



Coochiemudlo Island Shoreline Erosion Management Plan: Stage 2 - Shoreline Erosion Management Study

Reference: R.B23255.001.03
Date: February 2020
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Document Control Sheet

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	Title:	Coochiemudlo Island Shoreline Erosion Management Plan: Stage 2 - Shoreline Erosion Management Study
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	Client Reference:	
Synopsis:		

REVISION/CHECKING HISTORY

Revision Number	Date	Checked by	Issued by
0	27/06/2019	MJA	JGC
1	9/09/2019	MJA	JGC
2	1/10/2019	MJA	JGC
3	05/02/2020	KOJ	JGC

DISTRIBUTION

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1 Introduction

The Coochiemudlo Island foreshore is an important asset to residents, wider community and the islands' Traditional Owners, and has high environmental, cultural, economic and social value. BMT has been engaged by Redland City Council to complete a Shoreline Erosion Management Plan (SEMP) for Coochiemudlo Island to provide strategic direction for the sustainable use of the Islands coastal zone and facilitate coordinated planning of their long-term shoreline erosion management obligations.

The Coochiemudlo Island SEMP program, as laid out by Redland City Council, has the following 5 key stages:

- Stage 1 – Project initiation
- Stage 2 – Shoreline erosion management study
- Stage 3 – Draft SEMP Plan and Operational Plan
- Stage 4 – Revised draft SEMP and Operational Plan
- Stage 5 – Presentation of revised draft SEMP and Operational Plan to the Community Reference Group.

An investigation of coastal process related issues together with other environmental, social, economic, and cultural needs has been undertaken (Stage 2 of the SEMP) to inform assessment of management options appropriate to Coochiemudlo Island (Stage 3) and is detailed in the following chapters.

2 Environmental, Cultural and Legislative Context

This section describes the values and context of the study area relevant for identifying and planning for shoreline erosion management options. It includes discussion of the existing environmental and heritage values (including physical, biological, socio-cultural, regulatory environment) and the planning and legislative framework.

2.1 Environmental and Heritage Values

2.1.1 Physical and Biological Environment

2.1.1.1 Overview

Coochiemudlo Island is a small terrestrial island, formed as an extension of the basaltic geology of the mainland at Victoria Point (Rob Friend & Associates, 2004). The island features a mosaic of different land types, including sandy beaches, cliffs, wetlands, forests and woodland, and open tidal flats.

Within these land types, the island supports a variety of important habitat assemblage (Rob Friend & Associates, 2004). These are described in Table 2-1 together with relevant mapped vegetation units from Olsen (2000). The mapped vegetation and habitat units are shown in Figure 2-1.

The nearshore area of the island also supports a variety of marine habitat types. This includes inshore reef to the north and seagrass meadows surrounding the island.

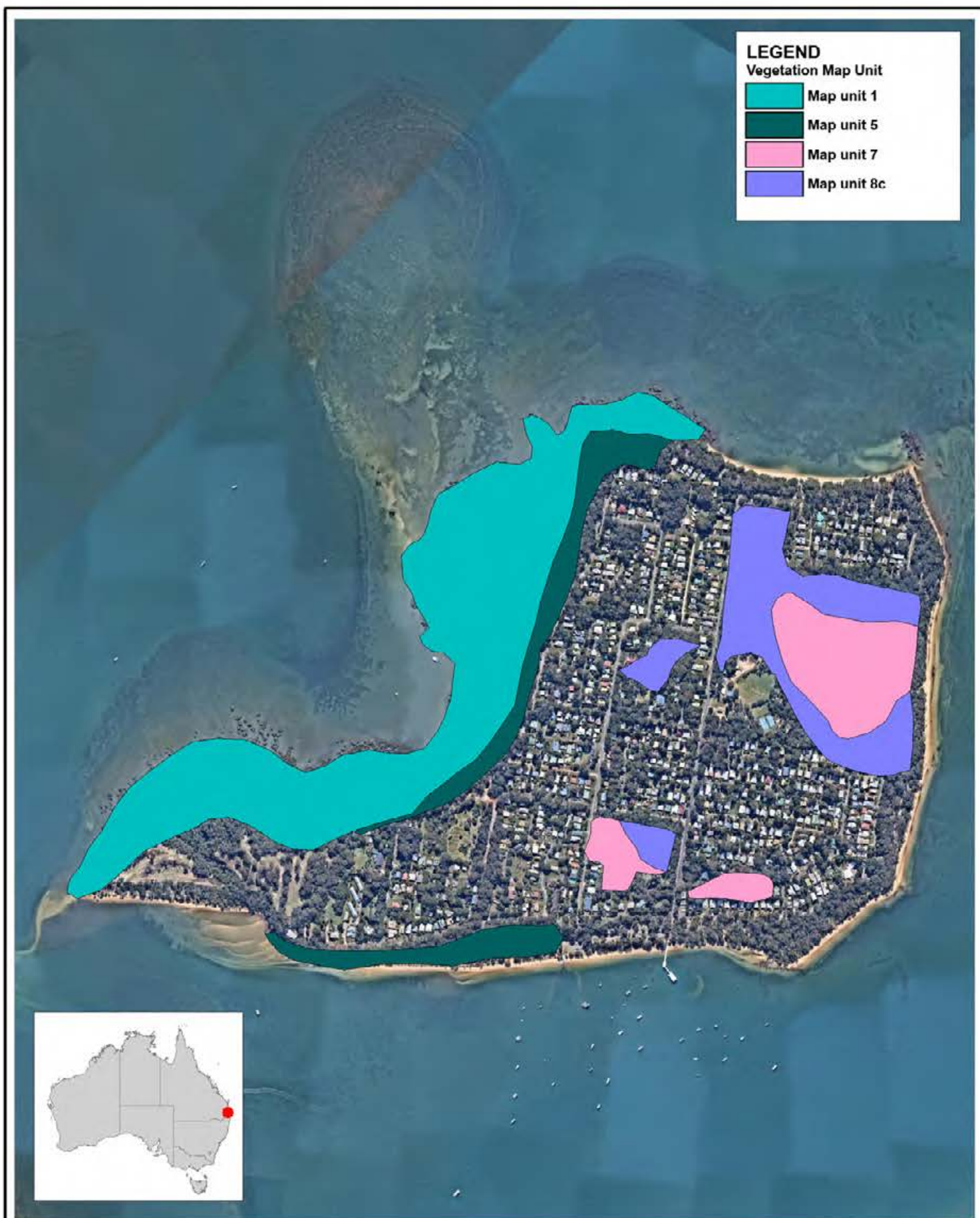
Figure 2-2 shows the mapped location of reef and potential seagrass, while Figure 2-3 shows the extent of seagrass (*Halophila ovalis*) off the southern coastline based on 2015 surveys (BMT WBM, 2015). The nearshore habitat also includes wetland areas which provides habitats for migratory bird species (Figure 2-4).

These physical and biological features provide habitat for many marine species including several fish and crab species that are important to local diversity and fisheries. Seagrass meadows provide habitat and feeding grounds for turtles and dugongs while inshore reefs help to provide structural habitat for marine species.

The environmentally significant areas on Coochiemudlo Island are formed from: Matters of National Environmental Significance (MNES), Matters of State Environmental Significance (MSES) and Matters of Local Environmental Significance (MLES). These areas are designed to protect native vegetation and wildlife habitat areas by managing development, which includes protecting corridors for wildlife movement.

Table 2-1 Habitat and Vegetation Units of Coochiemudlo Island

Habitat type	Equivalent map unit (Olsen, 2000)	Equivalent regional ecosystem	Habitat and vegetation description
Mangal Areas Intertidal and supratidal areas dominated by mangrove communities).	Map unit 1	12.1.3 Mangrove shrubland to low closed forest on marine clay plains and coastal estuaries.	Species commonly occurring in this area include <i>Avicennia marina</i> , <i>Aegiceras corniculatum</i> , <i>Ceriops tagal</i> , <i>Rhizophora stylosa</i> , <i>Bruguiera gymnorhiza</i> and <i>Excoecaria agallocha</i> . <i>Hibiscus tiliaceus</i> sometimes fringes the landward margins. This map unit covers the large mangrove areas to the west of the western cliffs and extends around the north-western point into the Morwong Beach area.
Basalt foreshores and nearby slopes and crests.	Map unit 5	12.5.2 <i>Eucalyptus tereticornis</i> , <i>Corymbia intermedia</i> on remnant Tertiary surface, usually near coast on deep red soils.	The canopy species includes <i>Eucalyptus tereticornis</i> , <i>E. siderophloia</i> , <i>Corymbia intermedia</i> and <i>Callitris columellaris</i> . This map unit covers the western cliffs and the north western bushlands.
Pure <i>Melaleuca quinquenervia</i> wetlands.	Map unit 6	12.3.5 <i>Melaleuca quinquenervia</i> tall open forest near coastal alluvial plains.	This map unit covers the headwaters of Curlew Creek and describes the wettest type of <i>Melaleuca quinquenervia</i> wetlands with almost a pure canopy of <i>M. quinquenervia</i> over a simple community typically dominated by sedges such as <i>Lepironia articulata</i> , <i>Baumea</i> spp. and the culturally significant fern <i>Blechnum indicum</i> .
<i>Melaleuca quinquenervia</i> / <i>Eucalyptus tereticornis</i> / <i>Lophostemon suaveolens</i> wetlands and riparian areas.	Map unit 7	12.3.6 <i>Melaleuca quinquenervia</i> , <i>Eucalyptus tereticornis</i> , <i>Lophostemon suaveolens</i> woodland on coastal alluvial plains.	This map unit covers the Melaleuca Wetlands Reserve area as well as an area within the private lands behind Main Beach.
<i>Eucalyptus racemosa</i> on areas of land zone 5.	Map unit 8c	12.5.3 <i>Eucalyptus tindaliae</i> +/- <i>E. racemosa</i> open forest on remnant Tertiary surface. Deep red soils.	<i>Eucalyptus tindaliae</i> , <i>E. siderophloia</i> , <i>E. tereticornis</i> and <i>Corymbia intermedia</i> can also dominate the canopy. <i>Lophostemon suaveolens</i> is also common where there is temporary water logging of the soil profile. This map unit is identified on large blocks in the centre of the island



Title:
Coochiemudlo Island - Vegetation Map Unit

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Coochiemudlo Island - Key Marine Habitats

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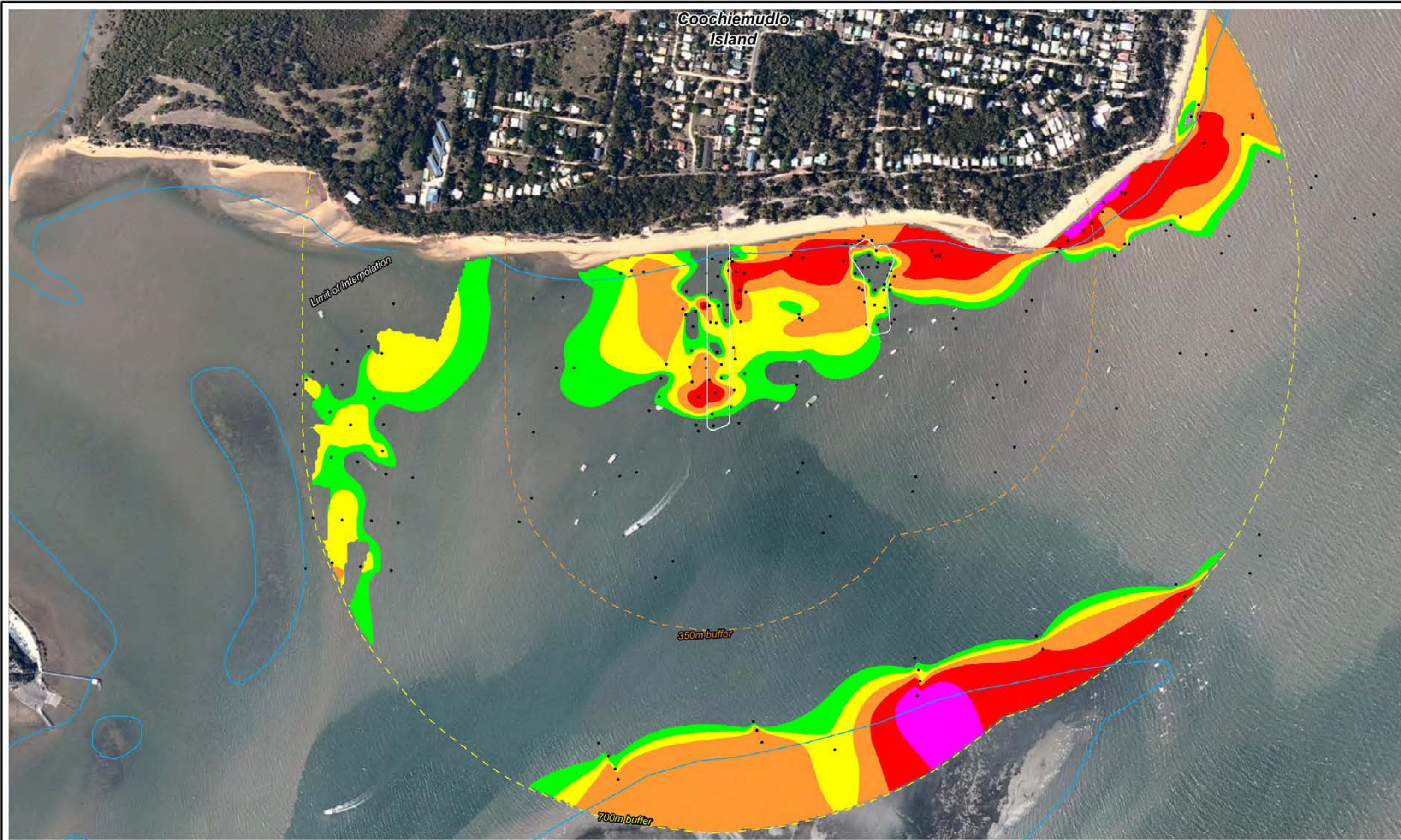
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- Data Points
- ▬ Channel Batters
- - - 350m buffer extent
- - - 700m buffer extent
- Lowest Astronomical Tide (Indicative Only)

Seagrass

- 1 - 2.5 % cover
- 2.5 - 5 % cover
- 5 - 10 % cover
- 10 - 20 % cover
- > 20 % Cover

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Cover of *Halophila ovalis* 2015

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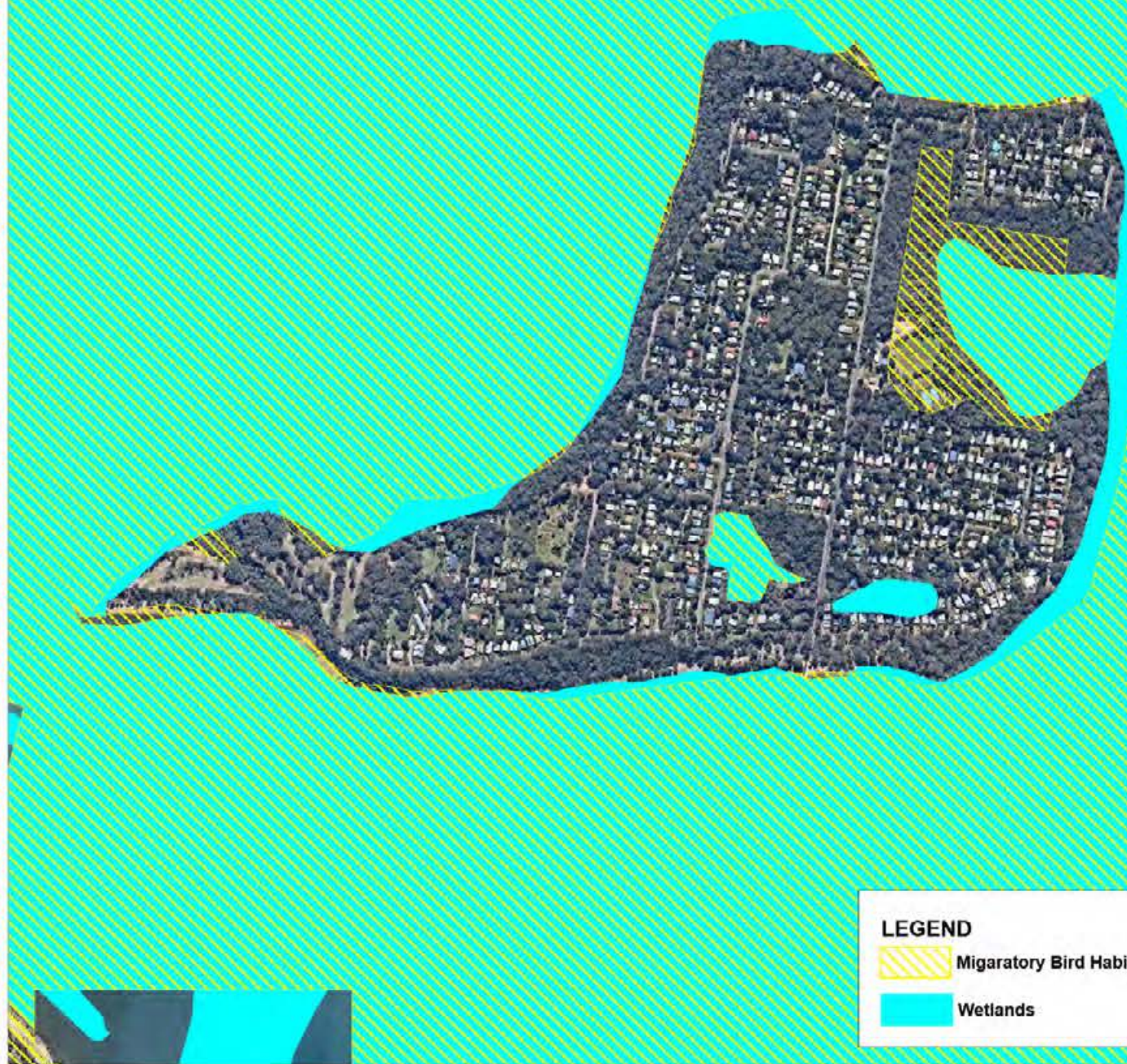


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LEGEND

-  Migratory Bird Habitat
-  Wetlands

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Coochiemudlo Island - Environmental Values

Figure:
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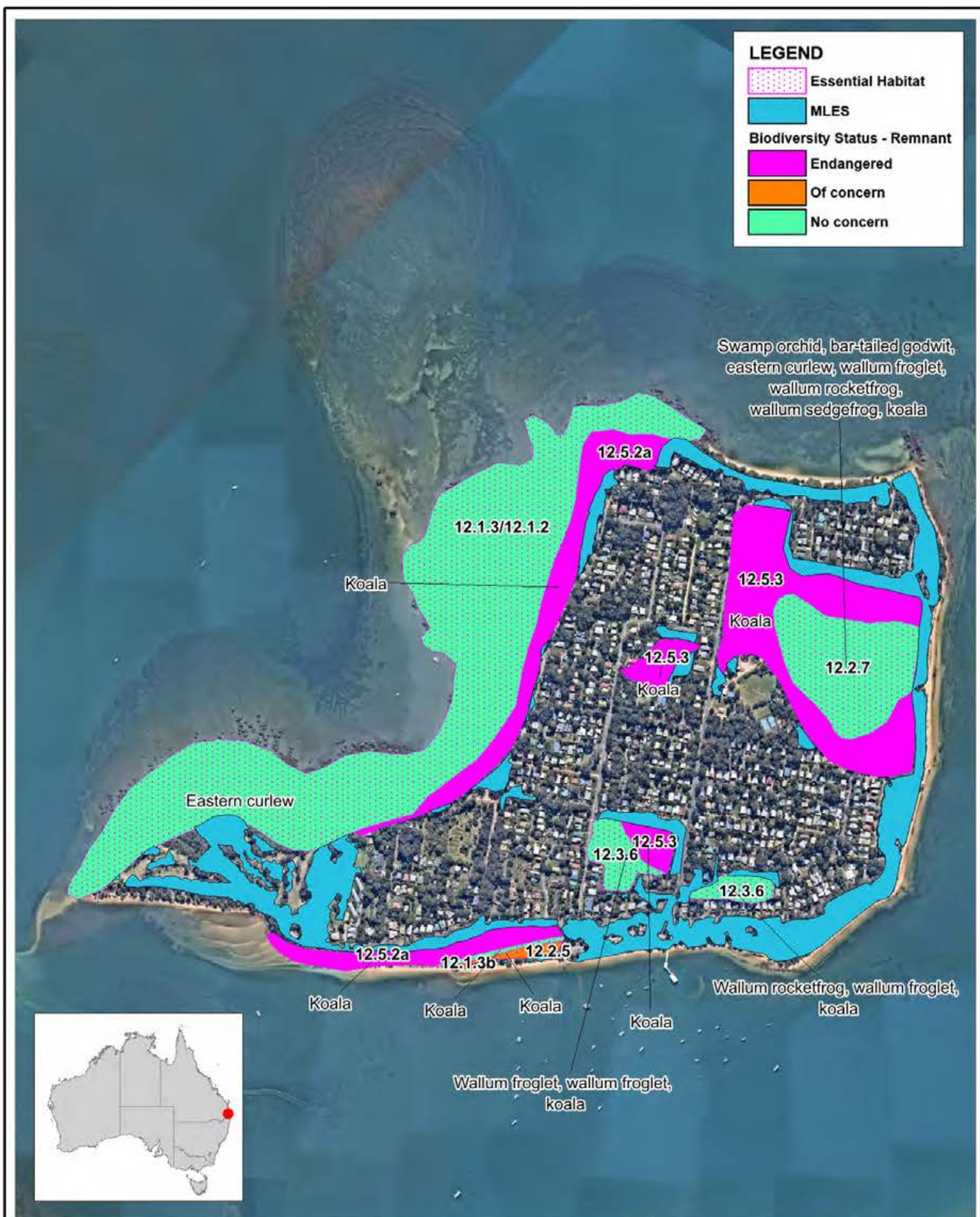
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Coochiemudlo Island - Remnant Vegetation, Essential Habitat and Matters of Local Environmental Significance

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2.1.1.2 Flora and Fauna

Wetlands and intertidal habitats on Coochiemudlo Island provide essential habitat for a large range of migratory bird species. Moreton Bay is internationally recognised as important for migratory birds as it supports at least 43 shorebird species and over 1% of at least nine migratory species flyway populations including the Critically Endangered bird species eastern curlew (*Numenius madagascariensis*) and curlew sandpiper (*Calidris ferruginea*). There are a range of summer and winter migratory species that visit the island due to the large number of invertebrates available. Wader surveys have found there to be a stable bush stone-curlew (*Burhinus grallarius*) population of approximately 200 individuals (Queensland Wader Study Group, 2010).

The seagrass beds around Coochiemudlo Island in Moreton Bay provide essential food to the local dugong (*Dugong dugon*) population. Moreton Bay was estimated to have just under 900 dugongs in 2011 (Department of Environment and Heritage, 2013). The seagrass areas in Moreton Bay also provide food for several turtle species including: green (*Chelonia mydas*), hawksbill (*Eretmochelys imbricata*), loggerhead (*Caretta caretta*), leatherback (*Dermochelys coriacea*), flatback (*Natator depressus*) and olive ridley (*Lepidochelys olivacea*). There are no known turtle nesting sites on Coochiemudlo Island.

The wetlands also provide habitat for several terrestrial species including reptiles, mammals and amphibians. The reptiles found in the island's wetlands include several species of snakes and skinks, while the amphibians include a few frog species and an invasive toad species. Most of Coochiemudlo Island's mammal population is comprised of a variety of bat species, and there are also bandicoots and flying foxes.

2.1.1.3 Melaleuca Wetlands Reserve

The melaleuca wetlands within and adjacent to Lot 2 on SP222653 are a key habitat value of the island, making up 15% of the total landmass. These wetlands are formally grouped as part of the Melaleuca Wetlands Reserve. Vegetation types within the reserve include:

- Frontal dune heath and scrub association
- Mixed eucalyptus/corymbia and melaleuca woodland
- Mixed eucalyptus/corymbia woodland with wallum understorey
- *Melaleuca quinquenervia* woodland/open forest with reeds, sedges and aquatic vegetation.

A fauna survey of the reserve conducted by Green in 2016 found a total of 12 mammal, 52 bird, nine reptile, three amphibian and 55 invertebrate species (Green, 2016). Species identified included bandicoots, flying foxes, microbats, bats and feral and domestic mammals, curlews, owl, kites, eagle, lorikeets, doves, kingfishers, honey eaters, whistlers, fantails and butcherbirds, and an assortment of skinks and snakes.

A water quality review of the reserve conducted by Deveco (2017) found the heavy metals (copper and zinc) levels to exceed the 95% protection of freshwater species. Heavy metals concentration in the area has been elevated for a long duration and is thought to have been impacting the ecosystem for over 16 years (Deveco, 2017).

2.1.2 Regulatory Values

Most of Moreton Bay is designated within the Moreton Bay Marine Park (MBMP). The land and waters of Coochiemudlo Island below high water are part of the Moreton Island to Broadwater habitat protection zone (HPZ) of the MBMP. This zone is gazetted under the *Marine Parks Act 2000* (MP Act) as an area intended for protection of marine habitat, such as benthic environment, reefs and seagrass. This zoning is shown in Figure 2-6.

A similar area of Moreton Bay is also designated under the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) as Wetland of International Importance ('Ramsar wetland'). This includes the intertidal areas of Coochiemudlo Island as well as the Melaleuca Wetlands Reserve. Ramsar wetlands are declared due to their importance as habitat for migratory shorebirds. The migratory shorebirds potentially utilising Coochiemudlo Island are described Table 2-2.

The marine waters surrounding Coochiemudlo as well as the Melaleuca Wetlands Reserve are also noted as high environmental significance (HES) waters on the map of referable wetlands. This indicates the importance of this area as wetland habitat. The extent of this is shown in Figure 2-6.

Of the different remnant vegetation communities of the island, two are listed as Endangered and one Of Concern under the *Vegetation Management Act 1999* (VM Act) (Figure 2-5). These are also designated as Essential Habitat for seven threatened species, being:

- Eastern curlew (*Numenius madagascariensis*)
- Bar-tailed godwit (*Limosa lapponica*)
- Wallum sedgefrog (*Litoria olongburensis*)
- Wallum rocketfrog (*Litoria freycineti*)
- Wallum froglet (*Crinia tinnula*)
- Koala (*Phascolarctos cinereus*)
- Lesser swamp orchid (*Phaius australis*).

Table 2-2 identifies the threatened and migratory species that could occur in the coastal environment of Coochiemudlo Island based on surveys discussed in Section 2.1.1 and the results of Protected Matters Search Tool and Wildlife Online searches. This include species that do not occur within tidal environments but are within wetland environments that could be impacted by erosion events (e.g. increased penetration of marine waters).



Title:

Coochiemudlo Island - Marine Protected Areas and Associated Values

Figure:

2-6

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Environmental, Cultural and Legislative Context

Table 2-2 Threatened and Migratory Species Potentially Occurring in Study Area8

Common name	Scientific name	EPBC status	NC status
<i>Occur in coastal and/or marine environment*</i>			
Common sandpiper	<i>Actitis hypoleucos</i>	Migratory	Special Least Concern
Ruddy turnstone	<i>Arenaria interpres</i>	Migratory	Special Least Concern
Sharp-tailed sandpiper	<i>Calidris acuminata</i>	Migratory	Special Least Concern
Red knot	<i>Calidris canutus</i>	Endangered & Migratory	Special Least Concern
Curlew sandpiper	<i>Calidris ferruginea</i>	Critically Endangered & Migratory	Special Least Concern
Pectoral sandpiper	<i>Calidris melanotos</i>	Migratory	Special Least Concern
Lesser sand plover	<i>Charadrius mongolus</i>	Endangered & Migratory	Special Least Concern
Gull-billed tern	<i>Gelochelidon nilotica</i>	Migratory	Special Least Concern
Caspian tern	<i>Hydroprogne caspia</i>	Migratory	Special Least Concern
Western Alaskan bar-tailed godwit	<i>Limosa lapponica baueri</i>	Vulnerable & Migratory	Special Least Concern
Northern Siberian bar-tailed godwit	<i>Limosa lapponica menzbieri</i>	Critically Endangered & Migratory	Special Least Concern
Eastern curlew	<i>Numenius madagascariensis</i>	Critically Endangered & Migratory	Special Least Concern
Whimbrel	<i>Numenius phaeopus</i>	Migratory	Special Least Concern
Eastern osprey	<i>Pandion cristatus</i>	Migratory	Special Least Concern
Pacific golden plover	<i>Pluvialis fulva</i>	Migratory	Special Least Concern
Crested tern	<i>Thalasseus bergii</i>	Migratory	Special Least Concern
Grey-tailed tattler	<i>Tringa brevipes</i>	Migratory	Special Least Concern
Common greenshank	<i>Tringa nebularia</i>	Migratory	Special Least Concern
Terek sandpiper	<i>Xenus cinereus</i>	Migratory	Special Least Concern
Loggerhead turtle	<i>Caretta caretta</i>	Endangered & Migratory	Endangered
Green turtle	<i>Chelonia mydas</i>	Vulnerable & Migratory	Vulnerable
Leatherback turtle	<i>Dermochelys coriacea</i>	Endangered & Migratory	Endangered
Hawksbill turtle	<i>Eretmochelys imbricata</i>	Vulnerable & Migratory	Endangered
Olive ridley turtle	<i>Lepidochelys olivacea</i>	Endangered & Migratory	Endangered

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Common name	Scientific name	EPBC status	NC status
Flatback turtle	<i>Natator depressus</i>	Vulnerable & Migratory	Vulnerable
Dugong	<i>Dugong dugon</i>	Migratory	Vulnerable
<i>Occur in wetland environment immediately adjoining tidal limits*</i>			
Lesser swamp-orchid	<i>Phaius australis</i>	Endangered	Endangered
Wallum froglet	<i>Crinia tinnula</i>	-	Vulnerable
Wallum rocketfrog	<i>Litoria freycineti</i>	-	Vulnerable
Wallum sedgefrog	<i>Litoria olongburensis</i>	Vulnerable	Vulnerable

*Coastal and marine species are only included where they rely on intertidal habitat for breeding, roosting or feeding purposes or where significant changes to shoreline structures may impact on marine habitat used for breeding, roosting or feeding purposes (i.e. seagrass). Relevant wetland species are those reliant on freshwater wetlands adjoining coastal areas that could become inundated with tidal waters, and thereby inhabitable, following significant erosion.

2.1.3 Heritage and Amenity

Coochiemudlo Island supports a variety of cultural and heritage values of both Indigenous and European origin.

The name Coochiemudlo is derived from the Aboriginal words 'kutchie' and 'mudlo' meaning the place of red stone (Rob Friend & Associates Pty Ltd 2004). The Coochiemudlo red ochre was used for ceremonies amongst the Moreton Bay Indigenous communities. Aboriginal people are thought to have used Coochiemudlo Island for thousands of years before European settlement for hunting and gathering activities to source items such as fish, shellfish, crabs, waterlilies, bungwall ferns and honey (Rob Friend & Associates Pty Ltd 2004). Reptiles and dugongs were also hunted in the bay. Physical evidence of the use of Coochiemudlo Island is still present today through artefacts such as shell middens Figure 2-7).

A Cultural Heritage Management Plan (CHMP) Agreement has been entered into between the Quandamooka Yoolooburrabee Aboriginal Corporation (QYAC) and Council over the Coochiemudlo Foreshore. This identifies several cultural heritage features, including:

- Western (West Coast) Ridgeline – marked as a high risk area for cultural heritage finds.
- Intact melaleuca and eucalypt forest – marked as moderate risk areas for cultural heritage finds.
- East Coast Site Complex – contains low density artefacts and a scar tree but with potential for further artefact scatter.
- North Coast Site Complex – contains artefact scatter and scar trees.
- Southwest Artefact Scatter – contains low density artefact scatter.
- Red Rock Resource Area – has potential for cultural heritage finds in addition to having inherent heritage significance as an area of red rock and volcanic soils.
- Isolated artefacts throughout the island foreshore.
- Various other scar trees.

The location of these features includes overlap with areas that are likely subject to shoreline erosion actions. These collective features indicate the importance of the foreshore of Coochiemudlo Island to historical indigenous activity and its continued significance to the Traditional Owner community.

The European heritage values of Coochiemudlo predominately stem from Matthew Flinders' brief landing on the island in 1799 on Norfolk Beach. European settlement of the island began in the late 19th Century with a small subsistence farm (Rob Friend & Associates Pty Ltd 2004). During World War II the present-day golf club was a training ground for the 43rd Landing Craft Company of the Royal Australian Engineers. There are several artefacts and heritage sites around the island including the Morton family steps, evidence of the wooden railway constructed in the early 1940's and a number of jetty sites (Figure 2-7).

Morton's steps and jetty are local heritage places located on the western side of Coochiemudlo Island. These heritage sites are remnants from Doug Morton's production of a selection of produce, cattle and pig farm that was transported from Morton's farm on Coochiemudlo Island to Brisbane by

Environmental, Cultural and Legislative Context

Captain John Burke. Morton then turned the jetty and farming into a tourist venture, bringing tourists from Brisbane to Coochiemudlo Island and then selling them fruit from his farm.

The Coochiemudlo Island Community Hall was built in 1973 to hold community events and meetings and was funded by the Coochie Island Reserve Club fundraising and the Redland Shire Council. The initial opening of the first stage of the hall (Elliot Hall) was in 1973 and was named after Mr Gerald Elliot, the former President of the Progress Association. Stage two of the hall opened in 1991 and is used for meetings, church, dancing and other community functions.

The predominant land uses of the island are residential, recreation and tourism. Coochiemudlo Island is a recreational destination during the warmer months and receives both local and regional tourists. The island's recreation value is a result of its scenic landscape, secluded beaches, safe swimming and proximity to Queensland's capital.

Coochiemudlo Island's Emerald Fringe is a unique feature of the island that has high social significance. The reserve is approximately 30m wide and lies between the commercial and residential allotments in the centre of the island and the water's edge. The Emerald Fringe originated from Queensland Surveyor General's directions in 1878 to leave a publicly owned reserve that encircles the island. The Emerald Fringe was recently included in the local heritage listing for the Redland City Council on the basis of the following three criteria (Redland City Council, 2018):

- Criteria A: The place is important in demonstrating the evolution or pattern of the region's history.
- Criteria E: The place is important to the region because of its aesthetic significance.
- Criteria G: The place has a strong or special association with a particular community or cultural group for social, cultural or spiritual reasons important to the region.

The Emerald Fringe is important in demonstrating the evolution or pattern of Queensland's history by being an example of an intact coastal reserve from the Surveyor General's requirement of a coastal reserve. This intact encircling esplanade is rare and is therefore considered to demonstrate a rare aspect of Queensland's heritage. The fringe is aesthetically significant due to its diversity of natural beauty that it provides in land, beach and seascape environments as well as a diverse range of ecosystems. The vegetation fringe provides habitat for various flora and fauna. This feature has high community significance as it is the location of major island events, such as the commemoration of Flinders' Day, which is an annual celebration of the landing on Norfolk Beach. The fringe also provides privacy to residents. The Emerald fringe is a part of Coochiemudlo Island's identity and hold aesthetic, environmental and indigenous values. Most of the esplanade was zoned as recreational and environmental reserve within the 2000s.

As part of the Emerald Fringe, Coochiemudlo Island Foreshore Park is a designated open space area that provides recreational amenities for: picnicking, sport, festivals and events. This area was designated open space by the Redland Open Space Strategy 2026 (2012) for a number of reasons including: human health benefits, connectivity, green living, biodiversity and cultural heritage. Additionally, the area is a T1 Destination Park, recognising its importance for local recreation.

LEGEND

Heritage Sites

- Care free remains
- Caves
- Community Hall, Jetty and Steps
- Flinders landing
- Military kitchen remains
- Moretone walkway
- Mortons steps and stone jetty
- Possible smoking tree
- Scar tree
- Shell midden
- Stonefish traps
- Tramway remains

Recreation Areas

- Coochiemudlo Foreshore East
- Coochiemudlo Foreshore North
- Doug And Mary Morton Reserve
- Isle of Coochie Golf Course
- Laurie Burns Recreation Reserve
- Melaleuca Wetlands



Title:
Coochiemudlo Island - Heritage Values

Figure:

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Approx. scale



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2.2 Planning and Legislative Framework

2.2.1 Planning and Permissibility

A SEMP is a tool prepared under the Coastal Management Plan (CMP) that, if approved, can be relied on to support applications for coastal work approvals (see below). The SEMP, and associated management options, should be prepared in accordance with the CMP and other prevailing planning instruments. Additionally, any actions proposed for shoreline erosion management should be compatible with the policy and regulatory framework set under state and federal instruments (see below). The relevant elements of this framework in the context of the SEMP are set out below:

- Management should preference the maintenance of natural processes as far as practicable, with protection typically only acceptable where needed to protect the safety of people and integrity of assets or infrastructure. Management options should not be costlier than the infrastructure or assets they intend to preserve.
- Where retreat and/or relocation are not possible, management should preference 'soft' approaches where possible (e.g. beach nourishment, reprofiling), with 'hard' engineering approaches only adopted where these softer approaches are not feasible. Hard engineering structures should generally not be used to protect assets that are not built or trunk infrastructure.
- No works should be undertaken that will cause reclamation. This include construction of hard structures significantly below the high-water mark and backfilling. Reclamation works such as these are not supported in the Moreton Bay Marine without significant justification and amendment to regulated boundaries (i.e. legislative changes).
- The values of Ramsar wetlands, including those of the Melaleuca Wetlands Reserve, should be preserved from impacts associated with anthropogenic activities.
- Sediment for beach nourishment must be sourced from outside of the marine park, if possible, or taken from navigation channels as part of maintenance dredging works.
- Management should avoid works that disturb or obscure items of Aboriginal cultural heritage. If such disturbance is necessary, it requires consultation and agreement with the relevant Aboriginal parties.
- Where possible, natural assets and public use areas, including beaches, should be retained as part of shoreline management works. However, this should be managed in balance with the principles above.
- Similarly, the Emerald Fringe should be retained where possible due to its heritage values and the current consideration of this feature as a local heritage site (Redland City Council 2018).
- Management should avoid works that, if undertaken, would cause the loss of important breeding and nesting habitat for threatened species.

Note that the above is the *current* prevailing framework. The authorisation of a SEMP and the approval of specific management actions requires further assessment from relevant regulatory agencies, including the Department of Environment and Science. Thus, there are opportunities for further discussion of preferred policy rules at these points. Therefore, except where an action is

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explicitly prohibited or not preferred under legislation (which is unlikely to change), management measures not completely aligned with the framework can be considered.

2.2.2 Approvals and Duties

Shoreline management works in Queensland are regulated primarily under the following systems:

- *Environmental Protection Act 1994* (Qld) – establishes a general environmental duty of care and pollution licencing conditions. This prevents taking action that could cause environmental harm except where licenced under the Act or other legislation, or (if not licencing regime exists) where all reasonable and practical measures are taken to avoid harm. Any works not requiring a licence, therefore, must account for the potential environmental harm they could cause. There is no duty, however, to undertake action to prevent natural loss of environmental values (e.g. erosion causing loss of coastal vegetation).

The Act establishes a framework for Environmental Authorities required for environmentally relevant activities (ERAs) including dredging and placement. Works involved with sourcing and placing sand for beach nourishment purposes, therefore, may require an Authority under the Act.

- *Planning Act 2016* (Qld) – establishes a system for obtaining planning permits, including those triggered under some other legislation and local planning scheme. For shoreline erosion management relevant triggers for permits include:
 - Tidal works, including beach nourishment, groynes and seawalls.
 - Works interfering with state coastal land, including dune management works.
 - Disturbance of marine plants, including seagrass, mangroves, saltmarsh and melaleucas (where occurring below highest astronomical tide).
 - Bulk earthworks.
 - Disturbance of state-listed heritage features.
- *Coastal Protection and Management Act 1995* (Qld) – requires Quarry Material Allocation for sand that is to be removed from below high-water mark (e.g. placement of dredged material onshore).
- *Marine Parks Act 2000* (Qld) – requires Marine Park Permit for works within the marine park, including any works below high-water mark.
- *Aboriginal Cultural Heritage Act 2003* (Qld) – establishes a duty of care to not impact on known and unknown cultural heritage items. Where there is a risk of activities causing impacts (e.g. fresh excavations, works around scar trees) works must either adhere to the duty of care guidelines or be undertaken in agreement with the relevant Aboriginal party.
- *Nature Conservation Act 1992* (Qld) – requires permits for works that may impact on protected species, especially where works relate to relocating species and breeding habitat (e.g. nests).
- *Environment Protection and Biodiversity Conservation Act 1999* (Cth) – requires referral, assessment and potential permits for any works that could significantly impact on matters of national environmental significance (MNES) such as the Moreton Bay Ramsar wetlands and protected species.

3 Coastal Processes

3.1 Beach Naming Convention

While local names exist for different segments of Coochiemudlo Island's foreshore the Island only has three officially named beaches.

- Main beach - covers the entire southern foreshore from west of the golf course to the rock outcrop east of the ferry.
- Norfolk Beach - covers the eastern foreshore from the eastern edge of Main Beach to the most north-eastern rock outcrop.
- Morwong Beach - covers the northern foreshore.

Where identification or discussion of smaller beach segments or compartments than those officially named is required, and to avoid causing confusion by using local names, the following naming convention has been adopted. These descriptions will be used in the SEMP for identification purposes only and no attempt is being made to alter existing official beach names.

Official beach names and extents and local topographical features used to identify beach segments are shown in Figure 3-1.

- Morwong Beach – covering the northern sandy beach between the start of the mangroves to the west and the rock outcrop to the east.
- North-eastern Norfolk Beach – covering the north-east aligned beach north of the wetlands and south of the most north-eastern rock outcrop.
- Norfolk Beach fronting the wetlands – segment of beach in front of the wetlands.
- Norfolk Beach fronting Victoria Parade East – eastern aligned segment of beach north of the southern rock outcrops and south of the wetlands.
- South-eastern Norfolk beach – south-eastern aligned section of beach between the 2 most southern rock outcrops.
- Main Beach east of the ferry terminal – between the ferry terminal and the rock outcrop at the southern end of Norfolk beach.
- Main beach between the ferry terminal and barge ramp – covering the beach west of the ferry terminal and east of the barge ramp.
- Main beach between the barge ramp and red cliffs – the segment of beach east of the outcropping red rocks and west of the barge ramp.
- Main Beach fronting the red cliffs – beach in front of the outcropping red rock and red soil slope above.
- Main Beach fronting the golf course – most western section of the southern beach in front of Doug and Mary Morton Reserve.



LEGEND

- Topographical features
- Beach Extent

Title:
Coochiemudlo Island official beach names

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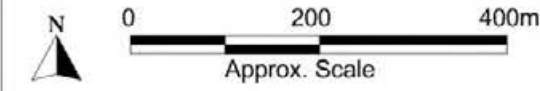


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3-1

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3.2 Water Level Variations

3.2.1 Astronomical Tide

Tides within Moreton Bay are mesotidal (i.e. variation of 2 to 4 m) and predominantly semi-diurnal with, on average, two distinct high and low tides per day. Tidal planes for the Brisbane Bar (closest Standard Port) and for Victoria Point are shown in Table 3-1.

Table 3-1 Study area tidal planes in metres above Lowest Astronomical Tide (Maritime Safety Queensland, 2019)

Location	Time Difference (minutes)		Highest Astronomical Tide (HAT)	Mean High Water Springs	Mean High Water Neaps	Australian Height Datum	Mean Sea Level	Mean Low Water Neaps	Mean Low Water Springs	Ratio
	HW	LW		(MHWS)	(MHWN)	(AHD)	(MSL)	(MLWN)	(MLWS)	
Brisbane Bar	Standard Port		2.73	2.17	1.78	1.24	1.27	0.76	0.36	1.00
Victoria Point	14	18	2.96	2.38	1.97	1.41	1.39	0.91	0.5	1.04

3.2.2 Extreme Water Levels

Elevated water levels occur during storm tide events due to the combination of decreased atmospheric pressure, wind set-up and wave action. Storm tide levels represent still water levels due to the combination of storm surge and astronomical tide variations.

Redland City Council, Logan City Council and Moreton Bay Regional Council commissioned Cardno Lawson and Treloar to undertake a Storm Tide Hazard Modelling Study for the Moreton Bay Region, completed in 2009. A summary report of the model study was prepared by Cardno in 2011. Victoria Point was included in the modelling but not Coochiemudlo Island, therefore for this study the results for Victoria Point have been assumed to apply to Coochiemudlo Island. The study investigated the combined effects of astronomical tide, storm surge, and wave-induced effects (wave set-up), and the possible impacts of enhanced-Greenhouse climate change. Storm tide levels in Moreton Bay are assessed through a Monte-Carlo type numerical modelling analysis of wind and pressure fields, tidal forcing, hydrodynamics and waves.

Design water levels at Victoria Point were derived by Cardno Lawson and Treloar (2009) and reported in Cardno (2011) as part of a regional storm tide risk assessment. Representative non-cyclonic and cyclonic design water levels inclusive of wave setup are provided in Table 3-2. Note that non-cyclonic conditions dominate up to the 200 year return period.

Subsequent to the Cardno Lawson and Treloar assessment, inundation levels and mapping were refined by Water Technology in 2017. The Water Technology work:

- Updated the Cardno 2009/2011 storm tide levels to the 2016 planning horizon to account for sea level rise.

- Provided a more realistic estimate of the 1% AEP (i.e. 1 in 100 year) storm tide elevation by taking into account the joint probability of cyclonic and non-cyclonic events occurring. This was applied as a standard 23 mm increase on the Cardno 2009/2011 storm tide levels. It is unclear how the increase was applied to the Cardno 2100 storm tide levels.
- Prepared new mapping based on a 2014 Digital Elevation Model (DEM) which used a 1 m grid rather than the 5 m grid developed for the 2009 DEM used by Cardno (2011). It is known that within Redland City the 2014 LiDAR capture (i.e. the source of the elevation data) only covered mainland areas, therefore for Coochiemudlo Island the 1 m DEM was interpolated from the 2009 5 m DEM. This coarse data has a vertical order of accuracy of +/- 0.15 m (Geoscience Australia, 2011).

The refined storm tide mapping was ultimately reflected in the Flood and Storm Tide Hazard Overlay of the Redland City Plan (version 1). Detailed refined storm tide levels around Coochiemudlo Island were not provided for use in this project.

Given that the increases in inundation levels between Cardno Lawson and Treloar (2009) / Cardno (2011) and Water Technology (2017) are within the order of accuracies of the survey data, for the purposes of the SEMP, the Cardno Lawson and Treloar (2009) / Cardno (2011) storm tide inundation levels have been adopted.

Table 3-2 Non-cyclonic and cyclonic design storm tide level at Victoria Point including wave setup (Reporting site RL-033, Cardno, 2009)

	20 yr (mAHD)	50 yr (mAHD)	100 yr (mAHD)	200 yr (mAHD)	500 yr (mAHD)	1,000 yr (mAHD)	10,000 yr (mAHD)
Non-cyclonic	2.07	2.15	2.21	2.26	2.34	2.39	2.57
Cyclonic	1.99	2.10	2.18	2.27	2.38	2.46	2.73

3.3 Wind Climate

Long-term wind data recorded at the Bureau of Meteorology (BOM) Banana Bank North Beacon weather station (station number 40925) was analysed. The wind rose of average winds for this site is provided in Figure 3-2 and shows the directional spread of wind speed. This weather station is located approximately 4 km north of Coochiemudlo Island, and is positioned on a beacon over water. The wind speeds are therefore expected to be higher than those observed at land-based locations. Small changes to wind direction would also be expected as winds move over the local terrain.

The variation in wind climate for the summer (December to February), autumn (March to May), winter (June to August) and spring (September to November) seasons is also shown in Figure 3-2. The region experiences a seasonal wind climate. Northerly winds occur more frequently in spring and summer, whereas southerly winds are more frequent in winter and autumn. Winds also tend to be stronger over the spring and summer period.

There have been some suggestions that the ambient wind direction may have changed in recent times (post 1990). However, as beach erosion is mostly associated with extreme events (discussed in Section 3.5 and Section 4.4) it is not considered to be of sufficient relevance to this study to warrant further detailed investigation.

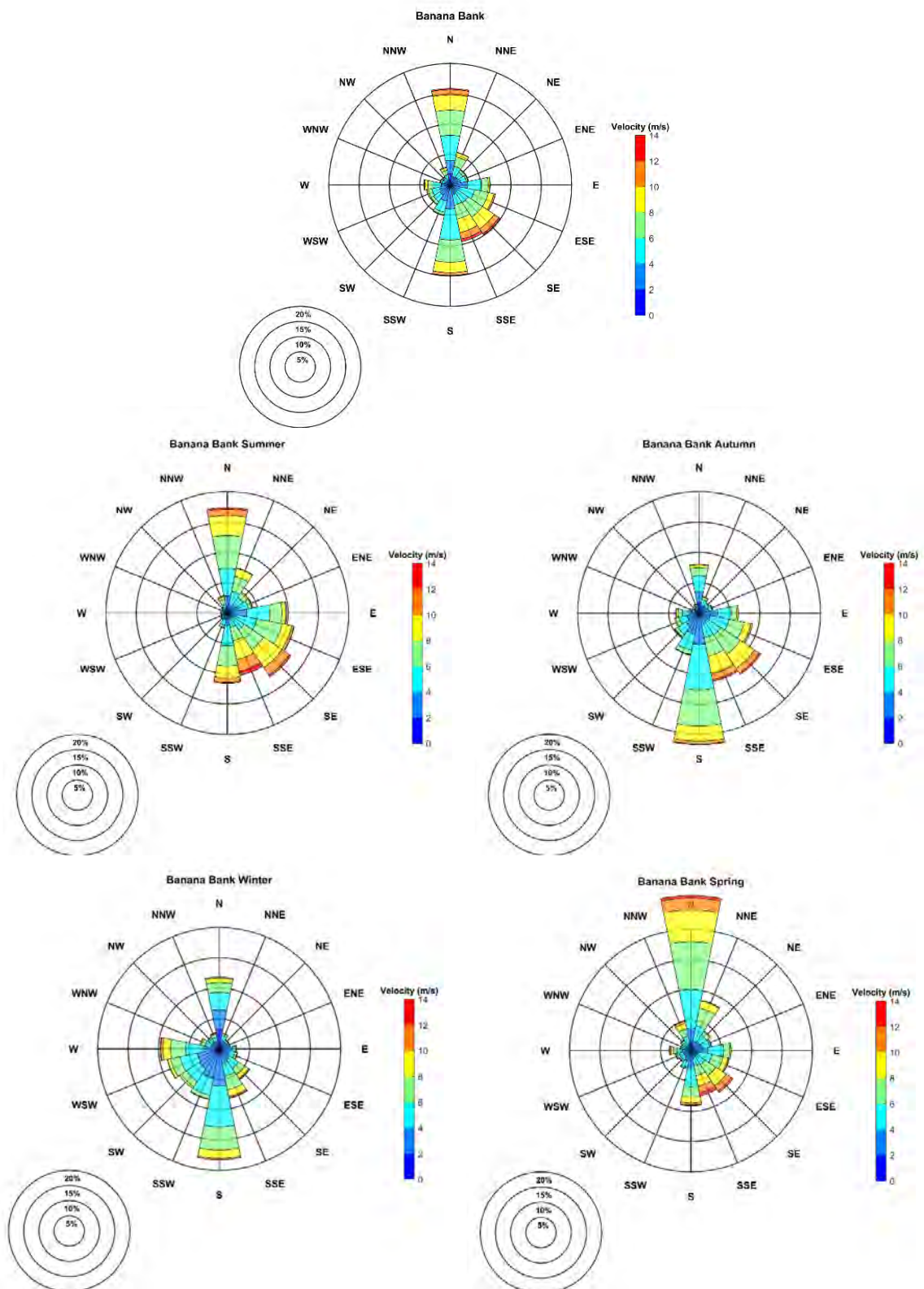


Figure 3-2 Long-term average winds (2002 – 2017) Banana Bank
All records (top), Summer (middle left), Autumn (middle right), Winter (bottom left) and Spring (bottom right)

3.4 Wave Climate

Coochiemudlo Island is sheltered from “swell” waves by North Stradbroke and Moreton Islands. The ocean swell energy that enters Moreton Bay and reaches the bay shorelines is substantially attenuated by the processes of refraction, diffraction, bed friction and breaking across the shallow shoals at the bay entrances.

Moreton Bay is dominated by waves generated by winds from within the bay itself. The available fetch lengths and depths are limited and restrict wave development substantially compared to the ocean. The height and direction of Moreton Bay waves are determined directly by the prevailing winds and are highly seasonal in nature. These small “sea” waves can develop quickly with the onset of stronger local winds and, at certain times of the year, substantial daily variability may be observed.

As no directly recorded wave data is available for Coochiemudlo Island a 10-year wave hindcast has been undertaken to assess the long-term wave climate, which is discussed further in Section 4.2.

3.4.1 Extreme Wave Climate

Extreme wave conditions were derived by Cardno Lawson Treloar (2009) as part of the regional storm tide risk assessment. Representative non-cyclonic and cyclonic significant wave heights for Victoria Point are provided in Table 3-3.

**Table 3-3 Non-cyclonic and cyclonic significant wave heights for Victoria Point
(Reporting site RL-033, Cardno, 2009)**

	20 yr (m)	50 yr (m)	100 yr (m)	200 yr (m)	500 yr (m)	1,000 yr (m)	10,000 yr (m)
Non-cyclonic	0.65	0.68	0.70	0.72	0.74	0.76	0.83
Cyclonic	0.99	0.99	0.99	0.99	0.99	0.99	0.99

3.5 Erosion Processes

3.5.1 Sediment Transport Mechanisms

Sediment transport within Moreton Bay is primarily driven by tidal currents and local wind waves. There are two considerations for sand transport in the coastal zone: cross-shore and longshore transport, which are described below. Although analysed separately, these processes will often act together, particularly in storm conditions.

Sediment transport may be limited by several factors. Beach sand deposits are thin in many places on Coochiemudlo Island, overlying a heterogeneous substrate composed of solid rock, boulders, pebbles, indurated sand, mangrove “mud” with mangrove stumps and roots, conglomerate indurated sand/mud with pebbles embedded in it, as well as pebbles on the beach face, particularly in depressions. Shells and coral are also found in/on the Island’s beaches, particularly Morwong Beach.

The Norfolk Beach Shoreline Erosion Study (BMT WBM 2015) identified five rocky reefs/headlands on the eastern side of the island that control beach alignment, as shown in Figure 3-3. Sand movement along the shoreline is influenced by the degree of exposure of the rocky reefs/headlands and may be significantly different at high tide compared to low tide.



Figure 3-3 Control points for beach alignment (BMT WBM 2015)

3.5.1.1 Cross-shore Sediment Transport

Cross-shore sand transport is generally associated with:

- Rapid erosion of sand from the upper shoreline area during large storm wave events, with the sand being transported down the beach profile where it is commonly deposited as a sand bar located in the vicinity of the wave break area; and
- Subsequent slow transport of the eroded sand back to the upper shoreline through combined wave and wind processes, often occurring over many months or several years.

On dynamically stable shorelines or beaches there is a balance in the amount of sand that is taken offshore and subsequently returned to the upper beach.

3.5.1.2 Longshore Sediment Transport

Longshore sand transport results predominantly from waves breaking at an angle to the shore, which generates a current running parallel to the shoreline. Wind and tide may also contribute to the generation of currents near the shoreline. Longshore transport can therefore occur in either direction along a beach depending on the wave conditions. Sand transportation is distributed across the surf zone and typically peaks near the wave break point where the wave height, longshore current and bed shear are greatest.

Shoreline compartments will remain stable in the long term (without net recession or accretion) where there is a balance between the sand entering the system and the sand leaving the system. Long-term recession of a sandy beach is usually the result of a continuing net loss of sand from the beach compartment. This arises when more sand is leaving than entering the beach compartment. Recession tends to occur when:

- Outgoing longshore transport from a beach compartment is greater than the incoming longshore transport;
- Sand supply is reduced by sediment sinks that trap sand (e.g. rivers or creeks), or permanent sand removal from the active beach system (e.g. through sand sourcing activities); and/or
- There is a landward loss of sediment by aeolian (windborne) transport.

A beach may remain stable (without net recession or accretion) where the longshore sand transport is uniform along the coast. However, where there are differentials in the rates of longshore transport, including any interruption of the sand supply to an area, the beach will erode or accrete in response. Because longshore and cross-shore transport coexist, progressive net sand losses due to a longshore transport differential may not be observed until storm erosion occurs, when less sand is subsequently returned to the upper beach than was in place prior to the storm.

3.5.1.3 Aeolian Sand Transport

The beaches of Coochiemudlo Island are exposed, not only to waves, but also to seasonally strong winds and storm winds. Whereas wave driven sediment transport is likely to be greatest at high tide, strong winds are likely to have the most impact on the beach when the tide is low and the sand is dry. Sand transport by the wind alone is called aeolian sand transport and it is generally accepted that, except on open beaches with very high dunes, the aeolian sand transport is of a much lower rate than wave induced sand transport.

The direction of aeolian sand transport will align generally with the prevalent wind. This may coincide with the direction of wave induced transport as the waves are generated wind, although they may change direction by refraction in shallow water. However, aeolian transport will not occur when water covers the beach or when the sand is wet. Similarly, wave transport can only occur below the water when waves are present.

Noting the height of the vegetation along the eastern, northern and southern shorelines, it is likely that dry sand will mainly be transported when the wind is blowing along the beach rather than perpendicular to the beach, as the wind will flow up over the vegetation causing lower velocities at ground level near the base of the vegetation.

Therefore, it is expected that aeolian sand transport will be along the beaches in similar directions to the wave induced transport but likely at different times and directions, i.e. seasonally and when beaches are dry. Because of the many variations to the elements required to initiate aeolian sand transport no attempt has been made to quantify this process in this report.

3.5.2 Long-Term Erosion Assessment

Long-term shoreline changes have been assessed using georeferenced State government aerial imagery for Coochiemudlo Island from 1955 and 1997. It is important to note that at the time of the 1955 imagery there was very little development on Coochiemudlo Island. Georeferencing of older imagery relies on a high level of confidence in the positioning of consistent features that are visible in other georeferenced images, such as distinctive rock outcrops, or unchanged built development. The 1955 imagery has therefore been used for a qualitative assessment only, due to a lack of confidence in the accuracy of the shoreline position.

The 1997 imagery has a reported confidence of +/- 5 m accuracy (Department of Natural Resources, Mines and Energy, 2016). Ortho-rectified aerial images obtained from Nearmap for January 2013 (pre-Tropical Cyclone (TC) Oswald) and November 2018 show horizontal discrepancies and accuracy is expected to be in the order of +/- 5 m.

The approximate seaward edge of vegetation for 1955, 1997, 2013 and 2018 has been used as an indicative shoreline to assess erosion or accretion trends. While all care has been taken to provide an accurate assessment, difficulties associated with determining the shoreline position include overhanging vegetation (tree canopy), shadows, and coarse image resolution (pixelization) of images. As such, the erosion/accretion values discussed below are approximate. Beach names are as per those referenced in the Norfolk Beach Shoreline Erosion Study (BMT WBM, 2015).

It is noted that an image has been shared by Coochiemudlo Island Coastcare (Figure 3-4) indicating erosion of approximately 20 m on the eastern beaches since the survey of the high water mark in 1886 and may indicate significant changes between 50 and 100 years ago. Subsequent information provided by Mr Keith Slack confirms that this map shows the original survey plan (C3281) showing the surveyed High Water Mark as defined by surveyor George McDonald in 1886, georeferenced with the Digital Cadastral Data Base and Nearmap photography dated October 2011. The oldest aerial photography available through the Queensland Governments online collection (<https://qimagery.information.qld.gov.au/>) is the 1955 imagery discussed above it is not possible to confirm the degree of change taking place prior to 1955. In any case future management options should consider the recent changes as indicated below.

Beach profiles were surveyed by Redland City Council officers on Main Beach east of the ferry terminal in 2016 to 2018 and Norfolk Beach fronting Victoria Parade East in 2013 to 2018. The most landward surveyed point is not fixed between surveys and the survey extent is limited to the portion of the beach above the water level at the time of the survey, ranging between approximately -0.5 m to -1.5 mAHD. The surveys indicate that the width of the upper beach fluctuates annually, however were insufficient to confidently identify trends of beach recession or accretion, or lack thereof.

Analysis of over 60 years of aerial photography has indicated minimal change over this period to the majority of the Islands beaches, with the exception of the north-eastern segment of Norfolk Beach, discussed in further detail below. An investigation into bay wide changes based on anecdotal reports prior to aerial photography becoming available is not expected to add significant value to an assessment of potential shoreline management options for Coochiemudlo Island. and is beyond this scope of this project.



Figure 3-4 Comparison of the North East Corner High Water Mark (Provided by Coochiemudlo Island Coastcare and courtesy of Mr Keith Slack)

3.5.2.1 Morwong Beach and North-eastern Norfolk Beach

Consistent accretion of up to 14 m was observed along the majority of Morwong beach between 1955 and 2018. Aerial images show a build-up of sand on the intertidal area at the eastern end of the beach. It is likely that this sand has been eroded from north-eastern Norfolk Beach under south-easterly waves. Once on Morwong Beach it is progressively transported westward along the beach. A separate build-up of sand is visible across the inter-tidal area in the centre of the beach, close to a small ephemeral creek outlet that channels stormwater and drains the dune system following heavy rainfall. The proximity of this build-up close to the creek mouth indicates that the sand has been scoured from the upper beach by creek flows.

Aerial images from 1955 and 1997 show the rock outcrop (Control Point 5) connected to Morwong and Norfolk beaches by a sand spit forming a tombolo. Loss of vegetation on the rock outcrop and sand spit occurred between 1955 and 1997 with subsequent erosion of the connecting spit occurring between 1997 and 2013. Ongoing erosion has been observed on north-eastern Norfolk Beach (between Control Point 4 and Control Point 5 as shown in Figure 3-3), with aerial photography (refer Figure 3-5) indicating erosion of approximately 20 m since 1955. Minimal change in the vegetation line has occurred in the vicinity of Control Point 4 at the southern end of the beach segment.

Site inspections in October 2018 and March 2019 observed an exposed rocky substrate with patchy sand. A geotechnical investigation to determine the depth of the sand layer and extent and composition of the rocky substrate would be required to inform potential future erosion estimates.



Figure 3-5 Morwong Beach and north-eastern Norfolk Beach

3.5.2.2 Norfolk Beach

Analysis of the historical vegetation line at Norfolk Beach fronting Victoria Parade East and the wetlands indicates that there has been minimal change to this section of beach in the long term. Minor shoreline recession of up to 5 m between 1997 and 2018 is indicated on these sections of the

beach, however it must be noted that this is within the assumed accuracy of the georeferencing (+/- 5 m).

Aerial images up to 2013 show a periodic widening of the beach fronting the wetlands directly seaward of the creek, indicating a supply of sand scoured out from the upper beach in times of high flow. The position of the creek at the vegetation line is clearly visible in all imagery (refer Figure 3-6) and is denoted by a clear indentation in the general shoreline alignment.

Minimal shoreline change was observed on south-eastern Norfolk Beach (between control points 1 and 2). This relatively short, south-east facing section of beach would be expected to have overall low shoreline variance based on the dominance of ambient strong winds directly onshore from this direction, combined with the relative closeness of the two control points (refer Figure 3-7).



Figure 3-6 Norfolk Beach fronting the Melaleuca wetlands and Victoria Parade East (partial)



Figure 3-7 Norfolk Beach fronting Victoria Pde East (partial), south-eastern Norfolk Beach and Main Beach east of the ferry terminal

3.5.2.3 Main Beach

Figure 3-7 shows erosion of up to approximately 10 m between 1997 and 2018 for the shoreline between east of the ferry terminal to Control Point 1, while Figure 3-8 shows accretion of up to 12 m for the beach west of the ferry terminal and east of the red rock outcrop between 1997 and 2018. This implies that the south-easterly winds and waves drive longshore transport along this beach from the east towards the west.

Comparison of the historical vegetation lines between 1997 and 2018 suggests erosion of the section of Main Beach fronting the golf course (Figure 3-9) of up to 10 m, most of which had occurred prior to 2013. However, along the central-eastern portion of the beach, the 2013 profile was much further landward than the 2018 image. Examination of imagery captured between these dates confirms gradual accretion of the beach in the interceding period, with the 1997 and 2018 shorelines being in generally similar positions.



Figure 3-8 Main Beach west of the ferry terminal and east of the red rock outcrop



Figure 3-9 Main beach fronting the golf course and Red Cliffs

3.5.2.4 Red Cliffs

Small waves can impact the base of the cliffs at higher tides however the majority of wave energy is dissipated across the adjacent sand shoal. As such undercutting of the rock at the base of the cliff through the action of waves is expected to be a very slow process. Site inspections by BMT October 2018 and March 2019 lead to the conclusion that the current erosion of the cliff face affected primarily by terrestrial, as opposed to coastal, erosion processes (Figure 3-10 and Figure 3-11).

Erosion of the Red Rock cliff face was the subject of a geotechnical investigation in 2013 (Soil Surveys, 2013) which concluded that slumping of the cliff face due to terrestrial storm water flows was the primary cause of observed erosion.

Observations made by Soil Surveys (2013) as to the effect of coastal processes are given below. The time frame over which these processes act to cause erosion is not discussed. As noted above and discussed in section 4.2 the wave climate is mild and wave energy reaching the base of the cliffs is low and infrequent (i.e. only at high tide).

- The shape of the slope appears to be the result of undercutting along the shoreline, usually by higher tides undermining the soils and hence trees and vegetation, which then topple, opening the face to further erosion and scour resulting in steepening of the slope.
- The protruding rock beneath the soil exhibits a greater resistance to erosion, however, its low strength still contributes to the continued erosion and undercutting along the wave break zone at beach level. Once the lower portions of the slope have been removed, support for materials above is reduced, resulting in slumping of areas of the face.

Further to the report, email correspondence between Peter Honeysett from Redland City Council and Noel Perkins from Soil Surveys dated from October 2013 has been provided to BMT. The main points from this correspondence are:

- The assessment of timing for slope instability cannot be done with any certainty given the future variables that affect it.
- The slope below the hall is a natural slope which is subject to deterioration over time.
- Analysis suggests that the slope as it is should have failed given the materials found in the drilling and as exposed on the face and using what would be considered to be reasonable strength parameters for these materials.
- The fact that the slope is only suffering from minor slumping and scour rather than larger slope instability would suggest that vegetation and secondary cementation of the profile means it's much stronger than the materials would suggest.
- If the vegetation is removed then there may be a relatively rapid reduction in strength and also stability. Similarly, with respect to cementation exposure appears to cause a reduction in strength.
- The failure process is to some degree cyclic. Vegetation takes root in the weaker zone binding it, the weakening continues into the face past the reinforcing effect of vegetation until conditions (eg a storm causes saturation) result in this outer layer slumping off.

- There is also a process where water at the base causes softening followed by undercutting at the base causing local over steepening and this results in a progressive failure up the slope.
- The rate of these processes will depend upon environmental conditions.
- There is no evidence of large scale failures at this time and does not appear to be any evidence of them in the past.
- Potential for any failures/slumps/face scour etc affecting the hall in the short term (within a year or so) is very low to low but it may be affected in the medium term (5 to 10 years) and will be affected in the long term (10+ years).
- The slope should be monitored on a regular basis, annually or more frequently if an issue appears to be developing. This would also provide some way of identifying how rapid the processes are.
- The hall should be moved within say 5 years (monitoring may suggest a shorter or longer period and also if any measures are put in place to slow the pace of the failures).
- The distance the hall should be moved away will depend upon how long the hall is likely to be able to be used. As a minimum a distance at least equal to the height of the cliff from the top of the cliff.
- Battering (reshaping the face) would not be possible adjacent to the hall and unlikely elsewhere given the visual and other effects.
- The gabion walls would need to extend along the toe of the slope below the hall. Design is required however as a starting point Soil Surveys suggest 2 gabions high with a 0.5m setback and rock backfill. The issue would be durability.

The report recommendations included providing support to the toe of the existing slope with rock gabions, to prevent undercutting and provide support to the whole of the slope. Other recommendations were to revegetate the slope and, in the long term, to relocate the Community Hall at the top of the cliff.

The report discusses slumping of the slope due undercutting of the rock at the base off the slope and the use of gabions to provide support. How this would act to support the upper slope and if it would reduce the risk to the Hall is a geotechnical engineering question.

Stabilisation of the cliff face is a geotechnical engineering challenge and BMT are not able to review the geotechnical work or further comment on remediation options. If there are further questions to answer regarding geotechnical assessments or how slope stabilisation can be best achieved a geotechnical engineer will need to be engaged by Council.



Figure 3-10 Red Cliffs, BMT Site Inspection October 2018



Figure 3-11 Red Cliffs, BMT Site Inspection March 2019

3.5.3 Short-Term (event based) Erosion

In the past, erosion has been reported to have occurred on Coochiemudlo Island following storm events, and when strong winds coincide with a spring high tide.

Two specific events where erosion was reported are discussed below: TC Oswald in January 2013 and an event at the end of November 2018, where sustained strong winds (over 20 knots) coincided with a spring tide.

3.5.3.1 Ex TC Oswald, January 2013

The impacts of TC Oswald on Coochiemudlo Island beaches were presented in the Norfolk Beach SES (BMT WBM, 2015). An edited extract of that report is provided on the following pages.

During the Australia Day long weekend in January 2013, the south-east region of Queensland experienced strong winds from ex-TC Oswald. At Coochiemudlo Island this resulted in sustained wave action over a high tide with added storm surge.

The tidal records (predicted and recorded) for Brisbane Bar measured a residual water level (i.e. storm surge) of approximately 1 m as shown in Figure 3-12. On closer inspection (refer Figure 3-13), the maximum surge occurred around low tide during the early morning of the 28th although the water levels were consistently elevated from the morning of the 27th to the morning of the 28th (covering three high tides). While it is unlikely that the same amount of storm surge occurred at Coochiemudlo Island due to the significantly reduced fetch across the Bay, the spring high tides at the time would have been enhanced by a significant fraction of the recorded Brisbane Bar surge.

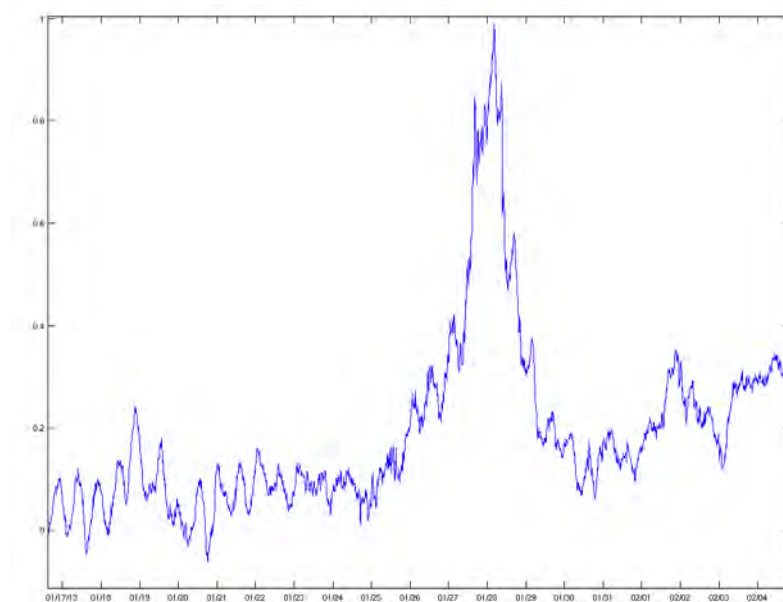


Figure 3-12 Storm surge at Brisbane Bar during ex TC Oswald

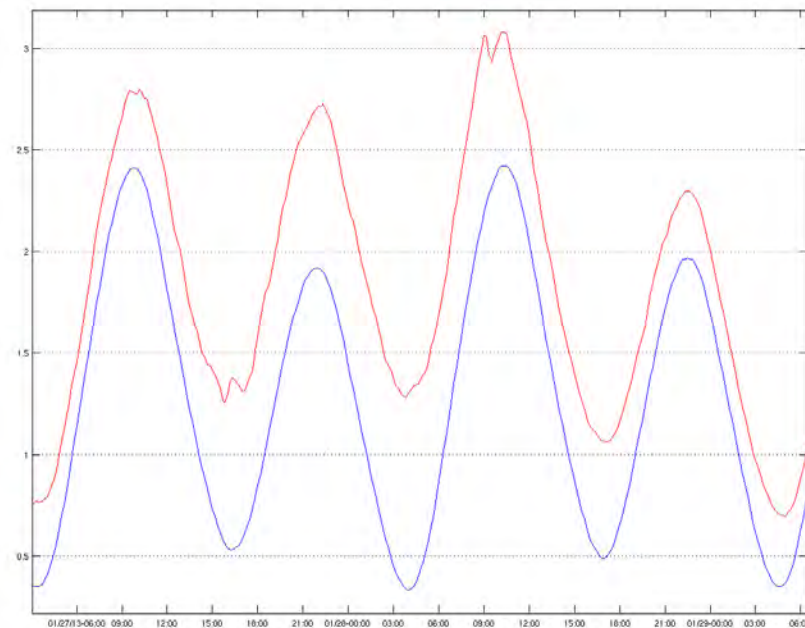


Figure 3-13 Tide levels including surge at Brisbane Bar: 27-29 January 2013

An indication of the tide height and wave conditions experienced at Coochiemudlo Island is shown in Figure 3-14 (image courtesy of Coochiemudlo Island Coastcare).



**Figure 3-14 Ex TC Oswald storm conditions at Norfolk Beach
(Image courtesy of Coochiemudlo Island Coastcare)**

In response to erosion resulting from TC Oswald a shoreline erosion study was undertaken for Norfolk Beach (BMT 2015). Following recommendations of the study two geotextile container seawalls were installed on Norfolk Beach to protect trees at risk of falling. These structures were constructed as emergency works and are still in place, however the subsequent DA has not been approved. Site inspections in October 2018 and March 2019 did not observe significant erosion at either end of the walls or loss of beach in front of the walls.

3.5.3.2 *Strong Wind Event, 28 November 2018*

Erosion was reported at Norfolk Beach and Morwong Beach, directly following a period of sustained, strong northerly winds that coincided with high tide on Wednesday 28 November 2018.

The recorded wind speed at Banana Bank North Beacon (10 minute averaged wind speed) reached a maximum of 25 knots from the north at 8:30 am. The wind direction remained northerly until 11 am before shifting to the west. The strong winds coincided with high tide, peaking at close to HAT (approximately 2.7 m relative to LAT, or nearly 1.5 m AHD) at 1:40 pm at the Whyte Island (Brisbane Bar) storm tide gauge. Figure 3-15 and Figure 3-16 show the wind speeds from the 26th to 29th November 2018 at Banana Bank North Beacon and Brisbane Airport respectively. Recorded water levels at Brisbane Bar (Whyte Island) are shown in Figure 3-17, and indicate a storm surge of nearly 0.4 m.

Redland City Council officers surveyed beach profiles along Norfolk Beach fronting Victoria Parade East on 18 December 2018. Appendix A shows the December survey compared against Council's pre-storm beach survey from June 2018. The survey extent is limited to the portion of the beach between the vegetation line and the water level at the time of the survey, which for these survey dates is approximately between -0.5 to -1.0 m AHD. The beach profile locations are illustrated in Figure 3-18.

No pre or post-storm beach profile survey data has been provided for Morwong Beach.

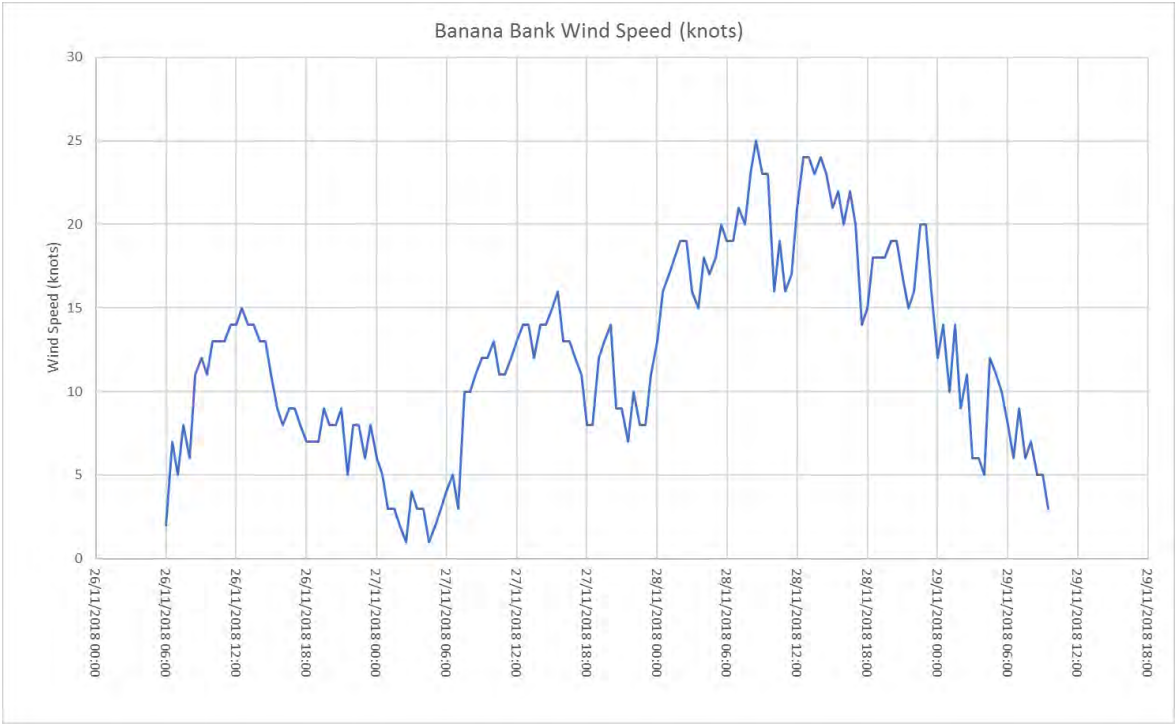


Figure 3-15 10 minute averaged wind speed (knots), Banana Bank North Beacon

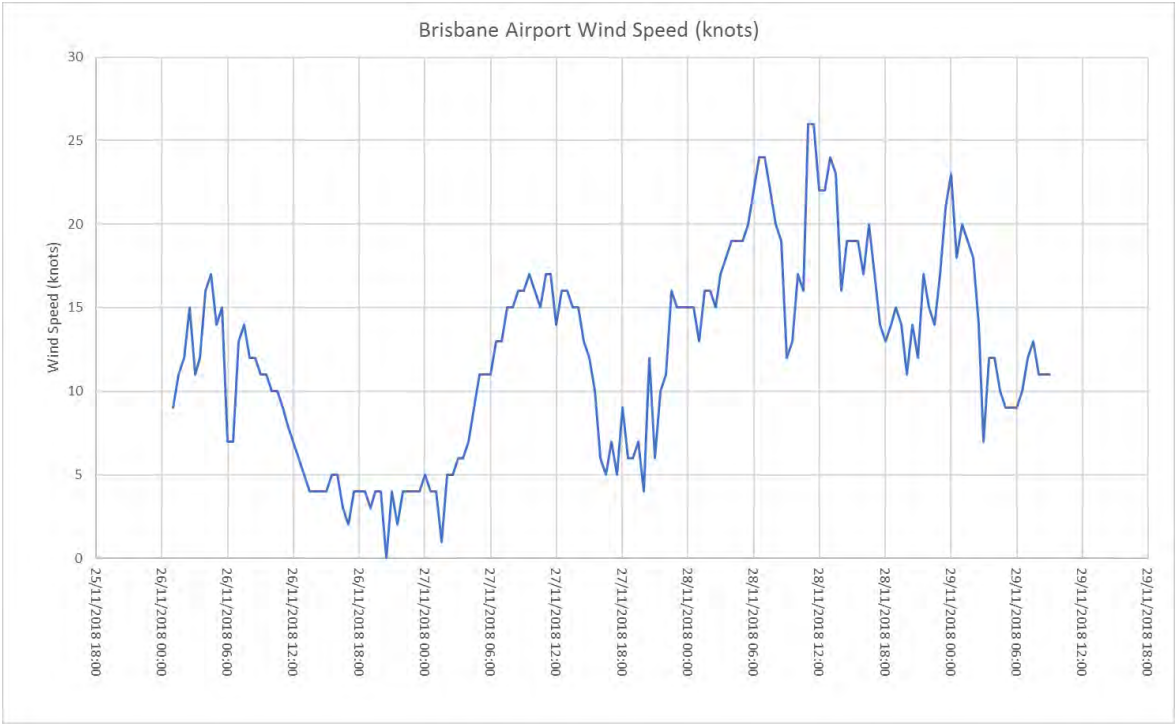


Figure 3-16 10 minute averaged wind speed (knots) Brisbane Airport

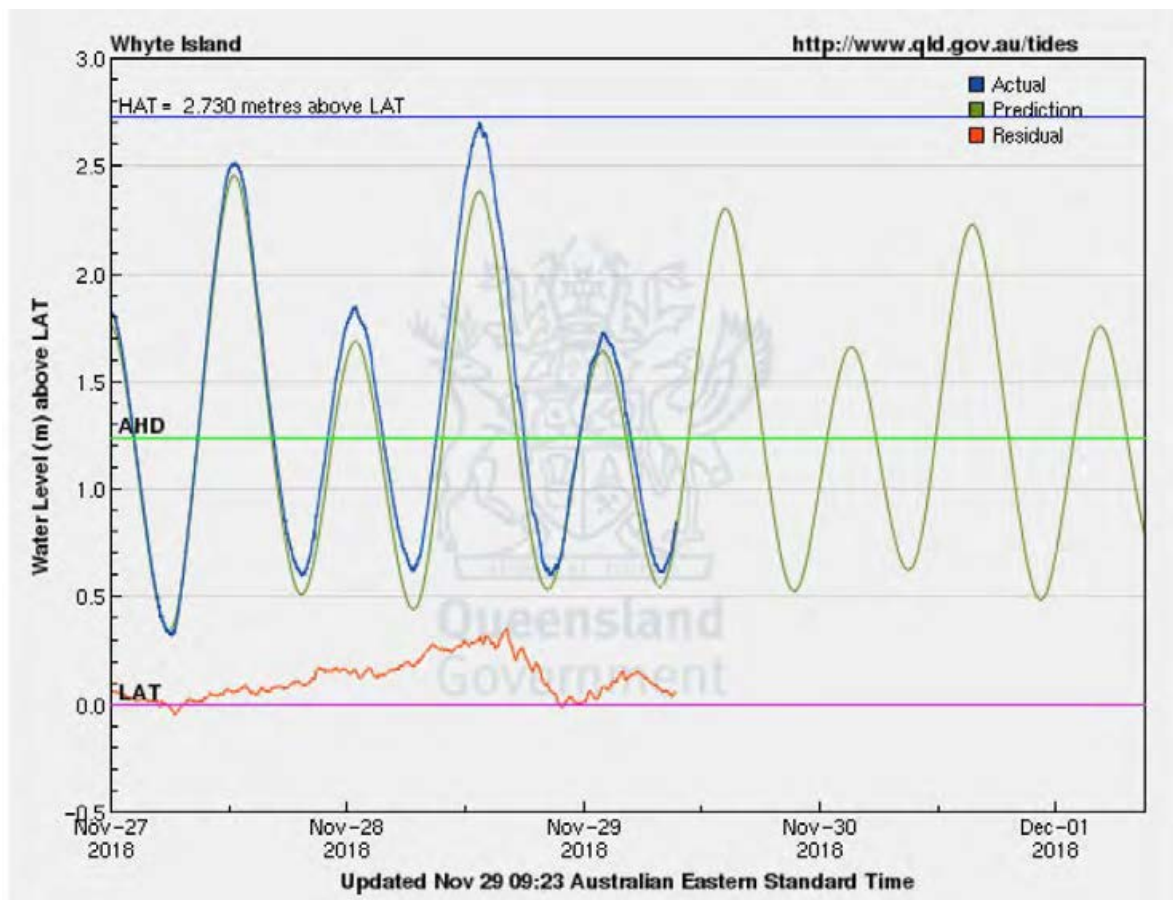
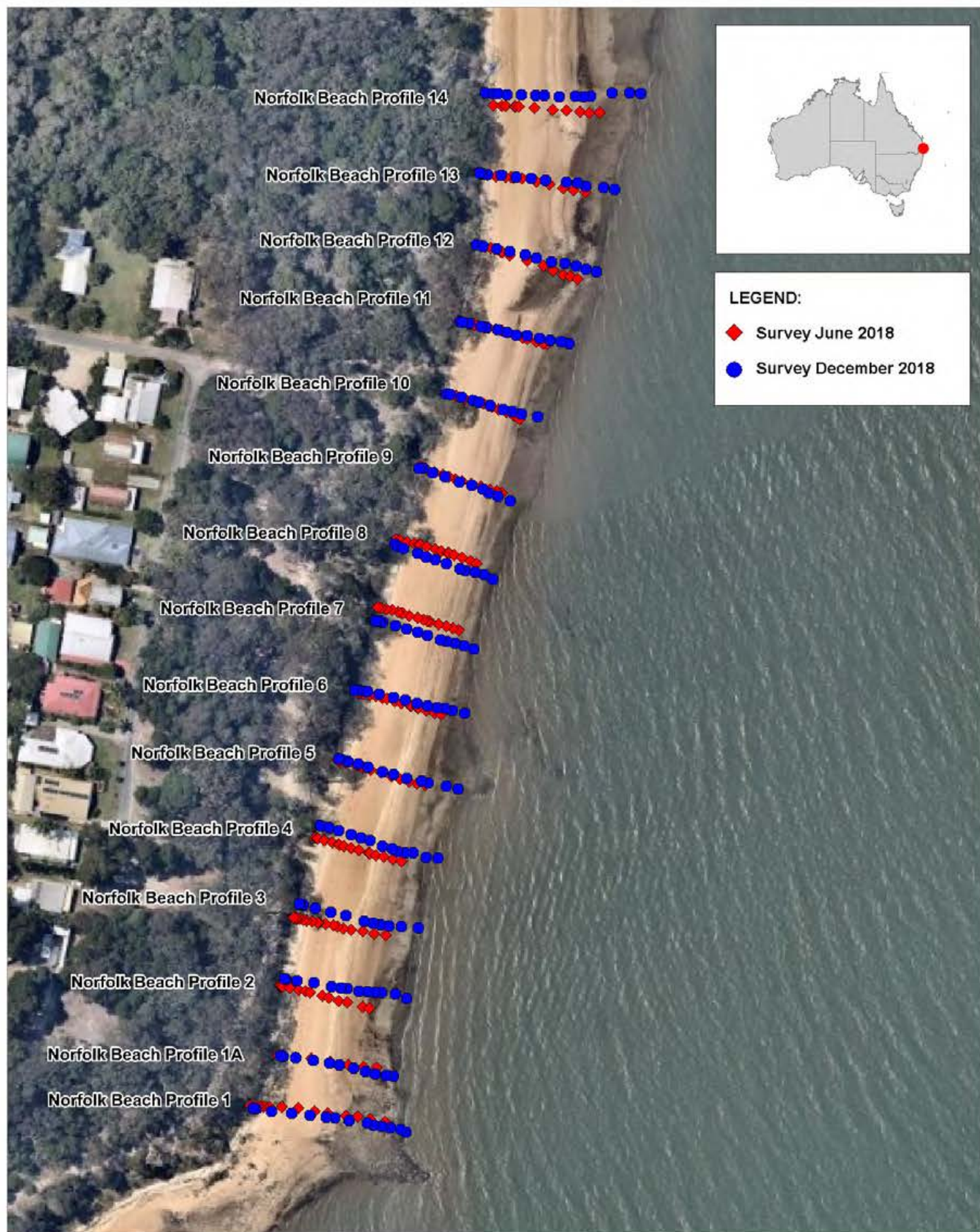


Figure 3-17 Recorded water level Brisbane Bar

The surveys extend from an elevation of between 1.5 and 2.5 mAHD to between -0.5 and -1 m AHD and do not provide information on changes to the dune behind the beach scarp or in the nearshore zone below approximately Mean Low Water Neaps (MLWN). Although the start and end points vary between surveys, the profiles have been compared using a consistent chainage convention.

Table 3-4 summarises the change in sediment volume between surveys across each profile. Profiles have been presented from north to south. Most of the profiles have insufficient overlap between the two survey dates to calculate volume changes above 1.5 mAHD or below 0 mAHD.

Most profiles show an increase in the total volume of sand between 0 mAHD and 1.5 mAHD. Notably, the greatest loss of sediment is seen at Profile 11 just south of the rock outcrop (Control Point 3), with the largest gains occurring at Profile 1 and Profile 1A at the southern end of Norfolk Beach fronting Victoria Parade and immediately north of Control Point 2. This indicates that sediment transport was from the north towards the south, with Control Point 3 and Control Point 2 acting as a groynes to intercept sediment transported southward along the beach.



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Norfolk Beach 2018 Survey Points

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Approx. Scale



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Table 3-4 Change in volume (m³) between June 2018 and December 2018

Profile	Approximate change in volume (m ³ /m)					
	1.5 m to 2 mAH	1 m to 1.5 mAH	0.5 m to 1 mAH	0 m to 0.5 mAH	-0.5 m to 0 mAH	Net volume change
Norfolk Beach Profile 14	-	-	1.3	1.9	-	3.2
Norfolk Beach Profile 13	-0.6	-0.2	0.3	1.6	-	1.1
Norfolk Beach Profile 12	-	0.3	2.5	0.2	-	3.0
Norfolk Beach Profile 11	-	0.6	-0.5	-2.6	0.0	-2.5
Norfolk Beach Profile 10	0.1	0.7	1.0	-0.9	0.0	0.8
Norfolk Beach Profile 9	0.0	-0.4	1.3	-0.7	-	0.4
Norfolk Beach Profile 8	-0.1	0.4	1.1	0.1	-	1.5
Norfolk Beach Profile 7	-	0.2	1.1	-0.1	-	1.2
Norfolk Beach Profile 6	-	0.4	1.3	-0.1	-	1.6
Norfolk Beach Profile 5	-0.6	0.2	1.3	-0.9	-0.4	-0.3
Norfolk Beach Profile 4	-	0.7	1.1	0.9	-	2.7
Norfolk Beach Profile 3	-	-1.1	1.4	-0.2	-0.1	0.1
Norfolk Beach Profile 2	-	1.7	-1.2	0.9	-	1.5
Norfolk Beach Profile 1A	-	0.3	1.4	2.9	-	4.6
Norfolk Beach Profile 1	-	0.2	3.3	1.7	-	5.2

Other cross-shore sediment transport mechanisms that may be acting across the beach profile above or below the region of overlapping surveys includes reprofiling where:

- Sand has moved from higher up the beach than surveyed and deposited lower on the profile; or
- Sand has moved from below the depth surveyed and deposited further up the profile.

This process is readily illustrated in the storm erosion assessments (refer section 4.4.2).

4 Modelled Coastal Processes

4.1 Numerical Modelling

The wave climate at Coochiemudlo Island was determined using a wave hindcast simulation for an approximately 10 year period from 2008 to 2018. This time period includes major storm events TC Debbie in March 2017 and TC Oswald in 2013. Hydrodynamic modelling for the same period provided variable water levels as an input to the wave model.

4.1.1 Model Bathymetry and Boundary Conditions

The bathymetry for the numerical wave and hydrodynamic models has been derived from:

- May 2017 hydrographic survey of the Coochiemudlo Island Foreshore undertaken by the Port of Brisbane (Port of Brisbane, 2017), using a combination of multibeam and single beam echosounders and covering the nearshore areas of the island except for the Morwong Beach area and the north-east corner of the island;
- February 2019 survey of the north-east corner of the island using a combination of stereographic aerial imagery obtained from an unmanned aerial vehicle (UAV) and echo-sounder readings from a remotely-piloted boat (AAM, 2019);
- Depth soundings provided by MSQ and referenced to a Mean Sea Level (MSL) Datum;
- Navigation chart data sourced from Australian Electronic Navigation Chart (AusENC) data. The bathymetric dataset was converted to a common vertical coordinate system, referenced to a Mean Sea Level (MSL) Datum; and
- 2009 LiDAR for elevations above approximately 0m AHD not covered otherwise.

The extent of the combined AAM and Port of Brisbane surveys are shown in Figure 4-1.

The wind boundary condition was derived from NOAA CFSR and CFSv2 global model datasets (Saha et al, 2010; 2014). The data applied to the numerical model was a 10 m elevation, 10-minute average wind vector. Mean sea level pressure also sourced from NOAA CFSR and CFSv2 global model datasets was applied to the hydrodynamic model. Example comparisons of these global model datasets to recorded winds and mean sea level pressure at Brisbane Airport are shown in Figure 4-2.

The hydrodynamic model was forced with predicted tidal water levels generated using harmonic constituents derived from the OSU TOPEX/Poseidon global ocean tide model (Egbert, Erofeeva, 2002).

An offshore swell boundary condition applied to the wave model was derived from recorded waves from the Queensland Government WaveRider buoy, located off Point Lookout.

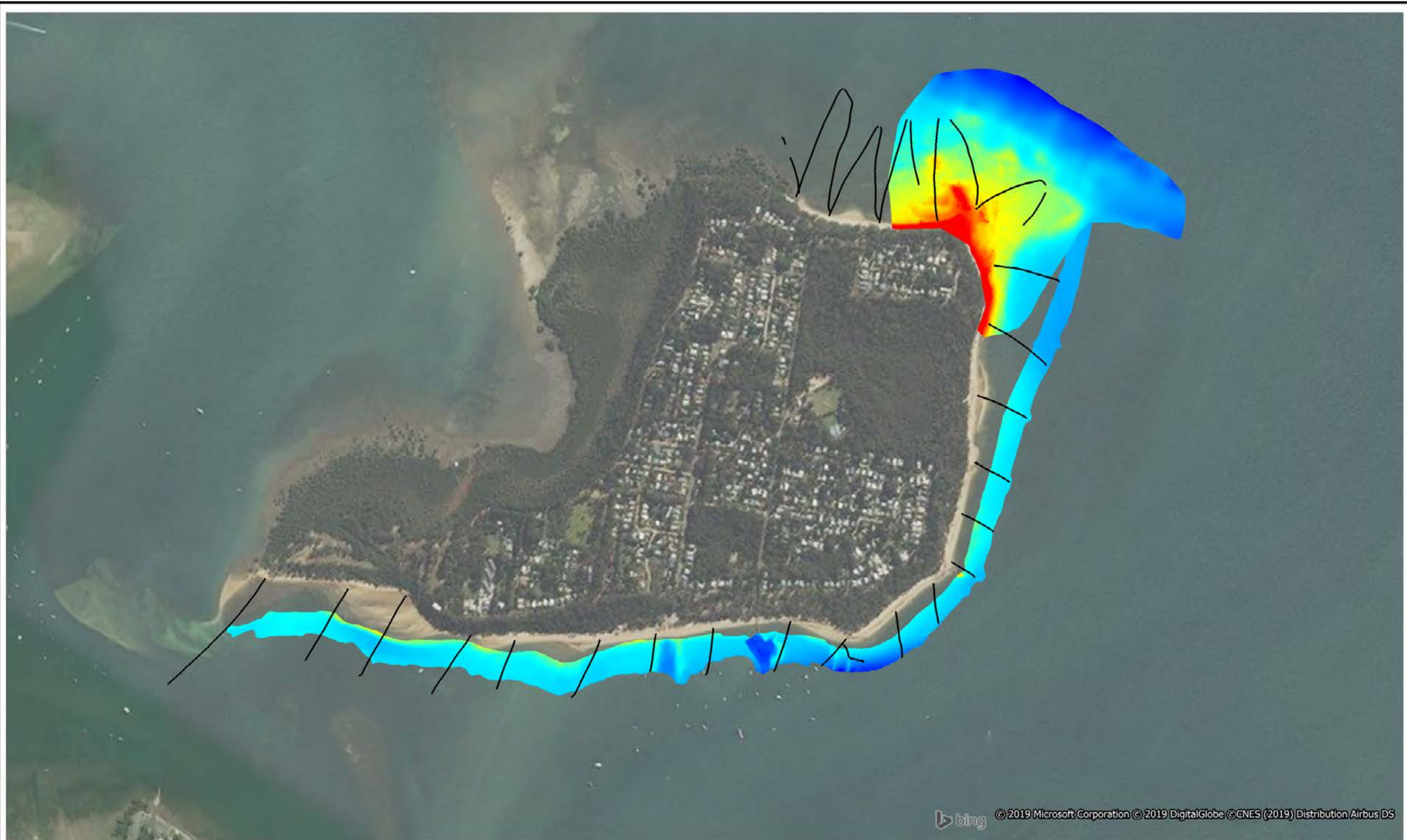
AusENC and MSQ datasets are coarse, with a minimum spacing of approximately 100 m in the nearshore areas of the island. These datasets are considered suitable for modelling coastal processes on a bay wide scale, however are insufficient for replicating wave and current processes on a local scale.

Modelled Coastal Processes

Detailed bathymetric surveys completed in 2017 by Port of Brisbane and 2019 by AAM provide confidence in the ability of the modelling tools to reproduce coastal processes locally. The survey of the north-east corner (AAM, 2019) extends onshore to approximately the vegetation line and seaward past the end of the shoal. The multibeam survey completed by the Port of Brisbane is further offshore, with a minimum depth of between -1 and -0.5 mAHD. Single beam profiles extend onshore to a minimum depth of approximately 0 mAHD and a horizontal spacing of approximately 150 m. The extent of the surveys and areas of missing data can be seen in Figure 4-1.

LiDAR has been used to provide elevation data above 0 mAHD. LiDAR flown for the Redland Council LGA in 2014 only covered the mainland and so the most recent LiDAR available for Coochiemudlo Island is from 2009.

Modelling has been completed at a scale sufficient to understand coastal processes around the island. Details of the numerical modelling tools are covered below in sections 4.1.2 and 4.1.3. High resolution modelling of waves and current interactions with rock outcrops has not been undertaken. Modelling of these processes would require a complete and up to date bathymetric and topographic survey dataset, and a local metocean data collection program for model calibration. As discussed in Section 3.5 and Section 4.4 the dominant erosion processes are event based and overwhelm the day to day processes which would be informed by additional detailed modelling.



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— Single Beam Profiles



Title:

Coochiemudlo Island Bathymetric Surveys

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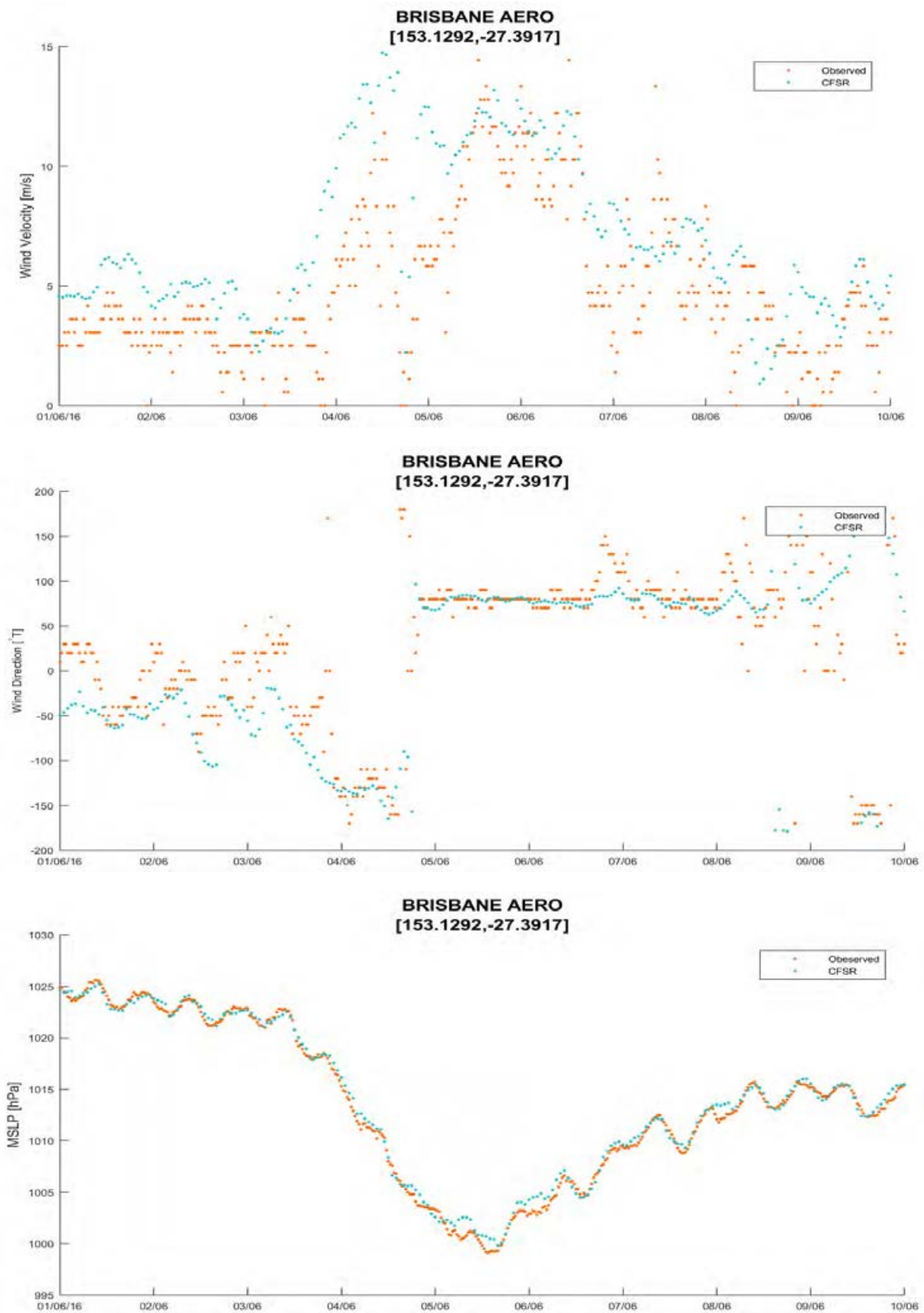


Figure 4-2 Wind speed (top), direction (middle) and mean sea level pressure (bottom) comparison at Brisbane Airport

4.1.2 Hydrodynamic Model

A two-dimensional hydrodynamic model has been developed for Moreton Bay using the TUFLOW FV software, which is developed and distributed by BMT (<http://www.tuflow.com/Tuflow%20FV.aspx>). The TUFLOW FV mesh domain extends from the southern Gold Coast to the Sunshine Coast encompassing within it the entire extent of Moreton Bay. Mesh resolution ranges from approximately 2000 m at the boundaries to 40 m at Coochiemudlo Island. The mesh extent and bathymetry are shown in Figure 4-3 (left) with detail around the eastern side of Coochiemudlo Island shown in Figure 4-3 (right).

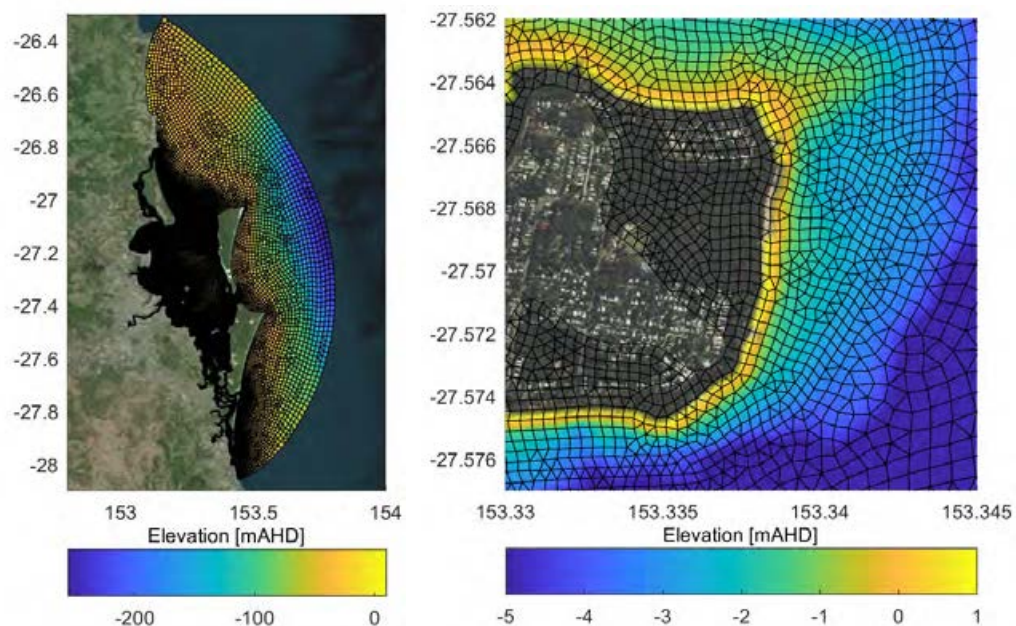


Figure 4-3 Regional (left) and local (right) mesh and bathymetry

4.1.3 Wave Model

In order to describe the wave conditions at Coochiemudlo Island a numerical model was developed utilising the Surface Waves Nearshore (SWAN) software package. SWAN (Delft University of Technology, 2006) is a third-generation spectral wave model capable of simulating the generation of waves by wind, dissipation by white-capping, depth-induced wave breaking, bottom friction and wave-wave interactions in both deep and shallow water. SWAN simulates wave/swell propagation in two-dimensions, including shoaling and refraction due to spatial variations in bathymetry and currents. This global industry-standard modelling package has been applied with reliable results to many investigations worldwide.

A nested-grid wave modelling approach has been adopted as shown in Figure 4-4. The nested system comprises a regional 400 m grid extending from the Gold Coast to the Sunshine Coast into deep water. Two smaller 160 m and 40 m nests were applied to improve the resolution of the waves inside Moreton Bay and around Coochiemudlo Island. A variable water level output from the hydrodynamic model has been applied to the 160 m and 40 m wave model nests to replicate tides.



Figure 4-4 SWAN model nests

4.2 Wave Climate

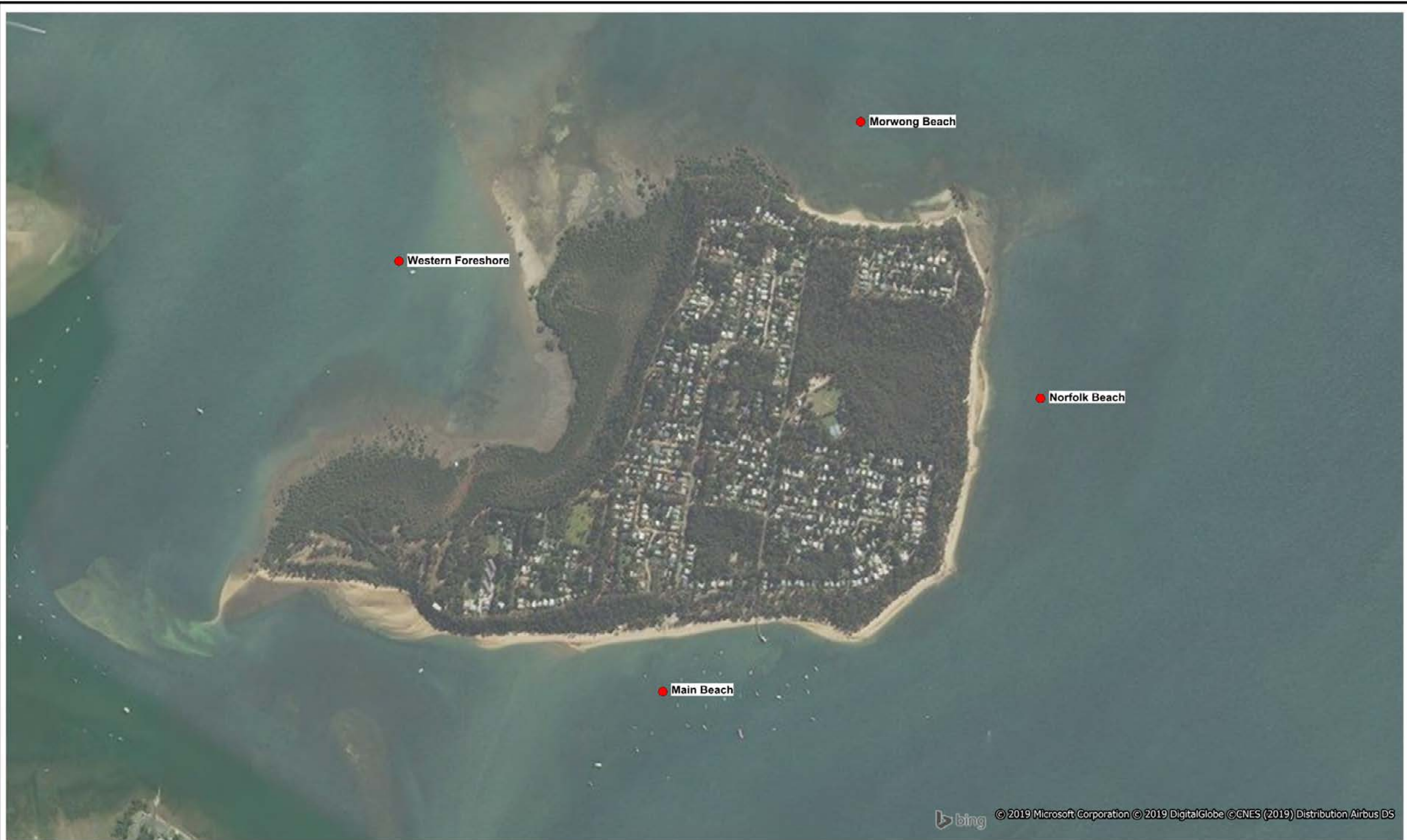
Results from the numerical modelling are presented for the nearshore locations near Morwong Beach, Norfolk Beach, Main Beach and the western side of Coochiemudlo Island (Western Foreshore) shown in Figure 4-5.

The islands and shoals in the study area influence the wave climate around Coochiemudlo Island. These features significantly limit the fetch area (that is, the area of the sea surface where the wind can generate waves).

The wave climate modelling results are summarised as average summer (October to April) and winter (April to October) rose plots shown in Figure 4-6 to Figure 4-9. Significant wave height (H_s), direction and peak period (T_p) recurrence frequency percentages, and timeseries of significant wave height, peak wave period, water elevation and wave direction for the hindcast period are provided in Appendix B.

The wave modelling results indicate:

- A distinct seasonality in wave climate, with stronger northerly events in the summer months and weaker southerly events over winter.
- A significant wave height less than 0.3 m at all locations for most of the time (93% off Main Beach, 95% off the western side of Coochiemudlo Island, 85% off Norfolk Beach and 89% off Morwong Beach. This indicates that Morwong and Norfolk Beaches are exposed to larger waves on a more frequent basis compared to Main Beach and the western side of the island.
- The significant wave height exceeds 0.5 m at Morwong Beach and Norfolk Beach approximately 1% of the time (less at the other 2 sites). This appears to be associated with high wind speeds during episodic storm events.
- The largest waves occurring off Morwong Beach and Norfolk Beach are approaching from the north to north-east.
- At Morwong Beach, nearly half (49%) of the time waves approach from the easterly sector, and 43% of the time from the northerly sector.
- At Norfolk Beach, the wave directions are far more spread, with waves approaching 24% of the time from the northerly sector, 44% of the time from the easterly sector, and 32% of the time from the southerly sector.
- At Main Beach, waves approaching from the easterly sector (43%) and southerly sector (42%) dominate.
- For approximately 99% of the time the peak wave period is less than 4 seconds, indicating waves are locally generated within Moreton Bay.



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- Model reporting locations

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Hydrodynamic and Wave Model Reporting Locations

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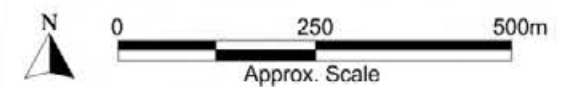


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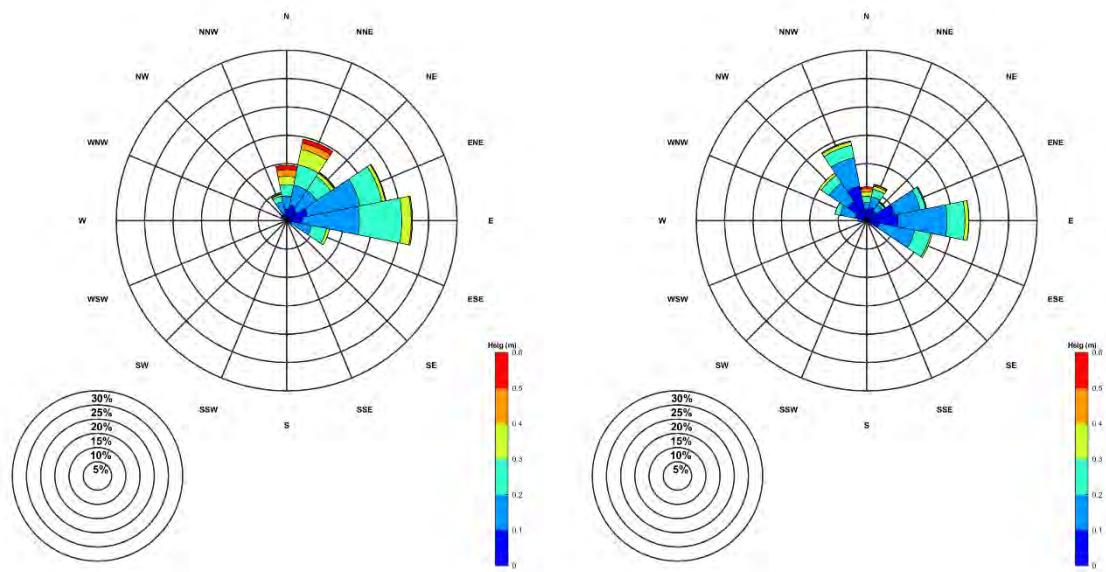


Figure 4-6 Morwong Beach average summer (left) and winter (right) wave rose

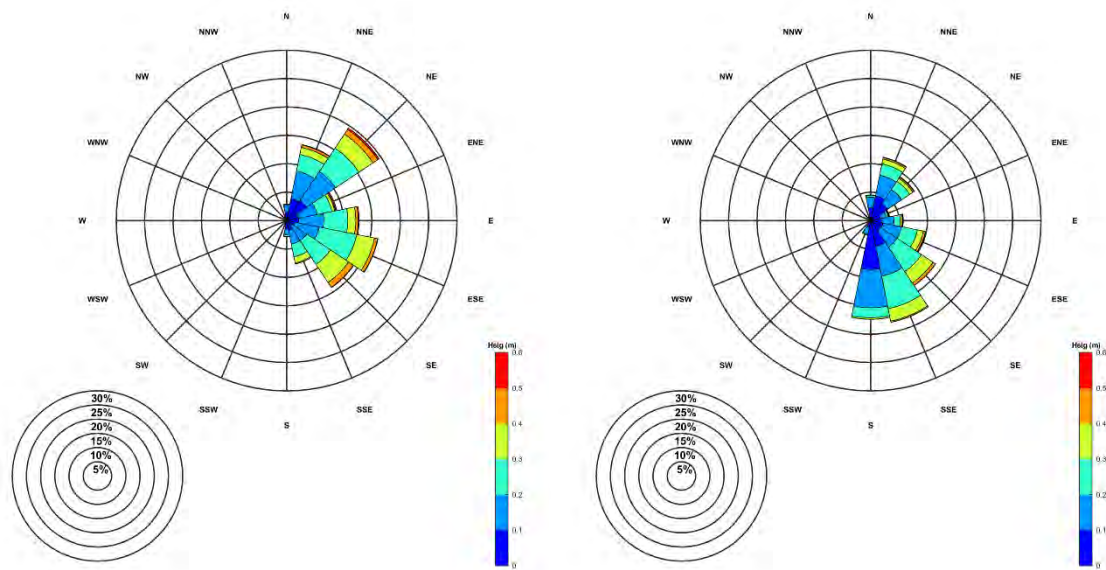


Figure 4-7 Norfolk Beach average summer (left) and winter (right) wave rose

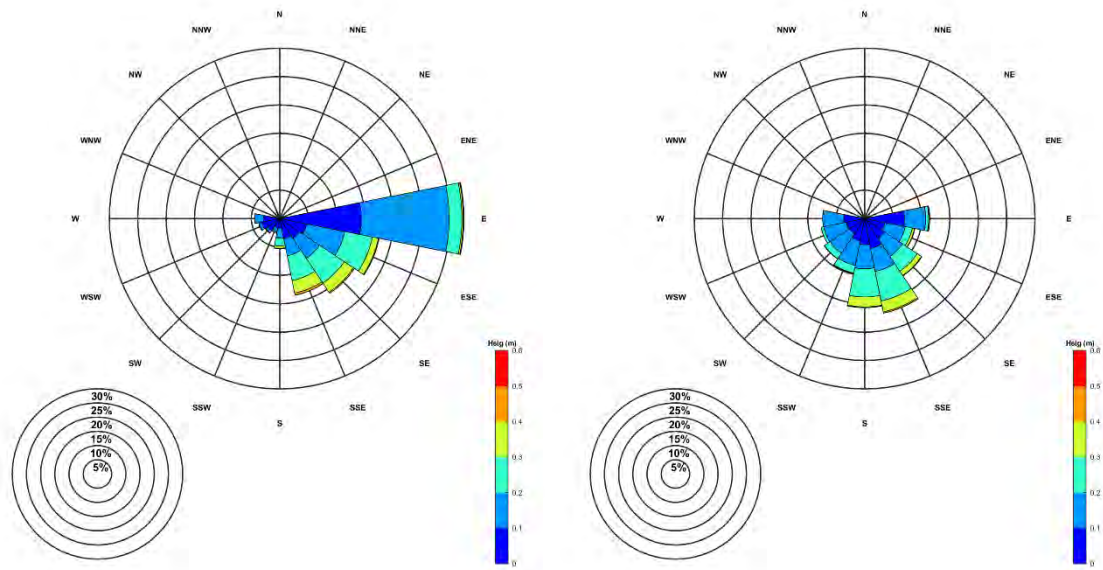


Figure 4-8 Main Beach average summer (left) and winter (right) wave rose

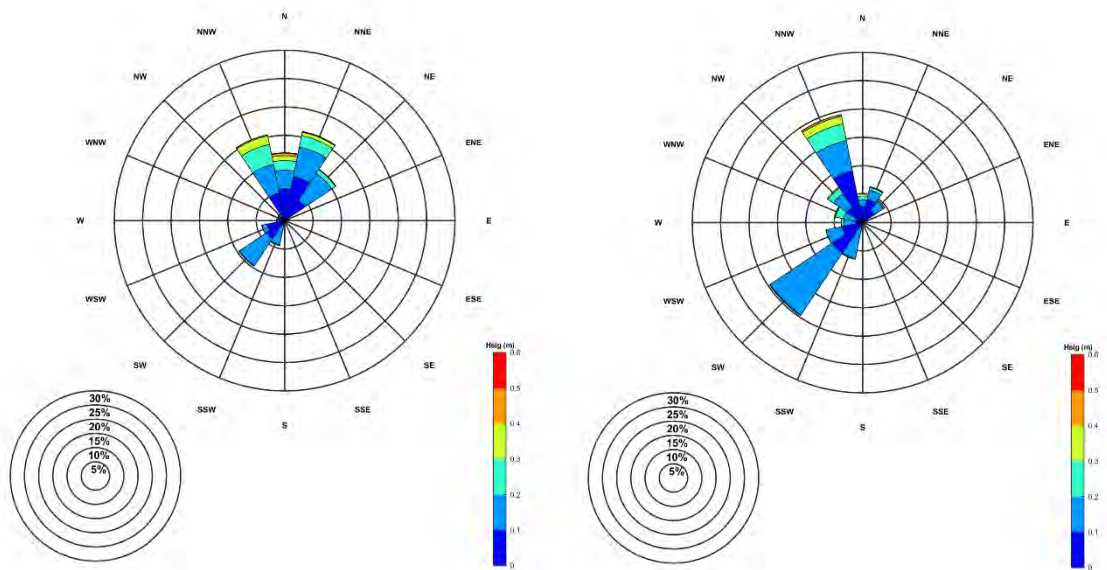


Figure 4-9 Western Foreshore average summer (left) and winter (right) wave rose

4.3 Currents

Tidal currents were assessed using an existing TUFLOW FV model of Moreton Bay with increased resolution in the vicinity of the study area. Time series of current speed and water level for the January 2018 spring tide are given in Figure 4-10 to Figure 4-13 for the locations shown in Figure 4-5.

The peak current speed on a spring tide is predicted to reach approximately 0.5 m/s offshore from Morwong Beach, Norfolk Beach and Main Beach, and approximately 0.2 m/s on the western side of the Island. Peak currents occur on the flood (incoming) tide at Morwong Beach and on the ebb (outgoing) tide at Norfolk Beach and Main Beach. Current velocities around the Island are generally small and unlikely to induce sediment transport under ambient conditions. Current speeds in excess of 0.35m/s are required to mobilise sand and are reached approximately 2% of the time off Morwong Beach, 4% of the time off Norfolk Beach, and 15% of the time off Main Beach. As peak currents occur at Main Beach on the ebb tide the majority of current induced sediment transport will be to the east. These results indicate that tidal currents are not responsible for significant sand movement around or onto the island.

Spatial plots of peak flood and peak ebb currents for the spring tide on 3 January 2018 are given in Figure 4-14.

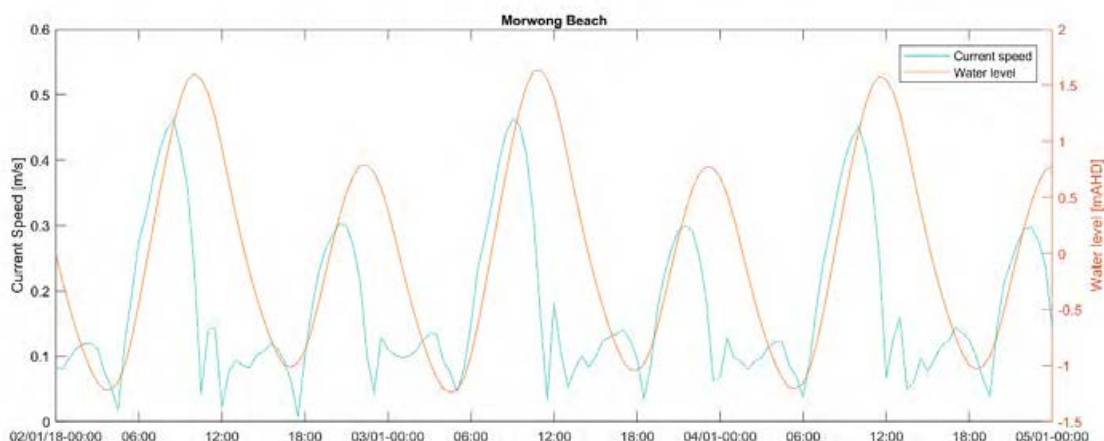


Figure 4-10 Morwong Beach spring tide current speed and water level

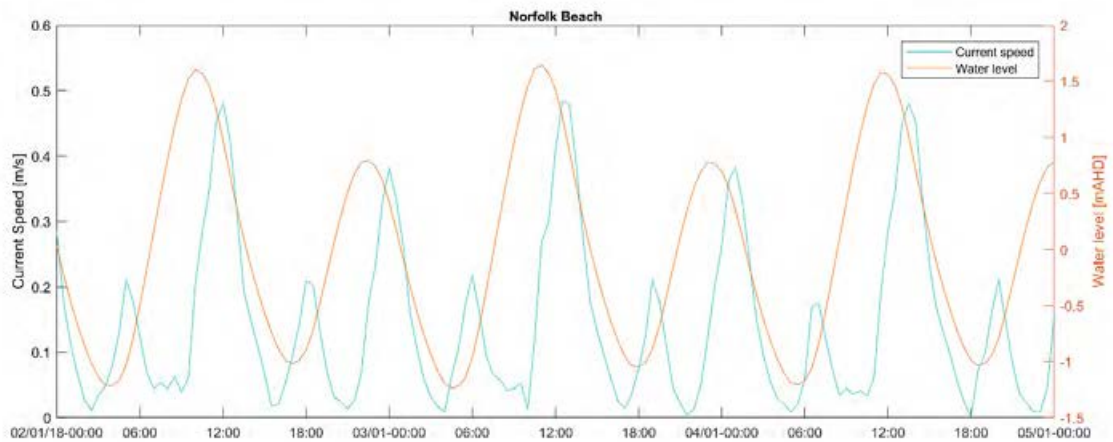


Figure 4-11 Norfolk Beach spring tide current speed and water level

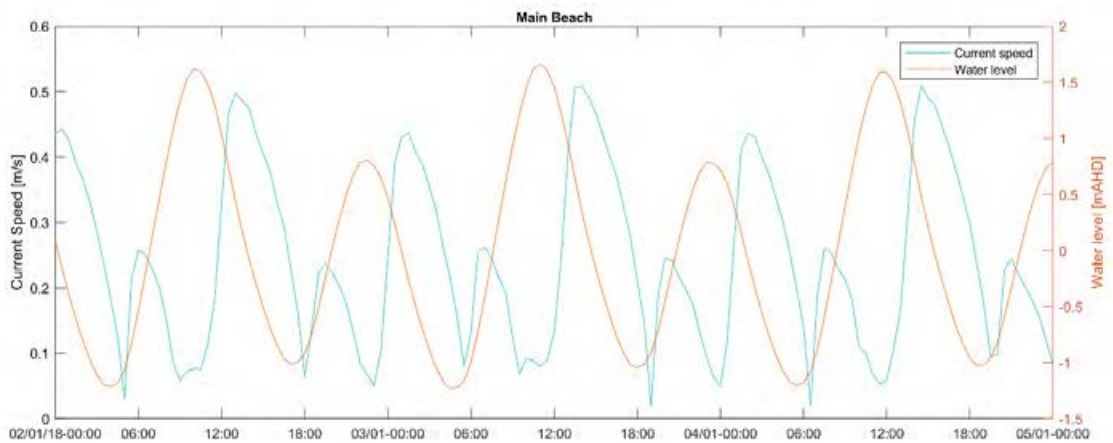


Figure 4-12 Main Beach spring tide current speed and water level

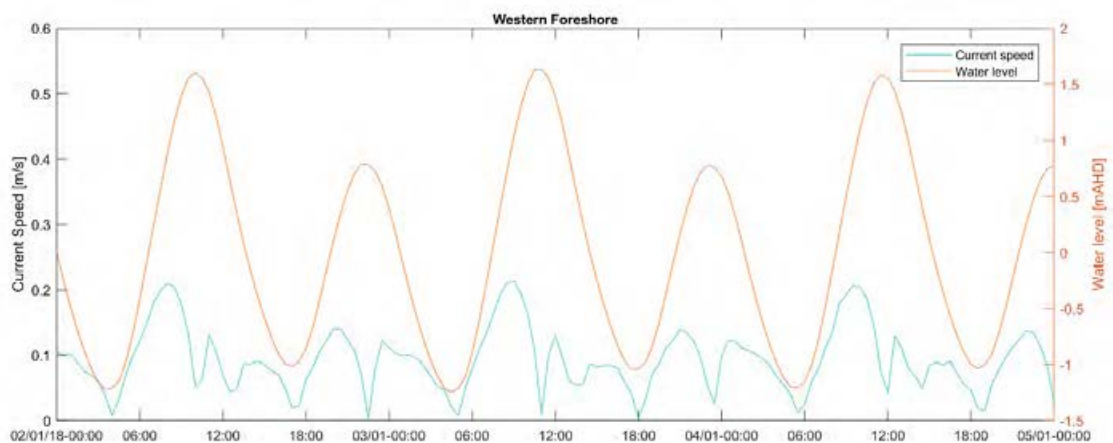


Figure 4-13 Western Foreshore spring tide current speed and water level

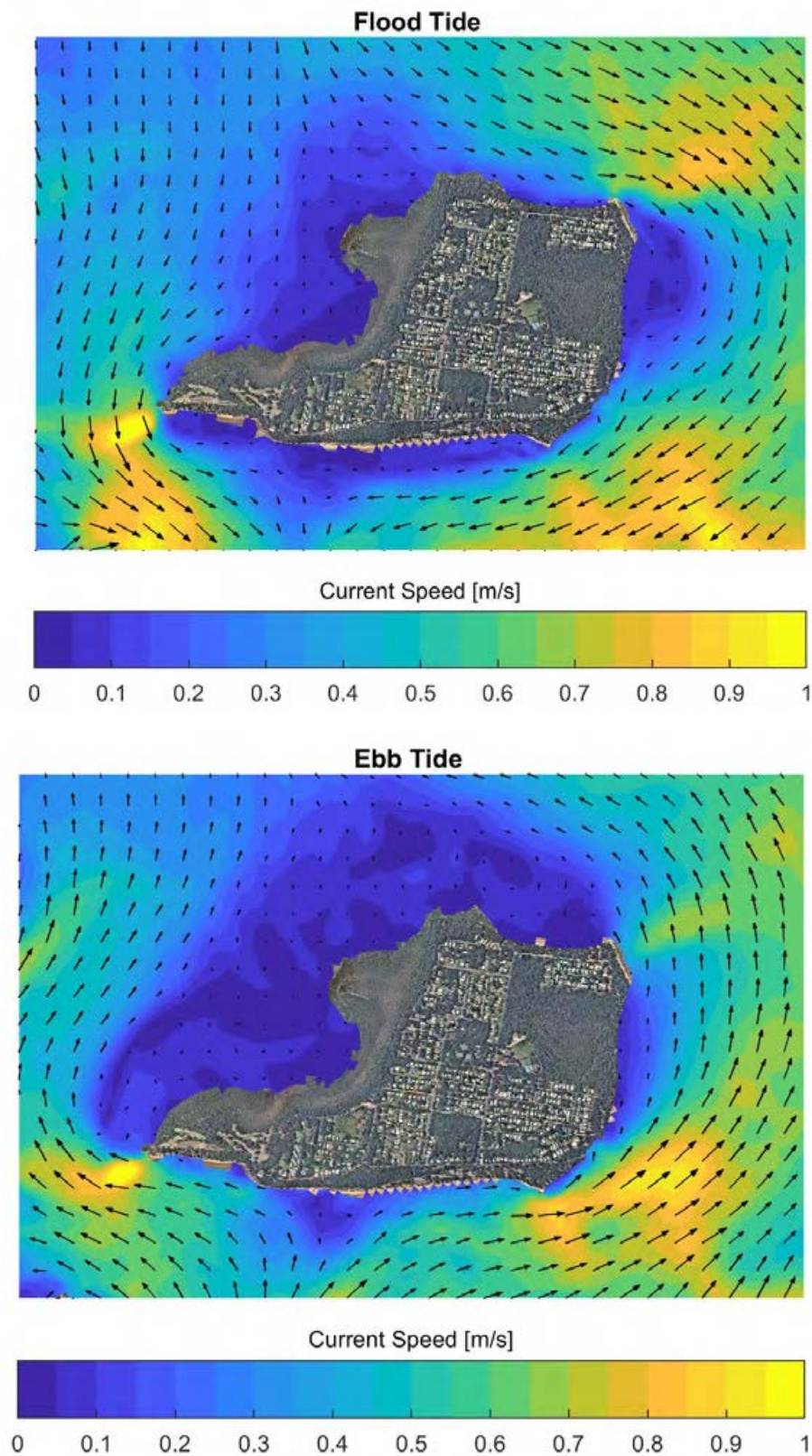


Figure 4-14 Typical Spring Tide Current Speed Contour and Vector Plot – Peak Flood (top) and Peak Ebb (bottom).

4.4 Sand Transport

Longshore sand transport patterns and storm erosion has been modelled for the northern, eastern and southern beaches of Coochiemudlo Island. These models, described in sections 4.4.1 and 4.4.2 below, were developed primarily for use on open coast beaches. It should be noted that under ambient conditions Coochiemudlo Island is a low wave energy environment and sediment transport estimates are indicative only.

The western side of the island is characterised by established mangroves and intertidal flats which, along with the results from wave and hydrodynamic modelling, suggests a very low energy environment. As such, the western side of the Island has been excluded from the assessments described below.

4.4.1 Longshore Sand Transport

The pattern of annual longshore sand transport potential within the study area was considered using an industry-standard approach known as the CERC formula. Developed by the US Army Corps of Engineers (US Army Corps of Engineers, 2006), the CERC formula relates the potential longshore sediment transport rate to the longshore component of the wave energy flux at the wave breaker zone. Results from the wave climate analysis (see Section 4.2) were used to evaluate the wave energy flux used for CERC formula input. For this study, the CERC formula has been used to inform sediment transport patterns only and not used to quantify sediment transport rates.

The CERC formula is valid for estimating non-cohesive (sand) sediment transport on open coasts and has been found to be most relevant in high wave energy areas such as the exposed beaches of the Gold Coast. The formula is calibrated by varying an empirical coefficient and is dependent on the wave height at breaking and wave angle to the shoreline at breaking. Estimates of potential longshore transport rate assume sand is always available for transport.

In the case of Coochiemudlo Island there are numerous rocky shelves in close proximity to the beaches which limit the available volume of sand. As the study area is exposed to low wave energy under ambient conditions the CERC formula tends to significantly overestimate the magnitude of longshore sediment transport due to the rocky nearshore substrate and limited sand supply.

Alternatives to assess sediment transport, including numerical modelling tools such as Tuflow FV, require extensive data for model calibration. Sediment modelling at this level of complexity was not considered for Coochiemudlo Island as the cost of data collection and model calibration would be excessive, not be achievable within project time frames, and would not be expected to add additional value compared to repeated high quality surveys.

The most significant erosion visible in aerial photography is on north-eastern Norfolk Beach, with observed recession of up to 20 m between 1955 and 2018 along approximately 170 m of beach. The volume change can be estimated assuming a constant beach profile over time. The “present day” profile (extracted from the 2009 LiDAR data) has been shifted 20 m seaward to approximate the 1955 beach profile and is shown in Figure 4-15. Volumes have been estimated below the crest of the vegetated dune (approximately 3.5 mAHD) as well as from the elevation of the existing vegetation line (approximately 2m AHD). The volume of eroded sand has been estimated at 50 m³ per metre length of beach based on the vegetation line and 80 m³ per metre length of beach based on the dune crest, which equates to changes of 1 to 1.5 m³/m per year or 170 to 255 m³ per year over the beach segment.

It should be noted that this approach assumes a sandy beach and does not take into account the presently exposed rocky substrate present on north-eastern Norfolk Beach. Unfortunately, previous aerial photography is unable to be geo-referenced to an accuracy suitable to assess the relatively localised and small observed changes to beach levels in other locations and over shorter time frames (the accuracy of georeferencing is discussed in Section 3.5.2).

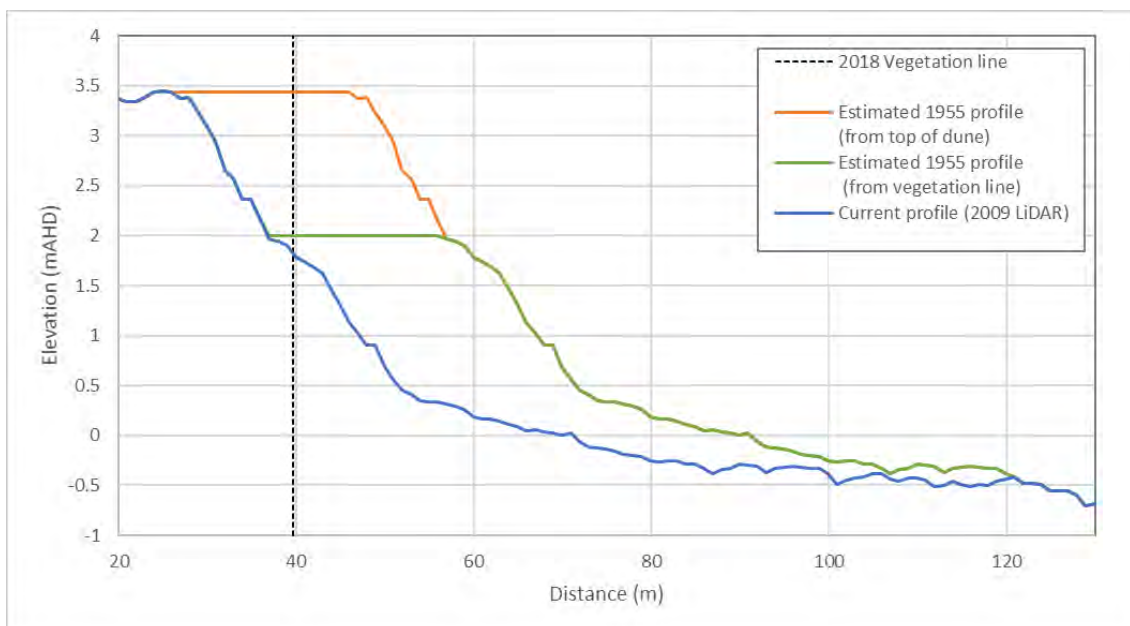


Figure 4-15 Current beach profile and estimated 1955 beach profile, north-eastern Norfolk Beach

As indicated in the Norfolk Beach Shoreline Erosion Study (BMT WBM 2015) the best indicator of sand volume changes and therefore sediment transport rates will be through accurate and repeated land surveys.

Sediment transport patterns are shown Figure 4-16 and Figure 4-17. Wave direction in the nearshore area is heavily influenced by water level, as shallow water depths over reefs and shoals trigger wave breaking and refraction. This complicates longshore transport processes, especially when combined with the irregular frequency of storms with their associated high waves and storm surge. Furthermore, longshore transport is also influenced by the various coastal features (natural headlands and creeks) present along the study area shoreline.

Modelled Coastal Processes

While sediment transport occurs in both directions, net westerly sediment transport is predicted along Morwong Beach. Most of this sediment transport is expected to occur in the summer months under the influence of north-easterly events, with minimal transport predicted during the winter months.

Potential exists for sediment transport to occur in both directions around the north eastern corner of the island, however easterly transport from Morwong Beach onto Norfolk Beach is expected to be negligible. Sand transport from north-eastern Norfolk Beach onto the adjacent tidal flat and Morwong Beach is possible at higher tides.

The direction of sediment transport may be northerly or southerly along Norfolk Beach, depending on prevailing conditions. In general, transport tends to be northerly in winter and southerly in summer. A weak net southerly transport is indicated long term under the influence of stronger north-easterly events occurring over the summer months. Rocky outcrops along Norfolk Beach will act to disrupt transport off the beach, depending on the tide level and protrusion of the outcrops above the sand surface of the beach at that time.

Westerly transport is indicated along Main Beach, with an eventual loss of sand off the south-western tip of the island. Peak currents off Main Beach occur on the ebb tide, with the associated transport of sediment likely to occur along the beach in an easterly direction which acts to slow the western transport of sediment and subsequent loss off the island. Transport of sand along Main Beach is further disrupted by the barge ramp and potentially by occasional navigation dredging at the passenger ferry terminal, which may act as a sediment sink.

The predicted wave climate and pattern of longshore sediment transport suggests sediment transport will largely be sporadic and dominated by episodic storm events, with minimal transport occurring under ambient conditions. This is supported by analysis of historical aerial photography (Section 3.5.2) which found minimal long-term change to the majority of the Island's beaches, with the exception of the north-eastern segment of Norfolk Beach. The disparate results between the TC Oswald storm in November 2013 (severe beach erosion) and the March 2018 storm event (mild beach erosion) indicate that the range and timing of parameters (wind, water level, pre-existing beach condition) necessary to successfully model these events is generally not sufficiently known and as such an attempt has not been made to predict outcomes from future storms.



LEGEND

↔ Dominant sediment transport direction

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Sediment transport pathways April to October

BMT endeavours to ensure that the information provided in this map is correct at the time of publication. BMT does not warrant, guarantee or make representations regarding the currency and accuracy of information contained in this map.

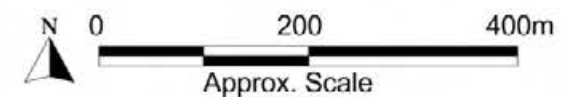


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Sediment transport pathways October to April

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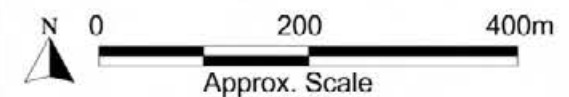


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4.4.2 Storm Erosion

Short-term or storm erosion occurs when larger than ambient wave heights, often combined with elevated water levels result in the erosion of sand from the beach face. The eroded sand is transported by cross shore processes into the adjacent nearshore area. Once wave conditions return to normal, the sediment is slowly transported back onshore, often over many months or several years, rebuilding the beach. No sand is lost from the system in this process.

The potential for short-term storm erosion due to severe wave and elevated coastal water levels (storm tide conditions) has been estimated using the simple cross-shore equilibrium profile model of Vellinga (1983). This empirical model calculates the upper beach and dune erosion volume associated with storm-induced extreme water level and wave conditions. The amount of shoreline recession is determined from the storm parameters and the initial (pre-storm) beach profile shape. The model assumes the volume of material eroded from the upper beach/dune system and deposited lower on the beach profile is balanced by a setback of the shoreline. The model assumes that there is no underlying bedrock or other cohesive sediment layer that limits changes to the beach profile.

The design storm characteristics have been sourced from Cardno (2009), with the larger of the cyclonic and non-cyclonic present day 100 year ARI design water levels and significant wave heights at Victoria Point selected (i.e. storm tide level of 2.21 mAHD and Hs of 0.99 m, as shown in Table 3-2 and Table 3-3). The present day 100 year ARI design water level is approximately equivalent to the elevation of the frontal dune in some locations on Coochiemudlo Island.

The pre-storm upper beach profile was extracted from a DEM based on the 2009 LiDAR capture. The nearshore and offshore beach profile was extracted from the combined bathymetry informed by the Port of Brisbane survey (2017), AAM survey (2019) and navigation chart data.

Initially, a median grain size of 0.2 mm was adopted for this assessment, consistent with the Victoria Point SEMP (BMT WBM 2016) and considered to be conservative for Coochiemudlo Island where there is less mud and more sand than at Victoria Point. Results from sediment sampling undertaken in 2018 across the Redland City Council local government area, including Norfolk Beach and Main Beach on Coochiemudlo Island (FRC Environmental 2018) was subsequently provided by Council. Particle size analysis of sand samples on Norfolk Beach and Main Beach estimated a median grain size (d_{50}) of 0.36 mm for the upper beach and an average of 0.52 mm for the lower beach.

Samples from two quarry sites (including a Redland City Council quarry) were also analysed, with an average median grain size of 0.22 mm. It should be noted that if sediment from these sources has previously been used for beach nourishment on Coochiemudlo Island then the assessed median grain size at previously nourished beaches may not be representative of natural conditions.

The Vellinga model is sensitive to sediment size, with storm erosion volumes increasing with decreasing grain size. Figure 4-18 shows the Vellinga beach profiles for median grain size inputs of 0.2 mm, 0.36 mm and 0.52 mm. Using the 1% AEP water level, the sensitivity analysis shows that regardless of sediment size, erosion occurs above approximately 1.5 mAHD with deposition occurring lower on the profile, indicating that it is the sand on the upper beach that is mobilised and eroded in a storm event.

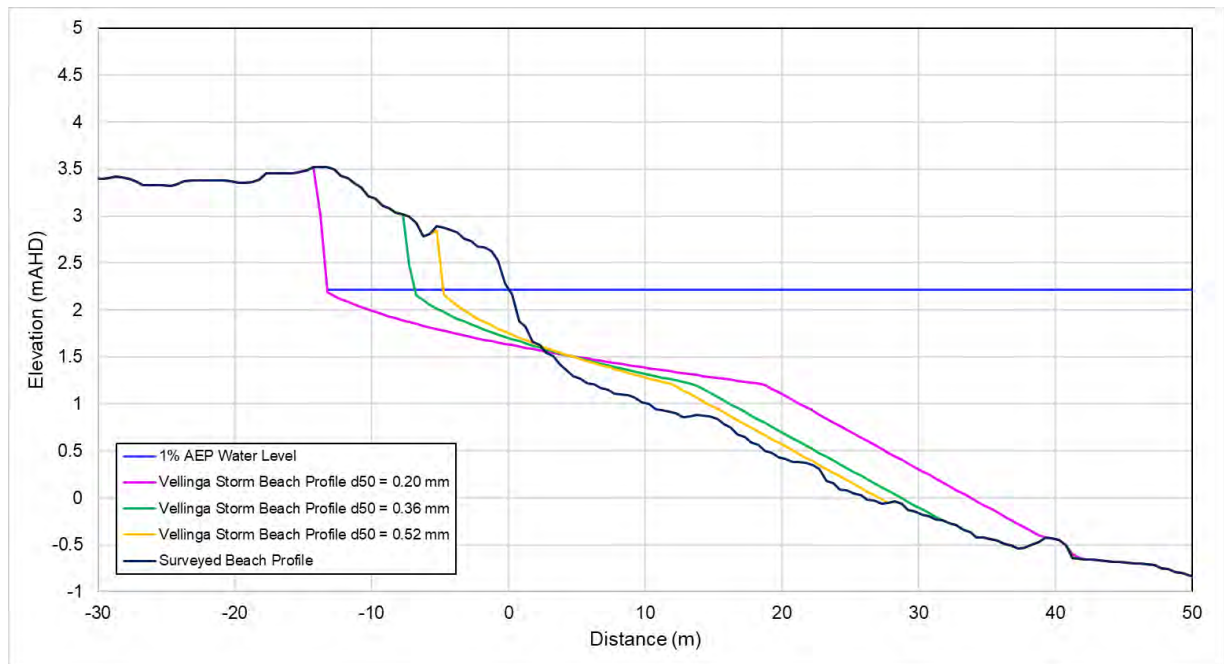


Figure 4-18 Design Erosion Setback at Norfolk Beach (Survey Profile 13) for different median grain size inputs

Given the mixed nature of sediments around Coochiemudlo Island storm erosion modelling has therefore been undertaken using both the initially adopted median grain size of 0.2 mm and the sampled upper beach median grain size of 0.36 mm.

The pre-storm and predicted storm erosion profiles at each assessment location for a median grain size of 0.2 mm are provided in Appendix C and the assessment results are summarised in Table 4-1.

It is important to recognise that the Vellinga storm erosion estimates do not account for erosion controls, such as the presence of bedrock behind the beach or man-made coastal erosion protection structures.

Table 4-1 Storm erosion estimates

Profile Location	Modelled Erosion Distance (m)		Modelled Erosion Volume (m ³ /m)	
Median Grain Size (d ₅₀)	0.36 mm	0.20 mm	0.36 mm	0.20 mm
Morwong Beach	10	19	5	10
Norfolk Beach (North)	10	19	7	12
Norfolk Beach (Survey Profile 13)	8	14	6	16
Norfolk Beach (Survey Profile 3)	7	16	4	10
Norfolk Beach (South)	7	16	5	10
Main Beach (Survey Profile 8)	12	21	4	7
Main Beach (Survey Profile 5)	7	16	8	13
Main Beach (West)	3	13	4	8
Golf Course	5	13	5	8

4.4.3 Sediment Sinks and Sources

Nearmap aerial imagery from 2015 (Figure 4-19) shows that the surrounding areas to the north and east of the Island are devoid of sand shoals and appear to be “swept clean” by tidal currents, with the only visible shoal being about 1.6 km to the north of the north-east corner. This shoal is separated from the Island by a channel up to 7 m deep which has some reef exposed on the bed indicating that there is no sand on the bed to move towards the island.

More broadly in the Bay, visual inspection of aerial photographs and satellite imagery indicates that marine sand ingress from Rainbow Channel and Jumpinpin Channel and fluvial sand supply from the Logan River all stop at some distance from the Island. Therefore, it is unlikely that there is “new” sand locally available for Coochiemudlo Island. Furthermore, removal of sand from elsewhere in Moreton Bay or further away will not affect sediment supply to Coochiemudlo Island.

As discussed in Sections 3.5.2.1 and 3.5.2.2 Morwong Beach and Norfolk Beach show periodic widening seaward of creeks/drains in times of high flow, indicating a small supply of sand scoured from the upper beach in times of high flow. While more difficult to discern due to the general westward flow of sand the same scouring would be expected at the mouth of Curlew Creek on Main Beach. While these waterways may deliver some sand to the beaches from the interior of the Island there is no indication that it is a large enough quantity to contribute significantly to beach building processes.

Sediment losses from the Island occur when sand is transported west along main beach and eventually lost off the south-western tip of the island. Dredging completed as part of the upgrade of the ferry terminal in 2014/2015 removed approximately 5000 m³ of sand, which was disposed of away from the island and as such removed from the active system. The dredged area has been reported by residents as acting as a sediment sink. Figure 4-20 shows sand infilling the dredged area, however Main Beach west of the ferry terminal has not experienced recession, indicating that sediment losses are small.



Figure 4-19 Aerial Photograph October 2015 (Nearmap)



Figure 4-20 Aerial Photograph July 2016 (Nearmap) – Coochiemudlo Island Ferry Terminal

5 Future Climate Change

While the Coochiemudlo Island SEMP is primarily focussed on managing current erosion issues, it is important to consider future climate conditions including sea level rise as this will impact on the effectiveness and design life of potential management options.

The Intergovernmental Panel on Climate Change Fifth Assessment Report (IPCC, 2014) provides sea level rise (SLR) projections for a range of global greenhouse gas emission scenarios.

Table 5-1 and Table 5-2 summarise projected increases to global mean surface air temperature and global mean sea level for the four principal emission scenarios, or Representative Concentration Pathways (RCPs). The global SLR projections are also illustrated in Figure 5-1. The IPCC give the following descriptions to the RCPs:

- RCP2.6: global greenhouse gas emissions peak between 2010 and 2020 and substantially decline thereafter
- RCP4.5: global greenhouse gas emissions peak around 2040 and decline thereafter
- RCP6.0: global greenhouse gas emissions peak around 2080 and decline thereafter
- RCP8.5: global greenhouse gas emissions continue to rise throughout the 21st century.

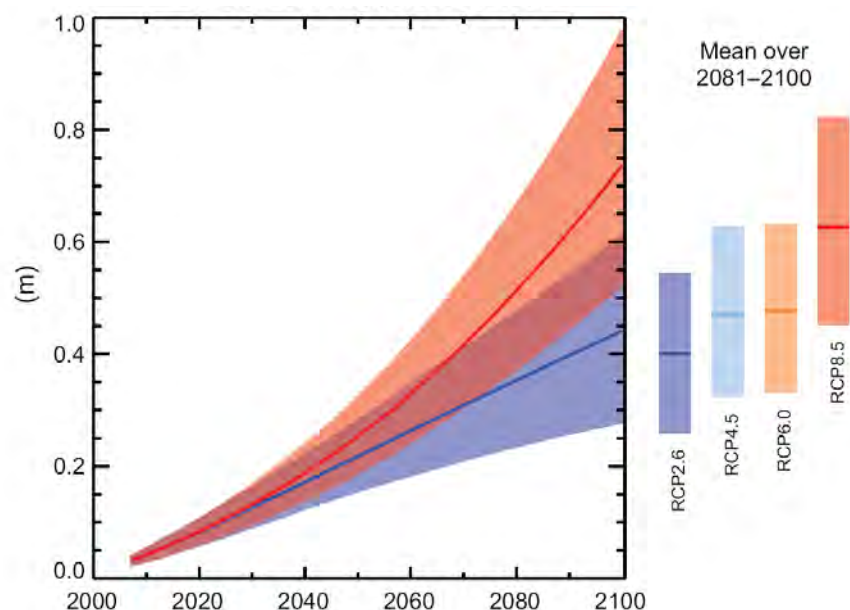


Figure 5-1 Projections of Global SLR Relative to 1986-2005 Mean Sea Level (IPCC, 2014)

Table 5-1 Projected Change in Global Mean Surface Air Temperature (IPCC, 2014)

Scenario	2046 – 2065 Mean & <i>likely</i> range (m)	2081 – 2100 Mean & <i>likely</i> range (m)
RCP2.6	1.0 (0.4 to 1.6)	1.0 (0.3 to 1.7)
RCP4.5	1.4 (0.9 to 2.0)	1.8 (1.1 to 2.6)
RCP6.0	1.3 (0.8 to 1.8)	2.2 (1.4 to 3.1)
RCP8.5	2.0 (1.4 to 2.6)	3.7 (2.6 to 4.8)

Table 5-2 Projected Change in Global Mean Sea Level (IPCC, 2014)

Scenario	2046 – 2065 Mean & <i>likely</i> range (m)	2081 – 2100 Mean & <i>likely</i> range (m)
RCP2.6	0.24 (0.17 to 0.32)	0.40 (0.26 to 0.55)
RCP4.5	0.26 (0.19 to 0.33)	0.47 (0.32 to 0.63)
RCP6.0	0.25 (0.18 to 0.32)	0.48 (0.33 to 0.63)
RCP8.5	0.30 (0.22 to 0.38)	0.63 (0.45 to 0.82)

The [Climate Change in Australia](https://www.climatechangeinaustralia.gov.au/en/) website (<https://www.climatechangeinaustralia.gov.au/en/>) provides coastal and marine SLR projections, recognising that the rates of SLR are not uniform around Australia. In addition to SLR, projections for 'sea allowance' are provided which represent the minimum distance required to raise an asset to maintain the current frequency of breaches under projected SLR. The sea allowance projections take into account the nature of extreme sea levels (storm surge) along the Australia coastline.

Queensland State planning policy and guidelines have adopted a projected sea level rise of 0.8m by 2100. BMT has been advised that as part of the QCoast₂₁₀₀ program, Redland City Council is also adopting a projected sea level rise of 0.4 m by 2070 for planning purposes.

Sea level rise is expected to exacerbate erosion on Coochiemudlo Island, as higher water levels will allow waves to impact on the upper beach with increasing frequency. Longshore transport rates and patterns may also be affected with sediment transport occurring further up the beach profile and in response to morphological changes.

6 Summary

Coochiemudlo Island is located within the Moreton Bay Marine Park and has significant environmental, as well as cultural, economic and social values.

Due to its geographical position within Moreton Bay, Coochiemudlo Island is sheltered from ocean swell waves by North Stradbroke and Moreton Islands. As a result, the Island has a generally mild wave climate with modelled significant wave heights below 0.3 m occurring 85% of the time on the eastern side of the Island (off Norfolk Beach) and less frequently on the north, west and south facing shorelines. Significant wave heights above 0.5 m are predicted to occur less than 1% of the time.

An assessment of historical aerial imagery suggests that long-term changes to most of the Island's beaches are minimal. Minor long-term erosion is indicated on Norfolk Beach (up to 5m observed between 1997 and 2018), however it must be noted that this is within the accuracy of the georeferencing of the aerial photographs (discussed in Section 3.5.2). Significant erosion of up to 20m over approximately 60 years has been observed on the most north-eastern section of Norfolk Beach. Main Beach has experienced erosion between the ferry terminal and southern-eastern Norfolk Beach of up to 10m and accretion west of the ferry terminal of approximately 10m over 60 years, indicating a slow rate of sediment transport westward along the beach. A geotechnical report (Soil Surveys, 2013) indicates that a low erosion rate at Red Cliffs is mainly due to terrestrial stormwater flows rather than undercutting by coastal processes.

Five rock/reef areas on the eastern beaches were identified by BMT WBM (2015) as acting as controls on beach alignment ("control points"). Aerial photographs show erosion of the sand spit previously connecting Morwong and Norfolk beach to the rock outcrop on the north-eastern corner of the Island (control point 5). Large changes were not identified at any of the other four outcropping rock areas on Norfolk Beach.

Modelling of longshore transport has qualitatively confirmed that sediment transport patterns vary seasonally. The direction of sediment transport may be northerly or southerly along Norfolk Beach, depending on prevailing conditions and tends to be northerly in winter and southerly in summer. A weak net southerly transport is indicated long term under the influence of stronger north-easterly events occurring over summer months. Sand transport northwards from north-eastern Norfolk Beach onto the tidal flat adjacent to Morwong Beach is possible under high tides and south-easterly conditions. Sand transport is westerly along Main Beach, with a low rate of sediment loss past the golf course. Tidal current speeds are too low to have a discernible impact on sand transport around most of the island, however some transport is possible from west to east along Main Beach on an ebb tide, interrupting the dominant westerly transport. Estimates of erosion volumes on north-eastern Norfolk Beach from 1955 to 2018 indicate long-term erosion rates are less than 1.5 m³/m per year.

Overall, the predicted wave climate and pattern of longshore sediment transport suggests sediment transport on all beaches will largely be sporadic and dominated by episodic storm events, with very low rates of net longshore transport occurring under ambient conditions.

Erosion caused by storm events is expected to be the critical erosion process acting on Coochiemudlo Island and sediment transport occurring during severe storm events with elevated water levels overwhelms ambient processes. Modelling of erosion resulting from an extreme event

Summary

(using the present day 1 in 100-year design water level and significant wave height) indicates potential for erosion of up to 19 m on Norfolk Beach and 21 m on Main Beach. It should be noted that this modelling assumes an unlimited supply of sand available to be mobilised and does not consider the effects of vegetation on reducing erosion, or erosion controls such as the presence of bedrock or man-made coastal erosion protection structures. Future erosion is likely to be exacerbated by the effects of climate change, specifically sea level rise.

Targeted and regularly repeated land surveys will be required to better inform sand movements around Coochiemudlo Island. Additional surveys after storm events and a geotechnical investigation to determine the depth of the sand layer and extent and composition of the rocky substrate will support further assessment to estimate potential future erosion.

Certain shoreline erosion management options are not permissible under current state and federal legislation, including construction of hard structures significantly below the high water mark, such as offshore breakwaters. Management should preference 'soft' approaches where possible (e.g. beach nourishment, reprofiling) over 'hard' engineering approaches, with these hard structures only adopted where softer approaches are not feasible or are proven to be unsuccessful.

The processes reported on herein will be used to inform Stage 3 of the SEMP, which is an assessment and recommendation of potential shoreline management actions suitable for Coochiemudlo Island.

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Appendix A Beach Profiles 2018

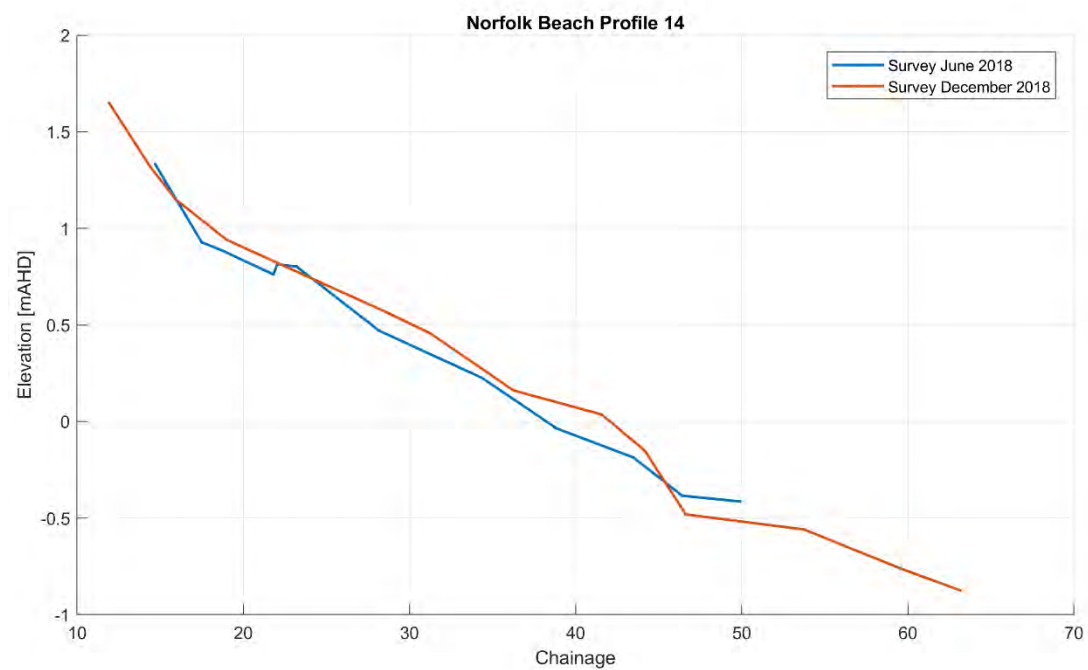


Figure A-1 Survey profiles, June and December 2018 - Norfolk Beach Profile 14

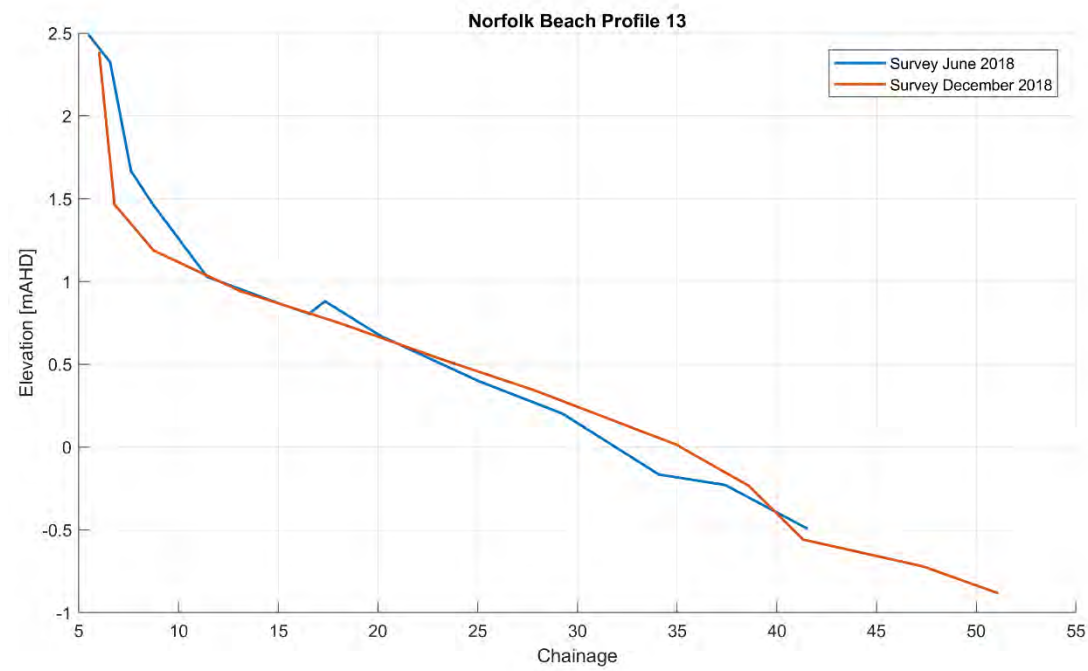


Figure A-2 Survey profiles, June and December 2018 - Norfolk Beach Profile 13

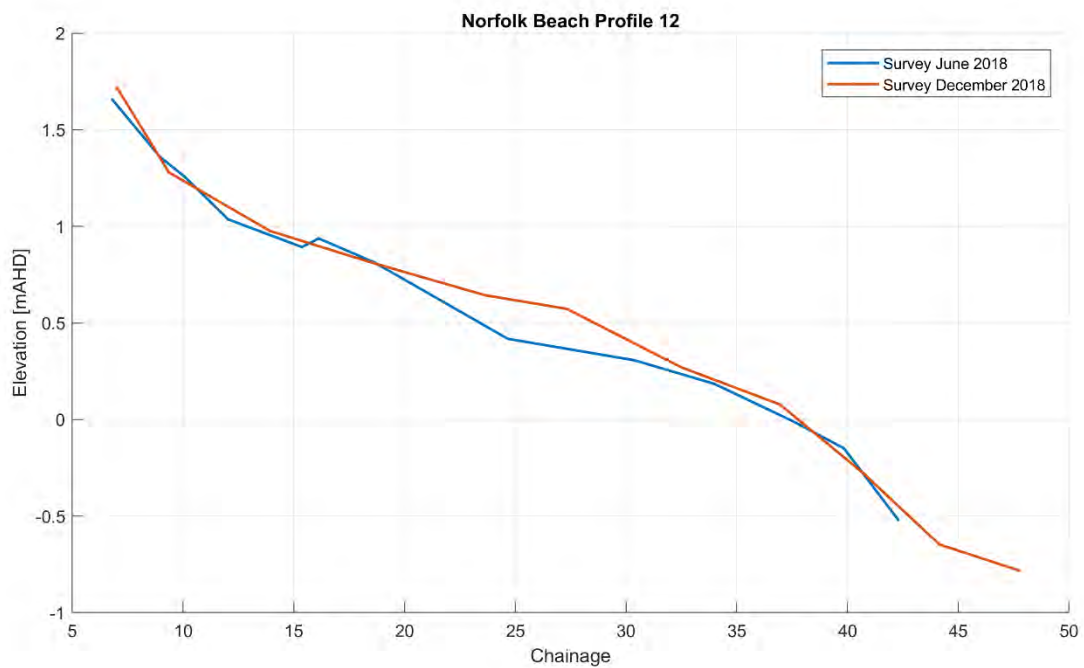


Figure A-3 Survey profiles, June and December 2018 - Norfolk Beach Profile 12

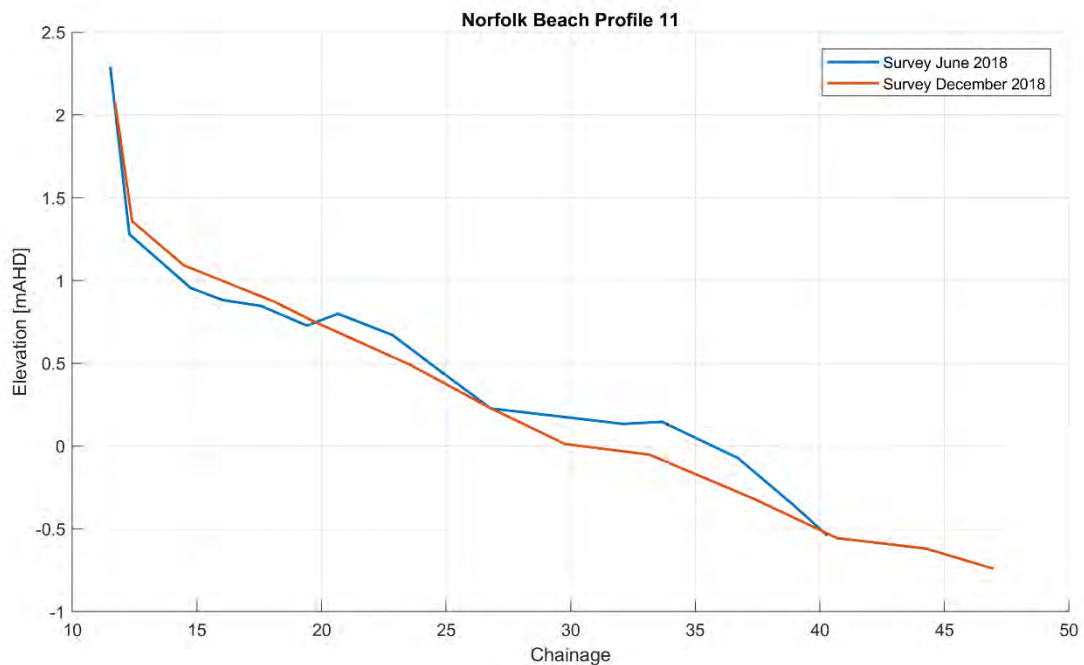


Figure A-4 Survey profiles, June and December 2018 - Norfolk Beach Profile 11

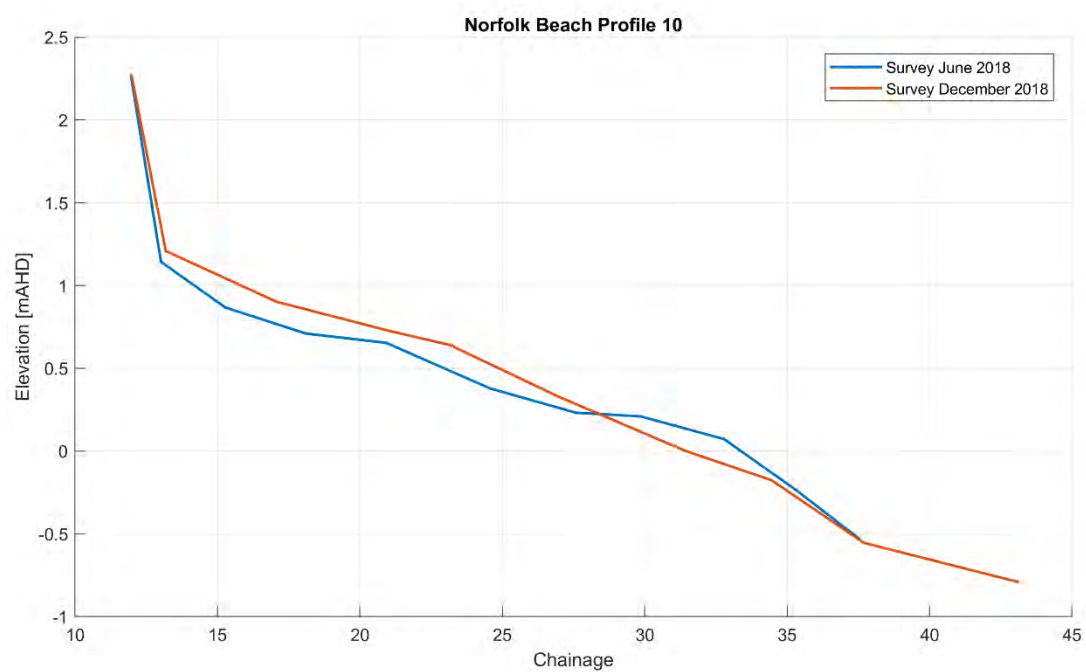


Figure A-5 Survey profiles, June and December 2018 - Norfolk Beach Profile 10

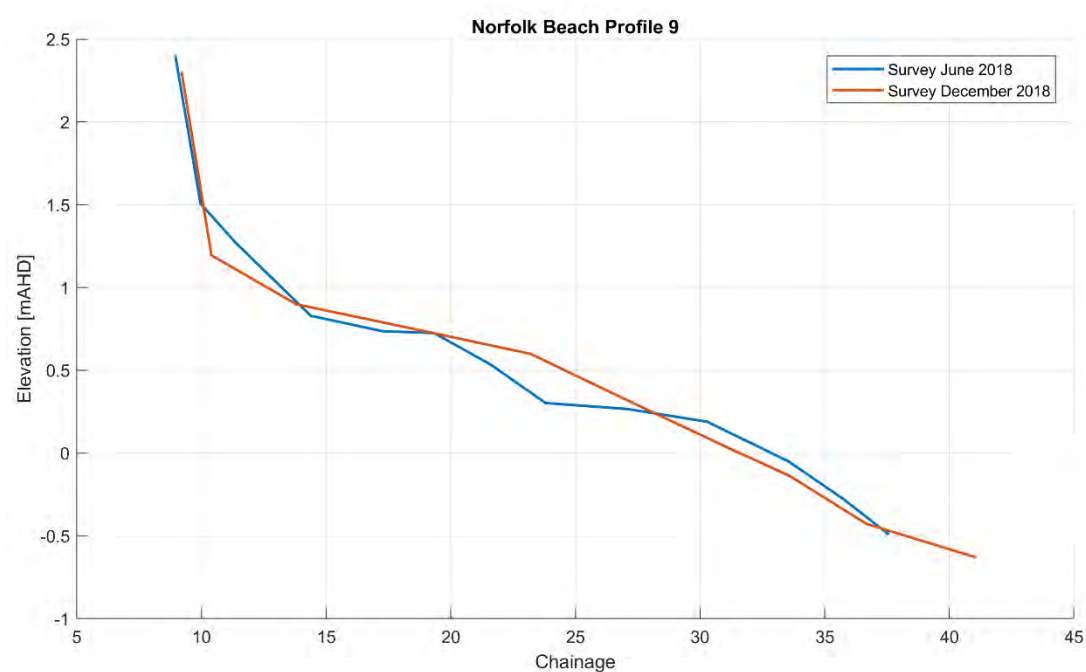


Figure A-6 Survey profiles, June and December 2018 - Norfolk Beach Profile 9

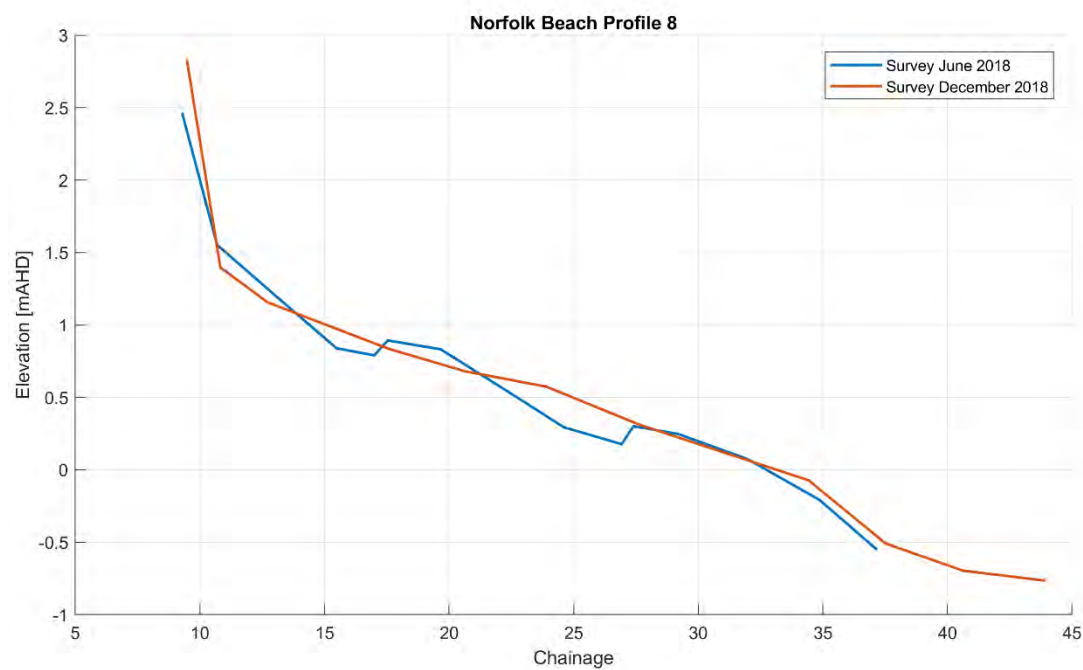


Figure A-7 Survey profiles, June and December 2018 - Norfolk Beach Profile 8

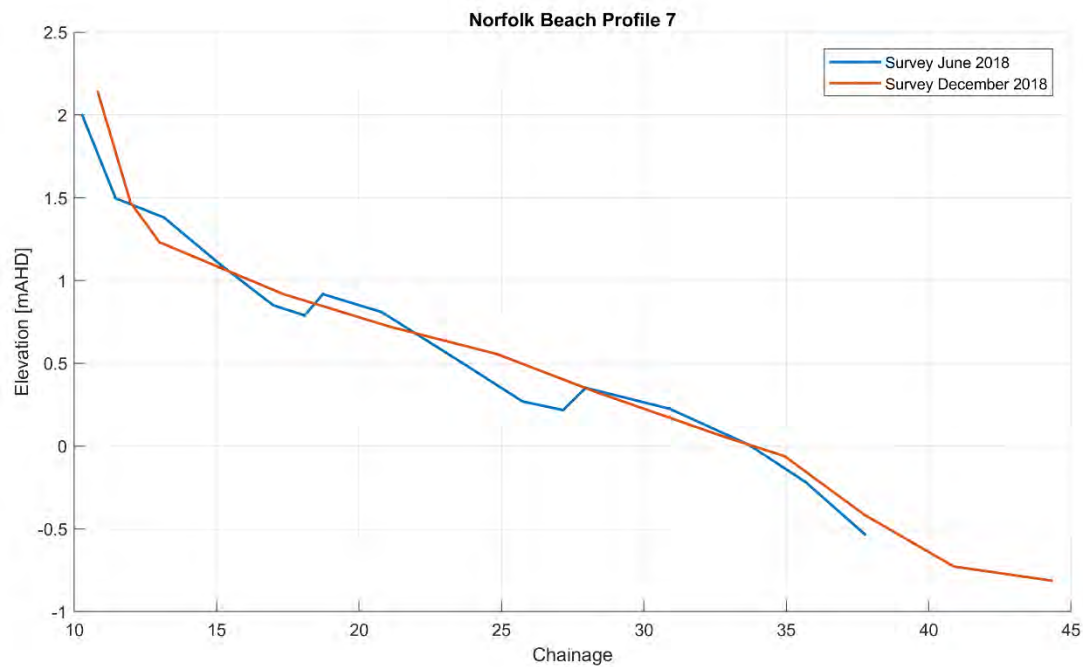


Figure A-8 Survey profiles, June and December 2018 - Norfolk Beach Profile 7

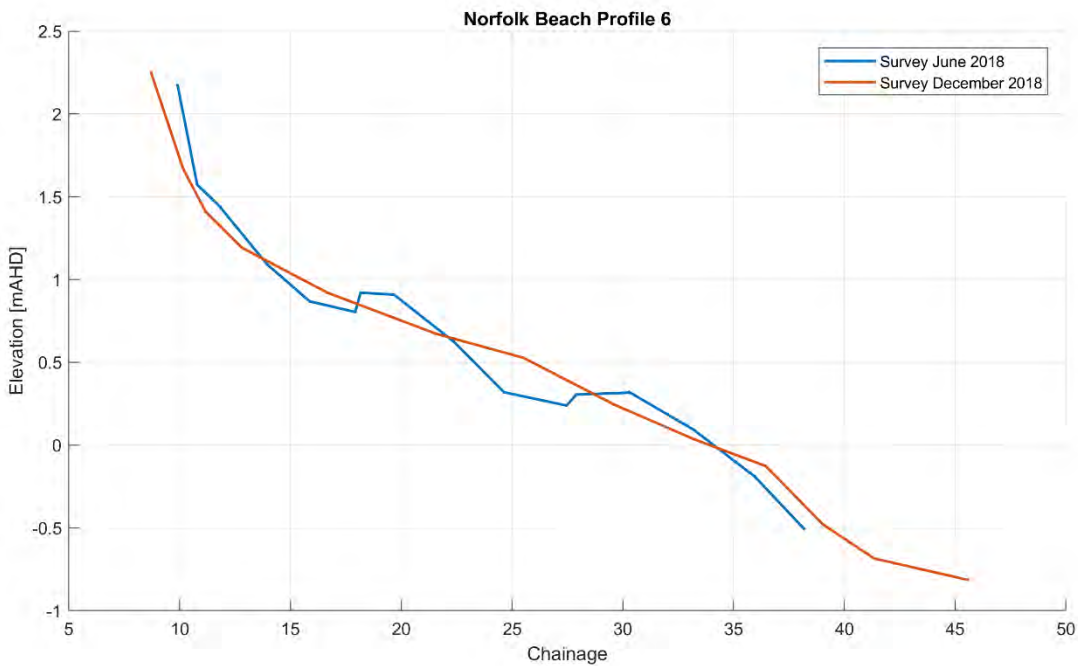


Figure A-9 Survey profiles, June and December 2018 - Norfolk Beach Profile 6

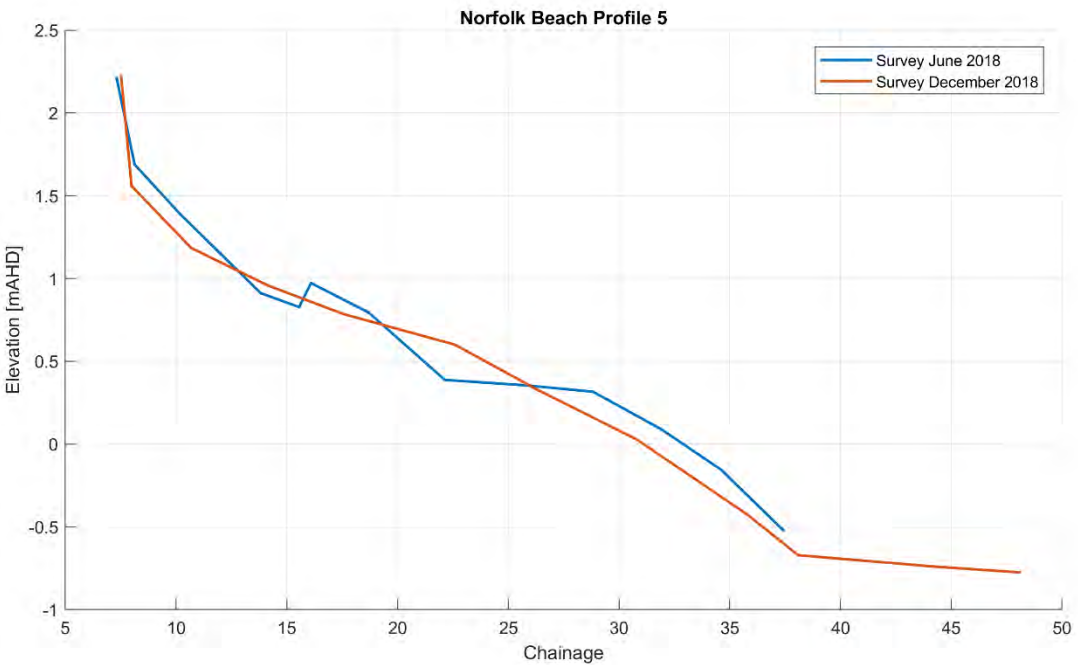


Figure A-10 Survey profiles, June and December 2018 - Norfolk Beach Profile 5

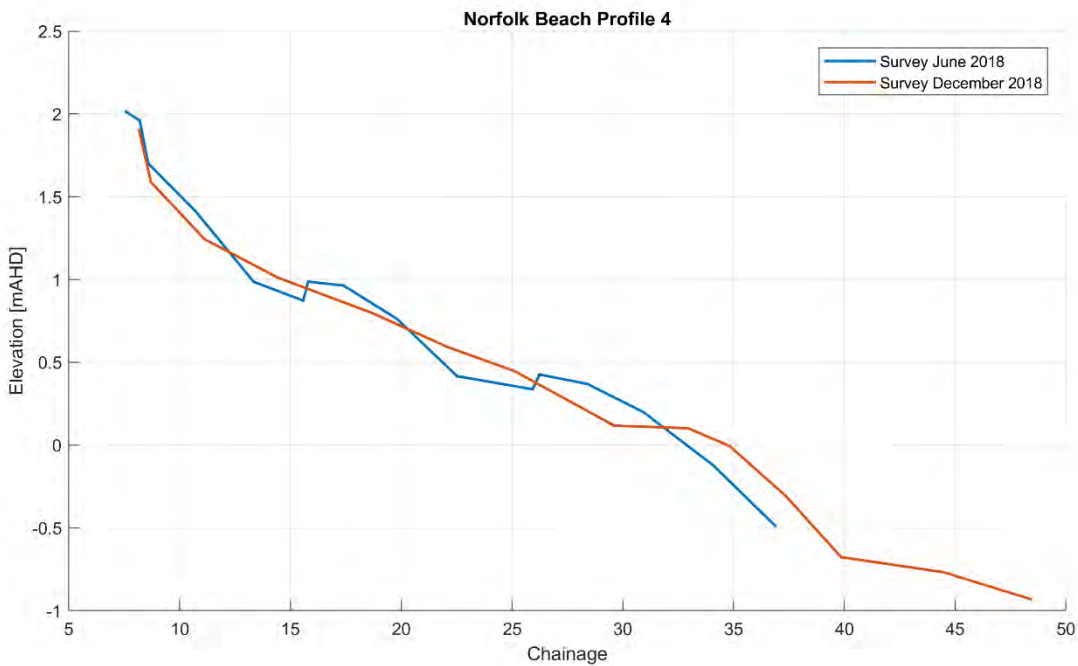


Figure A-11 Survey profiles, June and December 2018 - Norfolk Beach Profile 4

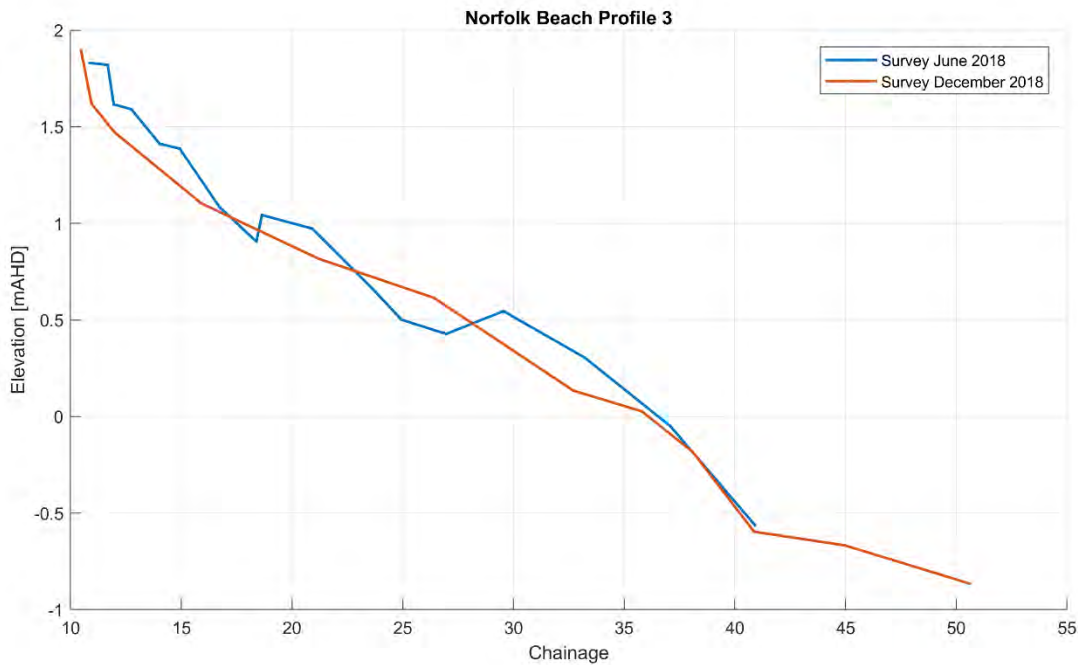


Figure A-12 Survey profiles, June and December 2018 - Norfolk Beach Profile 3

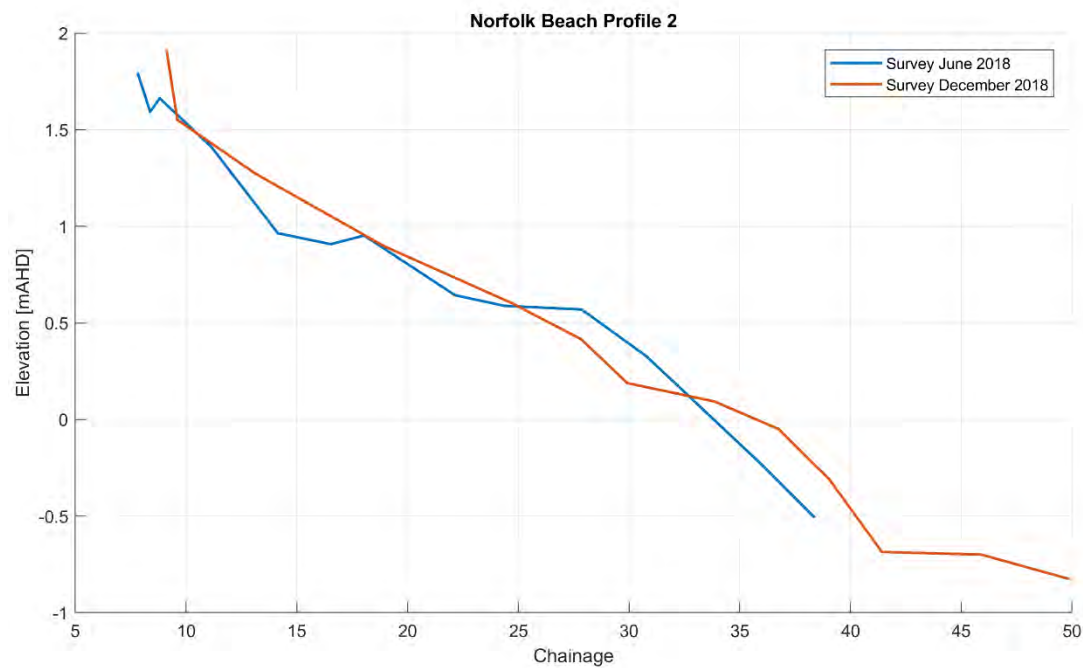


Figure A-13 Survey profiles, June and December 2018 - Norfolk Beach Profile 2

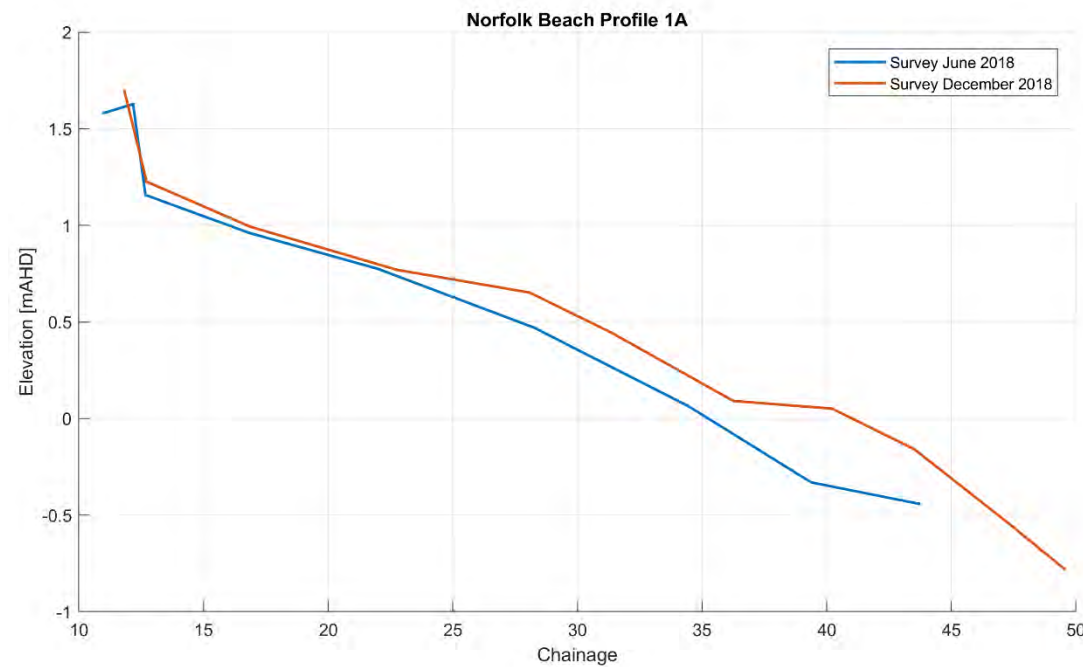


Figure A-14 Survey profiles, June and December 2018 - Norfolk Beach Profile 1A

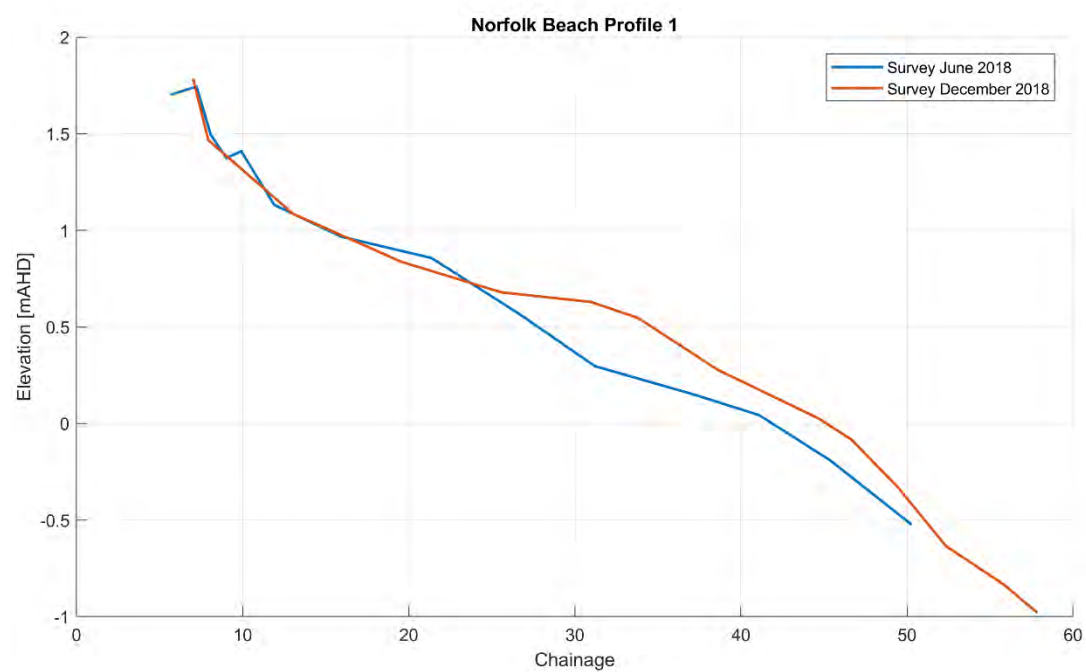


Figure A-15 Survey profiles, June and December 2018 - Norfolk Beach Profile 1

Appendix B Wave Modelling Results

Table B-1 Percentage of occurrence of Hs interval (rows) and Direction interval (columns) – Western Foreshore (2008 – 2018)

Hs [m]	Wave Direction [deg]												Grand Total
	0-30	30-60	60-90	90-120	120-150	150-180	180-210	210-240	240-270	270-300	300-330	330-360	
0 - 0.1	9.437%	4.286%	0.056%	0.015%	0.009%	0.017%	0.069%	6.281%	3.825%	1.528%	2.742%	15.843%	44.11%
0.1 - 0.2	5.065%	4.595%	0.332%	0.193%	0.152%	0.382%	3.290%	12.384%	2.102%	1.613%	2.158%	8.825%	41.09%
0.2 - 0.3	2.140%	0.675%	0.107%	0.020%	0.053%	0.045%	0.167%	0.141%	0.138%	0.751%	0.864%	4.980%	10.08%
0.3 - 0.4	0.912%	0.072%	0.007%				0.004%	0.002%		0.071%	0.123%	2.396%	3.59%
0.4 - 0.5	0.306%	0.010%									0.005%	0.593%	0.91%
0.5 - 0.6	0.056%											0.137%	0.19%
0.6 - 0.7	0.014%	0.001%										0.010%	0.03%
0.7 - 0.8	0.001%											0.001%	0.00%
Grand Total	17.93%	9.64%	0.50%	0.23%	0.21%	0.44%	3.53%	18.81%	6.07%	3.96%	5.89%	32.79%	100.00%

Table B-2 Percentage of occurrence of Hs interval (rows) and Tp interval (columns) – Western Foreshore (2008 – 2018)

Hs [m]	Peak Period [s]							Grand Total
	<2	2-4	4-6	6-8	8-10	10-12	12-14	
0 - 0.1	21.483%	22.332%		0.043%	0.130%	0.103%	0.017%	44.11%
0.1 - 0.2	26.609%	14.482%						41.09%
0.2 - 0.3	2.398%	7.681%						10.08%
0.3 - 0.4	0.021%	3.566%						3.59%
0.4 - 0.5		0.915%						0.91%
0.5 - 0.6		0.192%	0.001%					0.19%
0.6 - 0.7		0.022%	0.003%					0.03%
0.7 - 0.8		0.001%	0.001%					0.00%
Grand Total	50.51%	49.19%	0.01%	0.04%	0.13%	0.10%	0.02%	100.00%

Table B-3 Percentage of occurrence of Hs interval (rows) and Direction interval (columns) – Morwong Beach (2008 – 2018)

Hs [m]	Wave Direction [deg]												Grand Total
	0-30	30-60	60-90	90-120	120-150	150-180	180-210	210-240	240-270	270-300	300-330	330-360	
0 - 0.1	4.204%	2.893%	6.638%	3.061%	0.394%	0.094%	0.063%	0.081%	0.302%	1.194%	3.003%	6.543%	28.47%
0.1 - 0.2	3.911%	3.735%	11.610%	9.454%	0.472%	0.094%	0.041%	0.055%	0.118%	1.266%	2.933%	5.812%	39.50%
0.2 - 0.3	3.565%	2.282%	4.204%	6.336%	0.106%	0.012%	0.008%	0.003%	0.008%	0.363%	1.161%	3.275%	21.32%
0.3 - 0.4	2.521%	0.564%	0.720%	1.237%						0.004%	0.276%	1.552%	6.87%
0.4 - 0.5	1.428%	0.152%	0.129%	0.074%							0.025%	0.638%	2.45%
0.5 - 0.6	0.628%	0.055%	0.023%	0.012%								0.220%	0.94%
0.6 - 0.7	0.218%	0.021%	0.003%									0.067%	0.31%
0.7 - 0.8	0.066%	0.010%										0.024%	0.10%
0.8 - 0.9	0.015%	0.010%										0.002%	0.03%
0.9 - 1	0.007%	0.003%											0.01%
> 1		0.002%											0.00%
Grand Total	16.56%	9.73%	23.33%	20.17%	0.97%	0.20%	0.11%	0.14%	0.43%	2.83%	7.40%	18.13%	100.00%

Table B-4 Percentage of occurrence of Hs interval (rows) and Tp interval (columns) – Morwong Beach (2008 – 2018)

Hs [m]	Peak Period [s]								Grand Total	
	<2	2-4	4-6	6-8	8-10	10-12	12-14	> 14		
0 - 0.1	15.946%	10.885%	0.084%	0.171%	0.501%	0.668%	0.168%	0.047%	28.47%	
0.1 - 0.2	19.974%	19.522%	0.007%						39.50%	
0.2 - 0.3	2.043%	19.271%	0.009%						21.32%	
0.3 - 0.4		6.873%	0.001%						6.87%	
0.4 - 0.5		2.445%							2.45%	
0.5 - 0.6		0.938%							0.94%	
0.6 - 0.7		0.309%							0.31%	
0.7 - 0.8		0.100%							0.10%	
0.8 - 0.9		0.027%							0.03%	
0.9 - 1		0.010%							0.01%	
> 1		0.002%							0.00%	
Grand Total	37.96%	60.38%	0.10%	0.17%	0.50%	0.67%	0.17%	0.05%	100.00%	0.00%

Table B-5 Percentage of occurrence of Hs interval (rows) and Direction interval (columns) – Norfolk Beach (2008 – 2018)

Hs [m]	Wave Direction [deg]												Grand Total
	0-30	30-60	60-90	90-120	120-150	150-180	180-210	210-240	240-270	270-300	300-330	330-360	
0 - 0.1	5.220%	4.860%	2.522%	2.579%	2.138%	5.799%	2.740%	0.162%	0.068%	0.076%	0.152%	1.083%	27.40%
0.1 - 0.2	4.870%	5.721%	3.194%	5.236%	4.632%	5.502%	2.400%	0.137%	0.051%	0.052%	0.068%	0.355%	32.22%
0.2 - 0.3	2.203%	3.950%	2.127%	5.858%	6.925%	4.149%	0.331%	0.011%	0.007%	0.008%	0.011%	0.017%	25.60%
0.3 - 0.4	0.764%	2.037%	0.535%	2.404%	4.151%	1.451%	0.005%						11.35%
0.4 - 0.5	0.204%	0.731%	0.157%	0.551%	0.982%	0.122%	0.002%						2.75%
0.5 - 0.6	0.038%	0.184%	0.123%	0.098%	0.116%	0.003%							0.56%
0.6 - 0.7		0.035%	0.034%	0.001%	0.005%	0.001%							0.08%
0.7 - 0.8		0.010%	0.017%		0.001%								0.03%
0.8 - 0.9		0.007%	0.005%										0.01%
0.9 - 1		0.004%	0.004%										0.01%
> 1			0.005%										0.01%
Grand Total	13.30%	17.54%	8.72%	16.73%	18.95%	17.03%	5.48%	0.31%	0.13%	0.14%	0.23%	1.45%	100.00%

Table B-6 Percentage of occurrence of Hs interval (rows) and Tp interval (columns) – Norfolk Beach (2008 – 2018)

Hs [m]	Peak Period [s]							Grand Total
	<2	2-4	4-6	6-8	8-10	10-12	12-14	
0 - 0.1	21.754%	5.516%	0.025%	0.014%	0.029%	0.051%	0.009%	27.40%
0.1 - 0.2	25.728%	6.488%	0.001%					32.22%
0.2 - 0.3	10.261%	15.336%						25.60%
0.3 - 0.4	0.001%	11.347%						11.35%
0.4 - 0.5		2.749%						2.75%
0.5 - 0.6		0.562%						0.56%
0.6 - 0.7		0.076%						0.08%
0.7 - 0.8		0.028%						0.03%
0.8 - 0.9		0.012%						0.01%
0.9 - 1		0.009%						0.01%
> 1		0.005%						0.01%
Grand Total	57.74%	42.13%	0.03%	0.01%	0.03%	0.05%	0.01%	100.00%

Table B-7 Percentage of occurrence of Hs interval (rows) and Direction interval (columns) – Main Beach (2008 – 2018)

Hs [m]	Wave Direction [deg]												Grand Total
	0-30	30-60	60-90	90-120	120-150	150-180	180-210	210-240	240-270	270-300	300-330	330-360	
0 - 0.1	0.027%	0.029%	5.627%	8.571%	5.667%	5.226%	4.231%	4.056%	4.960%	1.235%	0.041%	0.021%	39.69%
0.1 - 0.2	0.014%	0.043%	3.494%	10.432%	5.370%	4.690%	3.275%	3.068%	3.110%	1.440%	0.039%	0.021%	34.99%
0.2 - 0.3		0.001%	0.231%	3.754%	5.675%	6.156%	1.899%	0.822%	0.181%	0.008%	0.001%		18.73%
0.3 - 0.4			0.016%	0.721%	2.047%	2.569%	0.382%	0.045%	0.004%				5.78%
0.4 - 0.5			0.010%	0.135%	0.253%	0.330%	0.020%						0.75%
0.5 - 0.6			0.001%	0.014%	0.008%	0.017%							0.04%
0.6 - 0.7				0.011%		0.004%							0.02%
0.7 - 0.8				0.001%									0.00%
Grand Total	0.04%	0.07%	9.38%	23.63%	19.02%	18.99%	9.81%	7.99%	8.26%	2.68%	0.08%	0.04%	100.00%

Table B-8 Percentage of occurrence of Hs interval (rows) and Tp interval (columns) – Main Beach (2008 – 2018)

Hs [m]	Peak Period [s]								Grand Total
	<2	2-4	4-6	6-8	8-10	10-12	12-14	> 14	
0 - 0.1	36.221%	3.329%	0.026%	0.020%	0.049%	0.036%	0.007%	0.003%	39.69%
0.1 - 0.2	31.192%	3.803%							34.99%
0.2 - 0.3	13.846%	4.880%	0.002%						18.73%
0.3 - 0.4	0.114%	5.670%							5.78%
0.4 - 0.5		0.746%							0.75%
0.5 - 0.6		0.040%							0.04%
0.6 - 0.7		0.015%							0.02%
0.7 - 0.8		0.001%							0.00%
Grand Tot	81.37%	18.47%	0.03%	0.02%	0.05%	0.04%	0.01%	0.00%	100.00%

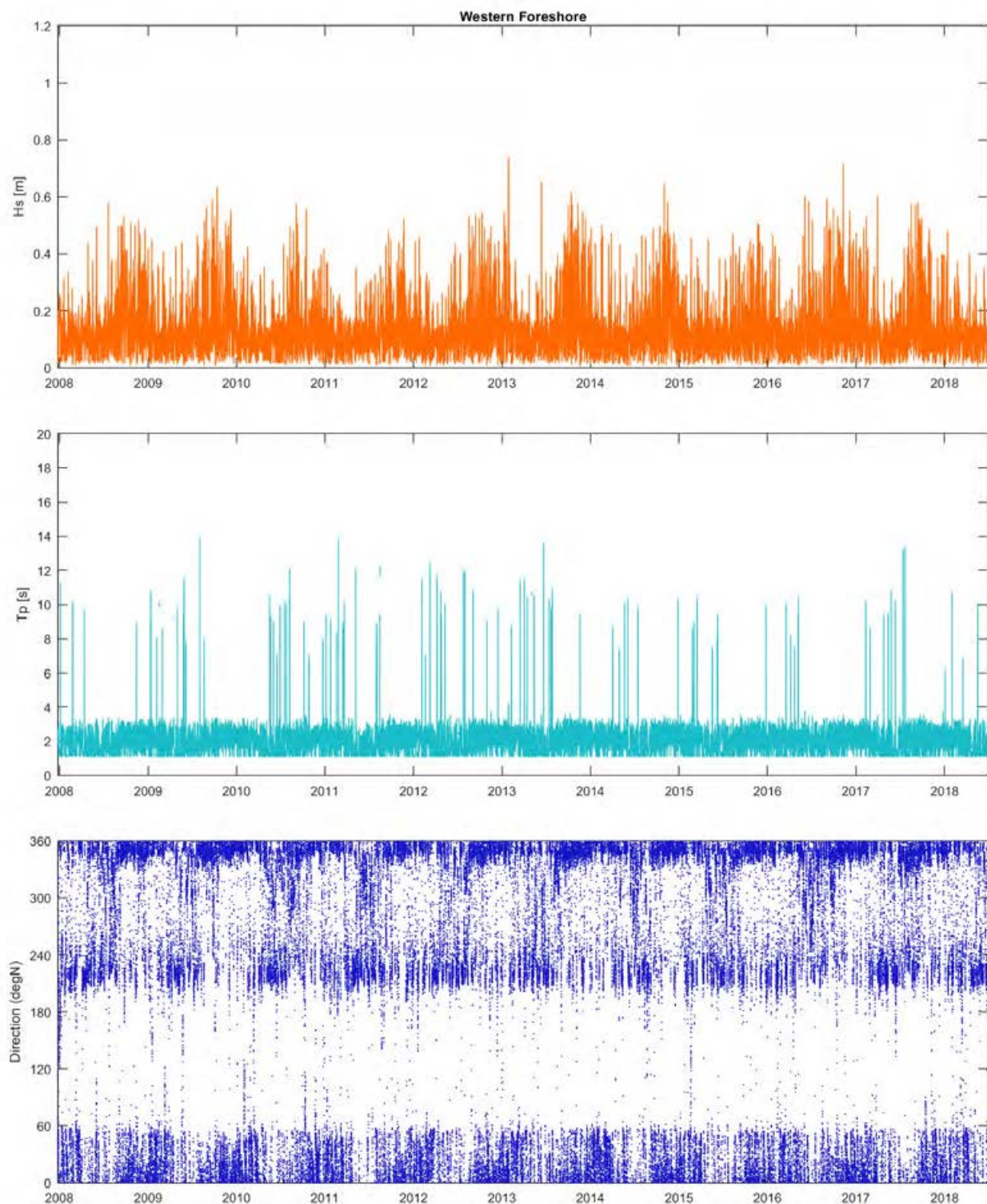


Figure B-1 Significant wave height, peak wave period and wave direction off the Western Foreshore for the hindcast period

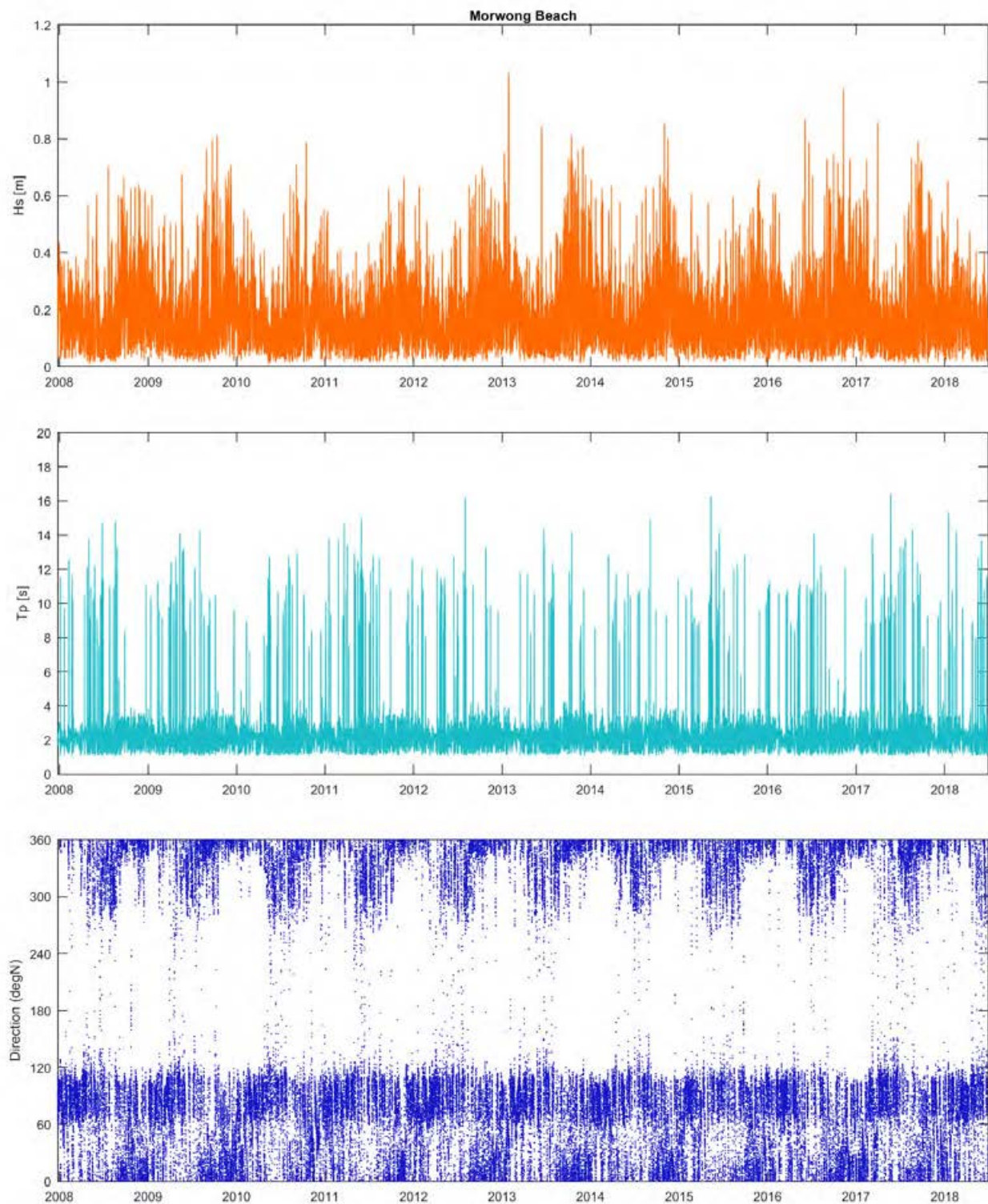


Figure B-2 Significant wave height, peak wave period and wave direction off Morwong Beach for the hindcast period

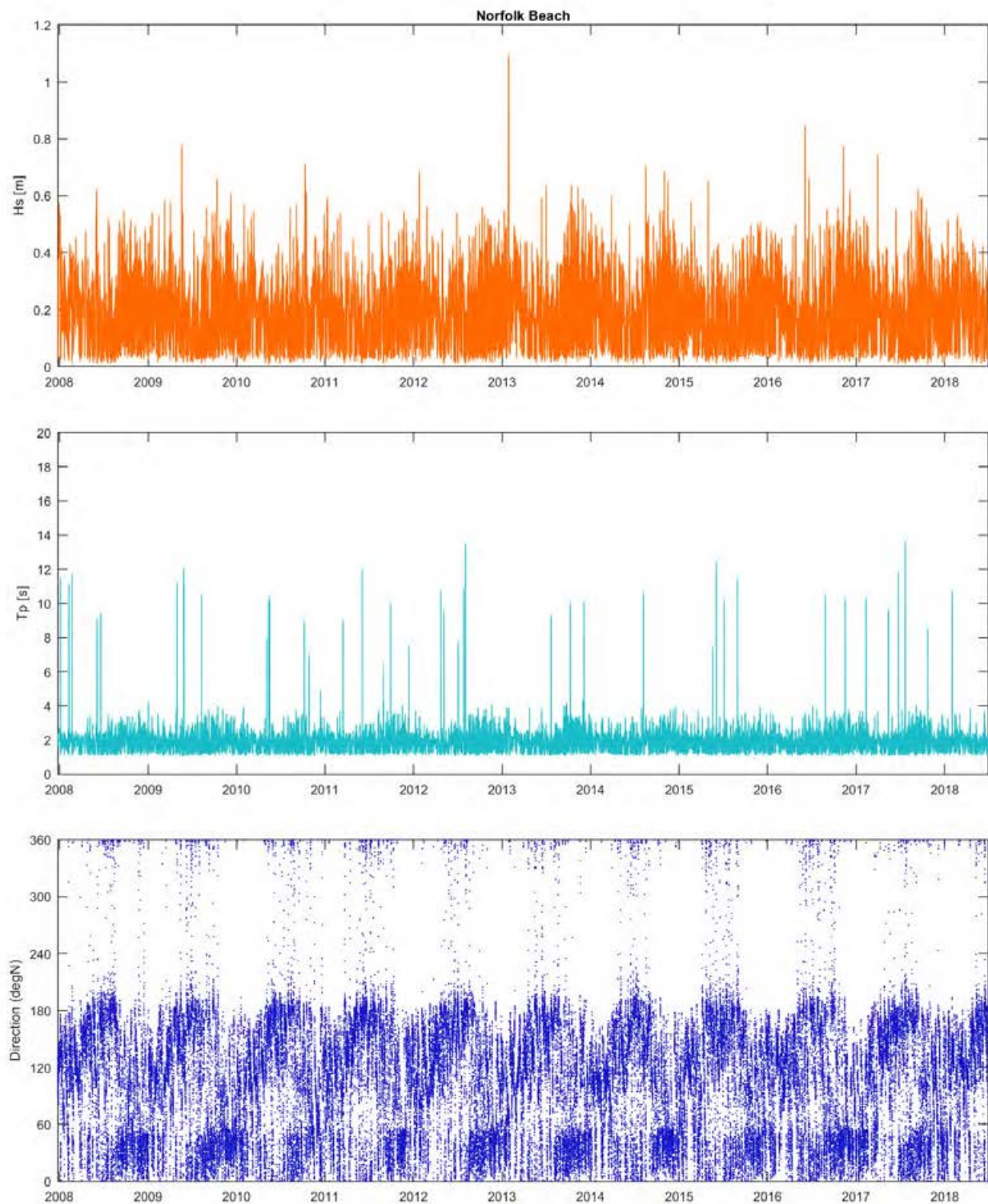


Figure B-3 Significant wave height, peak wave period and wave direction off Norfolk Beach for the hindcast period

Wave Modelling Results

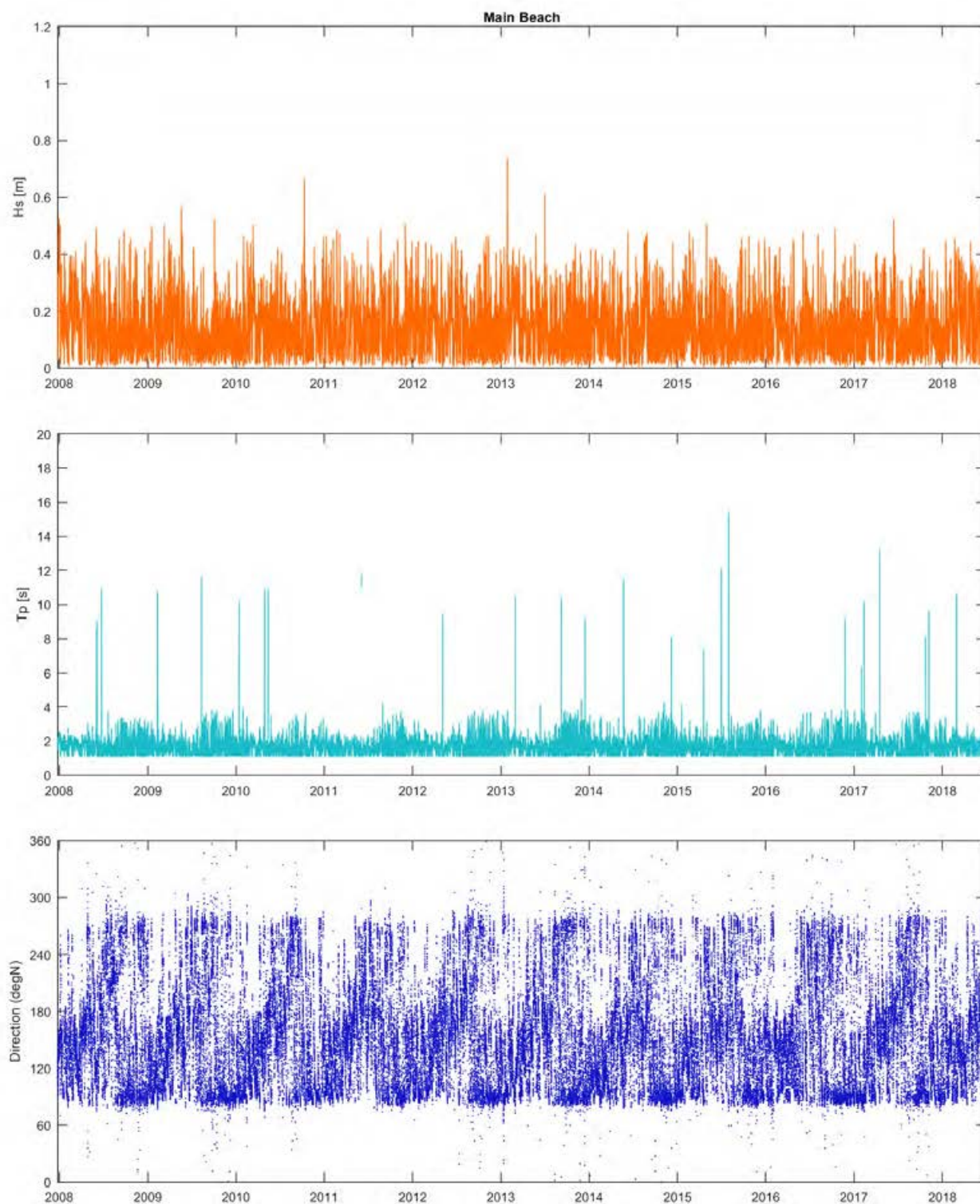


Figure B-4 Significant wave height, peak wave period and wave direction off Main Beach for the hindcast period

Appendix C Storm Erosion Modelling (0.2mm median grain size (d50))

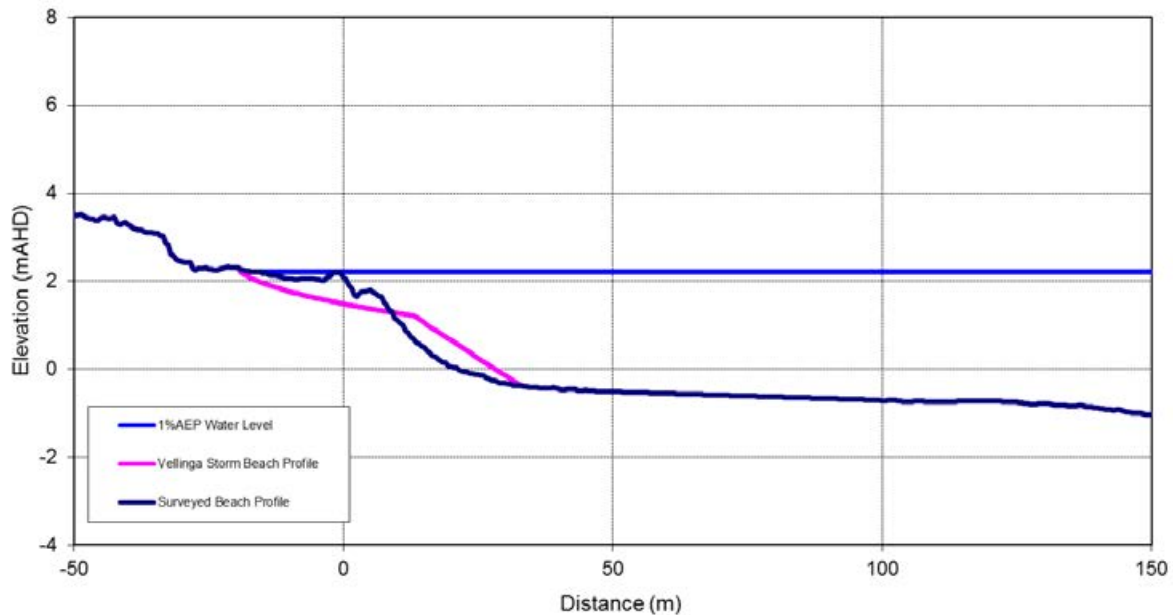


Figure C-1 Storm erosion estimate: Morwong Beach

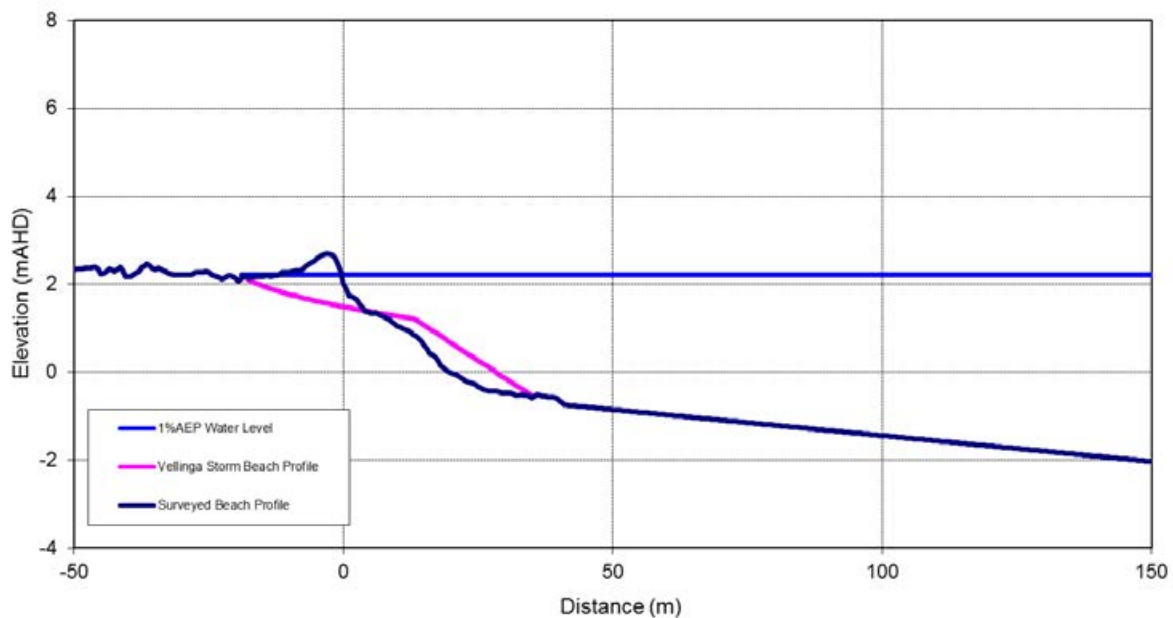


Figure C-2 Storm erosion estimate: Norfolk Beach (North)

Storm Erosion Modelling (0.2mm median grain size (d50))

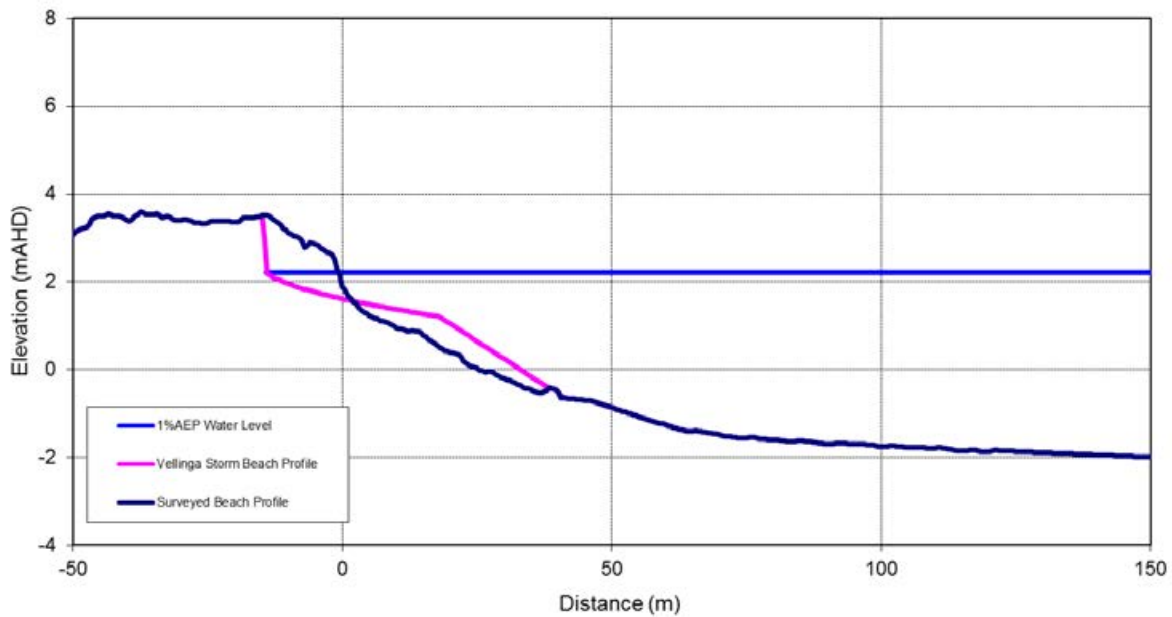


Figure C-3 Storm erosion estimate: Norfolk Beach (Profile 13)

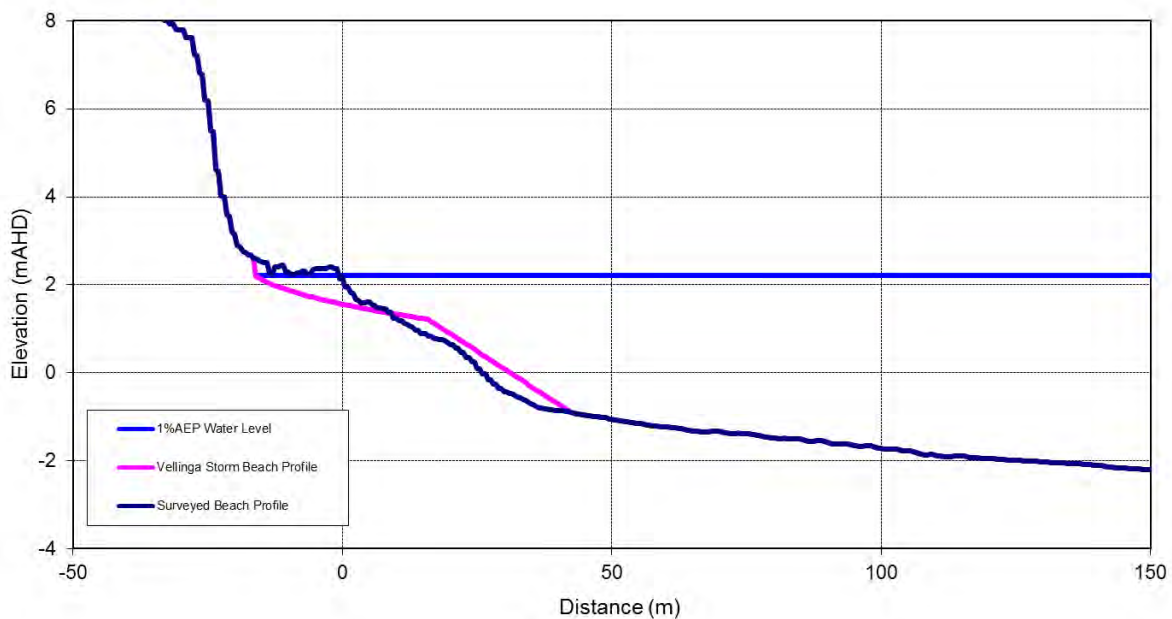


Figure C-4 Storm erosion estimate: Norfolk Beach (Profile 3)

Storm Erosion Modelling (0.2mm median grain size (d50))

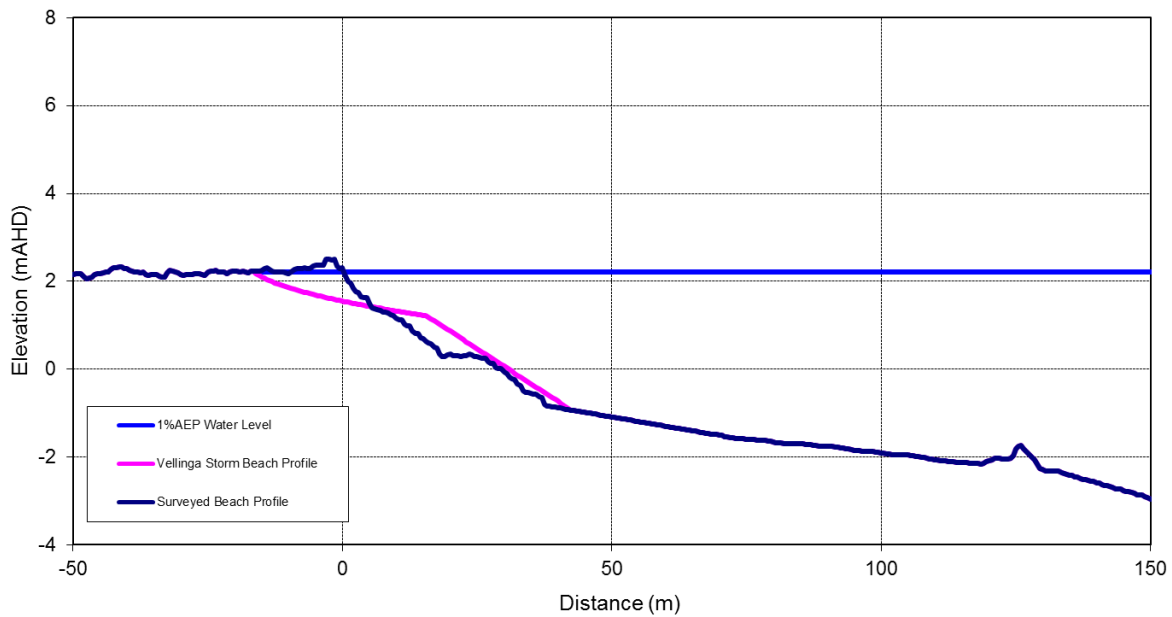


Figure C-5 Storm erosion estimate: Norfolk Beach (South)

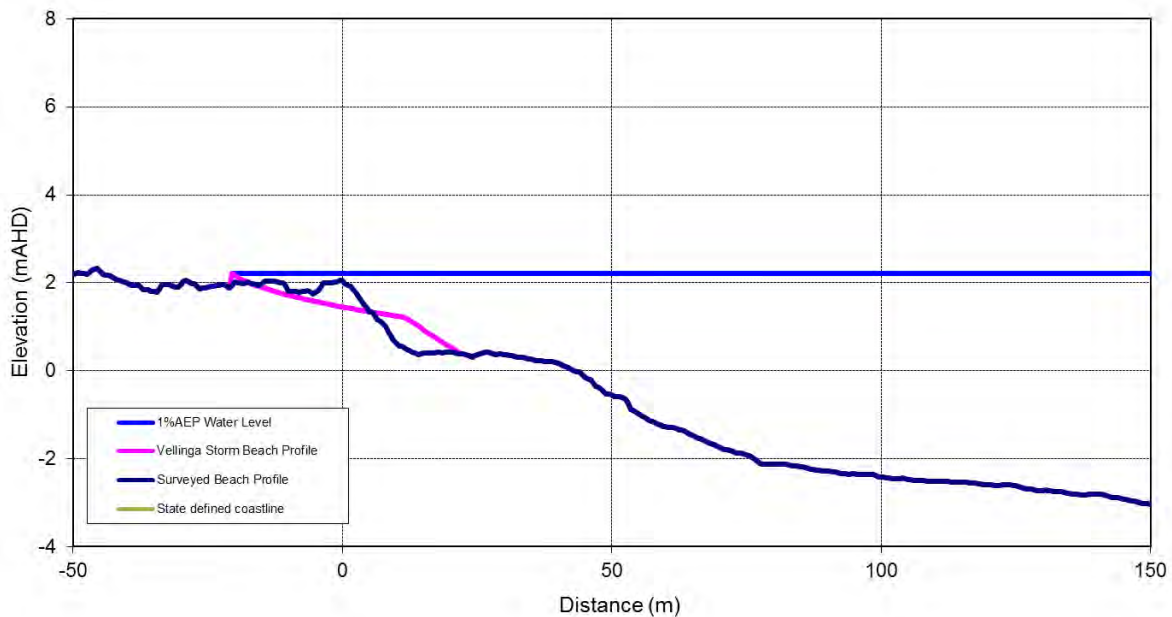


Figure C-6 Storm erosion estimate: Main Beach (Profile 8)

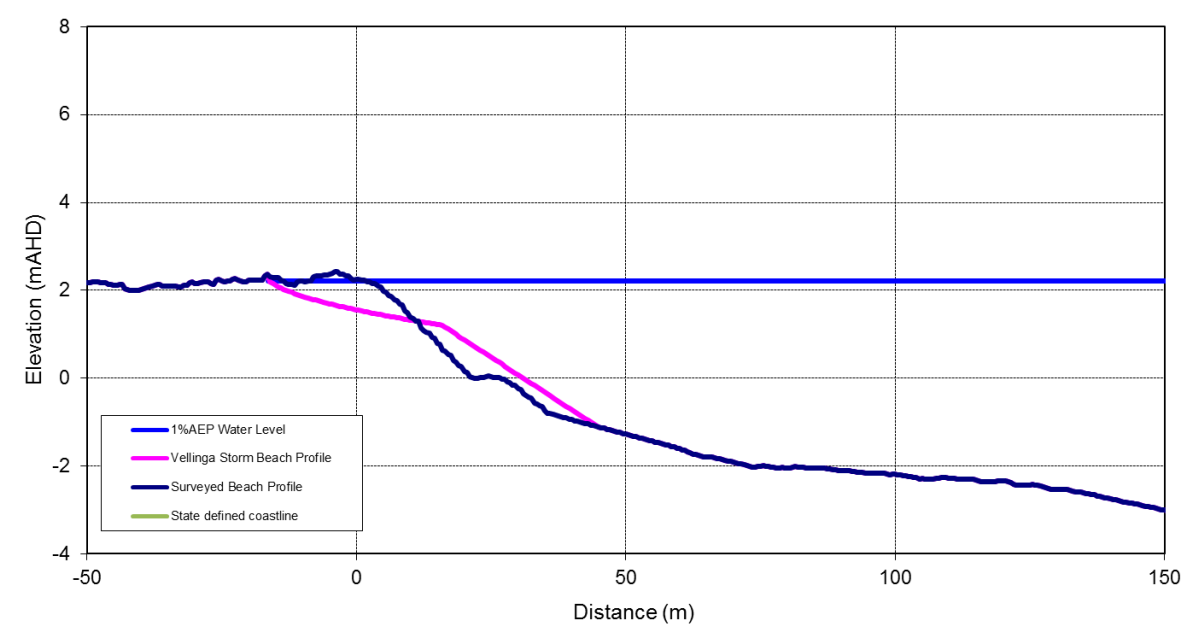


Figure C-7 Storm erosion estimate: Main Beach (Profile 5)

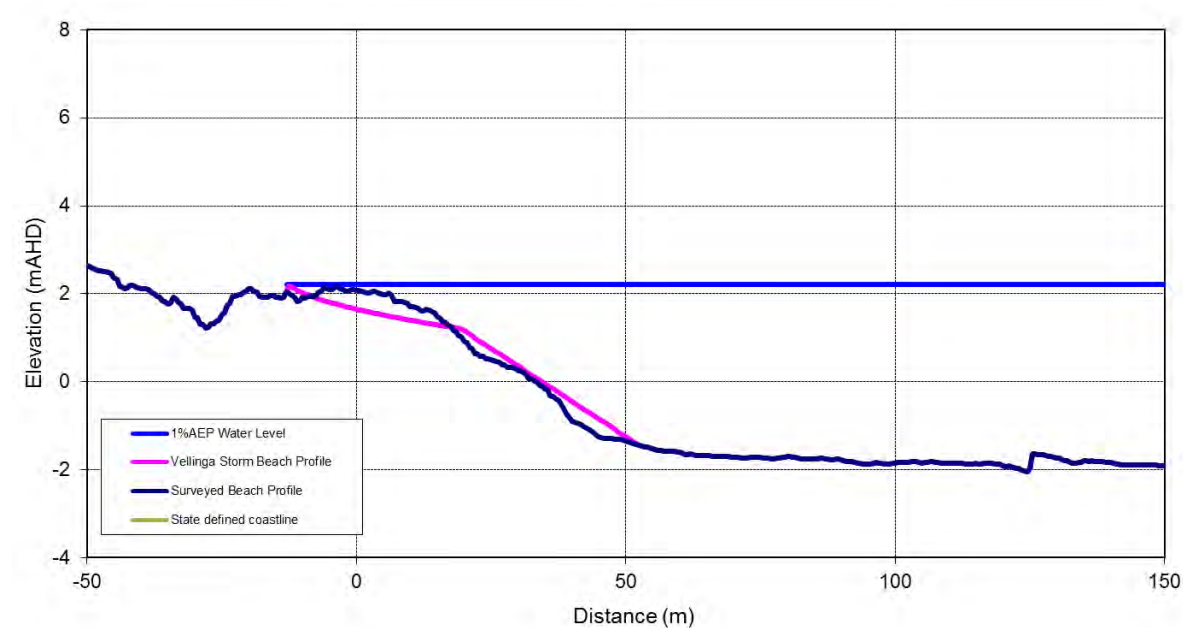


Figure C-8 Storm erosion estimate: Main Beach (West)

Storm Erosion Modelling (0.2mm median grain size (d50))

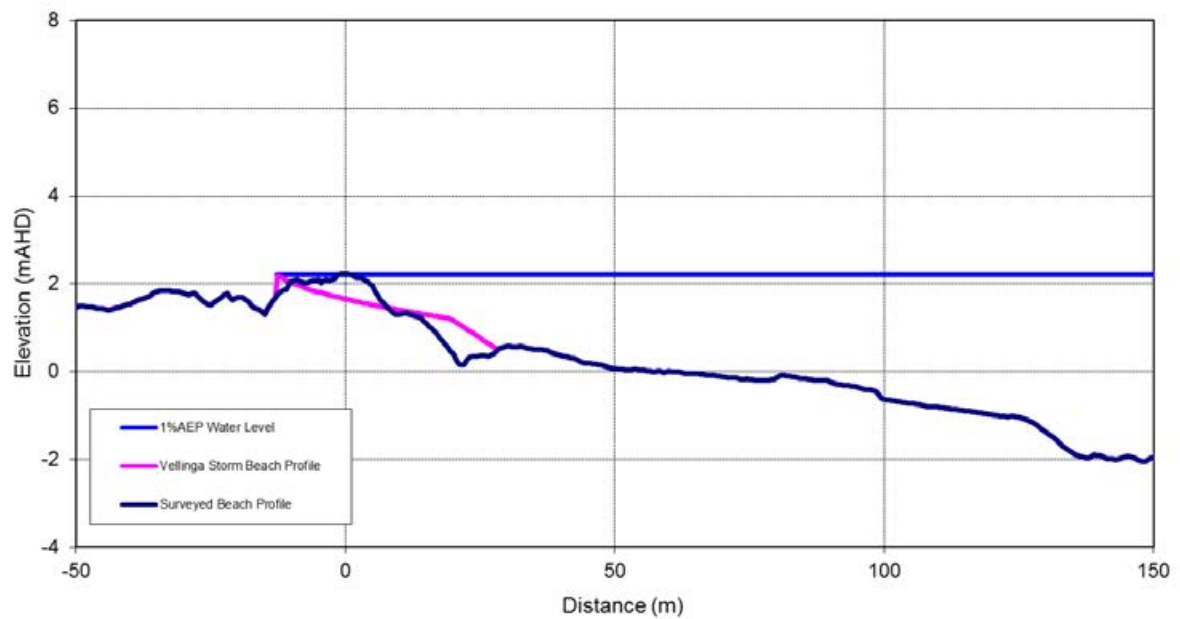


Figure C-9 Storm erosion estimate: Main Beach (Golf Links Beach)

Appendix D Historical Aerial Photographs

Historical Aerial Photographs

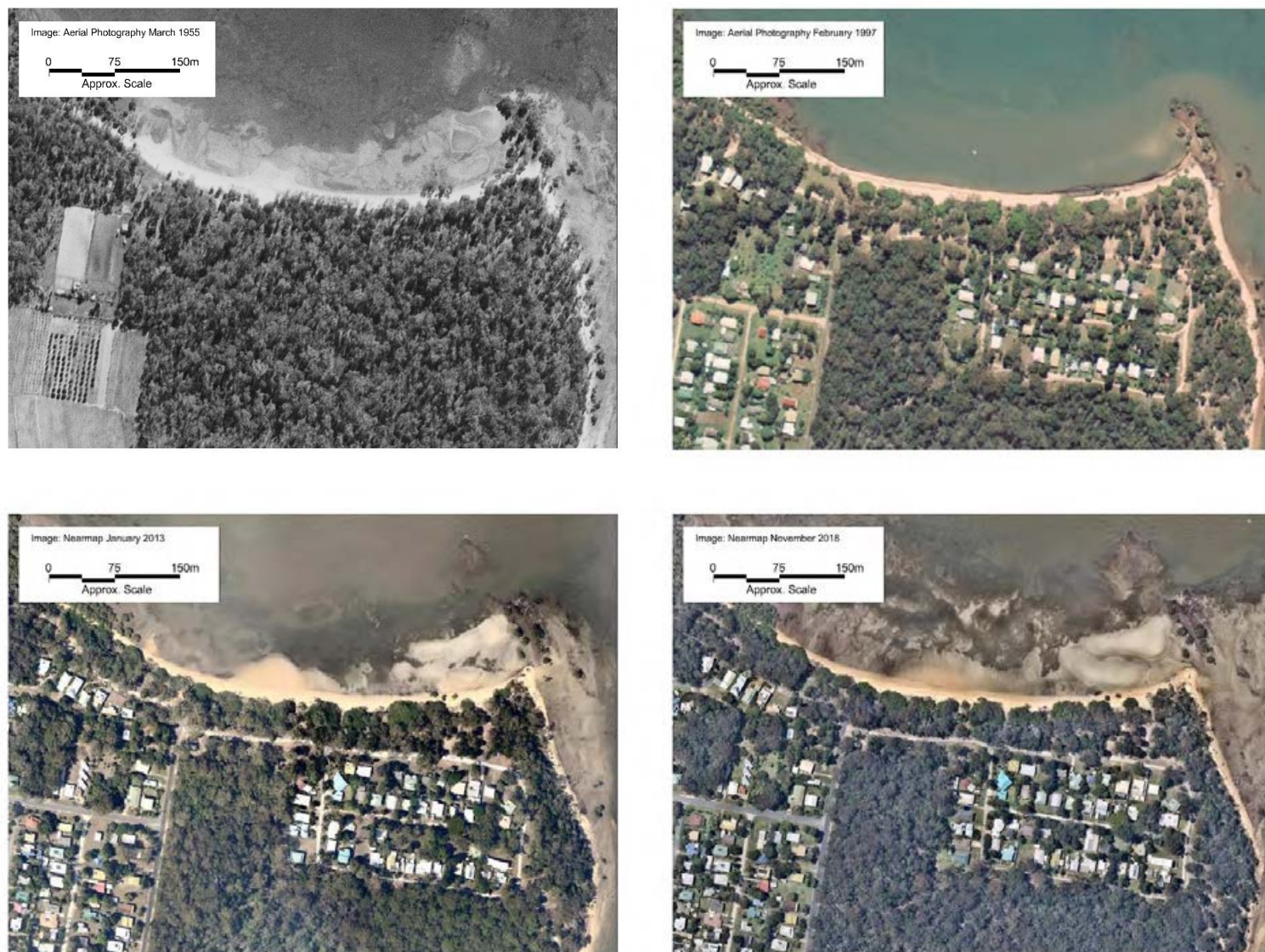


Figure D-1 Morwong Beach Aerial Images 1955 (top left), 1997 (top right), 2013 (bottom left) and 2018 (bottom right)

Historical Aerial Photographs

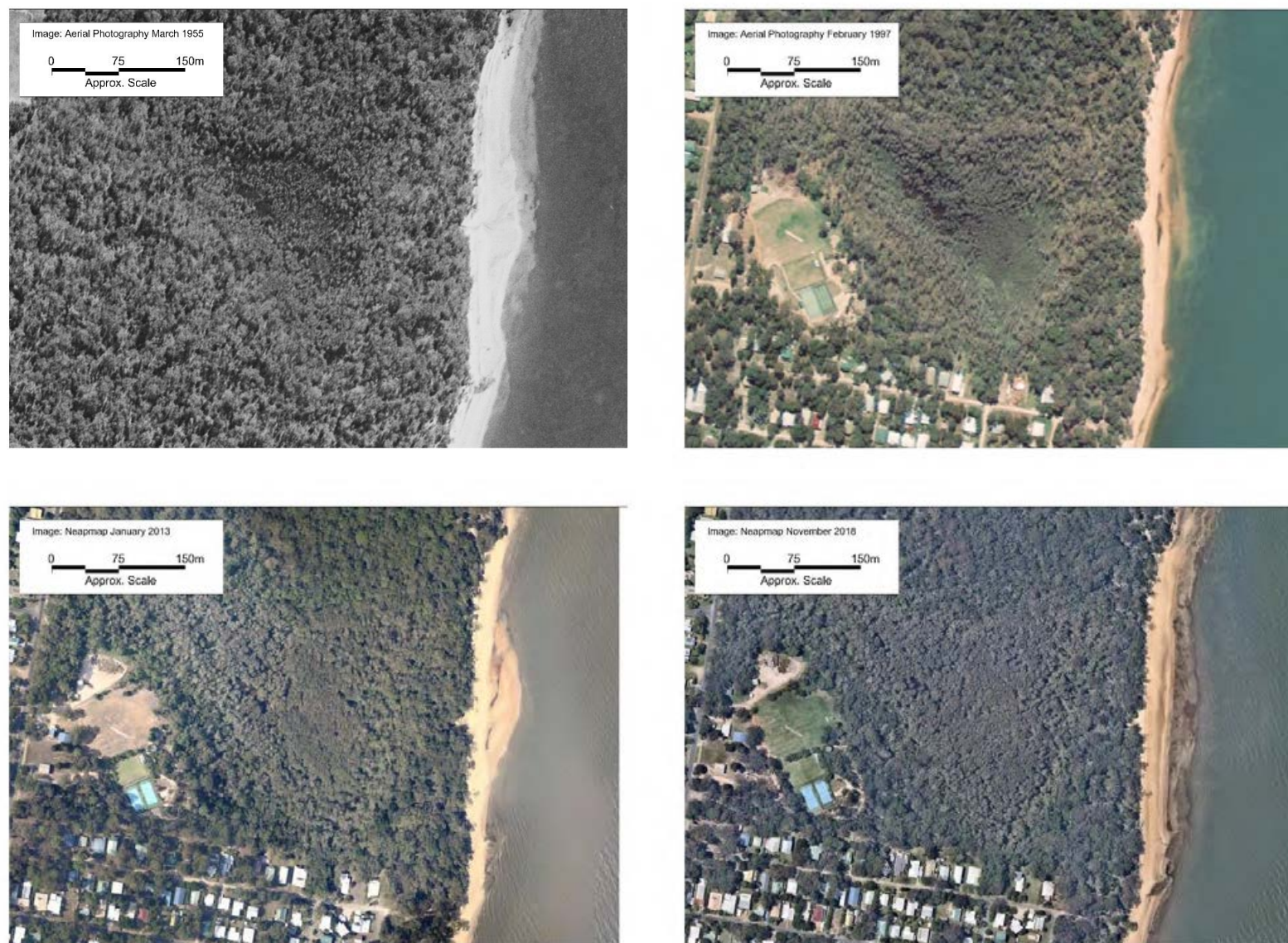


Figure D-2 Norfolk Beach Aerial Images 1955 (top left), 1997 (top right), 2013 (bottom left) and 2018 (bottom right)

Historical Aerial Photographs

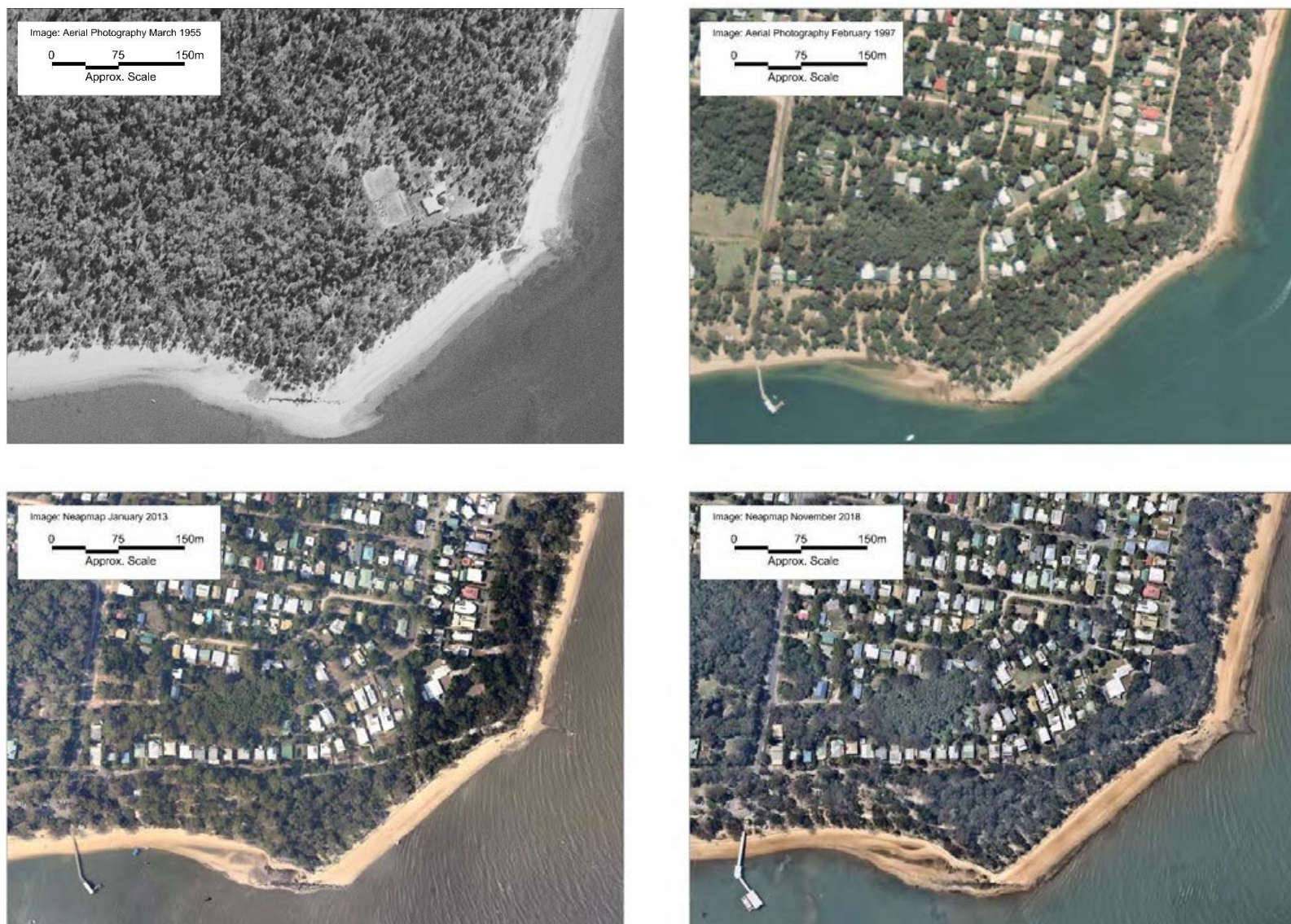


Figure D-3 Main Beach (east) Aerial Images 1955 (top left), 1997 (top right), 2013 (bottom left) and 2018 (bottom right)

Historical Aerial Photographs



Figure D-4 Main Beach (centre) Aerial Images 1955 (top left), 1997 (top right), 2013 (bottom left) and 2018 (bottom right)

Historical Aerial Photographs

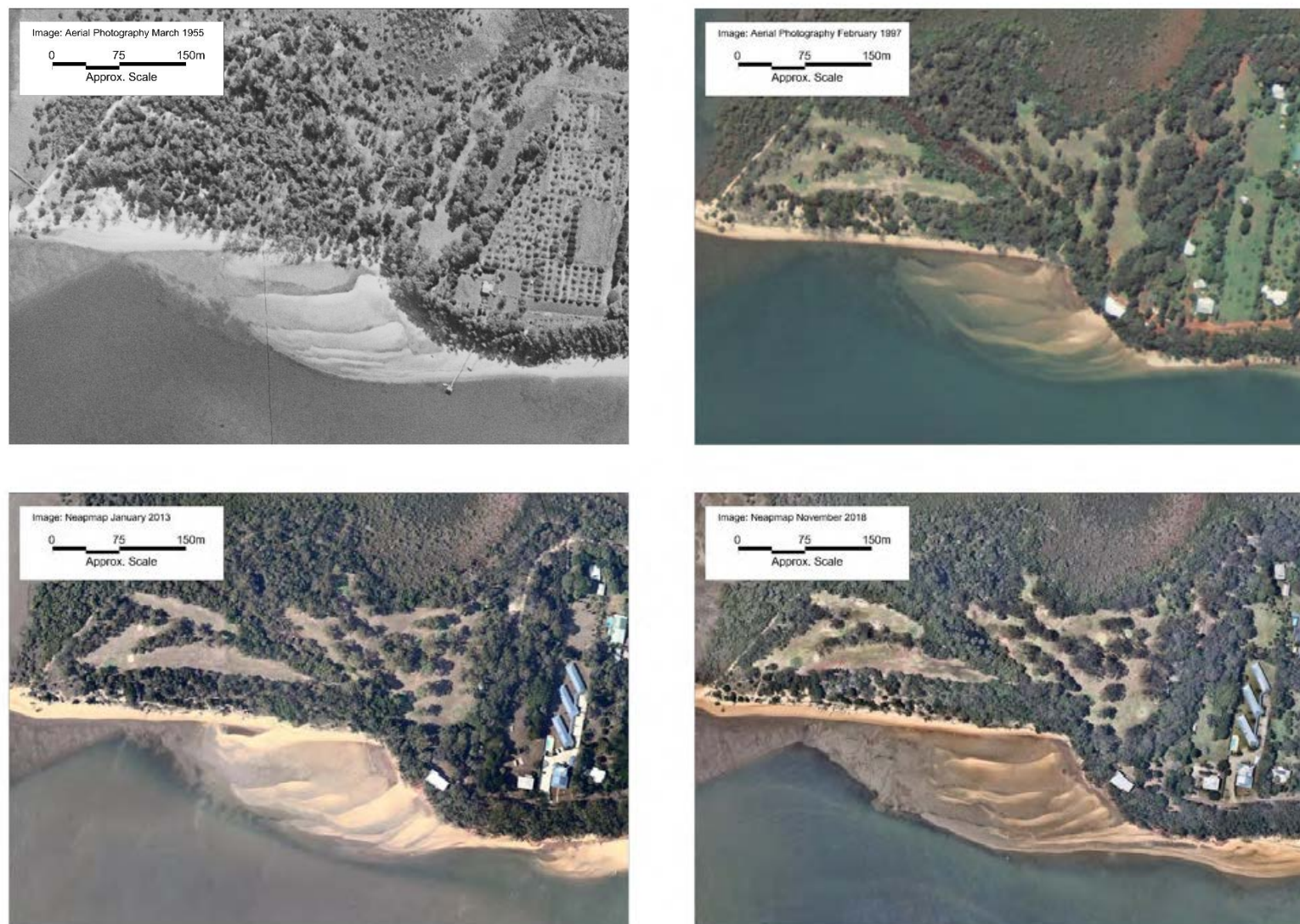
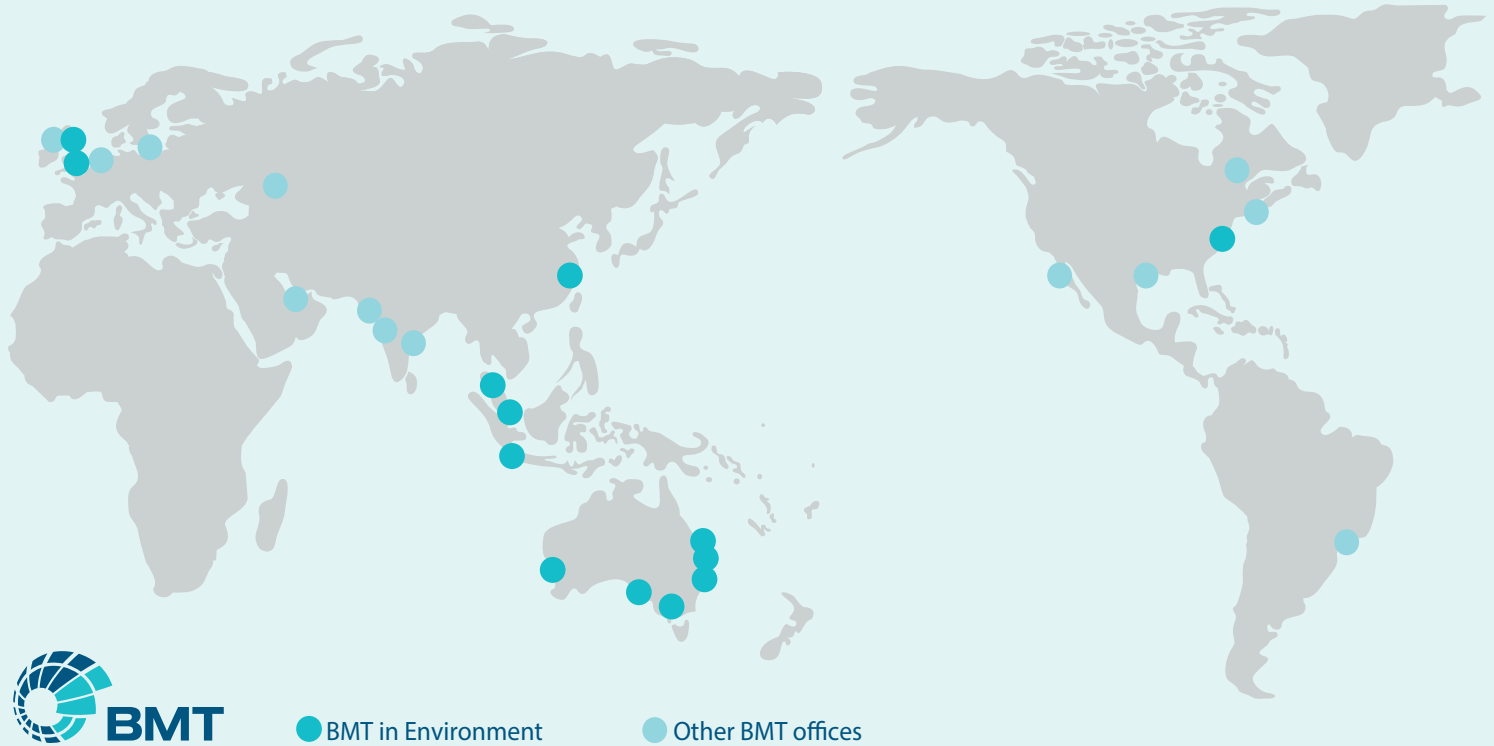


Figure D-5 Main Beach (west) Aerial Images 1955 (top left), 1997 (top right), 2013 (bottom left) and 2018 (bottom right)

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