the atmosphere through photosynthesis and storing it in the soil. This can help to mitigate the effects of climate change.[36]

7.4.1.1 Reduction of wave impacts and erosion

A field experiment was conducted in the Gold Coast, which investigated the effect of vegetation on wave run-up and dune erosion. This area is 150-200km south of the Sunshine Coast with similar coastal conditions. The researchers compared the response of dunes with and without vegetation to a range of

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33 Carter, R. W., Yates, M. L., & White, M. (2016). The effectiveness of dune stabilisation in mitigating impacts of sea-level rise and storm surges. Marine Pollution Bulletin, 107(1), 30-38.

34 Lovelock, C. E., Feller, I. C., Adame, M. F., Reef, R., Penrose, H. M., Wei, L., ... & Ball, M. C. (2015). Intense storms and the delivery of materials that relieve nutrient limitations in mangroves of an arid zone estuary. Functional Plant Biology, 42(2), 141-151.

35 Stork, N. E., Grimbacher, P. S., & Turton, S. M. (2014). The role of environmental heterogeneity in maintaining biodiversity of tropical insects and spiders. In Biodiversity in Australia (pp. 35-56). ANU Press.

36 Duarte, C. M., Losada, I. J., Hendriks, I. E., Mazarrasa, I., & Marbà, N. (2013). The role of coastal plant communities for climate change mitigation and adaptation. Nature Climate Change, 3(11), 961-968

wave conditions. The results of the study showed that dunes with vegetation had significantly lower wave run-up than those without vegetation. The presence of vegetation reduced wave run-up by up to 40% compared to unvegetated dunes.[37] The study also found that the presence of vegetation reduced the volume of sand eroded from the dunes during a storm event. Overall, the study demonstrated that the presence of vegetation on coastal dunes can be an effective way to reduce wave-based erosion and protect the coastline from storm damage.

While there are few studies that have reported that dune vegetation does not influence the magnitude of coastal erosion, it is important to note that the majority of studies have found that dune vegetation does have a positive effect in reducing coastal erosion. Some reports also suggest the effect of dune vegetation on coastal erosion is insignificant or marginal, but this does not necessarily mean that dune vegetation does not play a role in mitigating erosion.

In general, it can be expected that dune vegetation will provide some degree of protection against coastal erosion, with the extent of the reduction depending on the specific conditions and the type of vegetation used. However, it is important to note that dune vegetation is just one tool in a suite of measures that can be used to manage coastal erosion, and it may not be sufficient on its own in areas with particularly high erosion rates.

Figure 7-14: A well vegetated dune system located at Twin Waters Beach, Sunshine Coast

37 Short, A. D., Hogan, J. P., & Ranasinghe, R. (1995). The effect of vegetation on coastal dune erosion. In Proceedings of the 2nd Australian Conference on Coastal Zone Research (pp. 139-146).

7.4.2 Benefits of mangroves for flood and coastal risk management

Mangroves are tropical plants that have adapted to wet soil, salt water, and being periodically submerged by tides. Mangrove forests occur within low energy, sedimentary shorelines between mean tide and high tide elevations.[38] Analysis of satellite imagery shows mangroves already exist along the Sunshine Coast shoreline, particularly in estuaries and the Pumicestone Passage, and as such should be increasingly used for ecosystem-based adaptation, though in exposed locations (i.e., the open coast) mangroves are not a feasible strategy for shoreline stabilisation. In addition to their use in mitigating flooding and erosion issues, mangroves offer a range of ecological and social benefits, such as marine habitat and the provision of food and timber products.

7.4.2.1 Reduction of wave impacts

Mangrove forests will reduce wave heights, which can increase the resilience of a coastline or watercourse. This could benefit areas experiencing residual coastal waves, wind-generated waves over wide waterbodies or boat wash. The degree of wave height reduction will depend on the width of the forest, the mangrove tree morphology, water depth, topography, and the incoming wave height. Waves will be more effected by the density of the mangrove forest during high water levels, and the characteristics of aerial roots during low water levels. Both will directly reduce wave energy, in addition to reducing wind speeds over the water surface, which will reduce the potential for additional wave growth within mangrove areas. The reduction of wave height can be observed in Figure 7-15 based on data measured within a range of mangrove forests in Vietnam. Taking an average value, a mangrove forest between 20-40m in width can result in a reduction between 15-30% of the incident wave height.[39] Note that in these observations, the 'incident' wave height is relatively low, as mangroves tend to establish in sheltered environments.

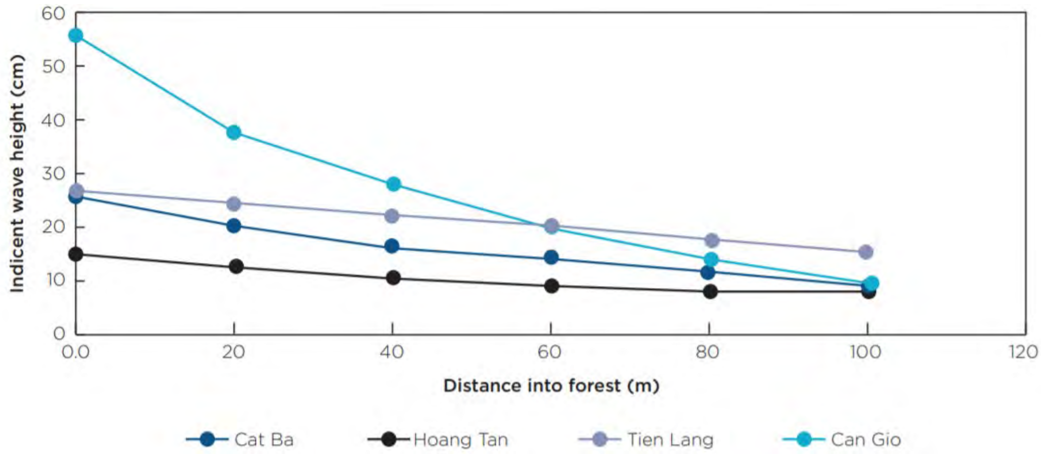

Figure 7-15: Variation in Wave Height with Distance Travelled through Mangrove Forests in Vietnam[40]

38 Ellison, J. (1997). Mangrove ecosystems of the western and Gulf Provinces of Papua New Guinea, a review [University of Tasmania].

39 World Bank. (2016). Managing Coasts with Natural Solutions: Guidelines for Measuring and Valuing the Coastal Protection Services of Mangroves and Coral Reefs (M. W. Beck & G-M. Lange, Eds.). Wealth Accounting and the Valuation of Ecosystem Services Partnership (WAVES), World Bank, Washington, DC.

40 World Bank, 2019. Managing coasts with natural solutions. Figure 2.2

7.4.2.2 Reduction of erosion

Mangroves help stabilise coastlines and shorelines, can support accretion, and offer protection against erosion. They limit the removal of sediments from the shoreline, which would otherwise result in the loss of land. Erosion can be caused by small, regular waves that lap against the shore on a daily basis, by infrequent large waves, storm surges, or tsunamis, and will be exacerbated by sea level rise. Erosion can result in a landward migration of the coast or waterway or a lowering of the surface, which can itself lead to more frequent flooding by waves and tides.

Mangroves have a long-term influence on the local topography by capturing riverine or coastal sediments deposited by tides and flood events, which will add to their own organic matter in the form of roots, leaves and woody material. Mangrove root growth can also push the soil upward, resulting in a raised soil levels which may reduce peak flood levels.[41]

7.4.2.3 Reduction of coastal flooding

Well documented field observations and hydrodynamic modelling studies have demonstrated the effects of mangroves and wetlands in mitigating storm surges. During a coastal storm surge, water flooding onto the land from the sea will encounter increased resistance by the mangrove vegetation and increased topography.[42] The degree of storm surge reduction will depend on local mangrove characteristics, such as forest width, tree density and forest complexity, physical characteristics, such as the presence of channels and pools, and the topography of the area (which is also influenced by mangroves). Observed rates of attenuation can range up to 25 cm/km, with even greater values observed in some cases - as shown in Table 7-1.[43,44,45] This reduction of storm surge can be observed in Figure 7-16 based on data measured within the Gulf Coast of South Florida, which shows mangrove forests of 1km reducing the storm surge height between 10-30%.[46]

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41 Spalding M, McIvor A, Tonneijck FH, Tol S and van Eijk P (2014) Mangroves for coastal defence. Guidelines for coastal managers & policy makers. Published by Wetlands International and The Nature Conservancy. 42 p. Accessed on 20 January 2021 from:

https://www.nature.org/media/oceansandcoasts/mangroves-for-coastal-defence.pdf

42 Costanza, Robert & Pérez-Maqueo, Octavio & Martínez, M. & Sutton, Paul & Anderson, Sharolyn & Mulder, Kenneth. (2008). The Value of Coastal Wetlands for Hurricane Protection. Ambio. 37. 241-8. 10.1579/0044-7447(2008)37[241:TVOCWF]2.0.CO;2.

43 Krauss, K.W., Doyle, T.W., Doyle, T.J., Swarzenski, C.M., From, A.S., Day, R.H. and Conner, W.H. (2009) Water level observations in mangrove swamps during two hurricanes in Florida. Wetlands 29(1), 142-149.

44 Wamsley, T.V., Cialone, M.A., Smith, J.M., Atkinson, J.H. and Rosati, J.D. (2010) The potential of wetlands in reducing storm surge. Ocean Engineering 37(1), 59-68

45 Zhang, K.Q., Liu, H., Li, Y., Hongzhou, X., Jian, S., Rhome, J. and Smith III, T.J. (2012) The role of mangroves in attenuating storm surges. Estuarine, Coastal and Shelf Science 102, 11-23.

46 World Bank. (2016). Managing Coasts with Natural Solutions: Guidelines for Measuring and Valuing the Coastal Protection Services of Mangroves and Coral Reefs (M. W. Beck & G-M. Lange, Eds.). Wealth Accounting and the Valuation of Ecosystem Services Partnership (WAVES), World Bank, Washington, DC.

Table 7-1: Rates of storm height attenuation across various tidal wetland and mangrove forests (Source: Van Coppenolle 2017)[47]

Location	Vegetation type	Event	Attenuation rate (cm/km)	Reference
Southern Louisiana	Coastal marsh	Compilation of 7 storms between 1909 and 1957	1.6–20	United States Army Corps of Engineers (2006)
Louisiana	Marsh and open water	Hurricane Andrew (1992), cat. 5	4.4–4.9	Lovelace (1994)
Cameron Prairie, Louisiana	Marsh	Hurricane Rita (2005), cat. 3	10.0	Wamsley et al. (2010) calculated with data from McGee et al. (2006)
Sabine, Louisiana	Marsh	Hurricane Rita (2005), cat. 3	25.0	Wamsley et al. (2010) calculated with data from McGee et al. (2006)
Vermillion, Louisiana	Marsh	Hurricane Rita (2005), cat. 3	4.0	Wamsley et al. (2010) calculated with data from McGee et al. (2006)
Vermillion, Louisiana	Marsh	Hurricane Rita (2005), cat. 3	7.7	Wamsley et al. (2010) calculated with data from McGee et al. (2006)
Ten Thousand Island National Wildlife Refuge, Florida	Mangrove and interior marsh	Hurricane Charley (2004), cat. 3	9.4	Krauss et al. (2009)
Shark River (Everglades National Park) Florida	Riverine mangrove	Hurricane Wilma (2005), cat. 3	4.3–6.9	Krauss et al. (2009)
Ten Thousand Island National Wildlife Refuge, Florida	Mangrove	Hurricane Charley (2004), cat. 3	15.8	Krauss et al. (2009)
Everglades National Park, Florida	Mangrove	Simulations validated with Hurricane Wilma (2005)	20–50	Zhang et al. (2012)
Everglades National Park, Florida	No vegetation	Simulations validated with Hurricane Wilma (2005)	6–10	Zhang et al. (2012)

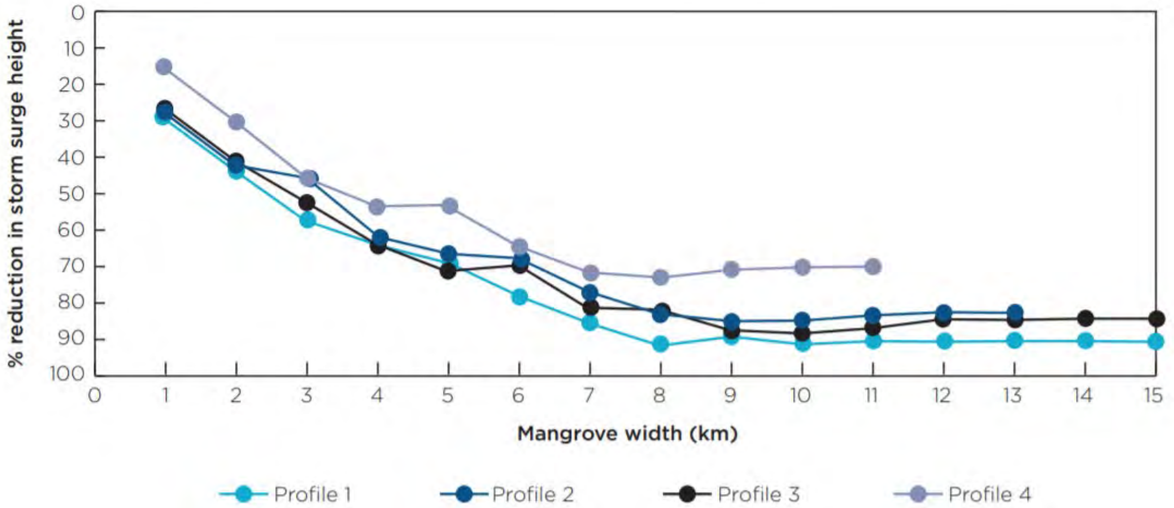


Figure 7-16: Reduction of Storm Surge Height by Mangroves on the Gulf Coast of South Florida[48]

7.4.2.4 Carbon sequestration

Mangroves are highly effective ecosystems for carbon sequestration, which refers to the capture and storage of carbon dioxide from the atmosphere. This makes mangroves efficient in mitigating climate change, which potentially triggers coastal erosion. Key features of mangroves in terms of carbon sequestration are:

- They are considered "blue carbon" ecosystems due to their remarkable ability to store large amounts of carbon in their biomass and sediments. They have dense vegetation that accumulates organic matter, including leaves, branches, and roots, which can trap and store carbon for extended periods.

47 Van Coppenolle R, Schwarz C., Temmerman S (2017) Contribution of Mangroves and Salt Marshes to Nature-Based Mitigation of Coastal Flood Risks in Major Deltas of the World

48 World Bank, 2019. Managing coasts with natural solutions. Figure 2.7

- Extensive root systems that penetrate deep into the soil. These roots not only provide stability and protection against erosion but also contribute to substantial below-ground carbon storage.
- Rapid growth rate compared to many terrestrial forests. The high primary productivity of mangroves results in increased carbon sequestration.
- Trap and retain sediments carried by rivers and tides, leading to the formation of mangrove soils. These sediment layers can serve as long-term carbon sinks, effectively storing organic carbon over time.

7.4.3 Nature based options

Natural systems can be incorporated into erosion management strategies through a range of Working With Nature (WWN), Soft Engineering, Nature Based Adaptation/Solutions (NbA/NbS), and bioengineering approaches. These are considered more appropriate in estuarine environments, where they are away from the open coast environment. This can include examples shown in Table 7-2.

Table 7-2: Nature based resilience options

New vegetation zones and mangrove areas – whilst a commonly quoted source of bank protection, studies show at least 30m of mangrove fringe is required to have an effect on blocking wave energy.	
Constructed habitat zones – which would include the strategic regrading of the foreshore to create natural features to block wind and wave energy and allow habitat and vegetation to form and stabilise a shoreline.	
Engineered timber deflectors and logjams – which is a nature-based structure consisting of piles and timber features placed to deflect currents or logs fixed along riverbank that can be interlocked together to help stabilise the shoreline.	

Rock fillets – these can be incorporated into estuarine foreshores to create a 'fish friendly seawall'. The placement of rock adjacent to the waterway banks which will absorb any wind-wave and current action and create an area of still water between the fillet and the bank.

Living Seawall habitat panels provide homes for marine life on otherwise largely flat and featureless surfaces, such as vertical walls. These vertical structures typically lack the complex 3D geometries of natural habitats such as holes, depressions, and crevices. These are installed in Brightwater Lake by Council as a trial and are expected to be used at new sites in the future.

Reef balls – These are artificial reef modules placed in the nearshore to form habitat zones for aquatic species. They can also act to dissipate wave energy.

8. Community consultation

8.1 Introduction

Community and stakeholder engagement was undertaken during the development of the SEMP and Healthy Coast Management Plan. It was designed to support Councils decision making and to help inform the direction and shape of both plans by providing a forum for local knowledge to be shared. The initial community engagement phase identified 366 'insights', including 229 individual coastal values and 122 spatial management intervention ideas, via early conversations with representatives of key stakeholder groups. Over 89 high impact/high influence community and coastal user groups were made aware of the commencement of the SEMP and HCMP drafting process, with 42 participants agreeing to share their thoughts across 4 workshops with Council in these early project phases. The full stakeholder engagement report is provided in Appendix B and is summarised below.

8.2 Process

The targeted community engagement process was run over October and November 2023 to gather key stakeholder insights. Four workshops were held over four days, hosted in targeted coastal zones. The primary objectives of the workshops were the early identification of coastal values and stakeholder views on current and historical management actions.

8.3 Results

Stakeholders raised a number of important issues and interventions relating to coastal hazards. Clashes between coastal hazard interventions and environmental and liveability values were often apparent, with community priorities more often lying with environment and liveability values. The top three (3) examples of important considerations held by Key Stakeholders in this space were:

- Resilient sand management
  Sand nourishment strategies were important in the face of climate change, involving an increase in the overall sensitivity applied to dredging and replenishment (with reference to the places they go/come from, and the micro-organisms that live within) and importantly, a more conscious and considered timing of works, to work in better with seasonal impacts and coastal processes occurring at certain times of the year.
- Coastal erosion
  Specific sites and general issues relating to increasing coastal erosions concerns were highlighted, with adaptation options needing to be carefully balanced against any impacts to environmental or liveability values. Seawall locations, and structural quality was also topical, with stakeholders indicating greater future consideration was required around the placement, impacts and purpose of some seawalls along the coastline.
- Coastal processes and monitoring
  Improved measurement and monitoring of coastal processes and characteristics with reliable, more current/accurate data sources was also considered to be needed urgently, if not overdue.

8.4 Use of consultation outputs within the SEMP

The community feedback has been an important part of the SEMP revision. The SEMP Volume 2 presents a proposed erosion management approach for each beach unit. Where possible this has continued the use of monitoring before any actions are implemented, and the use of sand nourishment where conditions and sources allow before hard options are considered.

9. Appendix A: Extreme Wave Study

A.1 Introduction

An extreme coastal conditions study has been undertaken to support the SEMP. This study provides updated tide, storm tide, wave, and sea level rise input conditions that can be used in the design of erosion protection options and management schemes throughout its ten-year implementation period.

This Appendix includes the following sections:

- A2 Available data
- A3 Tidal planes
- A4 Storm Tide levels
- A5 Sea Level Rise
- A6 Extreme wave assessment.

A.2 Available data

A range of datasets are available at a regional scale as well as specific to the study area. These provide information on wind, waves, tides, and local elevation.

A.2.1 Height datums

All height data is relative to the Australian Height Datum (AHD), unless otherwise specified.

A.2.2 Event frequencies

Event frequencies: This report has adopted the industry accepted terminology for event frequency description outlined in Book 1, Chapter 2.2.5 of Australian Rainfall and Runoff (ARR).[49] Very frequent events, occurring at least once per year, are referred to by exceedances per year (EY). Rare events are referred to by Annual Exceedance Probability (AEP). For ease of reading, AEP events may be referred to by their respective Annual Recurrence Interval (ARI) in the first instance, however the ARI frequency terminology is being phased out by industry.

A.2.3 Wave data

Review on historic wave conditions has been conducted for the Brisbane wave rider buoy (WRB) along with three wave rider buoys that operate adjacent to the SCC local government area:

- Brisbane WRB, Lat: -27.4871, Long: 153.6316. Depth: 70m. Installed: October 1976 (directional from November 1996).
- Mooloolaba WRB, Lat: -26.5660, Long: 153.1811. Depth: 30m. Installed: April 2000.
- Caloundra WRB, Lat: -26.8475, Long: 153.1556. Depth: 13m. Installed: May 2013.
- North Moreton Bay WRB, Lat: -26.8985, Long: 153.2788. Depth: 35m. Installed: March 2010.

49 Ball J, Babister M, Nathan R, Weeks W, Weinmann E, Retallick M, Testoni I, (Editors) Australian Rainfall and Runoff: A Guide to Flood Estimation, © Commonwealth of Australia (Geoscience Australia), 2019

Figure 9-1 and Figure 9-2 show wave roses of historic wave height and direction for each buoy. The Brisbane WRB shows predominate south-easterly wave direction (top left), which transitions toward easterly wave conditions at the remaining wave buoys due to sheltering from Moreton Island. Figure 9-3 to Figure 9-6 show joint analysis of the full record of wave data from each wave buoy, which includes wave height and wave direction at the buoy. This analysis shows the tendency for larger waves to arrive at the Brisbane WRB from the south-east and the tendency for larger waves to arrive from the east at the Caloundra and North Moreton Bay WRBs.

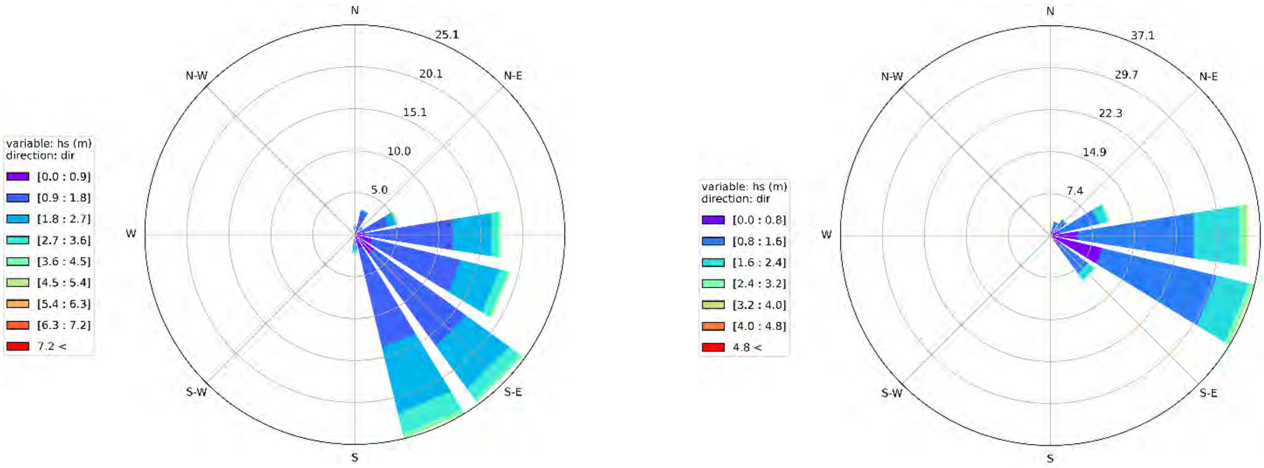


Figure 9-1: Wave roses of significant wave height and wave direction for the Brisbane WRB (left), Mooloolaba WRB (right)

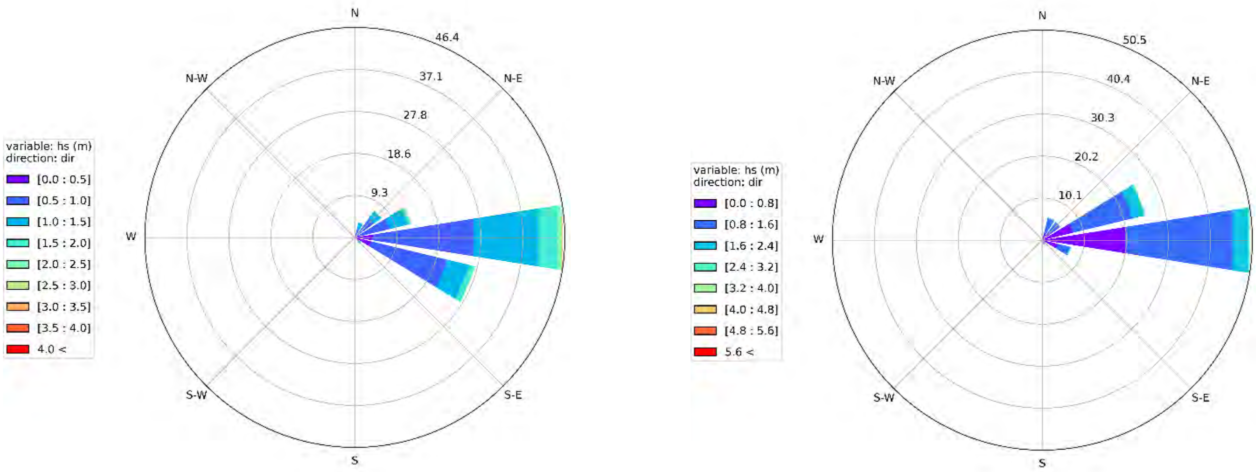


Figure 9-2: Wave roses of significant wave height and wave direction for the Caloundra WRB (left) and Northern Moreton Bay WRB (right)

Dir (°N)	Hs (m)													
	0.5-1	1-1.5	1.5-2	2-2.5	2.5-3	3-3.5	3.5-4	4-4.5	4.5-5	5-5.5	5.5-6	6-6.5	6.5-7	>7
0-30	0.8%	1.9%	0.6%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
30-60	0.6%	1.0%	0.2%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
60-90	1.9%	5.0%	3.2%	1.5%	0.6%	0.2%	0.1%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
90-120	4.0%	9.2%	6.7%	3.5%	1.5%	0.6%	0.2%	0.2%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%
120-150	5.8%	11.0%	7.9%	4.7%	2.3%	1.0%	0.4%	0.2%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%
150-180	2.1%	5.9%	5.7%	4.2%	2.2%	1.1%	0.4%	0.2%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%
180-210	0.1%	0.1%	0.1%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
210-240	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
240-270	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
270-300	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
300-330	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
330-360	0.0%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

Figure 9-3: Distribution of wave height and direction for Brisbane WRB

Dir (°N)	Hs (m)													
	0.5-1	1-1.5	1.5-2	2-2.5	2.5-3	3-3.5	3.5-4	4-4.5	4.5-5	5-5.5	5.5-6	6-6.5	6.5-7	>7
0-30	1.0%	0.9%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
30-60	3.3%	1.6%	0.2%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
60-90	6.8%	9.5%	4.8%	1.8%	0.5%	0.2%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
90-120	19.3%	17.9%	9.5%	3.4%	0.9%	0.3%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
120-150	7.6%	5.9%	2.7%	0.7%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
150-180	0.2%	0.1%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
180-210	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
210-240	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
240-270	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
270-300	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
300-330	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
330-360	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

Figure 9-4: Distribution of wave height and direction for Mooloolaba WRB

Dir (°N)	Hs (m)													
	0.5-1	1-1.5	1.5-2	2-2.5	2.5-3	3-3.5	3.5-4	4-4.5	4.5-5	5-5.5	5.5-6	6-6.5	6.5-7	>7
0-30	1.1%	0.4%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
30-60	7.1%	3.8%	0.2%	0.2%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
60-90	14.9%	10.1%	2.4%	0.4%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
90-120	35.4%	15.5%	4.4%	0.8%	0.2%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
120-150	2.0%	0.7%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
150-180	0.1%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
180-210	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
210-240	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
240-270	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
270-300	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
300-330	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
330-360	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

Figure 9-5 Distribution of wave height and direction for Caloundra WRB

Dir (°N)	Hs (m)													
	0.5-1	1-1.5	1.5-2	2-2.5	2.5-3	3-3.5	3.5-4	4-4.5	4.5-5	5-5.5	5.5-6	6-6.5	6.5-7	>7
0-30	3.0%	2.4%	0.4%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
30-60	5.1%	2.4%	0.3%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
60-90	24.8%	18.4%	6.4%	1.4%	0.3%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
90-120	19.5%	8.6%	2.3%	0.3%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
120-150	0.3%	0.3%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
150-180	0.8%	0.9%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
180-210	0.3%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
210-240	0.3%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
240-270	0.4%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
270-300	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
300-330	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
330-360	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

Figure 9-6 Distribution of wave height and direction for North Moreton Bay WRB

A.2.4 Available water level data

Recorded water level data used in modelling has been sourced from the Mooloolaba storm tide gauge: ID 011008A, Sept. 1978 – 2022. Astronomical tide data is not available for this gauge, therefore the Utide python-based tool has been used to reconstruct the tidal series from the recorded data. Utide derives the principle tidal constituents from the recorded signal and hindcasts the astronomical series. The tool can also be used to predict astronomical tides in the future.[50] Figure 9-7 shows the recorded and reconstructed astronomical signal for the Mooloolaba gauge during Tropical Cyclone (TC) Oswald. This gauge recorded around 0.5m of surge during this event.

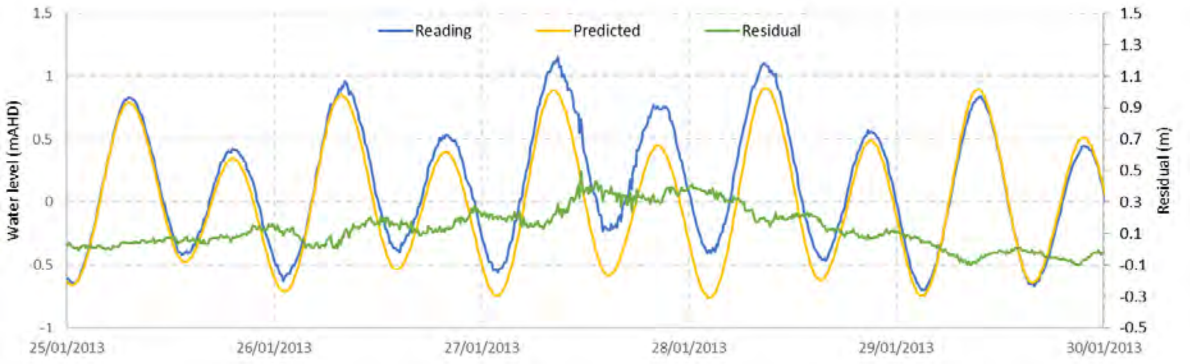


Figure 9-7: Water levels at Mooloolaba during TC Oswald (2013)

A.3 Tidal planes

Tidal plane information has been sourced from the 2023 Queensland Tide Tables[51] for the open coastline and are shown in Table 9-1 for Mooloolaba. Adjustments to these levels may be required if erosion management actions are being planned in areas upstream, where tidal range may be reduced.

Following the breakthrough of Bribie Island in early 2022, the tidal regime has changed within Pumicestone Passage and is more indicative of an open coast location (Figure 9-8). According to Maritime Safety Queensland (MSQ), the published tidal planes within Pumicestone Passage do not incorporate the effects of the breakthrough due to limited data available to accurately capture the stabilised changes caused by the breakthrough. These planes are expected to be updated in subsequent publications from MSQ, as new tide level data becomes available. Erosion design work within the Pumicestone Passage is required to seek the latest tidal data from MSQ as it becomes available.

Table 9-1: Tidal planes for Mooloolaba

Tide level	2023 (mLAT)	2023 (mAHD)	2100 (mAHD)*
HAT	2.21	1.20	2.00
MHWS	1.7	0.69	1.49
MHWN	1.38	0.37	1.17

50 Codiga, D.L., 2011. Unified Tidal Analysis and Prediction Using the UTide Matlab Functions. Technical Report 2011-01. Graduate School of Oceanography, University of Rhode Island, Narragansett, RI. 59pp.

51 Available from: Maritime Safety Queensland (MSQ) 2023, https://www.msq.qld.gov.au/tides/tidal-planes

Tide level	2023 (mLAT)	2023 (mAHD)	2100 (mAHD)*
MSL	1.01	0.00	0.80
MLWN	0.63	-0.38	0.42
MLWS	0.28	-0.73	0.07
PSM37055	5.719	4.71	-
AHD	1.01	0.00	-
LAT	0	-1.01	-0.21
* 2100 levels based on SSP5 Climate change scenario, 0.8m SLR			

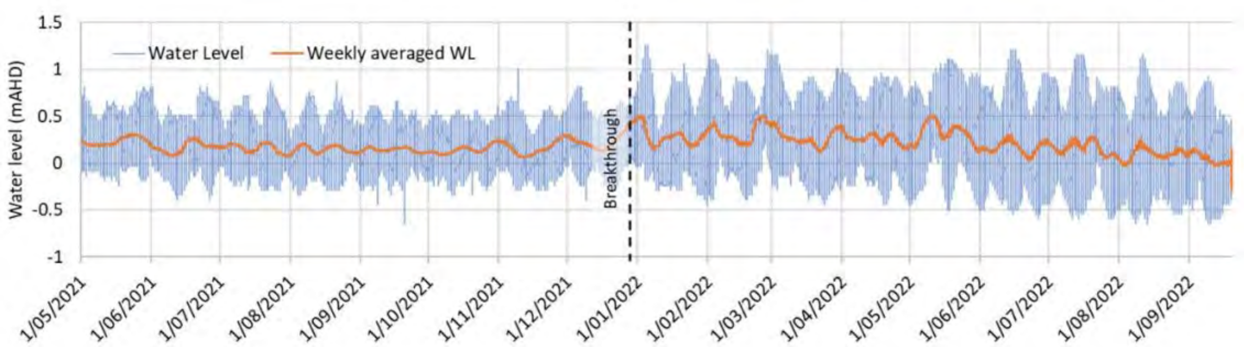


Figure 9-8: Golden Beach tide record, showing tide level variation pre- and post-breakthrough in January 2022

A.4 Storm Tide levels

Storm tide information for the Sunshine Coast is available within the Sunshine Coast Storm Tide Review (2023). This presents updated storm tide levels for coastal creeks, however retains the open coast levels from the previous Sunshine Coast Storm Tide Study (Aurecon 2013).

A.5 Sea Level Rise

The use of a general sea level rise projection of 0.8m by 2100 continues to have widespread use in Queensland for high level planning. However, a move towards probabilistic sea level rise projections is recommended, as presented within the Intergovernmental Panel on Climate Change (IPCC) within their sixth Assessment Report (AR6). In particular the SSP5-8.5 scenario is recommended by the IPCC for high profile or high-risk projects. This is a high reference scenario that assumes no additional climate policy is adopted through governments. Increasingly, end of life planning will project beyond 2100, and should follow a risk-based design approach where multiple sea level scenarios are considered. Figure 5-1 shows the projected sea level rise under SSP5-8.5 relative to a 1995-2014 baseline, which presents different probabilities. In 2100 the 50th percentile (median) sea level estimate is +0.77m above 1995-2014 levels, however estimates range between +0.50m to 1.31m (5th to 95th percentiles).

A.6 Extreme wave assessment

A.6.5 Extreme offshore waves

Extreme value analysis (EVA) has been conducted for offshore wave data at Brisbane WRB, for use in wave modelling. A generalised pareto distribution (GPD) has been applied to the wave record. The GPD is a probability distribution that can be used to model the distribution of the largest waves that exceed a certain threshold, and to estimate the probability of a wave exceeding a certain height. A peak over threshold (POT) method has been used to isolate wave events exceeding a threshold height. A mean residual life test was used to determine a suitable threshold. Figure 9-9 shows the fitting of the GPD function to wave data and estimation of extreme wave heights at Brisbane WRB.

In the previous coastal processes study (BMT 2013), a range of extreme offshore wave return periods were derived from the Brisbane WRB wave record. These conditions were applied to a numerical model and extracted at the -20m depth contour along the SCC. Since this study, an additional 10 years of wave data is available from the offshore buoy and the results of EVA on this updated dataset show that the conditions assessed in the previous study may underpredict extreme waves in the offshore, as shown in Table 9-2.

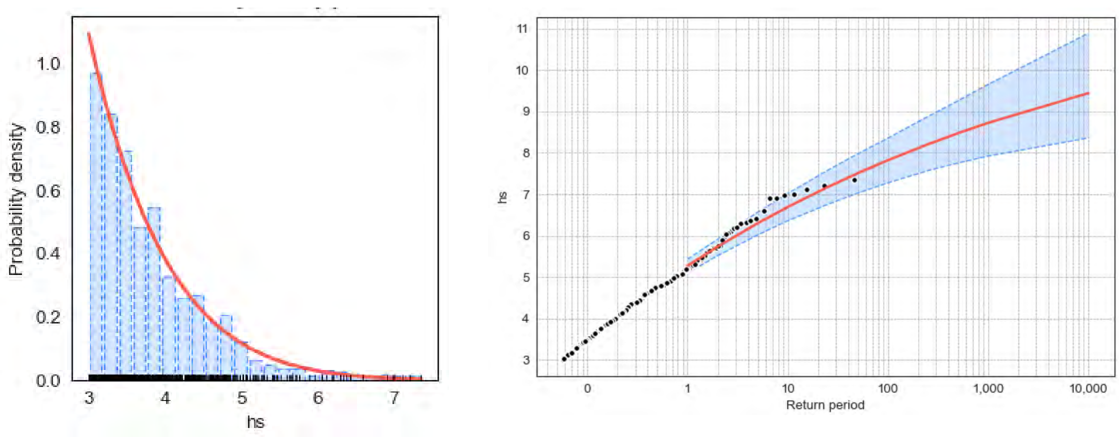


Figure 9-9 Left: GPD fit to wave heights above 3.0m and Right: GPD estimation of extreme wave height, for Brisbane WRB.

Table 9-2: Extreme wave height return periods for Brisbane WRB, compared with previous coastal assessment (BMT 2013)

ARI (yrs)	Hs (m) (JBP assessed)	Hs (m) (BMT (2013))	% increase
2	5.74	5.05	13.6%
5	6.30	5.85	7.7%
10	6.69	6.30	6.2%
20	7.10	6.70	6.0%
50	7.51	7.30	2.9%
100	7.82	7.80	0.3%

A.7 Extreme midshore wave assessment

Midshore wave extremes were previously evaluated in BMT (2013). These midshore design conditions were estimated using a nested spectral wave model. Extreme offshore wave conditions assessed at the Brisbane WRB were transferred through the model and extracted at the -20m contour for each beach unit. This approach assumes that the wave height exceedances at the offshore WRB are the same as in the midshore (i.e., a 1%AEP wave at the offshore location, when applied to the model, produces a 1%AEP wave at the nearshore location). This approach is conservative and does not consider the directionality of extreme conditions, which may be critical when assessing extremes for locations sheltered within bays or behind headlands.

Updated midshore extreme wave conditions have been assessed for the SCC coastline. These will be used to inform the planning of coastal options for each beach unit. A probabilistic approach has been used to establish a 10,000-year wave simulation, representing the full range of potential wave conditions for each nearshore location. The following methodology has been used to derive these conditions:

1. Metocean data collation: Historical offshore wave data is collated for the Brisbane WRB.
2. Data declustering: The historical data series is declustered into discrete events.
3. Data simulation: The declustered data is used to produce a large 10,000-year set of potential offshore conditions.
4. Data sampling: A subset of 200 representative events is sampled from the large dataset.
5. Wave modelling: The 200 representative events are applied as wave model boundary conditions, with results extracted in the nearshore at each coastal unit.
6. Midshore wave emulation: An emulator is used to translate the remainder of the large set of wave conditions to the nearshore.

A.8 Metocean data collation

Historic offshore wave data has been sourced from the Brisbane WRB, spanning from 1976 to 2022, as described in Section 0. Wave data from the Brisbane buoy before 1996 is non-directional. In order to capture the directional spread of wave conditions for the full Brisbane record, direction data from the ERA5 global wave hindcast model has been used to supplement the wave record prior to 1996. The hindcast model provides hourly estimates from 1979 to present day for a range of atmospheric conditions and has a spatial resolution of 0.5° for wave extraction. Figure 9-10 compares the ERA5 hindcast data with recorded wave conditions at Brisbane WRB

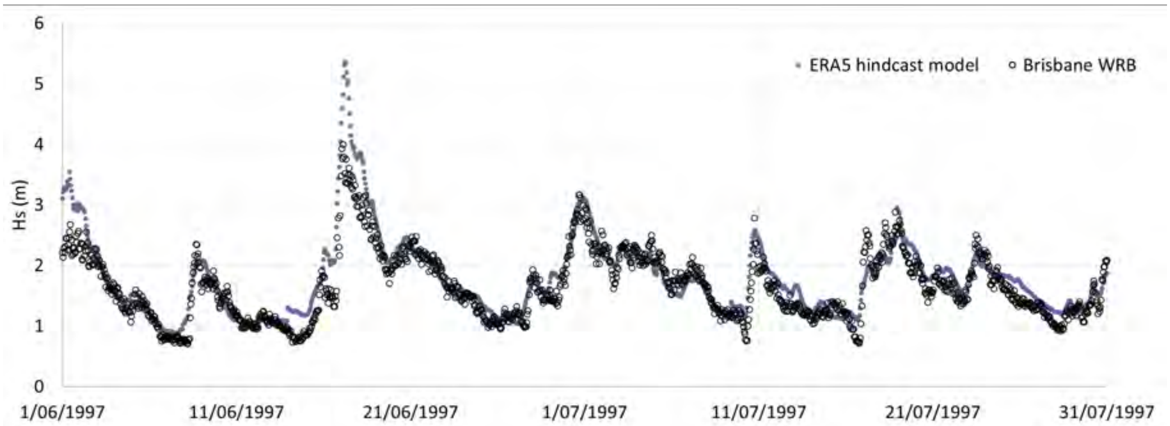


Figure 9-10 Left: Sample comparison of wave data from Brisbane WRB and ERA5 hindcast model

A.9 Data declustering:

Peak analysis has been conducted on the Brisbane WRB data to isolate discrete weather events. For the purposes of this study, a discrete weather event is defined as a peak in the wave height (Hs) record with a minimum duration of 3 days, and minimum prominence of 0.3m (i.e., wave heights above 0.3m to their nearest neighbour in the record). From the 47-year recorded data series, approximately 3045 weather events have been discretised. Figure 9-11 shows an example of declustered events of peak wave height and corresponding peak wave period within the record.

Figure 9-11: Declustering of discrete weather events in wave record, identified peak events as points showing significant wave height in meters (top) and peak wave period in seconds (bottom)

A.10 Data simulation

A probabilistic approach has been used to establish 10,000-years of potential offshore wave conditions. Conventionally, this would be accomplished by creating a set of conditions where all possible combinations for wave height, period and direction are favoured equally. However, a more robust method has been used which relies on multivariate analysis to simulate a full set of possible conditions, based on the recorded wave data. This method favours a more realistic distribution of wave conditions, as the characteristics of the historical data are used directly to simulate a much larger set of conditions.

First, the distribution of each of the declustered event parameters (Hs, Tp and Dir) is determined, as well as the correlation of each parameter to every other. Next, a Gaussian copula method is applied to the data. This method fits a univariate distribution to each parameter and creates a set of 10,000 years' worth of simulated conditions. Figure 9-12 shows a comparison of historical events to the larger simulated set for significant wave height, wave direction and wave period.

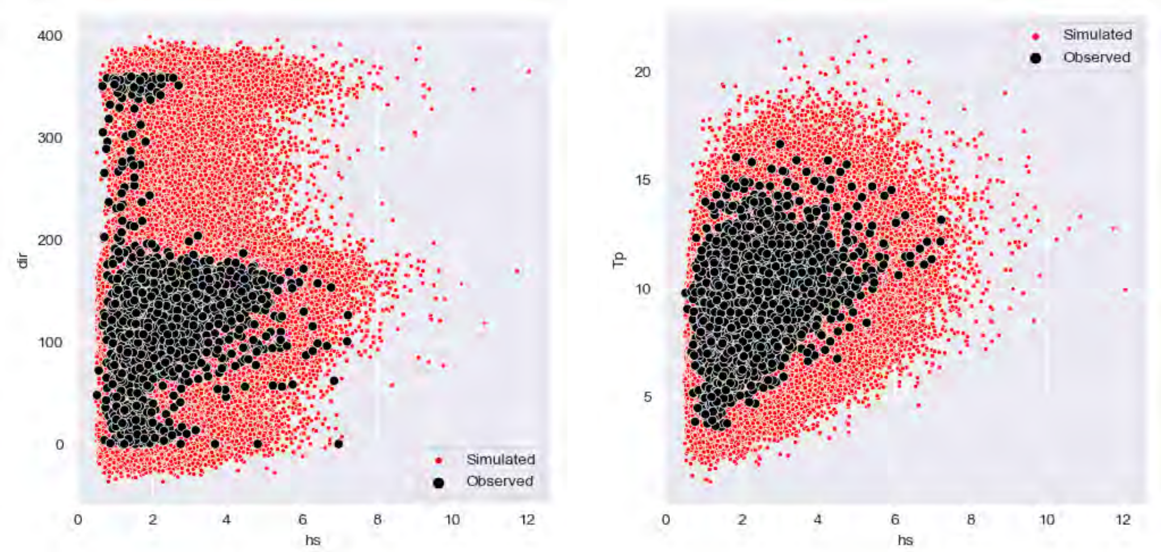


Figure 9-12 Historical and simulated offshore data showing significant wave height (Hs) and wave direction (dir) (left), and significant wave height (Hs) and peak wave period (Tp) (right).

A.11 Data sampling

The large 10,000-year set of offshore data is required to be translated into midshore wave conditions for each coastal unit. Numerical modelling will be used to simulate conditions into the nearshore, however it is not computationally efficient to model the full large dataset. Therefore, a subset of 200 events have been sampled from the large set to be used in numerical modelling. A Maximum Dissimilarity Algorithm (MDA) has been used for sampling. This method ensures that the full distribution and extremes of the larger dataset are retained in numerical modelling. Figure 9-13 compares the sampled events and the larger 10,000 year dataset.

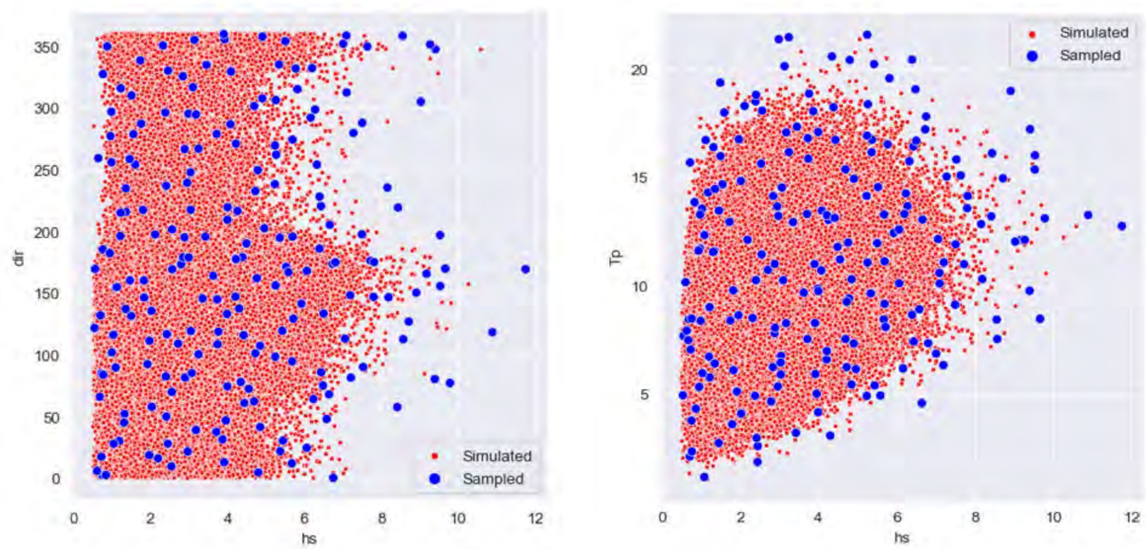


Figure 9-13: Simulated and MDA-sampled offshore data for Hs and Dir (left), and Hs and Tp (right).

A.12 Wave Modelling

A spectral wave model has been developed to model the subset of events. The SWAN wave model has been used. SWAN is an open source third-generation wave model, which is freely available, that simulates wave propagation in coastal and inland areas. It accounts for the following physics:

- Wind-wave interactions, which is the transfer of wind energy into wave energy, leading to the growth of waves.
- Shoaling, which is the build-up of energy as a wave enters shallow water, causing an increase in wave height.
- Refraction, which is the change in wave speed as waves propagate through areas of changing depth, causing a change in wave direction.
- Wave breaking, which is the destabilisation of a wave as it enters shallow water, causing broken waves with the characteristic whitewash or foam on the crest.
- Wave dissipation, which limits the size of waves through white-capping, bottom friction, and depth-induced breaking.

Midshore wave conditions will be extracted for each beach unit along the SCC coastline, aligning with the 10m depth contour.

A.12.6 Modelling domain

A flexible mesh has been developed for wave modelling which allows for regions of high grid resolution at targeted sites along the SCC coastline and around islands, with varying spatial resolution throughout the model domain. This approach optimises computational cost whilst resolving the wave interaction and complex geometry of the study area. The wave model extends offshore approximately 40 km towards the 70m depth contour aligned with the Brisbane WRB. The southern region of the domain extends from the northern tip of Moreton Island to the headlands at Noosa as shown in Figure 9-14. A minimum grid resolution of 30m spans the entirety of the SCC LGA coastline, with coarser resolution ranging from 30m to 3.5km out to the model boundary.

A.12.7 Model Bathymetry

Model bathymetry data has been sourced from the following datasets as visualised in Figure 9-14.

- 5m Sunshine Coast LiDAR Topo-Bathy 2011: This data has been derived by remotely sensed topographic (elevation) and bathymetric (depth) information, spanning the Maroochydore offshore area and Noosa offshore area using Airborne LiDAR Bathymetry during October – November 2011. Along the surveyed area from Noosa to Maroochydore, this dataset extends down to around -30m AHD and consequently has been used in model bathymetry to the extent of this dataset.

- 30m Geoscience Australia Bathymetry 2018[52]: A compilation of digital elevation models (DEM) and bathymetric data at a regional scale. Data collation consists of deep-water multibeam surveying, airborne lidar bathymetry, and chart data. This data set resolves features to a resolution of 30m and has been used for the overall model and offshore regions. The present-day bathymetry of the Pumicestone Passage channel system has been derived from this set.

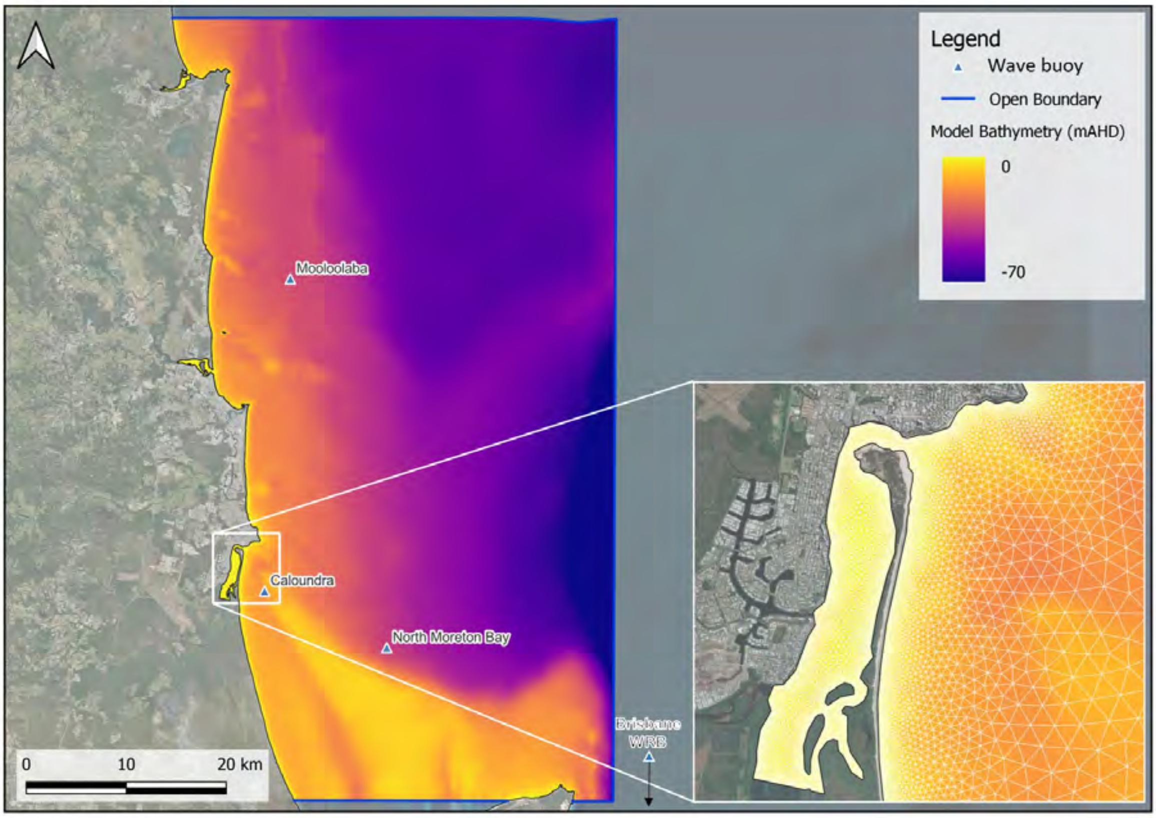


Figure 9-14: SCC LGA wave model domain and inset detail of present-day Bribie Island north

A.12.8 Model Calibration

The wave model has been calibrated against significant wave events observed at the Mooloolaba WRB. For each event, offshore conditions have been derived from the Brisbane WRB and applied to the wave model as a continuous timeseries. The calibration periods for each event are listed below:

- Event 01: 05/03/2004 to 6/03/2004, peak wave height at Brisbane WRB: 6.98m, peak wave height at Mooloolaba WRB: 5.84m
- Event 02: 27/01/2013 to 28/01/2013, peak wave height at Brisbane WRB: 7.1m, peak wave height at Mooloolaba WRB: 5.59m

52 Beaman, R.J. (2018) "100/30 m-resolution bathymetry grids for the Great Barrier Reef", SSSI Hydrography Commission Seminar, March 2018. Surveying and Spatial Sciences Institute (SSSI), Canberra, Australia.

- Event 03: 01/05/2015 to 02/05/2015, peak wave height at Brisbane WRB: 5.75m, peak wave height at Mooloolaba WRB: 5.20m
- Event 04: 21/08/2007 to 22/08/2007, peak wave height at Brisbane WRB: 5.47m, peak wave height at Mooloolaba WRB: 4.42m

Each event has been subject to sensitivity analysis to determine suitable calibration parameters. Physics parametrisation schemes for wave energy dissipation due to bottom friction has been calculated through the JONSWAP, Madsen et al. and Collins constant parameterisation, where dissipation is based on a constant coefficient applied throughout the modelling domain.

A.12.9 Results of calibration

Figure 9-15 shows a comparison of recorded (Mooloolaba WRB) and modelled wave height data for Event 01. Table 9-3 displays the mean square error and peak error statistics for wave height when adopting the various physics parametrisations for bottom friction. Under the Collins parameterisation the model produced the best agreement to observed peak wave height, with an average error of 0.3% across the four events. Under this schematisation, the model was deemed to satisfactorily reproduce a range of large historic wave events and has been used for the extreme wave assessment.

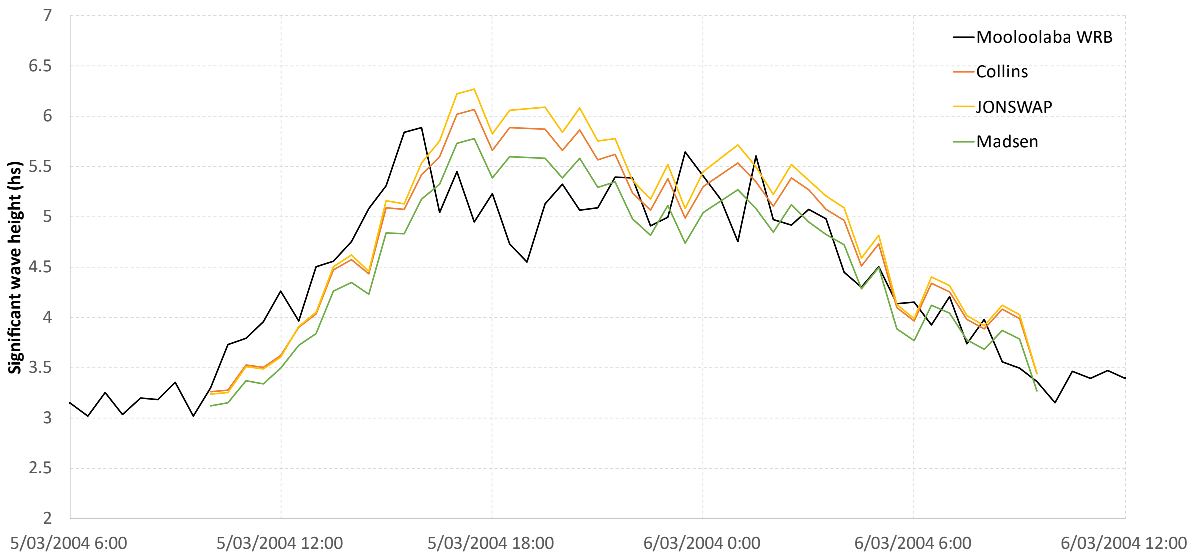


Figure 9-15: Modelled and recorded wave height at Mooloolaba WRB for Event 01, including each friction model applied for 5/03/2004 10:00 am to 6/03/2004 9:30 am.

Table 9-3: Comparison of recorded and modelled peak wave conditions for calibration events.

Model period		Peak recorded Hs (m)	Peak modelled Hs (m)	Peak Error (m)	Peak Error (%)
Event 01	05/03/2004 to 6/03/2004	5.9	6.1	0.2	3.0%
Event 02	27/01/2013 to 28/01/2013	5.6	6.1	0.5	8.7%
Event 03	01/05/2015 to 02/05/2015	5.2	5.1	-0.1	-1.5%
Event 04	21/08/2007 to 22/08/2007	4.4	4.0	-0.4	-9.1%
Average				**0.05**	**0.3%**

A.12.10 Midshore wave modelling

The calibrated model has been used in numerical wave modelling to extract nearshore wave conditions for present day and future 2100 planning horizons. Under the 2100 scenario the SSP5-8.5 climate pathway has been adopted from IPCC climate projections. This scenario includes 0.8m sea level rise. Additionally, the 2100 scenario includes a 'worst case scenario' of the loss of the northern section of Bribie Island. Under this configuration, the northern section of Pumicestone Passage has been modelled as fully open coast in 2100. The development of model bathymetry for this scenario is detailed below.

The 200 sampled offshore wave events have been applied to the model and extracted at each open coast location along the SCC coastline, as shown in Figure 9-16 to Figure 9-19. Output locations have been defined to align with each coastal unit at the 10m offshore depth contour (approximating the depth of closure).

Figure 9-16: SCC wave model output point locations aligning with SEMP Priority and Non-Priority Units.

Figure 9-17: SCC wave model output point locations aligning with SEMP Priority and Non-Priority Units.

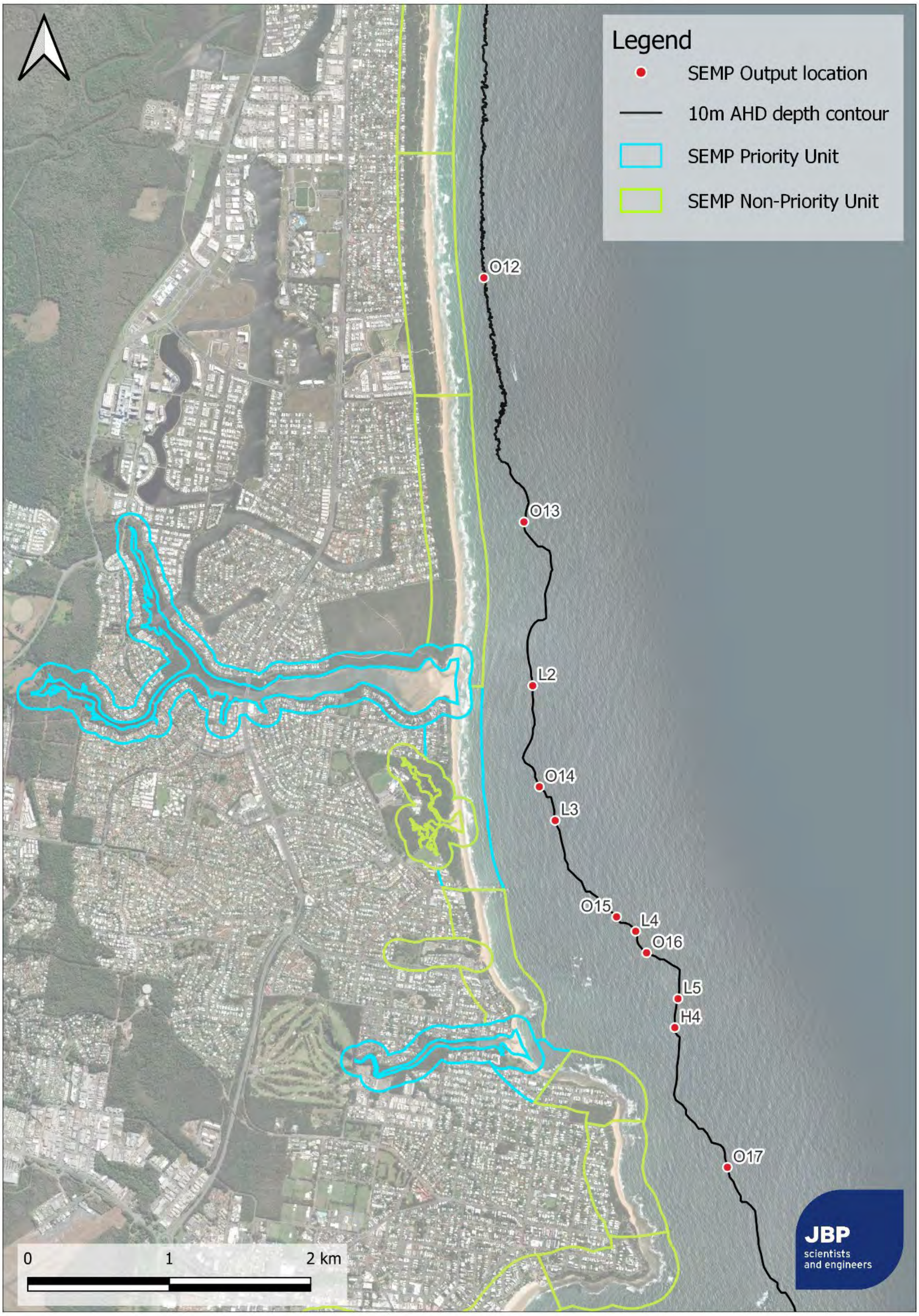


Figure 9-18: SCC wave model output point locations aligning with SEMP Priority and Non-Priority Units.

Figure 9-19: SCC wave model output point locations aligning with SEMP Priority and Non-Priority Units.

A.12.11 Pumicestone passage bathymetry

For the future 2100 modelling scenario, a representative 'worst case' scenario has been developed in the model bathymetry to reflect the complete loss of the north section of Bribie Island. Bathymetry in this area of the model has been modelled as fully open coast. The cross-shore profile has been derived from existing open coast sections of Bribie Island. Figure 9-20 shows the synthesized open coast section of Pumicestone Passage incorporated in model bathymetry for 2100 modelling scenario.

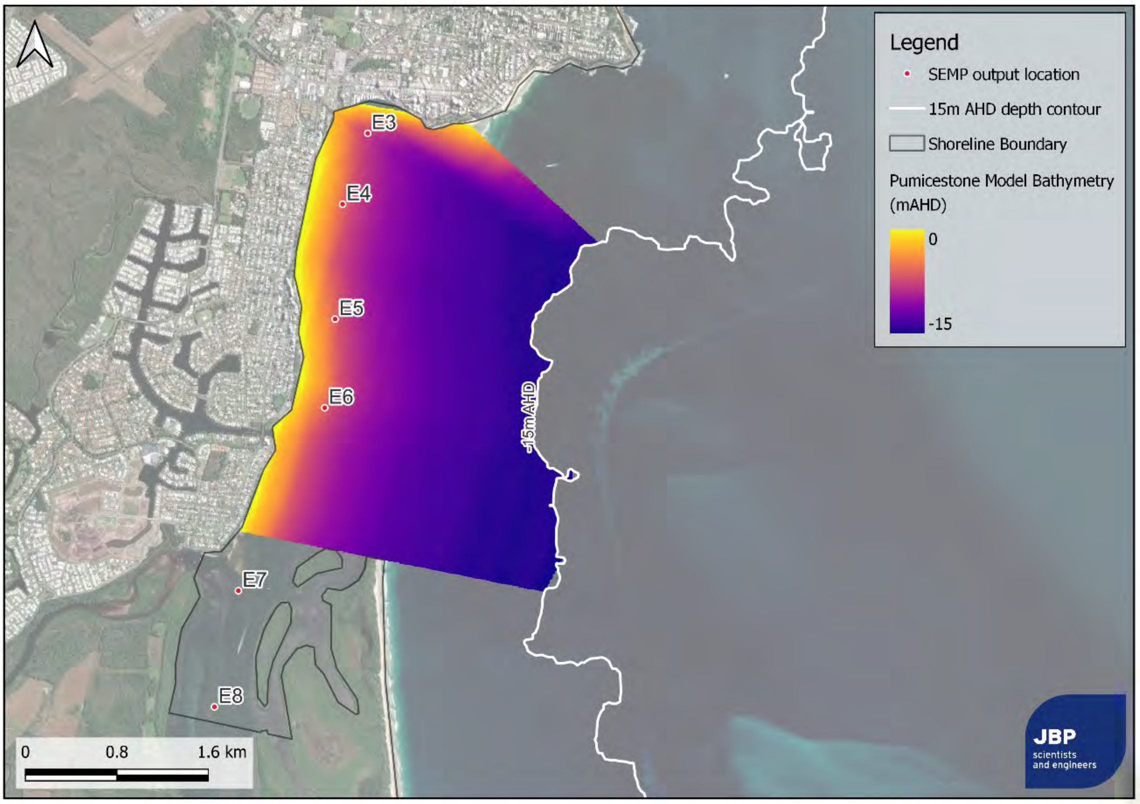


Figure 9-20: Open coast bathymetry of north Pumicestone Passage for 2100 scenario.

A.13 Midshore wave emulation

Following the modelling of the 200 sampled wave conditions, the full 10,000-year set can be translated to the midshore. This is accomplished using an emulation approach. For each coastal location, the 200 midshore modelled wave results are paired with their respective offshore input conditions. These offshore and midshore pairs are used to a train a radial basis function (RBF) machine learning algorithm. An RBF is a type of artificial neural network comprised of an input layer, a hidden layer, and an output layer. This method allows for universal approximation and faster learning speed than more complex neural networks. The trained RBF model has been used to emulate the full set of 10,000 years of offshore conditions to the nearshore for both present day and 2100 modelling scenarios.

A.14 Present day midshore wave results

Figure 9-21 shows emulated nearshore wave roses at Maroochydore Beach (O7), Mooloolaba Beach (O9), Buddina Beach (O10), and Warana Beach (O11). These wave roses display the distribution of wave height and wave direction for the full large wave dataset. The wave roses display the transition of easterly to south-easterly wave directions at Buddina Beach and Warana Beach to a north-easterly wave climate at Mooloolaba Beach due to wave sheltering at the headland of Point Cartwright (H3). A summary of nearshore wave roses for all SCC beach units has been included in Appendix 0.

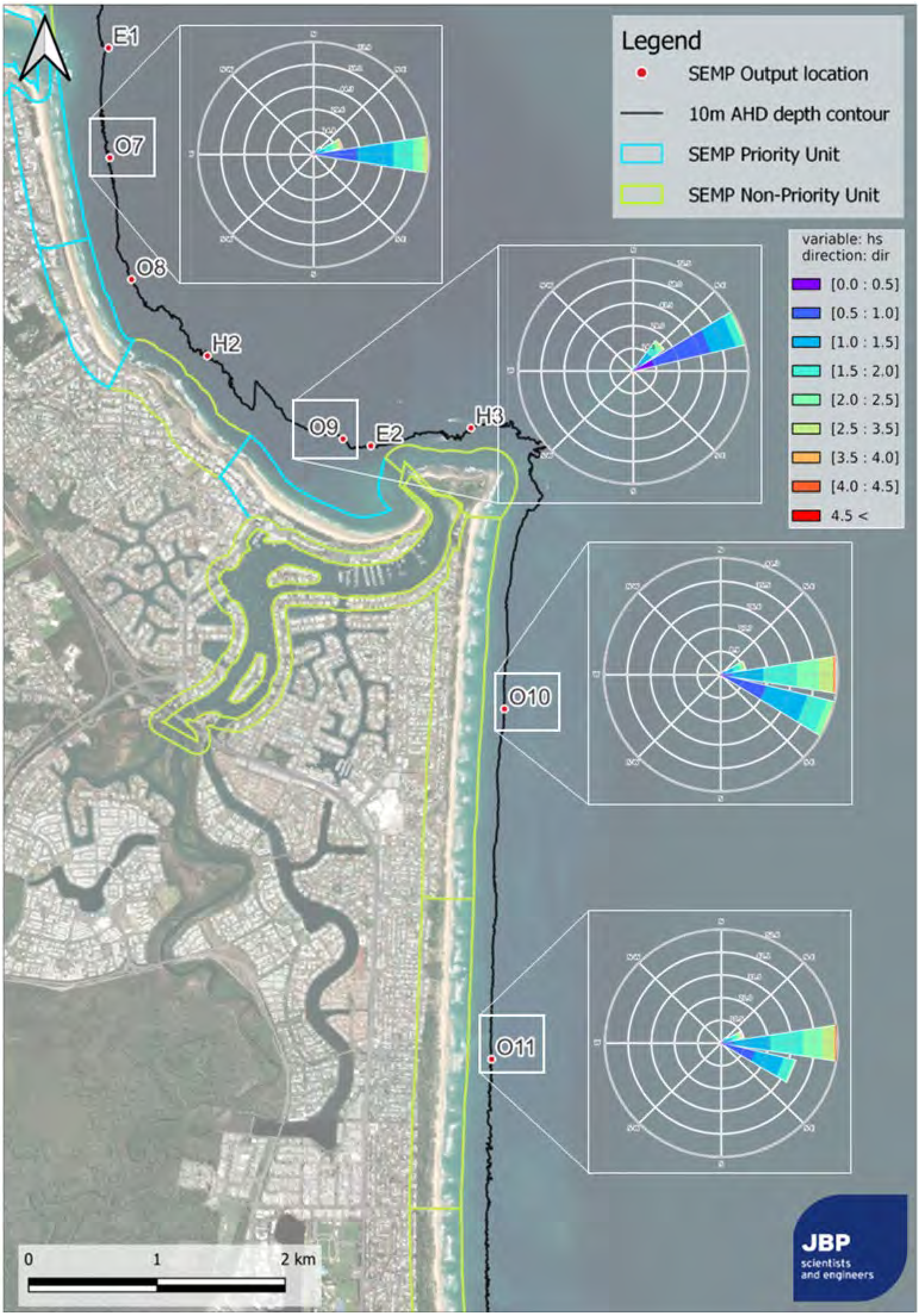


Figure 9-21: Present day emulated nearshore wave roses at Mooloolaba coastal units

A.14.12 Present day midshore extreme wave conditions

Following the translation of 10,000-years of wave conditions, extreme value analysis can be conducted for each midshore location. Table 9-4 shows extreme midshore wave heights for each coastal unit. A complete summary of extreme wave conditions for all units has been included in Appendix Table 9-7. Extreme wave conditions have been estimated for a range of return periods up to 0.01% AEP.

Table 9-4: Present day nearshore extreme wave heights.

Beach name	Unit	10%AEP Hs (m)	2% AEP Hs (m)	1% AEP Hs (m)
Coolum Beach	O1	4.65	5.16	5.31
Stumers Creek	L1	4.59	5.06	5.20
Point Perry to Point Arkwright	H1	4.61	5.17	5.35
Yaroomba Beach	O2	4.59	5.20	5.39
Mount Coolum Beach	O3	4.22	4.84	5.06
Marcoola Beach	O4	4.39	4.97	5.16
Mudjimba Beach	O5	3.25	3.67	3.85
Twin Waters Beach	O6	4.42	4.93	5.07
Maroochy River Estuary	E1	4.52	5.00	5.16
Maroochydore Beach	O7	4.28	4.80	4.96
Alexandra Headland Beach	O8	4.08	4.58	4.73
Alexandra Headland	H2	3.84	4.40	4.59
Mooloolaba Beach	O9	3.49	4.00	4.18
Point Cartwright	H3	4.32	4.63	4.72
Buddina Beach	O10	4.33	4.97	5.19

Beach name	Unit	10%AEP Hs (m)	2% AEP Hs (m)	1% AEP Hs (m)
Mooloolah River Estuary	E2	3.35	3.83	4.02
Warana Beach	O11	4.34	5.00	5.25
Bokarina Beach	O12	4.39	5.00	5.20
Wurtulla Beach	O13	4.44	4.69	4.73
Currimundi Creek	L2	3.89	4.36	4.53
Currimundi Beach	O14	3.92	4.49	4.67
Coondibah Creek	L3	4.14	4.65	4.82
Dicky Beach	O15	4.30	4.77	4.92
Bunbubah Creek	L4	4.35	4.86	5.03
Tooway Creek	L5	4.42	4.94	5.13
Moffat Beach	O16	4.42	4.86	5.01
Moffat Headland	H4	4.44	4.94	5.06
Shelly Beach	O17	4.34	4.84	4.98
Caloundra Headland	H5	3.48	3.74	3.83
Kings Beach	O18	3.33	3.51	3.57
Happy Valley	O19	3.71	4.04	4.13
Bribie Island Beach	O20	2.95	3.27	3.39

A.14.13 Comparison to previous study

The reassessed present day extreme midshore wave conditions have been compared to values published in BMT (2013). In the previous study, extreme wave conditions were assessed at the offshore Brisbane buoy. These were applied to a wave model and extracted at the -20m contour. As a result, these conditions are deemed conservative (i.e., a 1%AEP wave at Brisbane may not coincide with a 1% AEP wave at Mooloolaba) and do not necessarily account for local bathymetric effects including sheltering from headlands.

Table 9-5 compares reassessed extreme midshore waves for select beach units that are similar locations from the previous study. This table shows a decrease in extreme wave height for all locations, this is attributed to the differences in methodology described above, as well as the difference in depth of results between the previous study and the current study, -20m and -10m respectively.

Table 9-5: Comparison of BMT (2013) at -20m depth and JBP reassessed 1%AEP wave heights at -10m depth

Location (BMT 2013)	Hs (m) from 2013 study (-20m depth)	Coastal Unit (JBP)	Hs (m) from 2024 study (-10m depth)	Change (%)
Dicky Beach	6.0	O14	4.7	**-22%**
Currimundi	5.8	O13	4.7	**-19%**
Warana	6.1	O11	5.2	**-14%**
Buddina	5.7	O10	5.2	**-9%**
Mooloolaba Surf Club	5.9	O9	4.2	**-29%**
Maroochydoore	6.3	O7	5.0	**-21%**
Marcoola	6.0	O4	5.2	**-14%**
Coolum	6.1	H1	5.4	**-12%**

A.14.14 Comparison to wave record

The extreme wave model has been validated against recorded wave data at Caloundra WRB. Figure 9-22 compares the recorded data at Caloundra against the exceedance curve generated at this location, as well as a Generalised Pareto Distribution (GPD) fit to the recorded data. This plot shows a good agreement between the wave return periods assessed from the 10,000-year data set and the recorded data at the Caloundra buoy.

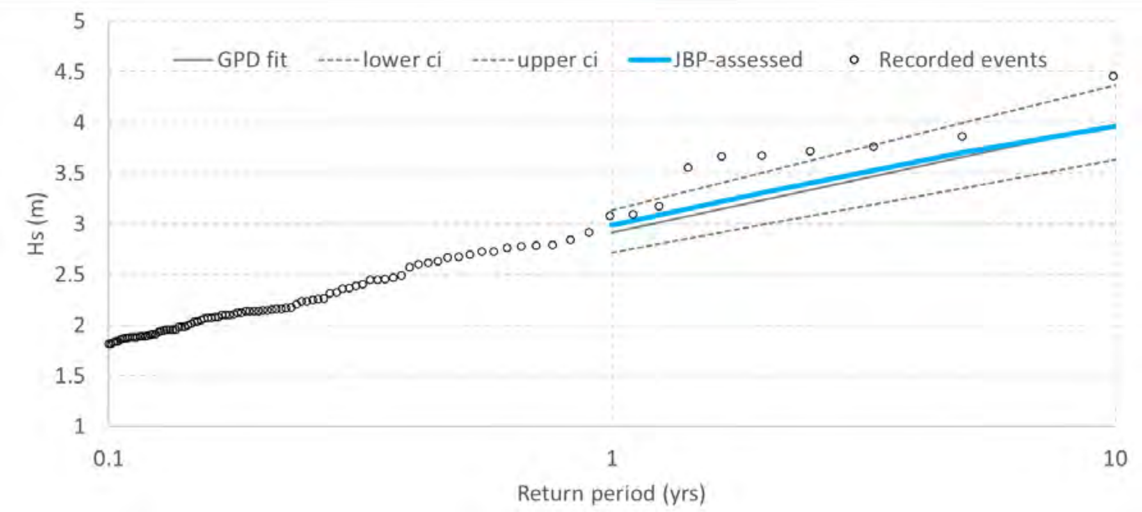


Figure 9-22: Comparison of wave height return periods to recorded data and GPD fit with 95% lower confidence interval (lower ci) and 100% confidence interval (upper ci) plotted.

A.15 Future 2100 midshore wave results

Figure 9-23 shows the midshore wave rose at the beach priority unit E4 within Pumicestone with Bribie Island removed within model bathymetry. This wave rose displays the distribution of wave height and wave direction for the full large wave dataset and the propagation of waves towards the shoreline of Golden Beach under open coast conditions. Wave roses for E3 to E6 have been included in Appendix 0. Extreme wave conditions for E7 and E8 are not shown as these units are sheltered behind the remainder of Bribie Island and extreme conditions at these units are presumed to be locally wind driven.

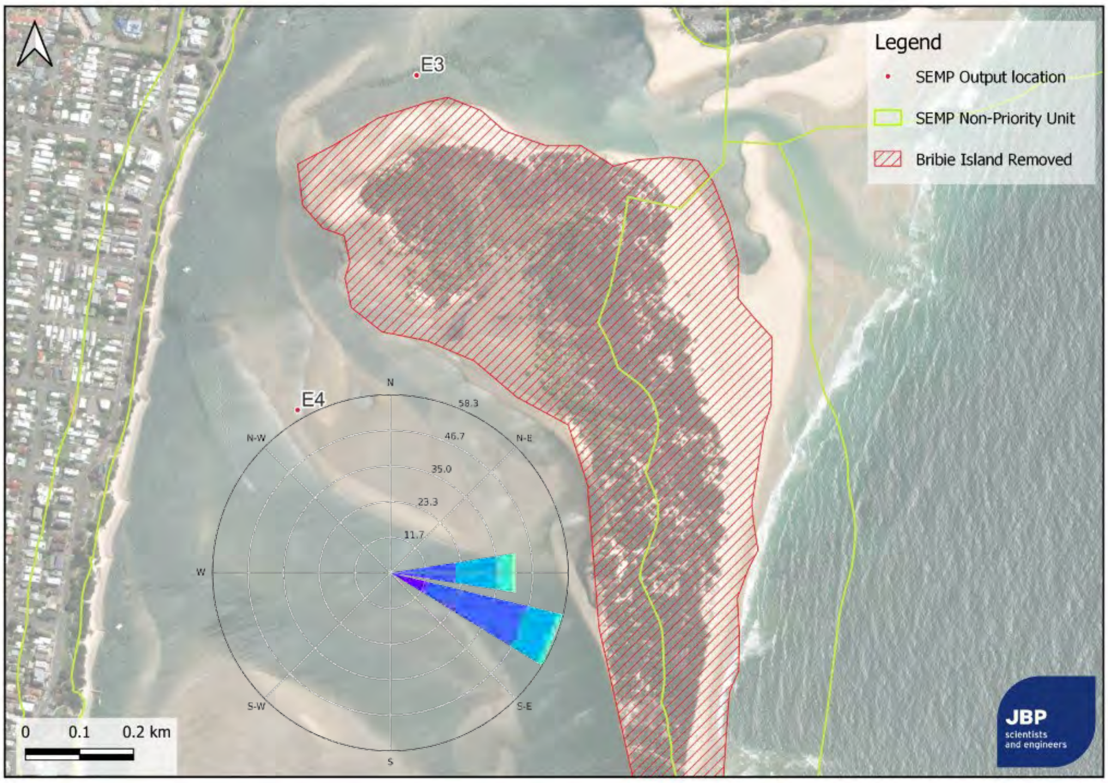


Figure 9-23: Future 2100 midshore wave rose at unit E4.

A.15.15 Future 2100 midshore extreme wave conditions

Table 9-6 shows extreme nearshore wave heights for coastal units E3 to E6 with the removal of Bribie Island north. A summary of extreme wave conditions has been included in Appendix 0 for these units. Extreme wave conditions have been estimated for a range of return periods up to 0.01% AEP. For the 2100 scenario, wave conditions are only displayed for Units E3 to E6 to show design wave conditions with the removal of Bribie Island. Extreme conditions for the rest of the SCC coastline are not significantly altered under the 2100 scenario, as future projections for climate change-driven variance in offshore wave climate have not been included in modelling.

Table 9-6: Future 2100 nearshore extreme wave heights for E3 to E6.

Beach name	Unit	10%AEP Hs (m)	2%AEP Hs (m)	1%AEP Hs (m)
Pumicestone Passage - Bulcock Beach to North Street	E3	1.35	1.51	1.59
Pumicestone Passage – North Street to Jellicoe Street	E4	2.62	2.90	2.98
Pumicestone Passage - Jellicoe Street to Onslow Street	E5	2.87	3.21	3.32
Pumicestone Passage - Onslow Street to Lamerough Canal	E6	2.90	3.19	3.27

A.16 Limitations

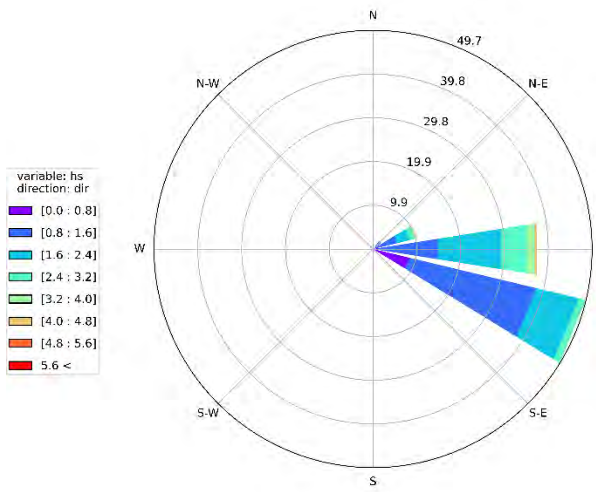
The following limitations were identified in this study and should be considered when designing coastal protection options and management plans:

- Wave modelling has been conducted assuming purely offshore input conditions, i.e., extreme conditions are generated at the model boundary and no wind forcing is applied within the model domain.
- Wave setup included in storm tide levels for each coastal unit has been taken from the previous storm tide study (Aurecon 2013) and has not been recalculated as part of the updated extreme wave modelling assessment.
- Future planning horizons have not included projections for climate change-driven variance in offshore wave climate (e.g., increases to wave height or changes in prevailing direction).
- The previous storm tide study (Aurecon 2013) does not extend south of Kings Beach, therefore the published levels for Kings Beach have been applied to coastal units within Pumicestone Passage and along the open coast of Bribie Island.
- According to Maritime Safety Queensland (MSQ), the 2023 published tidal planes for Golden Beach do not incorporate the effects of the breakthrough due to limited data available to accurately capture the stabilised changes caused by the breakthrough. These planes are expected to be updated in subsequent publications from MSQ, as new tide level data becomes available.

- Open coast bathymetry within the Northern section of Pumicestone Passage has been developed based on a "worst case" approach. For this reason, there are several limitations which should be considered. Firstly, this approach estimates an open coast topo-bathymetric profile by removing a nominal section of Bribie Island and as a result the bathymetric smoothness between the southern extent of the model bathymetry and the southern region of Pumicestone Passage consisting of Lamerough Canal to Bells Creek is affected. This essentially considers the sand to have disappeared from the system, which is not expected given the low rates of sediment transport experienced at Caloundra. Secondly, there is a degree of uncertainty in the state of Bribie Island when projecting to a planning horizon of 2100. Current climate trends can project a possible future at Pumicestone Passage, however a definitive prediction on the state of Bribie Island remains a challenge and has therefore been estimated through a simplistic modelling approach.

A.17 Present day nearshore wave results

As referenced in Section 0, wave roses for present day midshore emulation results have been collated for all coastal units along the SCC LGA. Each wave rose has an associated co-ordinate reference (MGA56-GDA94) and accompanying beach priority unit.



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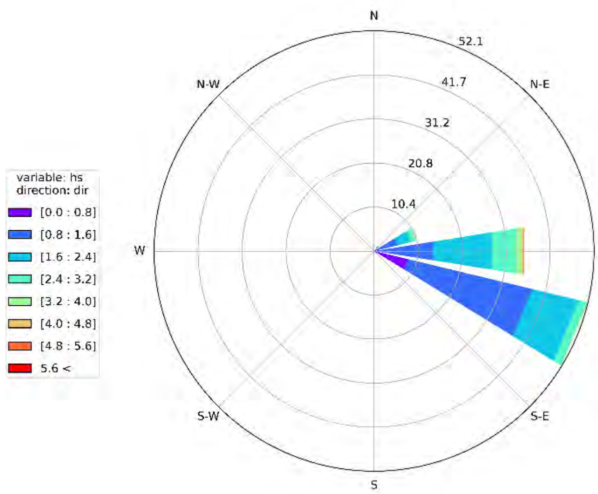

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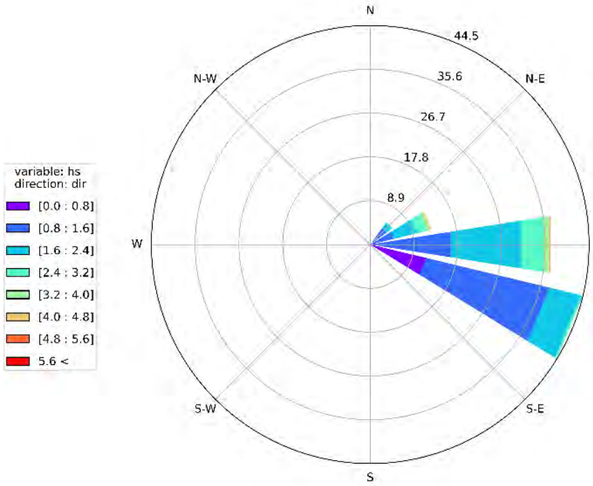

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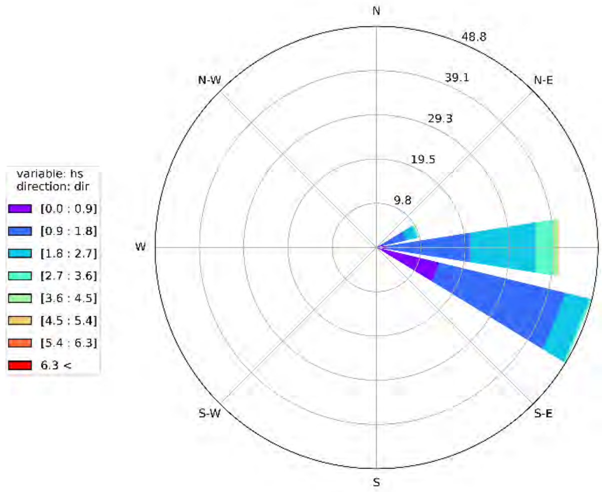

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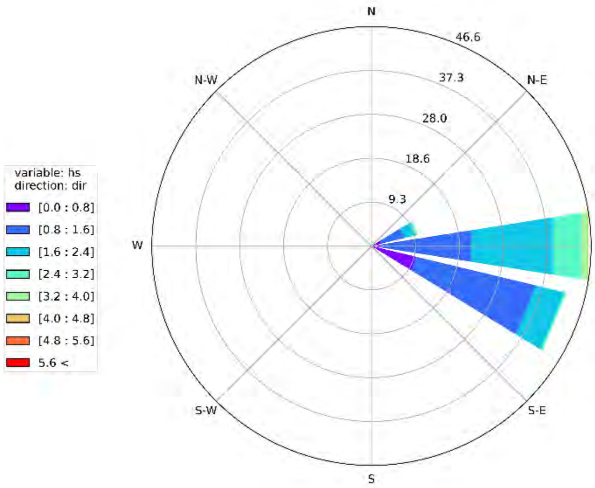

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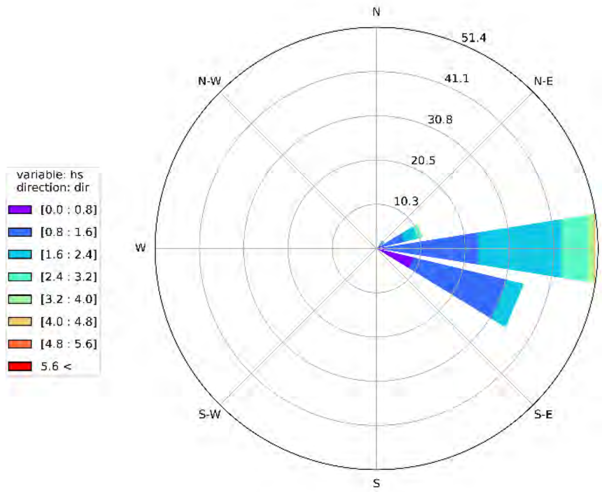

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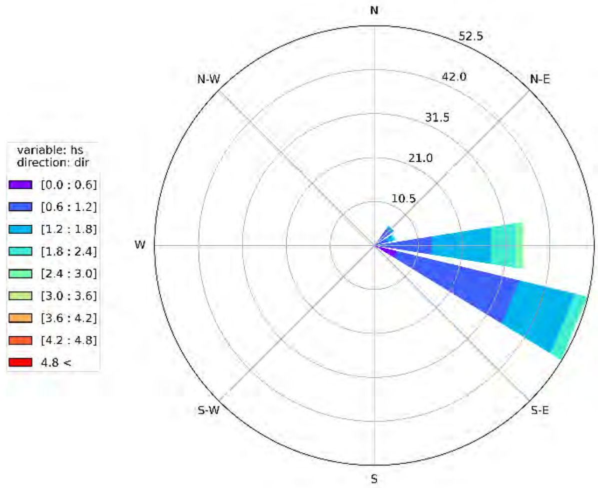

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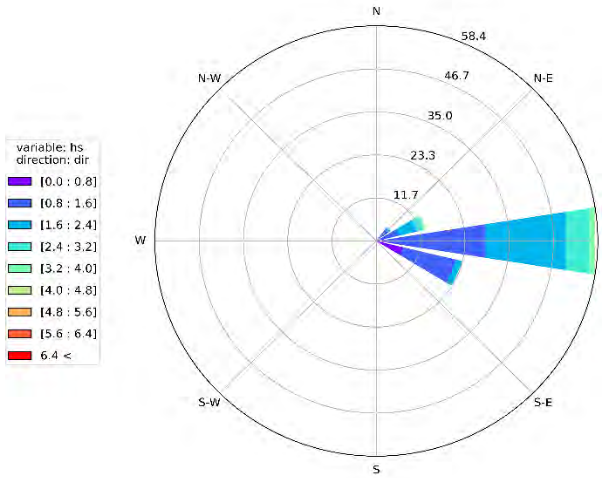

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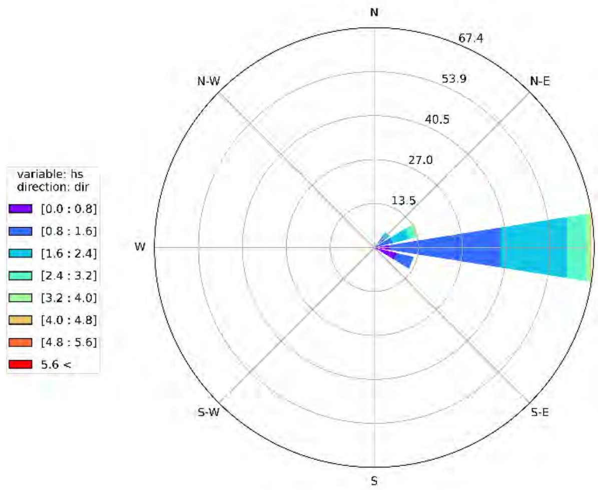

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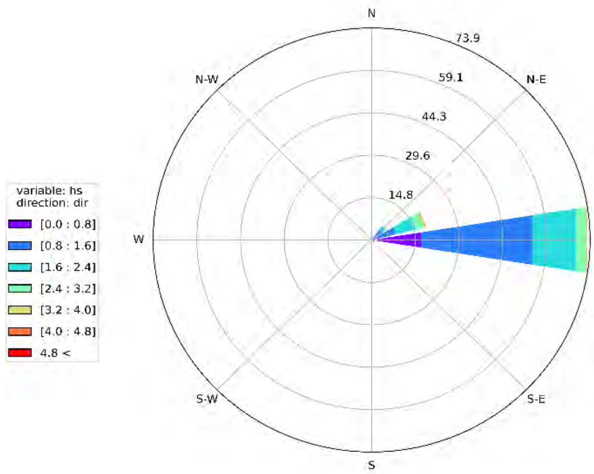

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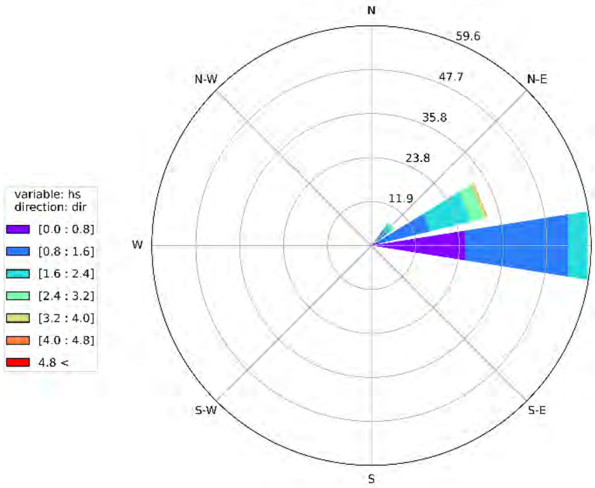

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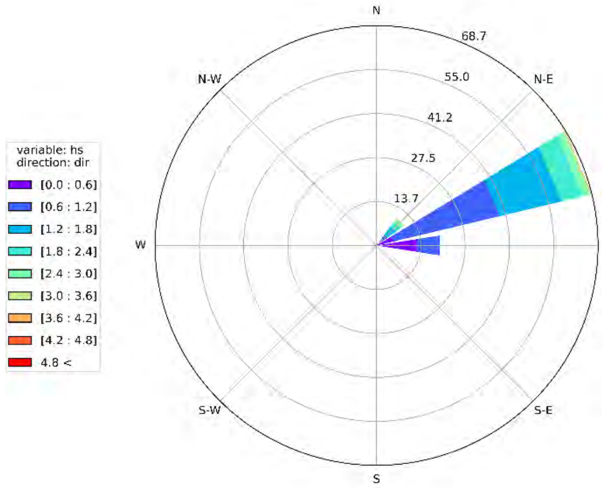

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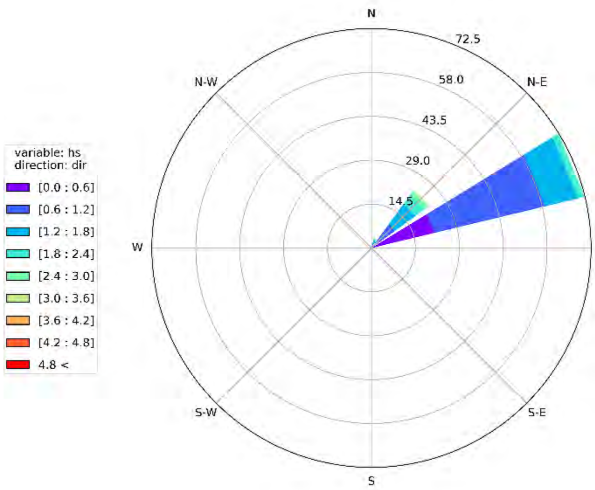

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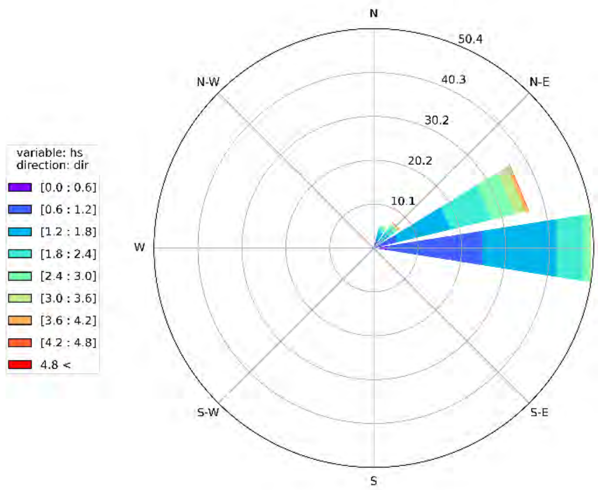

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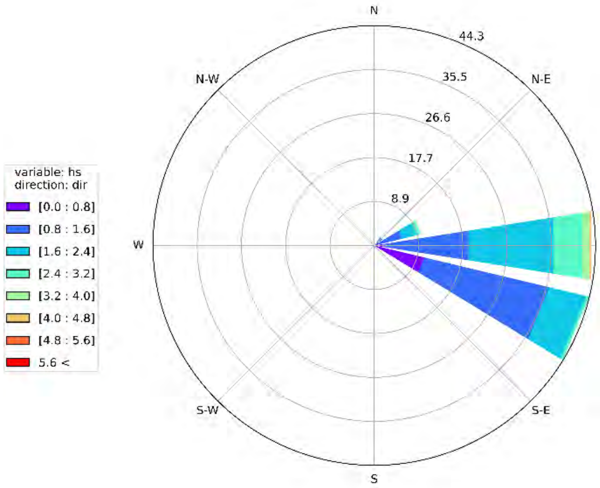

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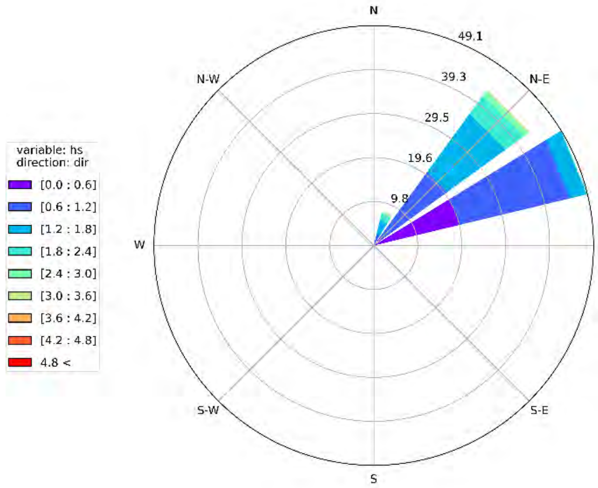

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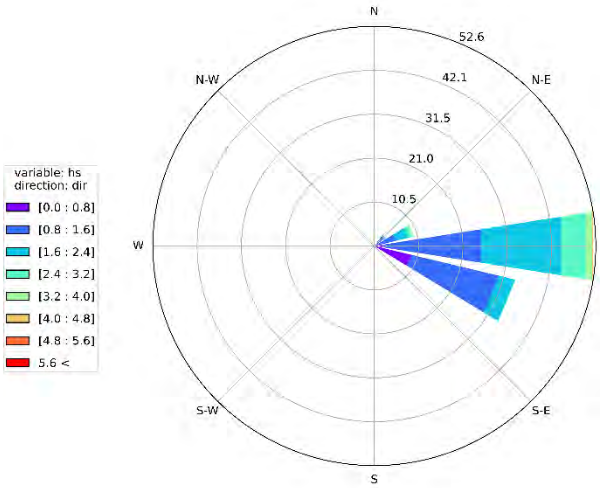

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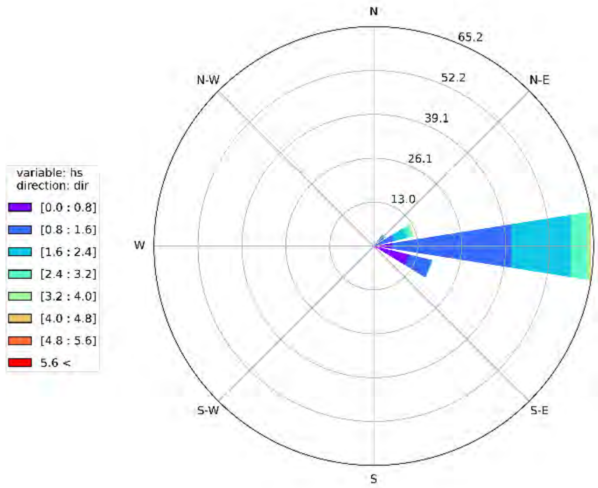

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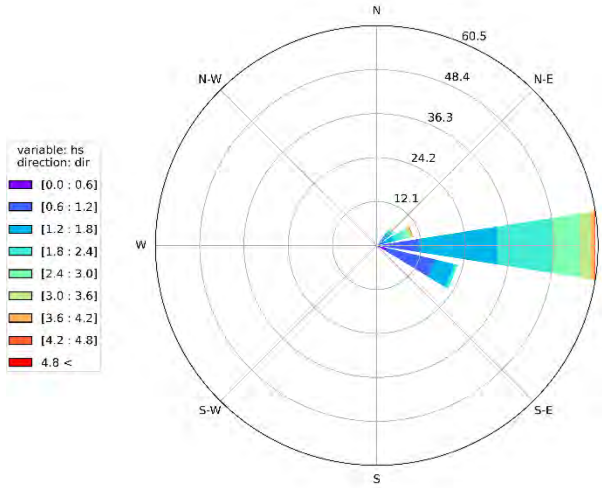

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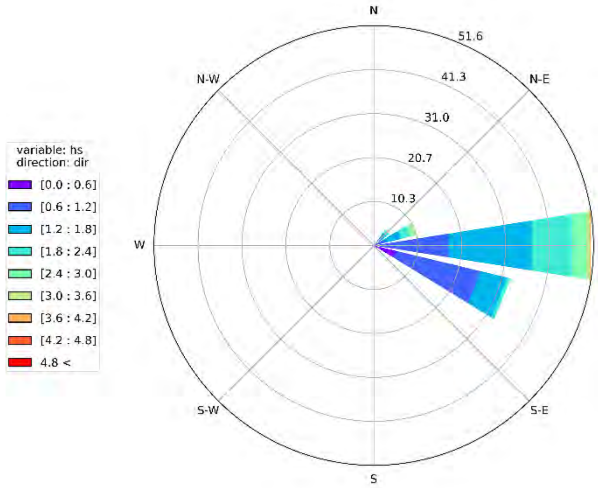
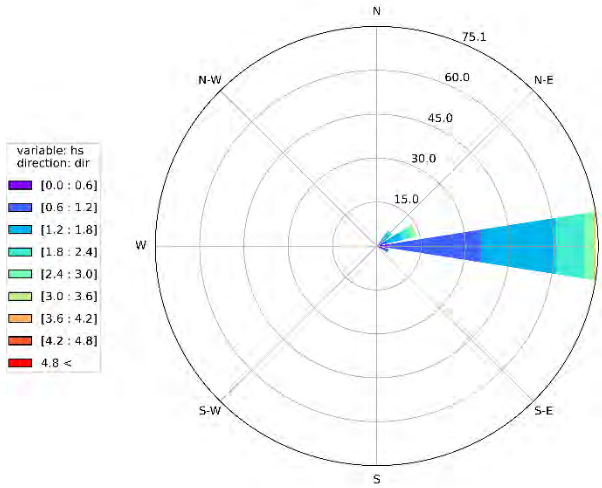
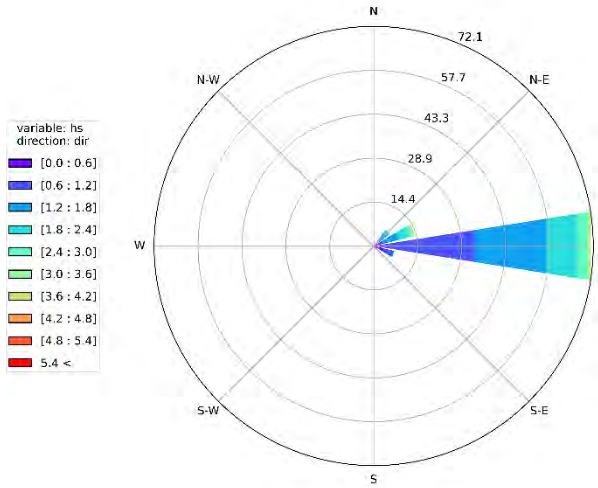


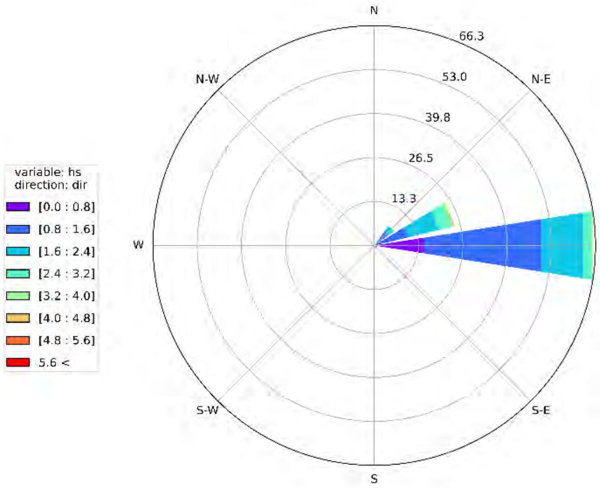
L2: (514164, 7039592)



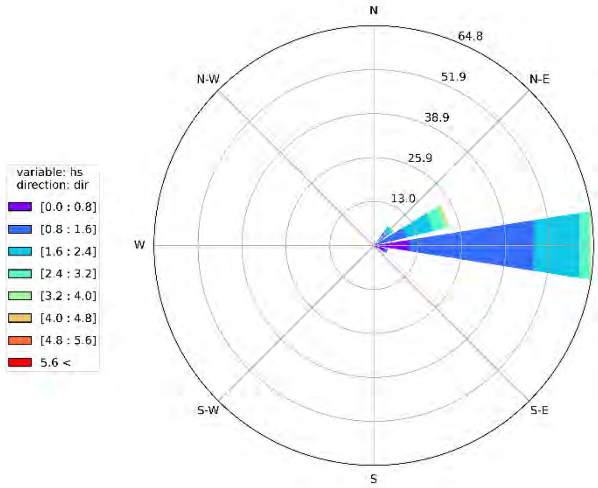
O14: (514211, 7038876)



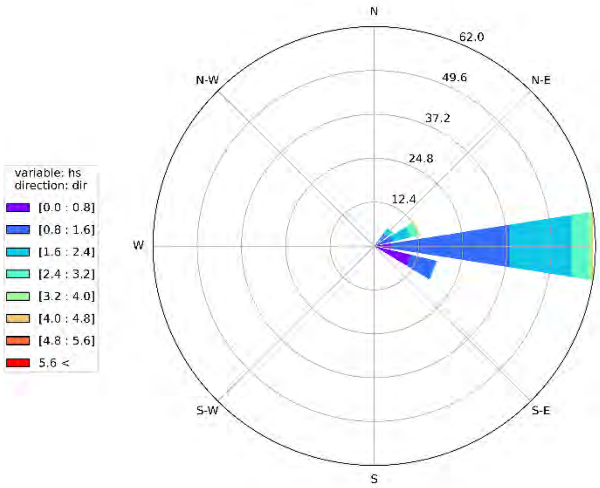
L3: (514323, 7038638)



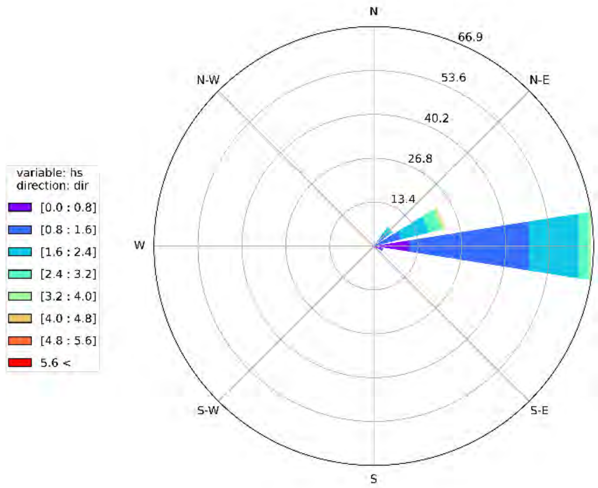
O15: (514757, 7037958)



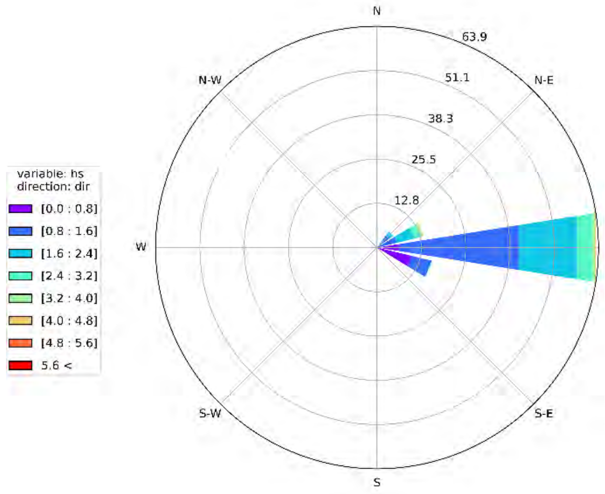
L4: (514892, 7037856)



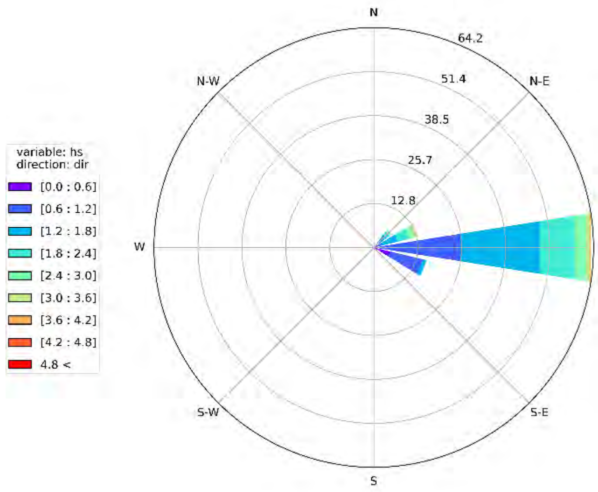
L5: (515191, 7037378)



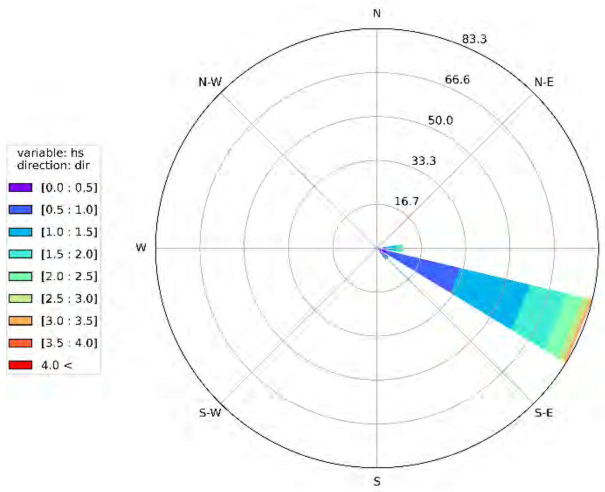
O16: (514969, 7037703)



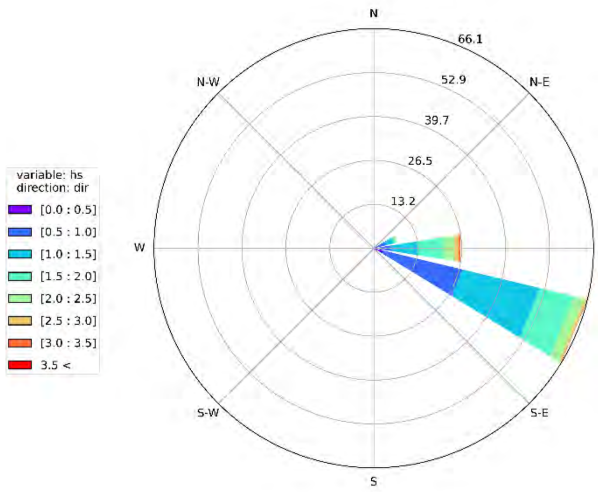
H4: (515168, 7037174)



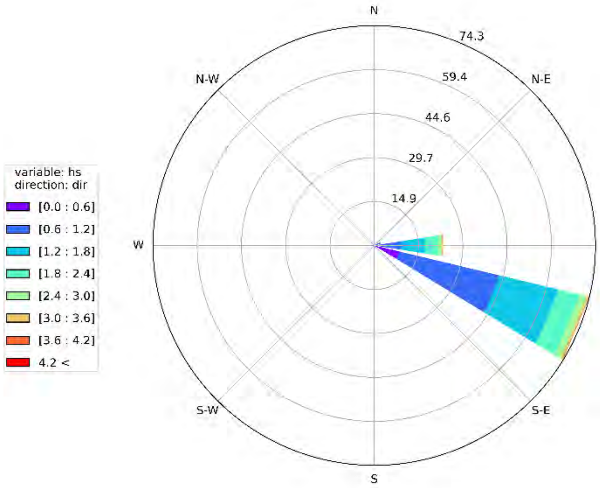
O7: (515540, 7036187)



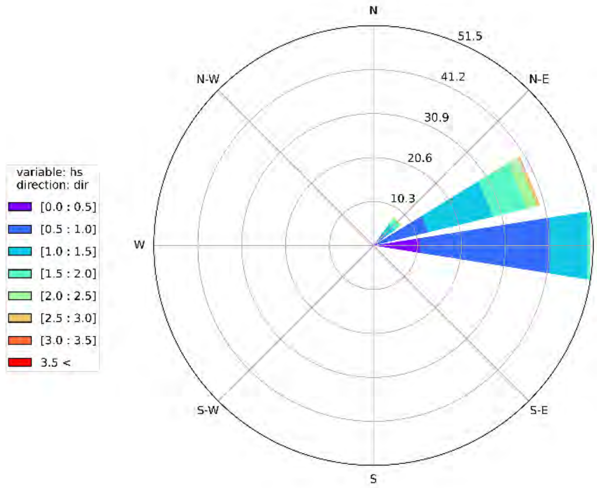
H5: (514969, 7035092)



O18: (514877, 7034338)



O19: (514141, 7034300)



O20: (513644, 7027710)

A.18 Present day extreme nearshore wave conditions

Table 9-7: Present day nearshore extreme wave conditions for each beach unit.

Hs, Tp, Dir									
Beach name	Unit	10%AEP	5%AEP	2%AEP	1%AEP	0.4%AEP	0.2%AEP	0.1%AEP	0.01%AEP
Coolum Beach	O1	4.6, 14.4, 84.4	4.9, 14.5, 84.2	5.2, 14.9, 83.8	5.3, 15, 83.7	5.5, 15.3, 83.7	5.6, 15.9, 83.9	5.7, 16.1, 84.6	6.3, 15.8, 86.9
Stumers Creek	L1	4.6, 14.2, 86.9	4.8, 14.5, 86.2	5.1, 14.8, 85.5	5.2, 15, 85.5	5.4, 15.6, 85.8	5.6, 16.3, 88.7	5.8, 16.6, 90	6.1, 18.2, 85.7
Point Perry to Point Arkwright	H1	4.6, 14.5, 77.9	4.9, 14.8, 77.1	5.2, 15, 76.2	5.4, 15, 75.6	5.5, 15.2, 75.2	5.5, 15.4, 75.1	5.6, 15.4, 75.3	5.8, 16.3, 76.5
Yaroomba Beach	O2	4.6, 14.6, 88.5	4.9, 14.9, 88.4	5.2, 15.2, 88	5.4, 15.5, 87.9	5.6, 15.3, 87.2	5.8, 15.9, 88.3	6, 16.4, 89.3	6.8, 15.5, 85.3
Mount Coolum Beach	O3	4.2, 14.5, 90	4.5, 14.7, 89.6	4.8, 15.1, 88.9	5.1, 15.6, 88.7	5.3, 15.9, 89.5	5.6, 16.2, 87.9	5.7, 15.9, 87.7	6.1, 16.3, 90.6
Marcoola Beach	O4	4.4, 14.2, 84.2	4.6, 14.5, 84	5, 15, 83.3	5.2, 15.3, 83	5.4, 15.8, 83.3	5.6, 16, 82.8	5.8, 16.1, 83	5.9, 16, 83.6
Mudjimba Beach	O5	3.2, 14.5, 94.8	3.4, 14.8, 94.6	3.7, 15.1, 94.1	3.9, 15.7, 94.6	4.1, 16.3, 94.8	4.3, 16.4, 94.4	4.5, 15.3, 92.4	5.3, 15.7, 86.1

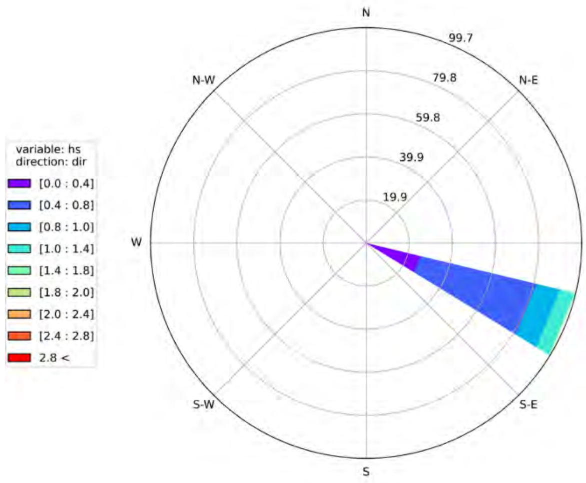
Hs, Tp, Dir									
Twin Waters Beach	O6	4.4, 14.5, 80.6	4.7, 14.7, 80.3	4.9, 15, 79.5	5.1, 15.1, 79.3	5.2, 15.5, 79.1	5.4, 16.2, 79.1	5.5, 16.5, 79.5	6.5, 16.5, 74.2
Maroochy River Estuary	E1	4.5, 14.3, 78.3	4.8, 14.6, 78.2	5, 15, 77.8	5.2, 15.2, 77.7	5.3, 15.7, 77.9	5.4, 16.4, 78.6	5.6, 16.3, 79.6	6, 19.8, 77.8
Maroochydore Beach	O7	4.3, 14.7, 75.3	4.5, 14.9, 75.3	4.8, 15.2, 75.4	5, 15.3, 75.3	5.1, 15.6, 75.5	5.2, 15.5, 75.8	5.3, 15.9, 76.4	5.5, 16.5, 77.2
Alexandra Headland Beach	O8	4.1, 14.7, 67.9	4.3, 14.9, 67.5	4.6, 15.2, 67.4	4.7, 15.3, 67.7	4.9, 15.4, 67.3	4.9, 15.5, 67.6	4.9, 15.5, 67.7	5.6, 15.6, 67.8
Alexandra Headland	H2	3.8, 14.3, 56.6	4.1, 14.9, 56.9	4.4, 15.3, 56.3	4.6, 15.4, 56	4.8, 15.5, 55.9	4.9, 15.7, 55.5	5, 15.8, 55.9	5.2, 16.3, 53.5
Mooloolaba Beach	O9	3.5, 13.8, 43.7	3.7, 14.1, 42.7	4, 14.4, 42	4.2, 14.9, 40.8	4.4, 15.3, 39.5	4.6, 15.8, 38.6	4.7, 16.1, 37.9	5.3, 17.1, 33.1
Point Cartwright	H3	4.3, 14.6, 61.2	4.5, 14.7, 59.5	4.6, 14.8, 58.2	4.7, 14.9, 56.9	4.8, 14.9, 55.5	4.9, 15.4, 53.2	5.1, 16.1, 52.7	5.3, 17.8, 46.7
Buddina Beach	O10	4.3, 14.5, 87.7	4.6, 14.9, 87.7	5, 15.3, 87.4	5.2, 15.7, 87	5.4, 16.1, 88.1	5.7, 16.1, 87.3	5.8, 16.1, 86.9	6.1, 16.2, 86.2
Mooloolah River Estuary	E2	3.3, 13.9, 38.5	3.6, 14.2, 37.5	3.8, 14.7, 36.2	4, 15.2, 34.7	4.2, 15.6, 33.3	4.4, 16.1, 32.2	4.5, 15.9, 31.1	4.9, 18.1, 27.4

Hs, Tp, Dir									
Warana Beach	O11	4.3, 14.6, 84.2	4.6, 15, 84.2	5, 15.4, 84.2	5.2, 15.6, 84.2	5.5, 15.9, 84	5.7, 16.1, 83.7	5.9, 16.1, 84.1	6, 16.7, 84.3
Bokarina Beach	O12	4.4, 14.5, 80.8	4.7, 14.9, 80.8	5, 15.3, 80.8	5.2, 15.4, 81	5.4, 15.8, 80.3	5.6, 16.4, 80.1	5.7, 16.5, 80.1	5.8, 16.4, 79.9
Wurtulla Beach	O13	4.4, 14.6, 80.5	4.6, 14.7, 79.8	4.7, 14.7, 79.5	4.7, 14.8, 79.6	4.8, 14.7, 79.3	4.8, 14.8, 78.8	4.9, 15.2, 78.1	5.2, 16, 83.3
Currimundi Creek	L2	3.9, 14.1, 80.2	4.1, 14.7, 80.9	4.4, 15.1, 82.2	4.5, 15.4, 82.8	4.7, 15.5, 84.7	4.9, 16, 85.7	4.9, 15.7, 85.7	5.1, 16.4, 86.8
Currimundi Beach	O14	3.9, 14.8, 78.5	4.2, 15.3, 78.6	4.5, 15.8, 78.7	4.7, 15.9, 78.8	4.9, 16.1, 79.2	5, 16.2, 79	5.1, 16.2, 78.4	5.3, 16.3, 78.6
Coondibah Creek	L3	4.1, 14.5, 78.6	4.4, 14.8, 78.7	4.7, 15.2, 78.8	4.8, 15.4, 78.7	5, 15.8, 79.1	5.2, 16.2, 79.2	5.2, 16.1, 79.2	5.4, 16.4, 79.4
Dicky Beach	O15	4.3, 14.4, 71.9	4.5, 14.7, 71.6	4.8, 15, 71.3	4.9, 15.2, 71.4	5.1, 16, 71.1	5.2, 16.4, 71.7	5.3, 16.5, 72.3	5.7, 15.4, 67.8
Bunbubah Creek	L4	4.4, 14.5, 72.9	4.6, 14.9, 72.8	4.9, 15.2, 73	5, 15.4, 72.7	5.2, 15.9, 72.7	5.3, 16.3, 73.3	5.5, 16.6, 73.8	5.6, 16.6, 73.4
Tooway Creek	L5	4.4, 14.6, 78.3	4.7, 15, 78.4	4.9, 15.5, 78.8	5.1, 15.8, 79	5.3, 16.5, 79.4	5.5, 16.8, 79.2	5.6, 16.8, 78.7	6, 15.9, 96

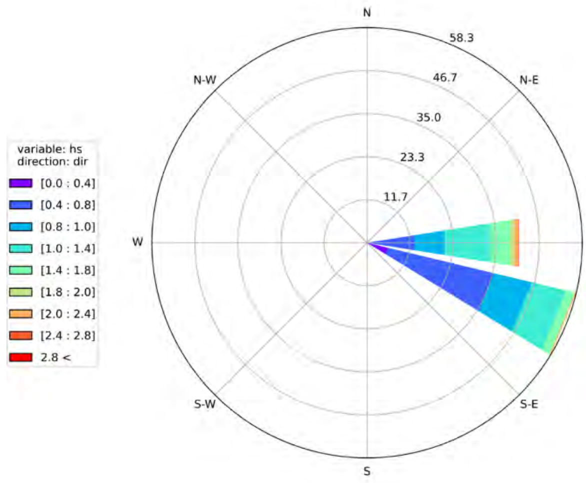
Hs, Tp, Dir									
Moffat Beach	O16	4.4, 14.7, 73.3	4.6, 14.9, 72.9	4.9, 15.2, 73.2	5, 15.7, 73.3	5.2, 16.5, 73.8	5.4, 16.7, 73.9	5.5, 16.7, 73.4	5.9, 18.7, 73.7
Moffat Headland	H4	4.4, 14.5, 77.3	4.7, 14.8, 76.9	4.9, 15.2, 77	5.1, 15.3, 76.9	5.2, 15.8, 77	5.3, 16.4, 77.9	5.4, 16.7, 78	6.1, 16.3, 51.1
Shelly Beach	O17	4.3, 14.2, 76.1	4.6, 14.6, 76.1	4.8, 14.9, 76.4	5, 15.1, 76.4	5.1, 15.5, 76.6	5.2, 15.8, 76.9	5.3, 16.4, 76.6	5.4, 17, 78.2
Caloundra Headland	H5	3.5, 14.4, 110.5	3.6, 14.7, 111	3.7, 15.1, 111.7	3.8, 15.5, 112.3	4, 16.1, 113.2	4.1, 16.3, 113.6	4.1, 16.2, 113.8	4.5, 12, 113.6
Kings Beach	O18	3.3, 14.3, 95.6	3.4, 14.4, 95.4	3.5, 14.7, 95.3	3.6, 14.8, 95.3	3.6, 15.2, 95.3	3.7, 15.4, 95.5	3.7, 15.8, 95.7	3.8, 16.8, 96.9
Happy Valley	O19	3.7, 14.5, 102.8	3.9, 14.8, 103	4, 15.1, 103.3	4.1, 15.3, 103.5	4.2, 15.5, 103.7	4.3, 15.8, 104	4.4, 16.2, 104.5	4.5, 16.7, 105.2
Bribie Island Beach	O20	3, 13.7, 62.7	3.1, 14, 62.4	3.3, 14.4, 62	3.4, 14.6, 61.6	3.5, 14.8, 61.3	3.6, 14.8, 61.9	3.7, 15.1, 62.4	3.9, 15.3, 64.9

A.19 Future 2100 nearshore wave results

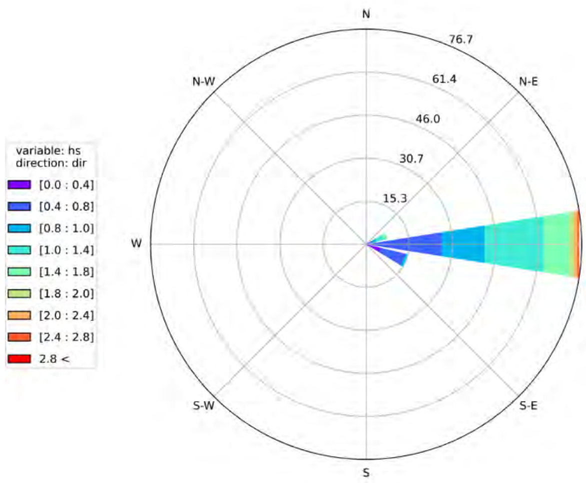
As referenced in 0, wave roses for priority units E4 to E8 have been collated below. Each wave rose has an associated co-ordinate reference (MGA56-GDA94) and accompanying priority unit.



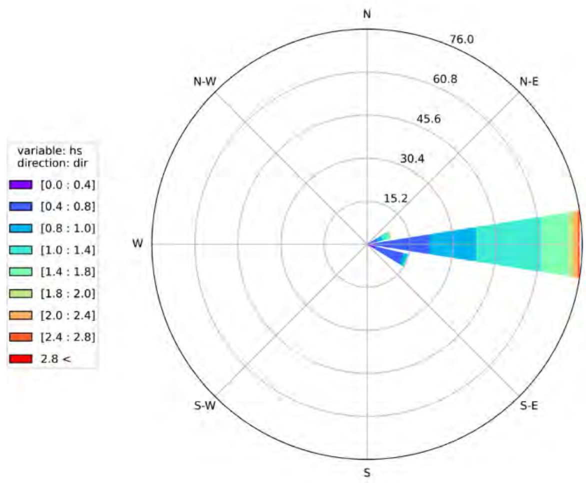
E3: (512851, 7034658)



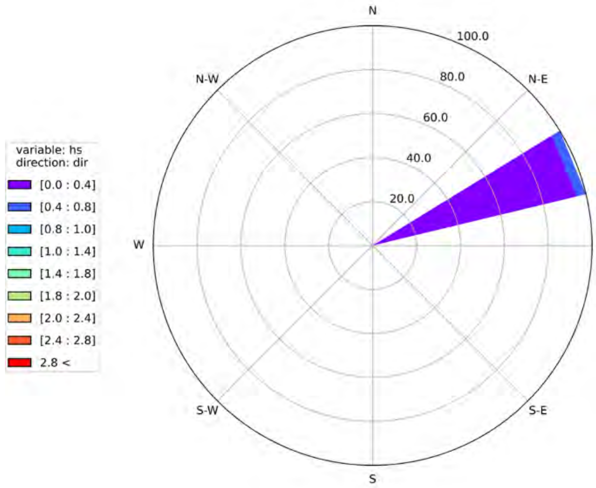
E4: (512796, 7034084)



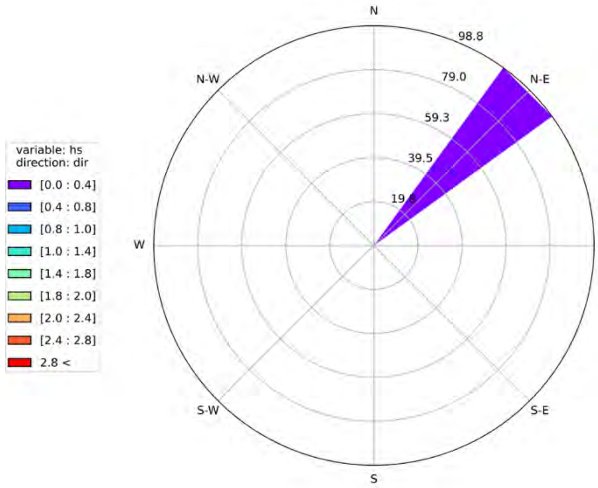
E5: (512740, 7033148)



E6: (512616, 7032279)



E7: (511542, 7030794)



E8: (511332 7029780)

A.20 Future 2100 extreme nearshore wave conditions

Table 9-8: Future 2100 nearshore extreme wave conditions for units E3 to E6 with removal of Bribie Island north

Hs, Tp, Dir									
Beach name	Unit	10%AEP	5%AEP	2%AEP	1%AEP	0.4%AEP	0.2%AEP	0.1%AEP	0.01%AEP
Pumicestone Passage - Bulcock Beach to North Street	E3	1.3, 13.4, 121.7	1.4, 13.5, 121.7	1.5, 13.5, 121.8	1.6, 13.3, 121.9	1.8, 11.8, 122.3	2, 7, 122.2	2.3, 5.7, 123	3.4, 4.9, 123.8
Pumicestone Passage – North Street to Jellicoe Street	E4	2.6, 14.4, 100.3	2.8, 14.7, 100.3	2.9, 15, 100.4	3, 15.2, 100.4	3.1, 15.4, 100.4	3.2, 15.5, 100.5	3.2, 15.7, 100.6	3.5, 14.5, 100.7
Pumicestone Passage - Jellicoe Street to Onslow Street	E5	2.9, 14.3, 88	3, 14.6, 87.9	3.2, 14.9, 87.9	3.3, 15.1, 87.9	3.4, 15.1, 88	3.5, 15.2, 88.1	3.6, 15.2, 88.1	3.8, 15.7, 88.6
Pumicestone Passage - Onslow Street to	E6	2.9, 13.7, 92.3	3, 14, 92.2	3.2, 14.6, 92.1	3.3, 15, 92.2	3.4, 15.3, 92.1	3.5, 15.6, 92.3	3.5, 15.8, 92.4	3.7, 16.9, 92.2

Hs, Tp, Dir									
Lamerough Canal									

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