Great Keppel Island Resort Revitalisation Plan

Coastal Environment Technical Report

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GLOSSARY

Advective Transport	The transport of dissolved material by water movement
Australian Height Datum (AHD)	A common national plane of level corresponding approximately to mean sea level
ARI	Average Recurrence Interval
AEP	Annual Exceedance Probability: The measure of the likelihood (expressed as a probability) of an event equaling or exceeding a given magnitude in any given year
Astronomical tide	Water level variations due to the combined effects of the Earth's rotation, the Moon's orbit around the Earth and the Earth's orbit around the Sun
Calibration	The process by which the results of a computer model are brought to agreement with observed data
Chart Datum	Common datum for navigation charts. Typically relative to Lowest Astronomical Tide
Diurnal	A daily variation, as in day and night.
Ebb Tide	The outgoing tidal movement of water resulting in a low tide.
Exceedance Probability	The probability of an extreme event occurring at least once during a prescribed period of assessment is given by the exceedance probability. The probability of a 1 in 100 year event (1% AEP) occurring during the first 25 years is 22%, during the first 50 years the probability is 39% and over a 100 year asset life the probability is 63%
Flood Tide	The incoming tidal movement of water resulting in a high tide
Foreshore	The area of shore between low and high tide marks and land adjacent thereto
Geomorphology	The study of the origin, characteristics and development of land forms
Holocene	The period beginning approximately 12,000 years ago. It is characterised by warming of the climate following the last glacial period and rapid increase in global sea levels to approximately present day levels.
HAT	Highest Astronomical Tide: the highest water level that can occur due to the effects of the astronomical tide in isolation from meteorological effects
MHHW	Mean Higher High Water: the mean of the higher of the two daily high waters over a long period of time. When only one high water occurs on a day this is taken as the higher high water
Hs (Significant Wave Height)	Hs may be defined as the average of the highest 1/3 of wave heights in a wave record (H1/3), or from the zeroth spectral moment (Hmo)
Intertidal	Pertaining to those areas of land covered by water at high tide, but exposed at low tide, eg. intertidal habitat
Littoral Zone	An area of the coastline in which sediment movement by wave, current and wind action is prevalent
Littoral Drift Processes	Wave, current and wind processes that facilitate the transport of water and sediments along a shoreline
MSL	Mean Sea Level

Neap Tides	Neap tides occur when the sun and moon lie at right angles relative to the earth (the gravitational effects of the moon and sun act in opposition on the ocean).
Pleistocene	The period from 2.5M to 12,000 years before present that spans the earth's recent period of repeated glaciations and large fluctuations in global sea levels
Semi-diurnal	A twice-daily variation, eg. two high waters per day
Spring Tides	Tides with the greatest range in a monthly cycle, which occur when the sun, moon and earth are in alignment (the gravitational effects of the moon and sun act in concert on the ocean)
Storm Surge	The increase in coastal water levels caused by the barometric and wind set-up effects of storms. Barometric set-up refers to the increase in coastal water levels associated with the lower atmospheric pressures characteristic of storms. Wind set-up refers to the increase in coastal water levels caused by an onshore wind driving water shorewards and piling it up against the coast
Storm tide	Coastal water level produced by the combination of astronomical and meteorological (storm surge) ocean water level forcing
Tidal Planes	A series of water levels that define standard tides, eg. 'Mean High Water Spring' (MHWS) refers to the average high water level of Spring Tides
Tidal Range	The difference between successive high water and low water levels. Tidal range is maximum during Spring Tides and minimum during Neap Tides
Tides	The regular rise and fall in sea level in response to the gravitational attraction of the Sun, Moon and Earth
Velocity Shear .	The differential movement of neighbouring parcels of water brought about by frictional resistance within the flow, or at a boundary. Velocity shear causes dispersive mixing, the greater the shear (velocity gradient), the greater the mixing.
Wind Shear	The stress exerted on the water's surface by wind blowing over the water. Wind shear causes the water to pile up against downwind shores and generates secondary currents

EXECUTIVE SUMMARY

The Great Keppel Island Resort Revitalisation Plan is a sustainable eco-tourism resort comprising a range of low rise eco-tourism accommodation, 18 hole golf course, airport and marina to be located on Great Keppel Island on the Central Queensland coast.

Water Technology Pty Ltd was commissioned by Tower Holding Pty Ltd to undertake investigations and impact assessments for the following sections of the Terms of Reference for the Environmental Impact Study of the Great Keppel Island Revitalisation Plan:

- Section 3.5 Coastal Environment
- Section 3.5.1 Hydrodynamics and Sedimentation
- Section 3.5.3 Sediment Quality and Dredging

Existing coastal environment assessment

The existing coastal environment assessment has included the following major tasks:

- An extensive literature review and evaluation of existing coastal data sets relevant to Great Keppel Island
- Site inspections and field data collection programs to augment existing coastal data sets
- Development and calibration of hydrodynamic and spectral wave models to assist in the existing coastal environment assessment
- Characterisation of the existing physical coastal environment with respect to the coastal geomorphology, tides, currents, waves and sediment transport processes in the vicinity of Great Keppel Island

Key findings from the existing coastal environment assessment are as follows:

Coastal Geomorphology

The Great Keppel Island bedrock is overlaid by a relatively thin veneer of Quaternary deposits. These deposits are comprised of fine to medium relict sands that have a terrigenous origin having been formed when Keppel Bay was a sandy coastal plain during previous glacial phases. Wave and tidal current action are slowly transporting these sediments shoreward across the continental shelf and a small percentage of these sediments have accreted around the bedrock outcrop of Great Keppel Island following the submergence of Keppel Bay in the Holocene. Nearshore wave and current action and aeolian processes have subsequently reworked and shaped these deposits into a variety of geomorphological features such as beaches, dunes and spits that in combination with the outcropping of bedrock, give rise to the present day Great Keppel Island topography and plan form.

Wind Climate

The wind climate in Keppel Bay is dominated by the subtropical belt of high pressure that generate predominately south-east to north-east winds over the Keppel Bay region. Summer months experience significantly higher wind speeds on average and this has important implications on the seasonal distribution of waves and wind driven currents at Great Keppel Island.

Astronomical Tides

The astronomical tides at Great Keppel Island are semi diurnal. The tide resonates on the shallow bathymetry of the southern Great Barrier Reef Lagoon such that tides at Great Keppel Island are macro tidal with a spring tidal range of approximately 4.0 meters. At Great Keppel Island, the tide propagates primarily from east to west however the complicated bathymetry and numerous island outcrops generate current fields with a high degree of spatial and temporal variability in the vicinity of Great Keppel Island.

Currents

Wind driven currents constitute a significant source of current variability in the vicinity of Great Keppel Island. Over the summer months, prevailing south easterly winds of moderate strength generate relatively strong north westward flowing residual currents at Great Keppel Island. Over the winter months, lighter wind conditions generate significantly weaker residual currents at Great Keppel Island.

Wave Climate

Great Keppel Island is exposed to wind-waves that may be generated within the southern Great Barrier Reef lagoon over fetches of 100-400 kilometres. Decaying swells propagating in from the Coral Sea also influence the wave climate at times in the vicinity of Great Keppel Island. Prevailing south east to north east winds generate relatively short 5-7 second period wind waves with significant wave heights generally less than 1.5m. Wave heights in the summer months are significantly greater than in the winter months in Keppel Bay. Extreme wind conditions provide estimates of design wave conditions of up to approximately 3.5m significant wave heights offshore of Putney Beach.

Tropical Cyclones

13 tropical cyclones since 1960 have tracked within a radius of 200km of Great Keppel Island. A tropical cyclone impact frequency of once every 4-5 years on average could there be expected at Great Keppel Island. Historically, Tropical Cyclones David, Simon and Fran resulted in significant erosion impacts on Putney and Fisherman's Beach. Keppel Bay has a relatively high storm tide risk profile however the westerly orientation of Putney and Fisherman's Beaches results in lower estimated storm tide levels than adjacent mainland, easterly facing coastlines. The existing 1% Annual Exceedance Probability (AEP) storm tide level at Putney Beach has been estimated as 2.67m AHD.

Putney and Fisherman's Beach Coastal Processes

Putney and Fisherman's Beach experience a significantly different wave climate in comparison to other beaches on Great Keppel Island due to their westerly aspect and the degree of sheltering afforded by the bounding headlands and offshore islands adjacent to these two beaches. Waves generally arrive at Putney Beach from a very narrow directional band centred around the north – northwest. These waves are small (less than 0.5m) and generally have periods exceeding 7.0 seconds.

Key findings from the detailed assessment of the Putney and Fisherman's Beach coastal processes are as follows:

- The alignment of Putney and Fisherman's Beach is primarily controlled by the diffraction and refraction of north easterly and south easterly waves around the northern and southern headlands of Great Keppel Island respectively. The refracted waves approach these beaches with small oblique angles and subsequently drift sand into the westerly projecting, trailing spit formation that divides these two beaches.
- The westward projection of the sand spit is curtailed by the increasing exposure to strong tidal current action that sweeps past the spit head as well as increasing exposure to wave action as the end of the spit extends beyond the sheltered zone afforded by the northern and southern headlands. The alignment of the spit is observed to vary in response to changes in the relative influence of refracted south easterly and northerly waves and the subsequent rates of sediment transport.
- A series of historical aerial photographs spanning a period of 50 years from 1961 – 2010 has been analysed to document the extent of historical shoreline change on Putney and Fisherman's Beach. This analysis showed that the southern end of Putney Beach has

experienced significant shoreline recession over the last decade with a subsequent shift in the spit head alignment southward when compared to earlier periods. A general decline in the beach widths on both Putney and Fisherman's Beach is also observed when compared with earlier periods.

- The shoreline changes observed on Putney and Fisherman's Beach over the last 50 years are considered to reflect the relatively mobile nature of this trailing spit landform and the dynamic processes operating on it. The variability observed in this landform is of the magnitude that could be expected with this type of landform, which is in a dynamic equilibrium with the physical processes operating on it.

Assessment of potential impacts and mitigation measures

Numerical modelling, data collection and analysis and interpretation of coastal processes was undertaken to identify potential impacts on the coastal environment from the Great Keppel Island Revitalisation Plan.

Key findings from the impact assessment and proposed mitigation measures are summarised as follows:

Tidal Flows and Hydrodynamics Assessment

Hydrodynamic modelling simulations incorporating the marine facility were undertaken and compared to existing conditions. The comparisons of the simulated current fields showed the following impacts:

- Tidal currents are diverted around the western side of the marina under both ebb and flood tide conditions resulting in local accelerations of peak current speeds west of the marina compared to existing conditions.
- Tidal current speeds along Putney Beach and between the marina and Putney Point are predicted to reduce due to the sheltering effect of the marina breakwaters.
- Negligible impact on water levels or tidal phases is predicted due to construction of the marina.

The relatively minor change to current speeds and directions predicted to arise from the construction of the marina are not considered to result in direct impacts requiring mitigation.

Sediment Transport and Coastal Processes Assessment

Potential impacts of the marina development on sediment transport and siltation have been assessed. The following impacts on sediment transport and coastal processes have been identified:

- Maintenance dredging is likely to be required periodically over the course of the marina's operation to maintain minimum required depths for navigation in the entrance channel. Low rates of sediment transport into the entrance channel are predicted, apart from an initial flux of sediment resulting from local morphological adjustment following construction of the breakwaters. Maintenance dredging of the entrance channel is therefore only expected to be required at a frequency of approximately 5 years or greater, or following a severe tropical cyclone.
- Construction of the marina will prevent the onshore migration of up to 1,500m^3/yr of sediment to Putney Beach by trapping the net westerly transport of sand along Leeke's Beach which inturn spills around Putney Point. Overtime, this sediment will accrete in the sheltered zone that will exist between the marina and Putney Point. To prevent siltation of the entrance channel by this accreting sand and to maintain the long term sand transport continuity on Putney Beach, periodic bypassing of approximately 5,000 – 7,000m^3 of sand every five years would be required from the area between the marina entrance and Putney Point.

- Construction of the marina will result in changes to the size and incident angles of waves on Putney Beach relative to existing conditions. In turn this is predicted to reduce the net sediment transport potential along Putney Beach. The impact of this change is expected to result in a reduction in the rate of shoreline recession currently being observed along Putney Beach and overtime, gradual accretion and progradation of the beach widths along Putney Beach.

Marina Wave Climate Assessment

Protection for vessels moored within the marina from waves generated in Keppel Bay is provided by the marina breakwaters such that waves may only propagate into the marina through the marina entrance. Detailed wave modelling of the entrance and marina basin was undertaken to predict the wave climate in the marina under design wave conditions. Under worst case design wave conditions from the north to north-west, a small number of berths immediately adjacent to the marina entrance could experience wave heights that would be considered to provide a 'good – moderate'' climate. The remainder of the berths under these conditions would all experience wave heights consistent with 'excellent' conditions.

Climate Change Risk Assessment

A risk assessment methodology has been adopted to assess the potential impacts of climate change. Relevant climate change impacts on the physical processes operating on the coastal environment are considered the following;

- Sea Level Rise
- Seasonal Distribution of Wind Speeds and Directions
- Tropical Cyclone Intensity and Frequency

The main components of the coastal environment and Great Keppel Island Resort Revitalisation Plan that are potentially exposed to climate change threats include:

- Putney and Fisherman's Beaches
  The consequences of shoreline recession related to sea level rise would include loss of beach amenity and beach access constraints associated with eroding shoreline. Shoreline recession hazards could be mitigated by nourishment of these beaches.
- Marina Breakwaters
  Increases in mean sea level, storm tide heights and increase in the size of extreme waves could potentially cause increased rates or overtopping and structural damage to the breakwater. The risk posed by climate change to the breakwater structures can be accommodated during the detailed design of the breakwater by increasing crest heights and the size of primary armour unit weights.
- Marina Infrastructure and Reclamation
  Marina infrastructure and the reclamation area are protected from wave action by the breakwater and as a result, the threats of climate change relate to inundation during large storm tide events. The marina infrastructure and reclamation area can be design to accommodate the risks posed by climate change by constructing finished surface levels and floor levels above the relevant projected storm tide inundation levels.
- Foreshore Development
  The majority of the proposed development is located at distances greater than 100m from the existing shoreline and at elevations above the projected storm tide inundation levels to 2100. The impact on minor areas of the development that could potentially be subjected to relatively shallow storm tide inundation under extreme 2100 storm tide conditions or impinged upon by shoreline recession can be accommodated by raising floor levels in these areas and/or landscaping to prevent the ingress of storm tides into these areas.

Marina Water Quality

Residence times within the marina are expected to be very low due to the relatively small marina basin volume and large tide range. Approximately 50% of the average marina volume will be exchanged over a single spring tidal cycle. Practical measures of residence times such as the e-folding time are therefore likely to be no greater than 1-2 days for all locations with the marina basin.

Copper concentrations in the waters of the marina basin are likely to be elevated due to the presence of copper in antifouling paints. Hydrodynamic model simulations have been undertaken to determine the resulting concentration and fate of copper leached from antifouling paint under a fully berthed marina scenario The advection and dispersion of the numerical tracer showed that elevated copper concentrations are generally confined to the marina basin.

Sediment Quality and Dredging

Approximately 300,000m^3 of sediment is required to be dredged to create the marina basin and approach channel. Approximately 10.5 Ha of seabed will be disturbed by dredging to create the marina basin and approach channel. The average depth of dredging is generally in of the order of 2.5 – 3.0m. The geophysical survey of the marina footprint identified a continuous reflector at depths greater than approximately 10.0m below the seabed that was interpreted as a bedrock surface. A series of horizontal reflectors overly the bedrock surface and penetration levels through this material are indicate of unconsolidated material.

Sediment cores were undertaken from 12 locations within the dredge area footprint. Particle size distribution analysis of the sediment cores showed that on average, 95% of the sediment is comprised of sand sized or greater fractions with minor (5%) silt and/or clay content. The characteristics of the sediment are such that their disturbance would not be expected to generate relatively large suspended sediment loads.

Construction constraints associated with the limited access to quarry material on Great Keppel Island and the desire to prevent the need for sea disposal of dredge spoil are such that it is proposed that all the spoil from the marina basin dredging will be contained within geotextile tubes to form the core of the breakwaters and to provide the majority of the material required for the reclamation.

The hydrodynamic model was coupled with a suspended sediment transport model to assess the likely magnitude and extent of suspended sediment plumes generated during construction and dredging of the marine facility.

The following total suspended solids (TSS) impacts are predicted from the modelling for the three main stages of construction:

Stage 1 – Western Breakwater Construction

- Median TSS concentrations over the course of dredging for Stage 1 are generally very low (<2mg/L) and confined to the immediate vicinity of the dredging and construction location
- Maximum TSS concentrations of 30mg/L are predicted at Putney Point
- Maximum TSS concentrations of up to 50mg/L are predicted at the Spit Head
- Maximum TSS concentrations of less than 5mg/L are predicted at Passage Rocks

Stage 2 – Marina Basin Revetment Construction

- Elevated median TSS concentrations over the course of Stage 2 construction are generally confined to the marina basin as much of the turbidity generation is now contained by the construction of the western breakwater
- Maximum TSS concentrations of 30mg/L are predicted occasionally at Putney Point
- Maximum TSS concentrations of less than 10mg/L are predicted at the Spit Head

- Maximum TSS concentrations of less than 5mg/L are predicted at Passage Rocks

Stage 3 – Northern Reclamation

- Elevated median TSS concentrations over the course of Stage 3 construction are generally confined to the marina basin.
- Maximum TSS concentrations of less than 10mg/L are predicted occasionally at Putney Point

Additional measures to mitigate the generation and impact of suspended sediment during construction include:

- Installation of silt screens at the entrance to the marina for Stage 2 and 3
- Design of the reclamation area to maximise the length of time fine sediments may settle out of suspension before the decant flows back to the marina basin
- Development of a Dredge Management Plan to manage and impacts of dredging and construction

Wet Weather Wastewater Outfall

An assessment of the wet weather wastewater outfall on the water quality of the receiving environment has been undertaken incorporating both near field initial dilution and far field mixing assessments.

In the near field it was predicted that an initial dilution of the buoyant plume of 70:1 to 100:1 could be achieved from the outfall under quiescent conditions at the water surface. From the far field modelling assessment it was predicted that under the worst case three consecutive wet weather day discharge scenario, rapid dilution of key wastewater constituents would be achieved. Concentrations of Total Nitrogen and Total Phosphorus are predicted to reduce to below relevant trigger values within a small mixing zone in the immediate vicinity of the outfall.

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1. INTRODUCTION

The Great Keppel Island Resort Revitalisation Plan is a sustainable eco-tourism resort comprising a range of low rise eco-tourism accommodation, 18 hole golf course, airport and marina to be located on Great Keppel Island on the Central Queensland coast.

This report has been prepared by Water Technology Pty Ltd for Tower Holding's Pty Ltd. The report has been completed to support the following sections of the Terms of Reference (ToR) of the Environmental Impact Study (EIS) for the Great Keppel Island Revitalisation Plan:

Section 3.5 Coastal Environment

Section 3.5.1 Hydrodynamics and Sedimentation

Section 3.5.2 Sediment Quality and Dredging

The report describes the detailed investigations and analysis undertaken to describe the existing physical processes and environmental values of the coastal environment in the study area. The investigations have been supported by detailed numerical modelling analysis to characterise the influence of tides and currents, waves, sediment transport, extreme events and water quality in the study area.

The report identifies and assesses the potential impacts on the existing coastal environment from the proposed Great Keppel Island Revitalisation Plan. Numerical models have been utilised to assist with the impact assessment and to quantify any impacts as precisely as possible and to enable cumulative impacts to be integrated. Options and methods to avoid or mitigate adverse impacts have been tested and refined with the numerical models.

Appendix A documents the data and results of the oceanographic data collection program undertaken to support the development of numerical models of the study area.

Appendix B documents the development and calibration of numerical models employed in the coastal environment assessment.

1.1 Scope and Objectives

This Report has been prepared to address section 3.5 of the Terms of Reference for EIS – Great Keppel Island Resort Project issued by the Queensland Coordinator-General, which requires the following issues to be considered in the Environmental Impact Statement (EIS):

Section 3.5 Coastal Environment

Section 3.5.1 Hydrodynamics and Sedimentation

The physical processes of the coastal environment related to the project should be described, including waves, currents, tides, storm surges, freshwater flows and the key influencing factors of cyclones and other severe weather events and their interaction in relation to the assimilation and transport of pollutants entering marine waters from, or adjacent to, the project area. This should include the following:

- The environmental values of the coastal resources of the affected area in terms of the physical integrity and morphology of landforms created or modified by coastal processes
- Description of the environmental values of the coastal resources of the affected area in terms of the physical integrity and morphology of landforms created or modified by coastal processes

- Description of the tidal hydrodynamics of the project area and the adjoining tidal waterways in terms of water levels and current velocities and directions at different tidal states. Two and/or three-dimensional modelling should be undertaken
- Details of water levels and flows associated with historical and predicted storm surges
- Details of water levels and flows associated with historical and predicted storm surges
- Wave climate in the vicinity of the project area and the adjacent beaches including a description of inter-annual variability and details of historical and predicted extreme wave conditions generated by tropical cyclones or other severe storm events
- Prediction of the likely changes to hydrodynamics (including water levels, currents, wave conditions and freshwater flows) and sedimentation in the project area due to climate change
- Detailed assessment of the morphology and variability of Putney Beach and Fishermans Beach including predicted impacts of climate change and sea level rise
- Description of the hydrology of the area and the adjacent catchments of the rivers and the associated freshwater flows within the study area and the adjoining tidal waterways in terms of water levels and discharges. The interaction of freshwater flows with different tidal states, including storm tides.

Potential impacts and mitigation measures

This section describes the potential changes to the hydrodynamic processes and local sedimentation resulting from the construction and operation of the project. This should include:

- Impacts on tidal flows and water levels
- Changes to sediment transport patterns including the potential of the proposal to affect the adjacent beaches particularly Putney Beach and Fishermans Beach
- Assess the environmental impact to Passage Rocks reefs of continual sediment accumulation and settlement, turbidity, and pollution from vessels.

This assessment also provides a discussion of the potential impacts associated with extreme events such as storm tide flooding, taking into account the predicted impacts of climate change. This must include an assessment of the vulnerability of the project to storm tide flooding and the potential of the project to affect vulnerability to storm tide flooding on adjacent properties.

Discussion on the analysis of feasible alternatives to the proposal that would avoid or minimise any impacts on coastal processes in the area. Where unavoidable impacts are predicated, describe proposed mitigation measures.

Section 3.5.2 Sediment Quality and Dredging

Assessment of marine sediments has been undertaken in accordance with the National Assessment Guidelines for Dredging 2009 (Department of the Environment, Water, Heritage and the Arts, 2009). It includes the following:

- Detail on specific measures to maintain sediment quality to nominated quantitative standards within the project and surrounding areas, particularly where future maintenance dredging may be required

- Comment on the choice of the disposal site in relation to coastal management outcomes, having regard to the nature of the spoil, cost of alternatives and potential impacts on coastal resources and their values
- Describe provisions for dredge material disposal and associated impacts on sediment quality
- Comment on disposal options for contaminated material, if required. Including a description of the arrangements to be put in place for long term (20 years) dredge material disposal including details of proposed material placement areas
- A prediction of time for spoil to be colonised (if dumped in the marine environment), and the measures proposed to expedite this

2. EXISTING COASTAL ENVIRONMENT

2.1 Environmental Values and Geomorphology

2.1.1 Keppel Bay

Keppel Bay is a large, shallow, macrotidal embayment situated between the mouth of the Fitzroy River Basin and the Southern Great Barrier Reef Lagoon. The bay is bounded to the north by the Keppel Island group and to the south by Curtis Island. The morphology of Keppel Bay is the product of a complicated history of marine transgressions and regressions, fluvial erosion and deposition and littoral and sublittoral sediment transport processes.

During the last glacial phase, which ended approximately 12,000 years ago, mean sea levels were approximately 120 metres lower than present day and the coastline was located off the edge of the continental shelf approximately 500km to the east of Keppel Bay. During this period, Keppel Bay was a sandy coastal plain upon which the Fitzroy River meandered across. Steep gradients resulting from the low sea levels caused the Fitzroy River to incise deep channels out across the shelf. These relict channels are still visible on the margins of the shelf and surface sediments in this area still reflect their terrigenous origin (Bostock H. et al 2006).

Towards the end of the last glacial phase and into the Holocene, sea levels rose steadily to reach approximate present day levels around 7,000 years ago. The sea transgressed across the continental shelf and submerged Keppel Bay during this period. The Fitzroy River mouth retreated landwards across the continental shelf and into Keppel Bay. Significant deposits of terrigenous sediment were placed near the mouth of the Fitzroy River in Keppel Bay as the river gradient reduced. (Ryan et al, 2006). Subtle hydro-isostatic flexure of the continental shelf in response to the loading of seawater following the marine transgression has resulted in a minor, relative sea level fall within the inner margins of the continental shelf, including Keppel Bay. This has occurred over a period of several thousand years following the mid-Holocene sea level rise maximum, approximately 6,000 years ago (Smithers et al, 2007).

The main coral reef systems of the outer Great Barrier Reef are concentrated on the edge of the continental shelf. Earlier in the Holocene, before major outer barrier reef growth, a relatively short interval existed when much greater oceanic wave energy entered Keppel Bay, leading to an active period of sediment mobilisation and beach and spit building along the coastline (Hopley D, 1984). The rapid growth of the main outer barrier reef systems over the Holocene are important to the physical processes operating in Keppel Bay as they now limit the extent of oceanic wave propagation as well as the fetches for the generation of wind waves in the Southern Great Barrier Lagoon and Keppel Bay. The main outer barrier reef systems also influence the behaviour and propagation of the astronomical tide into Keppel Bay (Beach Protection Authority, 1979). The contribution of calcareous sediments from the main outer barrier reef systems are however insignificant in Keppel Bay (Bostock H. et al 2006).

Under present conditions, sediments are delivered to Keppel Bay primarily during flood events in the Fitzroy River. These sediments are predominately advected northwards and inshore under prevailing tidal and wind driven current conditions (Beach Protection Authority, 1979). These sediment deposits within Keppel Bay are generally comprised of very fine sands with significant mud and high feldspar content (Ryan et al, 2006).

Surface sediments in deeper water in the outer eastern parts of Keppel Bay are primarily comprised of relict terrigeous sediment deposits formed when Keppel Bay was a coastal plain during previous glacial phases. These sediments are characterized by well sorted find to medium sands with very low mud and feldspar content (Beach Protection Authority, 1979). These sediments are slowly being transported shoreward by wave and tidal action. Between North Keppel Island and the mainland, these relict sands are migrating shoreward under the influence of tidal action as large underwater dune systems. They provide a significant source of sediment to the mainland coast north of Yeppoon (Beach Protection Authority, 1979).

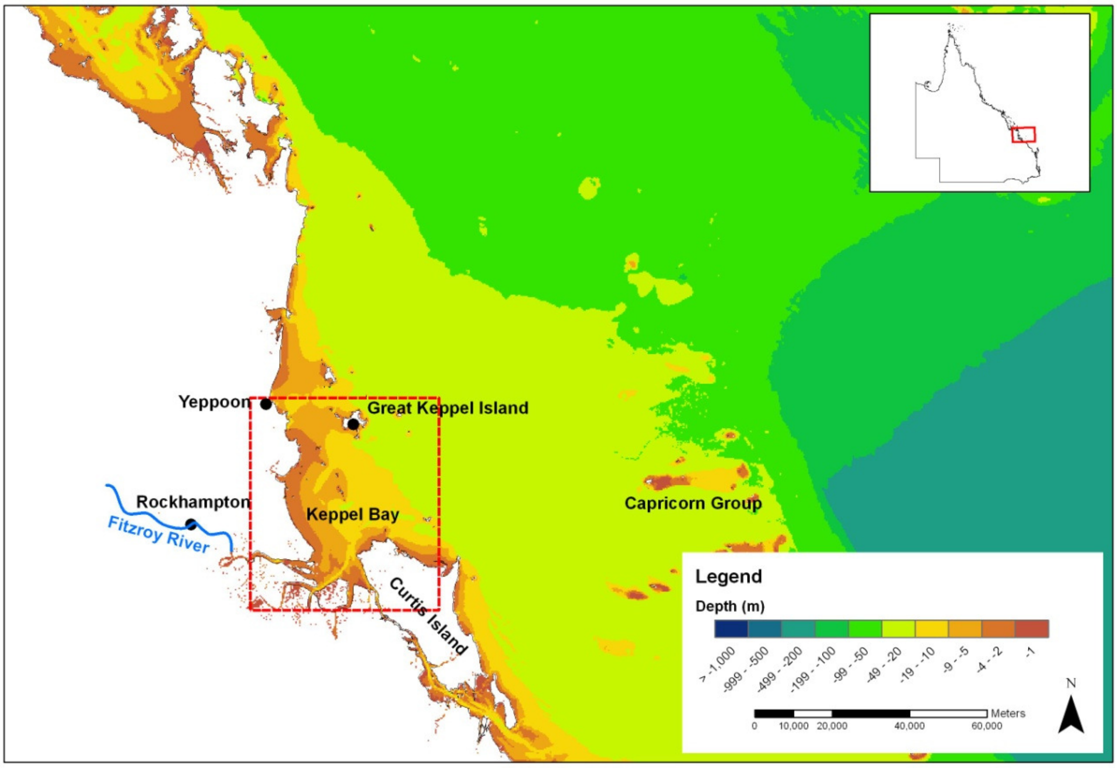

Figure 2-1 Keppel Bay Locality Plan

2.1.2 Great Keppel Island

Great Keppel Island is one of a series of continental bedrock island outcrops defining the northern edge of Keppel Bay. Figure 2-2 displays the main location names on Great Keppel and surrounding islands.

The Great Keppel Island bedrock is Carboniferous aged Shoalwater Formation comprising metamorphic quartzose and lithic sandstones, with some minor mudstones and schist (QWRC, 1980). The Great Keppel Island bedrock is overlaid by a relatively thin veneer of Quaternary deposits. These deposits are comprised of fine to medium relict sands that have a terrigenous origin having been formed when Keppel Bay was a sandy coastal plain during previous glacial phases. Wave and tidal current action are slowly transporting these sediments shoreward across the continental shelf. A small percentage of these shoreward migrating sediments have accreted around the bedrock outcrop of Great Keppel Island within the last 7,000 to 8,000 years following the re-submergence of Keppel Bay in the Holocene. Nearshore wave and current action and Aeolian processes have subsequently reworked and shaped these deposits into a variety of geomorphological features such as beaches, dunes and spits. These features combine with the outcropping of bedrock to give rise to the present day Great Keppel Island topography and plan form.

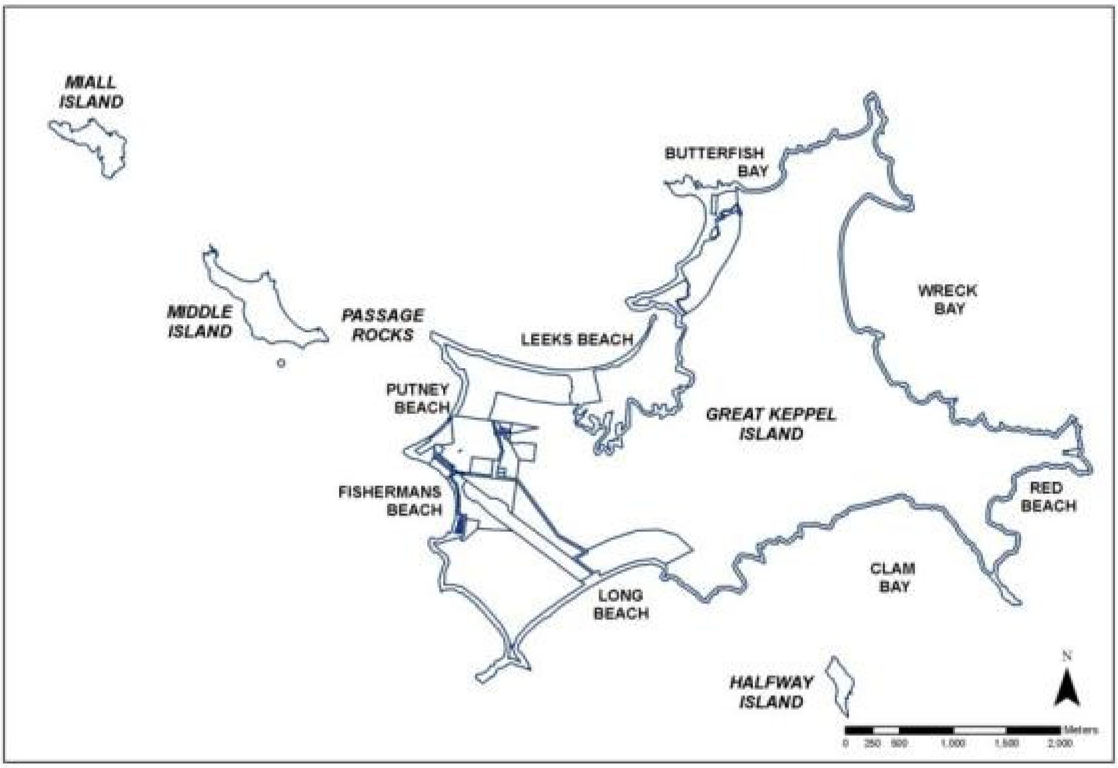

Figure 2-2 Great Keppel Island Locality Plan

The following main morphological features of Great Keppel Island have been modified by coastal processes:

Putney and Fishermans Beach Trailing Spit

Putney and Fisherman's Beach are components of a trailing spit formation located on the leeward side of Great Keppel Island. The spit is comprised of fine to medium grained sediments that have been slowly transported around from the eastern, higher wave energy side of Great Keppel Island, to the relatively sheltered western facing shoreline. The diffraction and refraction of waves around the northern and southern headlands of Great Keppel Island have sculpted the sediments of the spit into the curved beach alignments of Putney and Fisherman's beach.

Leeke's Beach Barrier

A coastal barrier system has built across what would have once been a shallow embayment on the northern side of Great Keppel Island. The barrier has been built by the longshore drifting of sediments across the embayment entrance caused by the refraction and diffraction of waves around the northern headlands of Great Keppel Island. The embayment behind the barrier is now largely filled with sediments and only a relatively minor intertidal area exists behind the barrier. The intertidal area behind the barrier is connected to Keppel Bay by a small tidal channel entrance located at the northern end of the barrier on Leeke's Beach.

Wreck Beach Parabolic Dune Fields

A parabolic dune field system exists behind Wreck Beach. The parabolic dune fields are initiated by the disturbance of stabilizing dune vegetation by either grazing or erosion of the foredune system from storm action. The parabolic dune systems have an advancing nose of bare sand that spills in the direction of the prevailing winds. The parabolic dune fields at Wreck Beach have advanced across the peninsula and are spilling into Butterfish Bay.

Wave Cut Shore Platforms

Shore-platforms exist along much of the exposed and rocky eastern facing coastline of Great Keppel Island. The shore platforms are however poorly formed and heavily dissected due to high variability in the resistance, composition and bedding planes of the bedrock upon which the platforms have been formed. The shore platforms are seaward-sloping and have an intertidal extent of approximately 30 - 50 meters.

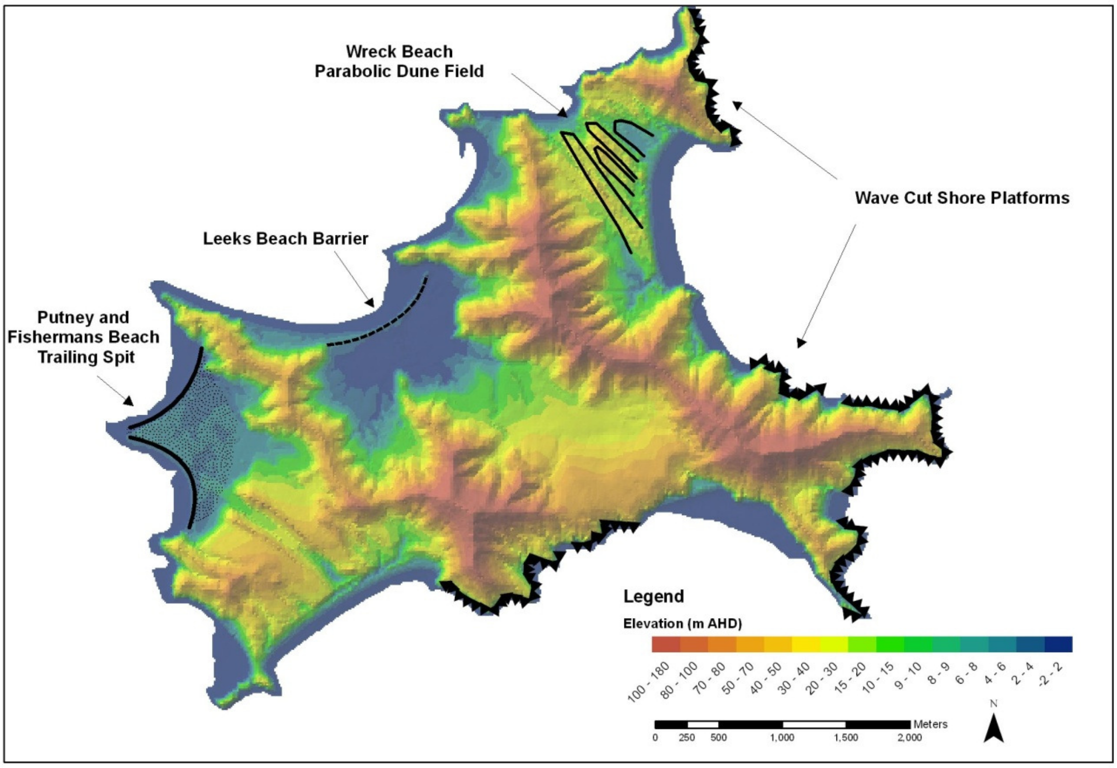

Figure 2-3 Coastal Morphology of Great Keppel Island

2.2 Bathymetry

The following sources of bathymetric data have been utilised for the assessment:

- 3DGBR Project DEM – ~100m grid resolution DEM of the Great Barrier Reef and Coral Sea developed from ship-based multibeam and single beam echo sounder surveys, airborne LiDAR bathymetric surveys and satellite data (Beaman, R. J. 2010)
- Project specific single beam hydrographic survey in the vicinity of Putney Beach, Fishermans Beach and their approaches Bennett & Bennett, 2011).

The extent and details of the bathymetry between Great Keppel Island and Middle Island is displayed in Figure 2-4. The main features of the bathymetry are summarized as follows:

- The profiles offshore of Putney Beach and Fisherman's Beach are relatively shallow, with mean depths generally less than 5.0m.
- Strong tidal current flows between Middle Island and Great Keppel Island have scoured deeper channels between the bedrock outcrop of Passage Rocks, with mean depths exceeding 12.0m.

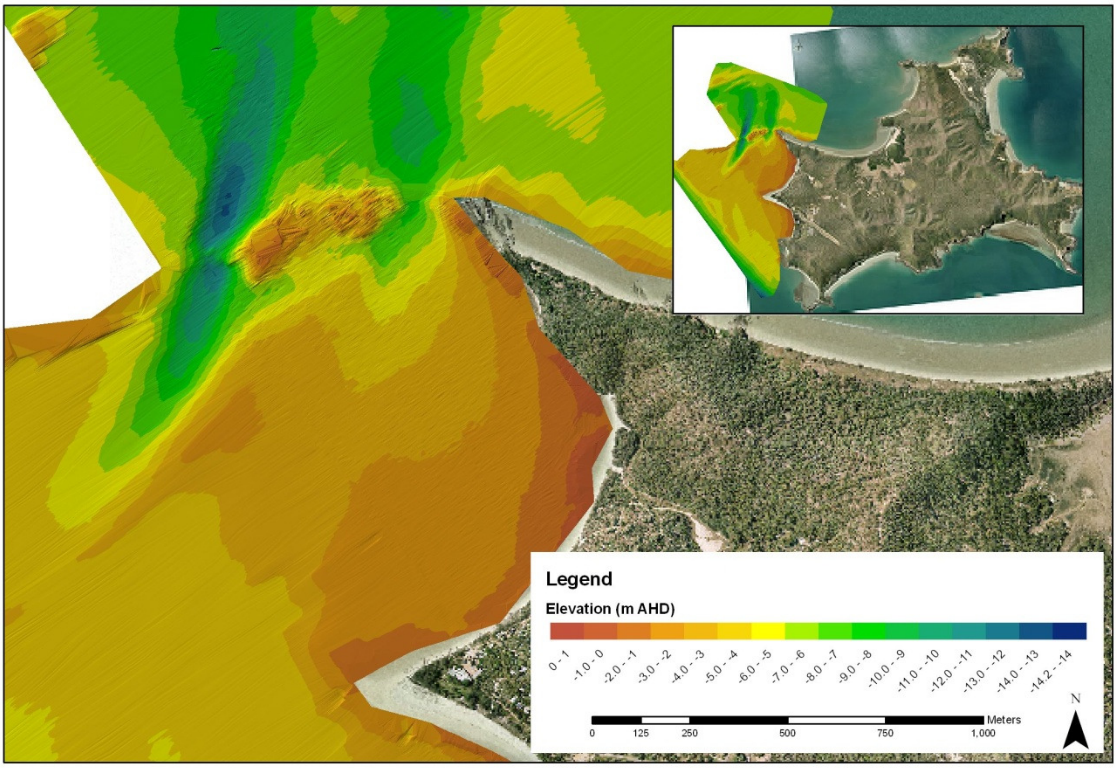

Figure 2-4 Bathymetry between Putney Beach and Middle Island

2.3 Wind Climate

The wind climate in Keppel Bay is dominated by the subtropical belt of high pressure that is generally centred around latitudes of 30 degrees south in winter and 40 degrees south in summer. The high pressure systems generate predominately south-east to north-east winds over the Keppel Bay region.

A reasonable representation of the long term wind climate of Keppel Bay is considered to be provided by the Yeppoon (033294) weather station operated by the Bureau of Meteorology (BOM) for 15 years from 1995 to 2010. The measurements consist of hourly observations of 6 minute average wind speed and direction. The data from Yeppoon was obtained from the BOM and has been analysed to describe the wind climate on the area. Summer (wet season) and winter (dry season) wind speed and direction rose plots are presented in Figure 2-5.

Features of the wind climate in Keppel Bay can be summarized as follows:

- Winds predominately have an easterly direction component in both major seasons, with wind speeds greater than 5m/s rarely observed from the west.
- Wind speeds in summer are significantly stronger than winter, with a greater portion of winds from the north east quarter observed. Wind strengths in summer can exceed 12.5m/s at times and may approach 20m/s offshore.
- In winter, a diurnal land-sea breeze causes a high occurrence of light westerly winds on the coast over these months.
- Strong winds in excess of 25m/s are rarely experienced except for tropical cyclones and local thunderstorm activity.

The wind climate experienced in Keppel Bay has a strong influence on the type and distribution of currents and waves at Great Keppel Island and is discussed further in Sections 2.4 and 2.5 respectively.

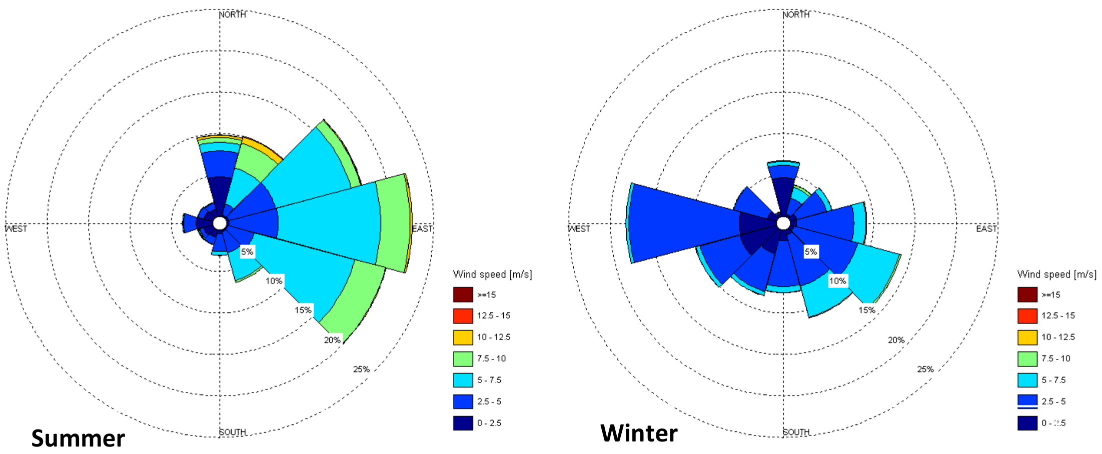

Figure 2-5 Seasonal distribution of wind speeds and directions at Yeppoon (1995 -2010)

2.4 Tides and Currents

Water level and current variability in the vicinity of Great Keppel Island is caused by a range of phenomena including:

- Astronomical Tides
- Wind Setup/Shear
- Coastally Trapped Waves
- Western Boundary Currents
- Waves

The above physical phenomena and their interactions within Keppel Bay result in a highly variable hydrodynamic environment around Great Keppel Island. The following sections describe the contributions that the different physical phenomena make to the overall hydrodynamic variability observed around Great Keppel Island:

Astronomical Tides

The astronomical tides are generated by the gravitational attraction and relative motions of the Earth, Moon and Sun. Astronomical tides in Keppel Bay are semi-diurnal (two tides a day) with only a minor diurnal inequality. The tide resonates on the shallow shelf bathymetry of the southern Great Barrier Reef Lagoon such that Keppel Bay is macro tidal with a spring tidal range of approximately 4.0 meters. The tide propagates from east to west in Keppel Bay. An example of the diurnal tides and transition from spring to neap tides at Great Keppel Island is displayed in Figure 2-6.

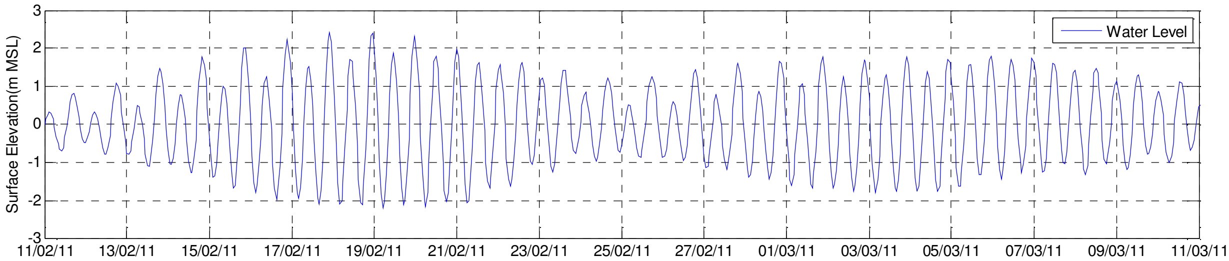

Figure 2-6 Example of the Astronomical Tidal Signal at Great Keppel island

Tidal plane information for Great Keppel Island is provided below in Table 2-1. This information has been obtained from the Middle Island, Keppel Island tidal data presented in the Australian National Tide Tables (2010).

Table 2-1 Astronomical Tidal Planes for Great Keppel Island (ANTT, 2010)

Datum	HAT	MHWS	MHWN	MSL	MLWN	MLWS	LAT
LAT (m)	5.0	4.2	3.2	2.4	1.6	0.6	0.0
AHD (m)	2.6	1.8	0.8	0.0	-0.8	-1.8	-2.4

The regular rise and fall of the ocean due to the astronomical tides generates periodic tidal current fields around Great Keppel Island. The tidal current patterns around Great Keppel Island are complicated by the many small island outcrops, large tidal range and relatively shallow bathymetry of Keppel Bay. Predicted tidal current fields in the vicinity of Great Keppel Island are displayed in Figure 2-7 and Figure 2-8 for typical flood and ebb spring tide conditions.

The following observations regarding the predicted current fields at Great Keppel Island are provided:

- The flood tide propagates from the east to west in the vicinity of Great Keppel Island. Flood tides generate moderate southward going currents at Passage Rocks between Middle Island and the Putney Beach headland.
- The ebb tide generates generally south eastward currents in the vicinity of Great Keppel Island. Ebb tidal currents at Passage Rock, between Middle Island and the Putney Beach headland are north going and moderately stronger than the flood tide currents
- The current fields developed by the astronomical tides can be significantly modified by wind driven currents at Great Keppel Island. Depending on the wind conditions, the magnitude of the current speeds can be significantly amplified or reduced. In some instances their directions can even be reversed locally The influence of wind shear on the current fields around Great Keppel Island is discussed in more detail below.

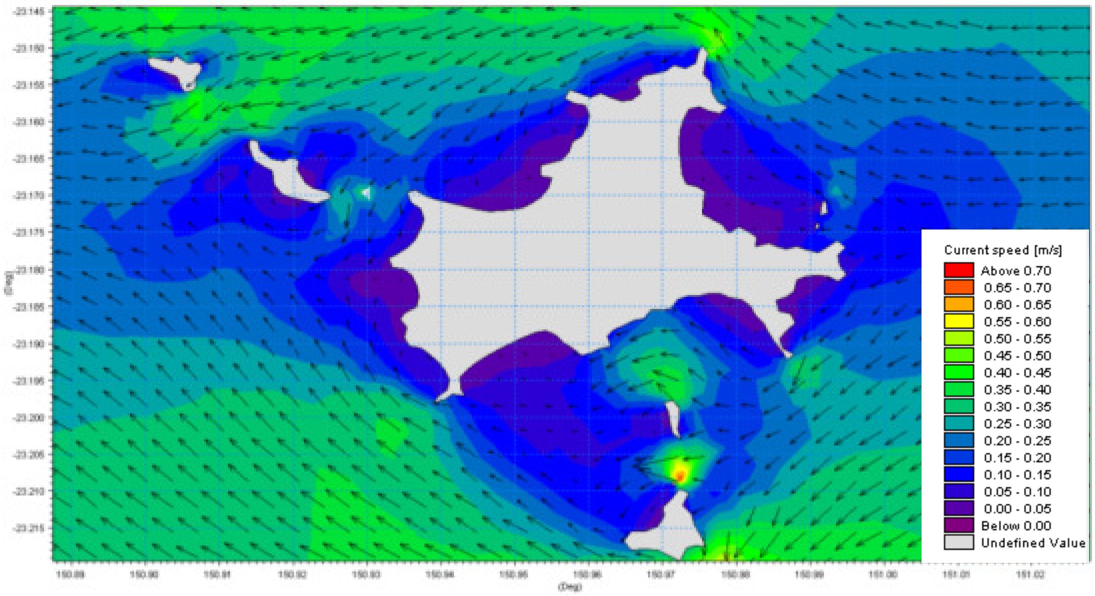

Figure 2-7 Typical Spring Flood Tide Current Fields in Vicinity of Great Keppel Island

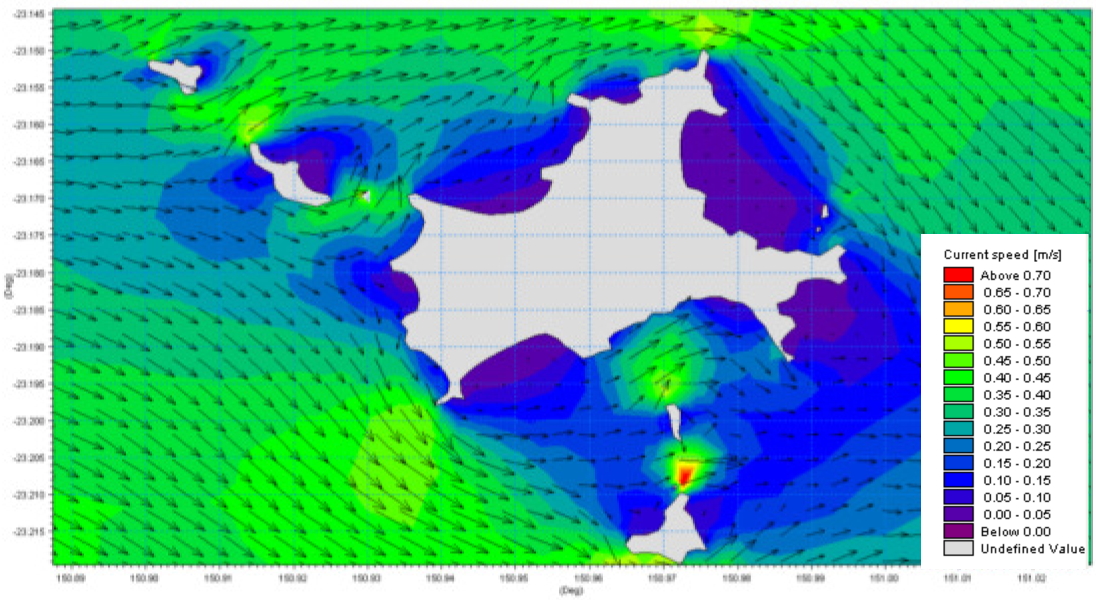

Figure 2-8 Typical Spring Ebb Tide Current Fields in Vicinity of Great Keppel Island

Wind Setup/Shear

Wind forcing on the ocean's surface transfers momentum to the water column generating wind driven currents. At the surface and in shallow water, wind driven currents flow in the direction of the wind, however a return current in the opposite direction is often evident in deeper water. Depending on their relative orientation, wind driven currents can also cause increases and decreases in water levels in the vicinity of coastlines. Wind shear and resulting wind driven currents constitute a significant source of current variability in the vicinity of Great Keppel Island due to the relatively shallow depths of Keppel Bay. Residual current fields (the currents remaining after filtering of the periodic astronomical tidal currents) show a strong seasonal signature related to the seasonal distribution of wind speeds and directions in Keppel Bay. Predicted residual current fields under typical summer (wet season) and winter (dry season) wind conditions are displayed in Figure 2-9 and Figure 2-10, respectively.

The following observations regarding the predicted seasonal residual current fields at Great Keppel Island are provided:

- During winter, relatively light and more variable winds generate weak residual currents around Great Keppel Island. Residual currents are generally northwest flowing at speeds of approximately 0.1m/s.
- In comparison to winter, prevailing south easterly winds of moderate strength generate significantly stronger northwest flowing residual currents throughout Keppel Bay. At Great Keppel Island, northward flowing residual currents of approximately 0.3m/s are generally observed in summer. These currents are however accelerated further around the eastern and western ends of the island.

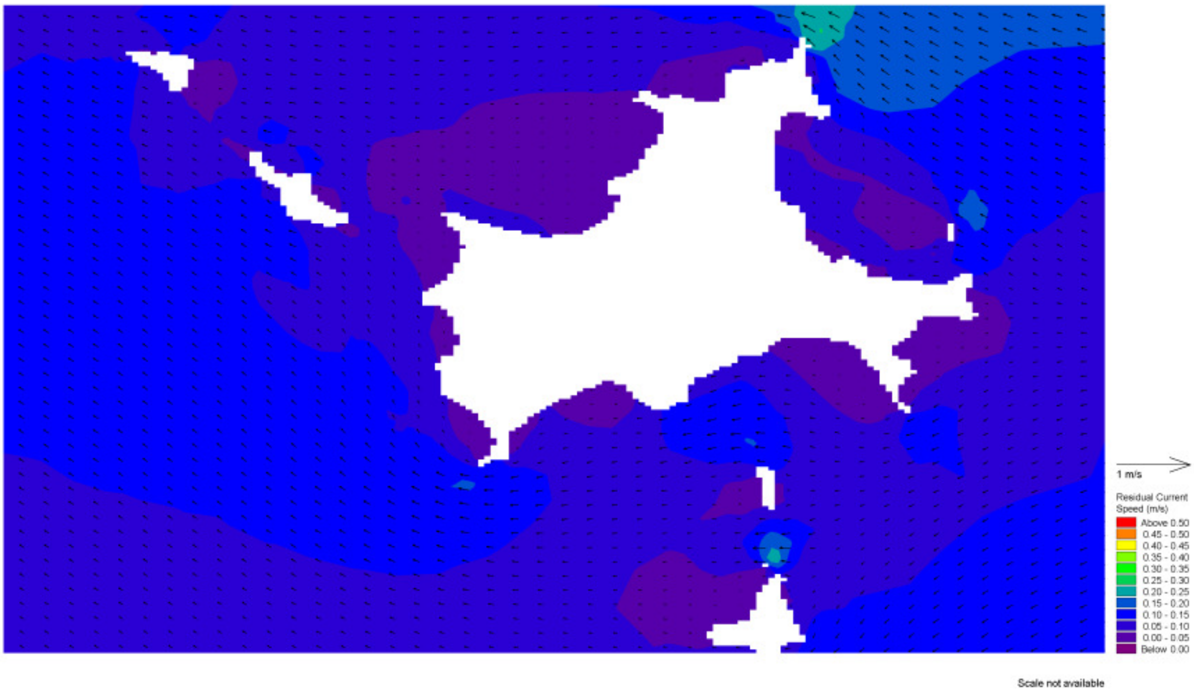

Figure 2-9 Predicted Winter (Dry Season) Residual Current Fields

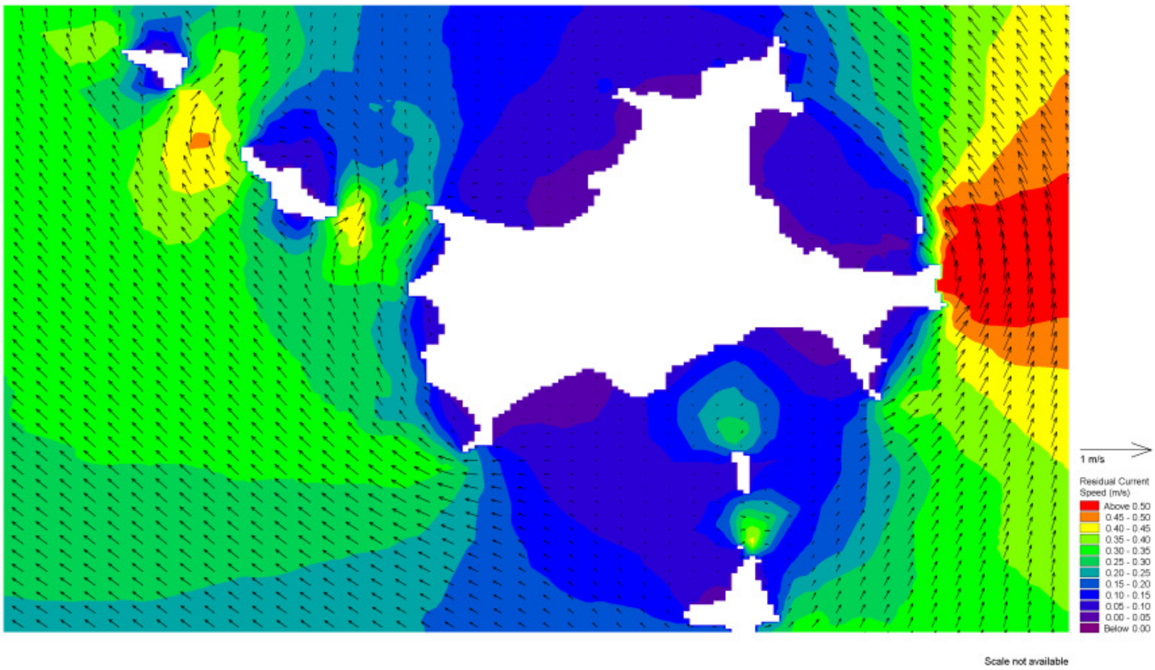

Figure 2-10 Predicted Summer (Wet Season) Residual Current Fields

Continental Shelf Waves

Distant meteorological forcing along the southern margins of the Australian continent generate low frequency waves that are trapped on the continental shelf by refraction and Coriolis forces. These waves propagate up the east coast of Australia and into Keppel Bay, and can produce irregular variations in water levels and currents over periods of a few days to one week. They contribute a small component to the magnitude and overall variability of water levels and currents in the vicinity of Great Keppel Island. More locally generated shelf waves in Keppel Bay can also be generated by variations in atmospheric pressure and wind shear associated with tropical and extra tropical cyclone disturbances on the east coast of Australia.

The influence of meteorological forcing and shelf waves on water levels at Great Keppel Island can be determined by analysing residual water levels following the filtering of the astronomical tidal water level variations. Figure 2-11 displays the tidal and residual water levels derived from the analysis of observed water levels captured during the ADCP deployment (Appendix A).

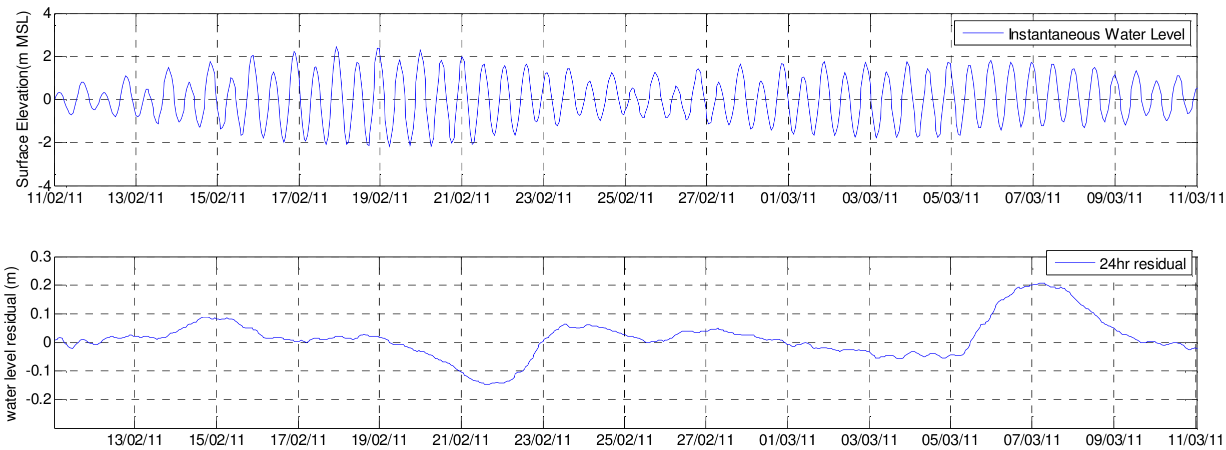

Figure 2-11 Analysis of Tidal Residual Water Levels at Great Keppel Island

The lower line on Figure 2-11 shows the low frequency variations in mean water levels generated by meteorological forcing and shelf waves at Great Keppel Island over the ADCP deployment period. This shows that these waves can have amplitudes of 0.2m or more at the measurementbt location.

Western Boundary Currents

The East Australian Current (EAC) is a western boundary current that generates warm, southward surface flows primarily along the margin of the continental shelf. The southward surface flows of the EAC peak in November to December and are at a minimum in April to May (Steinberg, 2007). Meandering of the EAC in response to changes in bathymetry and width of the continental shelf can generate large scale eddies that can contribute to minor changes to water level and current variability in Keppel Bay.

Waves

Wind waves and ocean swells contribute significantly to water level variability in the vicinity of Great Keppel Island and wave energy is important to the regional and local sediment transport processes. The wave climate is discussed in detail in Section 2.5.

2.5 Wave Climate

2.5.1 Regional Wave Climate

Great Keppel Island is exposed to wind-waves generated over fetches of 100-400 kilometres within the Southern Great Barrier Reef lagoon, as well as decaying swells propagating in from the Coral Sea

Long term statistics on the wave climate in the vicinity of Great Keppel Island can be derived from the Emu Park waverider buoy deployed approximately 20 kilometres to the south east of Great Keppel Island. This waverider is operated by the Queensland Department of Environment and Resource Management and has 15 years of wave data from 1996 to 2010.

Figure 2-13 displays the directional distribution of significant wave heights (Hs) for the 15 years of available record from the Emu Park wave rider buoy. Figure 2-13 displays the directional distribution of spectral peak period (Tp) for the same 15 years of available record. These figures show the following main features of the regional wave climate at Great Keppel Island:

- Prevailing southeast to northeast winds generate relatively short 5-7 second period wind waves with significant wave heights generally less than 1.5m.
- Approximately 5-10% of the time significant wave heights from the southeast through to northeast exceed 1.5m.
- The summer months generally experience greater wave activity than the winter months.
- The higher proportion of low long period waves (Tp>7.5 s) over winter indicates that swells from the Coral Sea make a larger contribution to the wave climate in winter.
- Waves from the west above 0.5m are almost completely absent from the record.

Since the installation of the Emu Park waverider buoy in 1996, there has been no near passage of a tropical cyclone. Extreme wave conditions associated with tropical cyclones are therefore absent from this record. Extreme wave conditions at Great Keppel Island associated with tropical cyclones are investigated in Section 2.6.2.

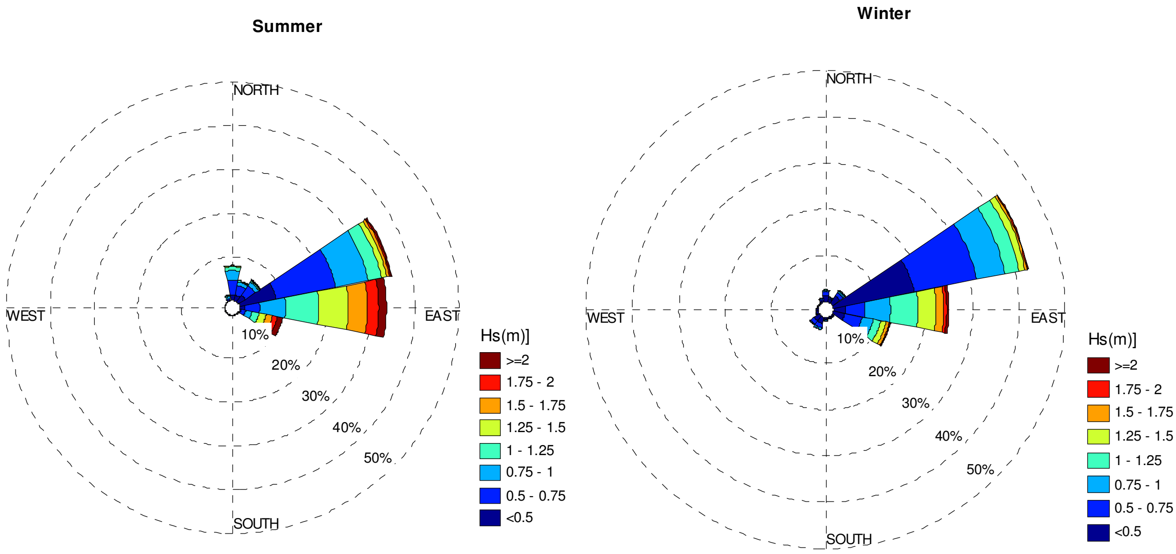

Figure 2-12 Emu Park Waverider Buoy Seasonal Wave Roses (Significant Wave Heights)

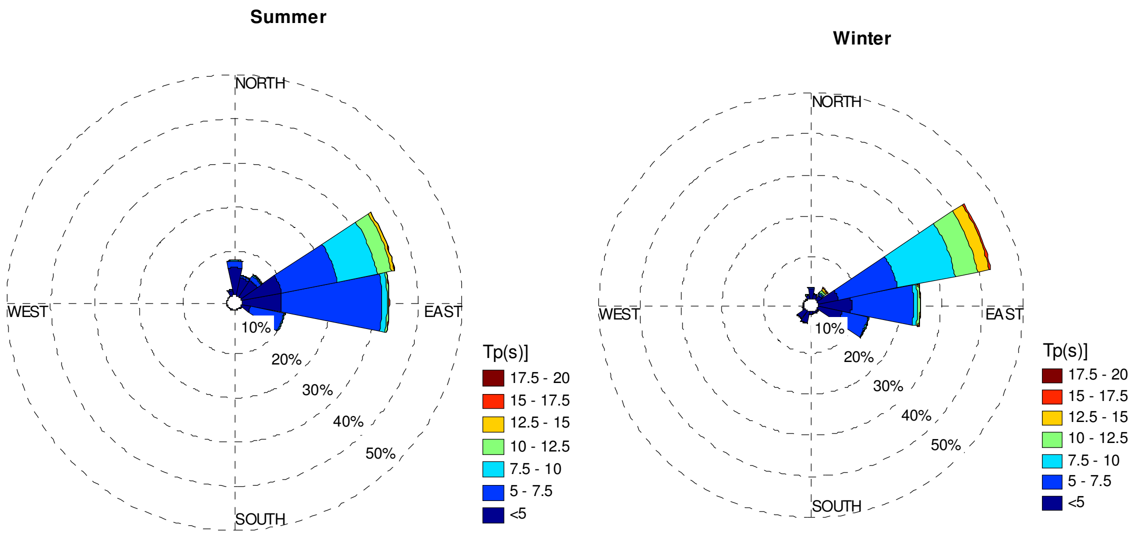

Figure 2-13 Emu Park Waverider Buoy Seasonal Wave Roses (Spectral Peak Period)

2.5.2 Putney and Fisherman's Beach Wave Climate

Putney and Fisherman's Beach experience a significantly different wave climate in comparison to other beaches on Great Keppel Island. This is due to their westerly aspect and the degree of sheltering afforded by the bounding headlands and offshore islands adjacent to these two beaches. The regional wave climate discussed in Section 2.5.1 is therefore significantly modified by shadowing, refraction and diffraction wave processes at Putney and Fishermans Beach.

In order to define the long term wave climate at these two beaches, the calibrated spectral wave model (discussed in Appendix B) was employed to hindcast the wave climate over a period of five years (2004 – 2009). An example of the hindcast wave model results under prevailing south easterly wind conditions in the vicinity of Great Keppel Island is displayed in Figure 2-14**Error! Reference source not found.**.

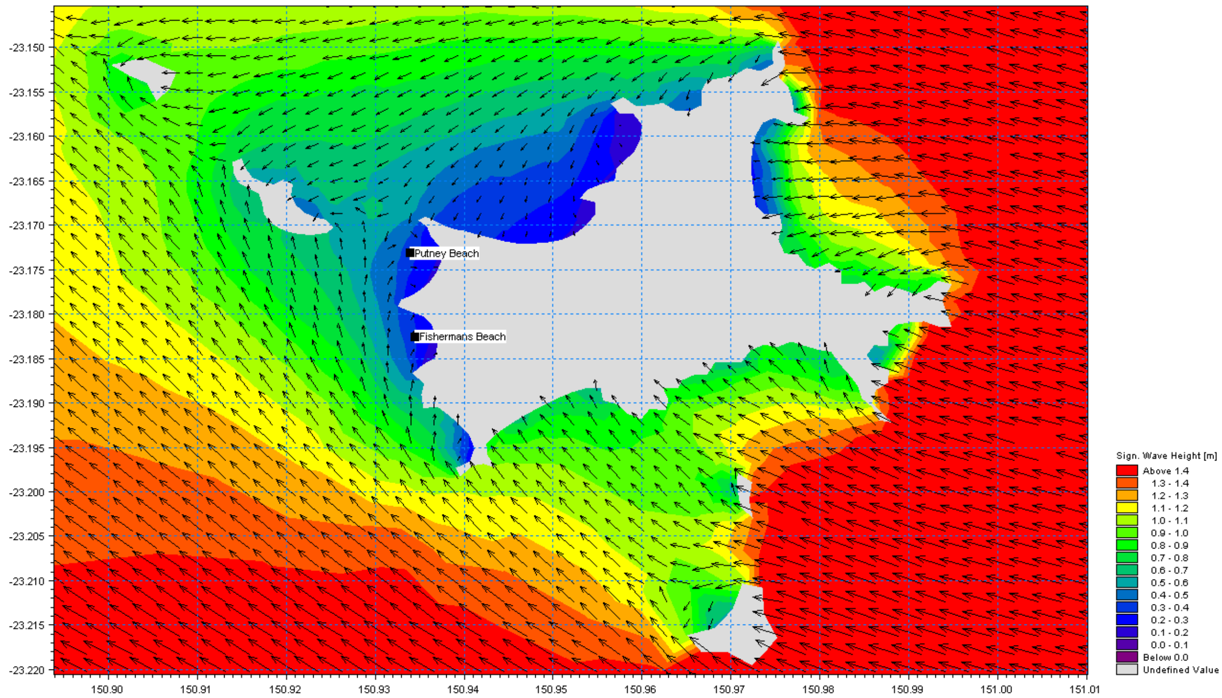

Figure 2-14 Example of Modelled Wave Field in vicinity of Great Keppel Island under Prevailing South East Wind Conditions

The results of the spectral wave model hindcasts have been summarised at the Putney and Fisherman's beach locations indicated in **Error! Reference source not found.**. The results presented in Figure 2-15 and Figure 2-16 compare the hindcast wave climate at these locations in terms of the summer and winter month distribution of wave heights, periods and directions respectively.

The following comparisons between the regional wave climate discussed in Section 2.5.1 and the Putney and Fisherman's Beach wave climate are provided below:

- Waves generally arrive at Putney Beach from a very narrow directional band centred around the NNW. These waves are generally small (less than 0.5m significant wave heights) and generally have periods exceeding 7.5 seconds. Wave energy impacting Putney Beach originates largely from the remnants of longer period north east to easterly waves that propagate into Keppel Bay from the Coral Sea and have refracted around the northern headland of Putney Beach. Putney Beach is only occasionally impacted by significant, locally generated wind-waves.

- In comparison to Putney Beach, waves arrive at Fishermans Beach from a wider directional band extending generally from the south through to west. These waves tend to be smaller than at Putney beach with significant wave heights generally less than 0.3m. The waves arriving at Fisherman's Beach also have a wider distribution of periods than Putney Beach with a larger percentage of short (less than 5 second) waves apparent. This is most pronounced in winter when larger, short period waves locally generated from the south to south west winds can impact Fisherman's Beach directly.
- Tropical cyclones have the potential to generate very large (relatively to background condition) waves on both Putney and Fisherman's Beach over short durations. The potential magnitude of extreme wave conditions due to tropical cyclones at Putney Beach is assessed in Section 2.6.2.

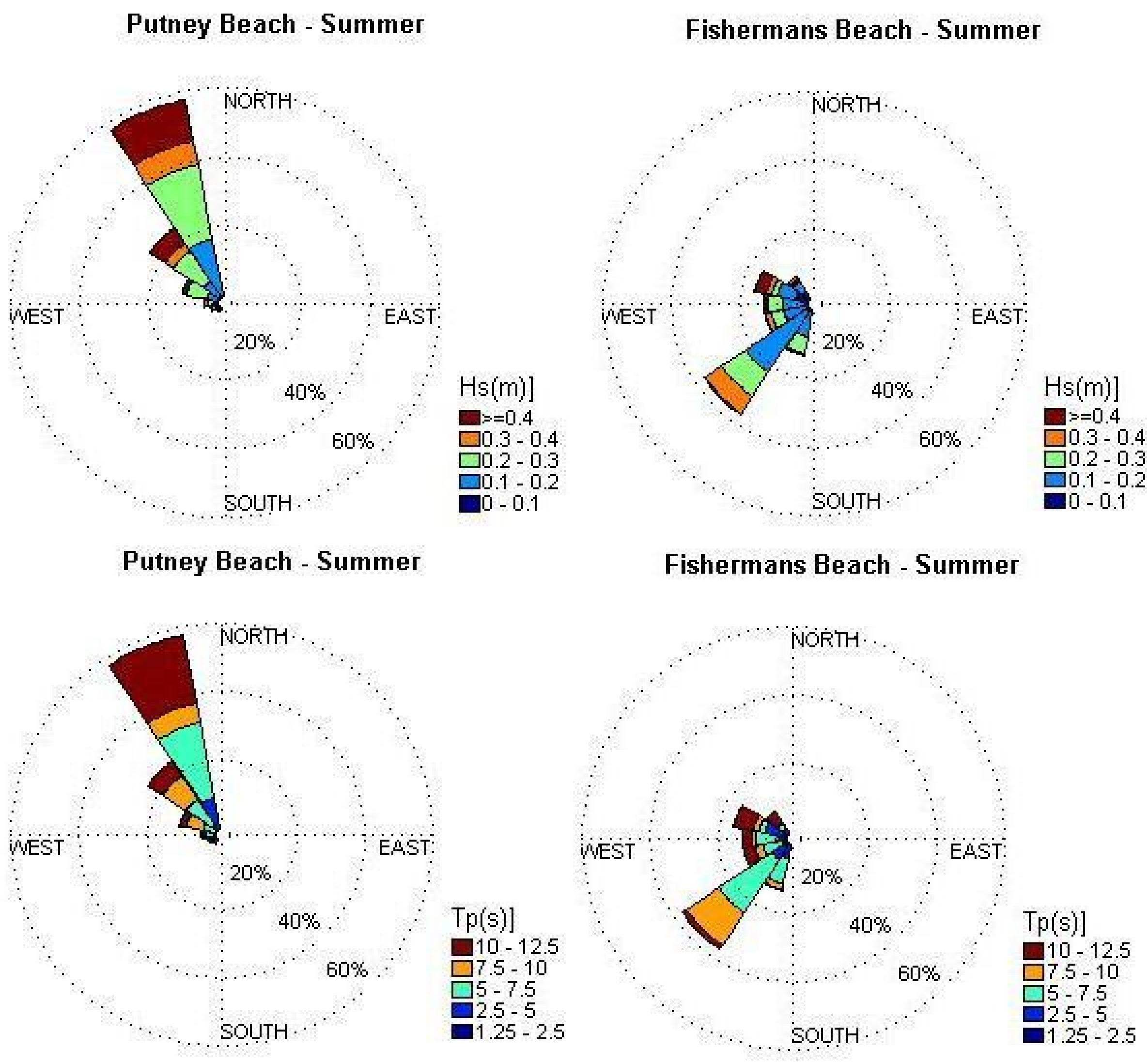

Figure 2-15 Putney and Fisherman's Beach Summer Wave Roses

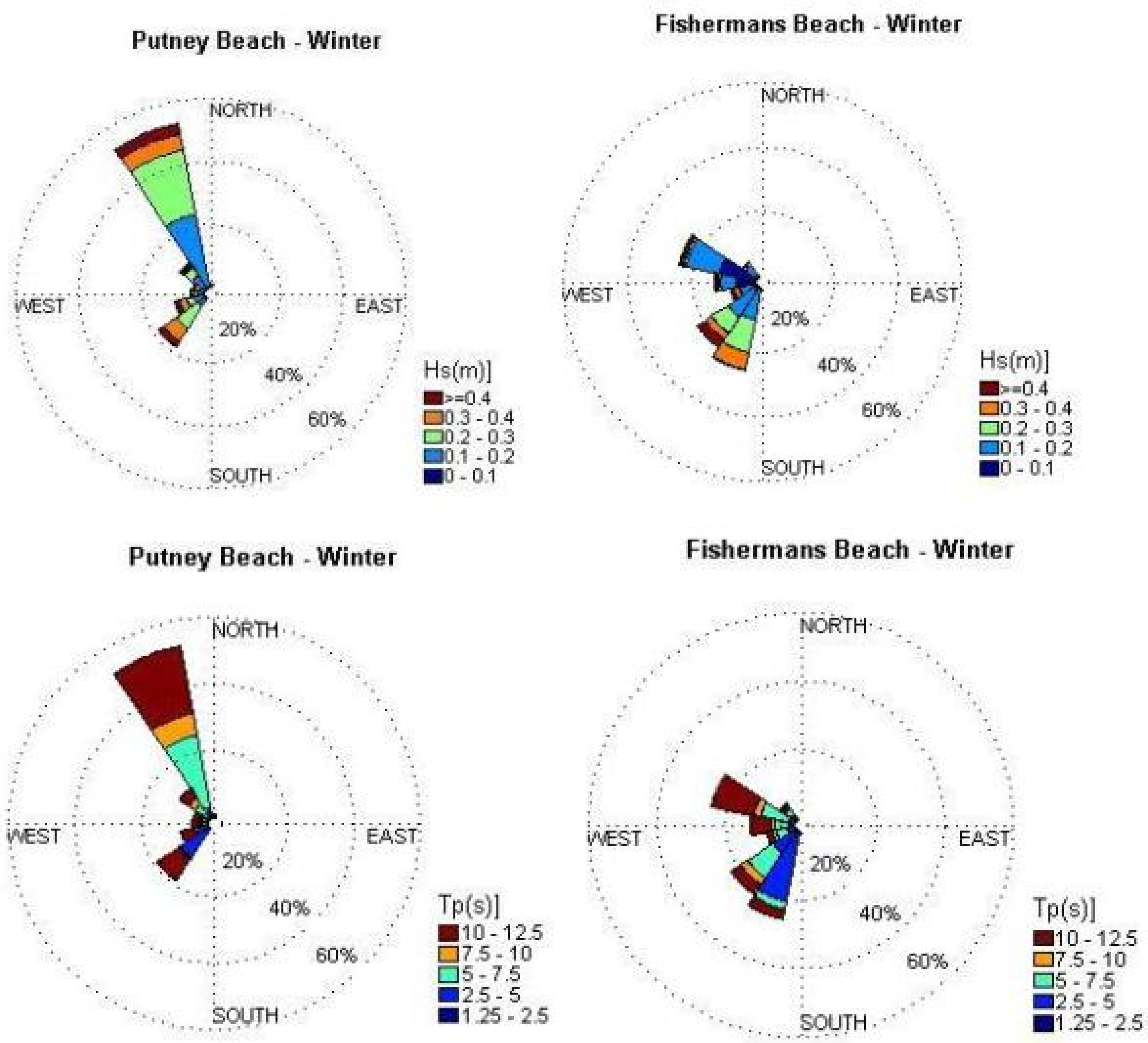

Figure 2-16 Putney and Fisherman's Beach Winter Wave Roses

2.6 Tropical Cyclones

Great Keppel Island can be subjected to tropical cyclone activity originating within the Coral Sea as well as the Gulf of Carpentaria. Tropical cyclone activity is generally concentrated between the months of January to March although tropical cyclones can and do occur outside this period.

The BOM maintains a database of cyclone tracks within Australia. Figure 2-17 displays all the tropical cyclones since 1960 that have been tracked within a 200km radius of Great Keppel Island. Thirteen tropical cyclone tracks are shown in Figure 2-17. Review of historical cyclone tracks shows no discernable pattern of movement of cyclones in the area, with cyclones passing in the vicinity of Great Keppel Island from both the landward and seaward direction and travelling both parallel to the coast and offshore.

Table 2-2 summarises the landfall central pressure (or minimum central pressure if the cyclone did make land fall) for each of the tracked tropical cyclones shown in Figure 2-17.

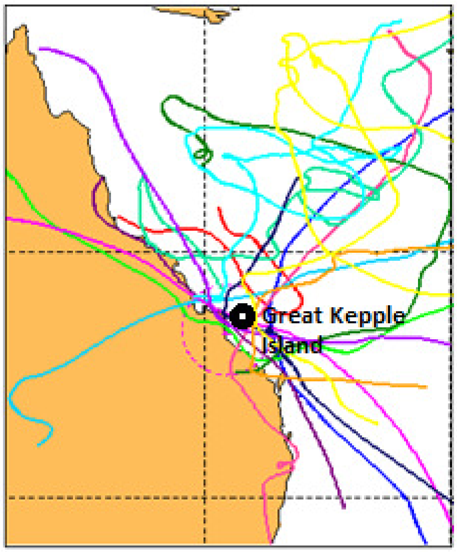

Figure 2-17 Tropical cyclone (1960 – present) tracks within a 200km radius of Great Keppel Island (Bureau of Meteorology 2007)

Table 2-2 Tropical Cyclones within 200km of Great Keppel Island (Bureau of Meteorology 2007)

Tropical Cyclone	Year	Landfall central pressure or minimum central pressure within 200km radius (hPa)
(Unnamed)	1961	
Dinah	1966	945
Fiona	1970	993
Emily	1971	985
David	1975	969
Beth	1975	996
Kerry	1978	995
Paul	1979	992
Simon	1979	950
Elinor	1982	935
Pierre	1984	998
Fran	1991	985
Rewa	1993	920

Based on Table 2-2, tropical cyclone impacts could be expected at Great Keppel Island on average once every 4-5 years. Some decades however have historically experienced much higher tropical cyclone frequencies, while others have experienced less.

The main structural features of the tropical cyclone are the eye, the eye wall and the spiral rainbands. The four main components of a tropical cyclone that combine to make up the total cyclone hazard are described below:

- **Extreme Winds** – Maximum wind speeds are a function of central pressure, the radius to maximum winds, the forward speed of the cyclone and local topographic effects. Cyclonic winds circulate clockwise in the Southern Hemisphere however the wind fields are generally asymmetric such that the strongest winds are generally observed on the left-hand side of the direction of cyclone movement. During a coast crossing in Keppel Bay, the cyclonic wind direction will be onshore south of the eye and offshore north of the eye.
- **Extreme Waves** – Tropical cyclones can generate very large ocean waves as a result of the transfer of energy from the wind to the ocean surface. The growth of ocean waves is a function of the fetch (the distance the wind acts over), wind speed, wind duration and the depth of water. The level of protection provided by the Great Barrier Reef diminishes south of Mackay and Keppel Bay has exposure to relatively larger fetches and greater water depths from the east and south east. As a result, extreme wave conditions can penetrate into Keppel Bay under a range of tropical cyclone conditions.
- ***Storm Surge*** – In the vicinity of the coastline, tropical cyclones can produce significant storm surges. Storm surges are meteorologically forced increases in coastal water levels caused by the combined action of extreme surface winds, which drive ocean currents towards the coastline and the reduction in atmospheric pressure which causes a local rise in sea level. The peak of a tropical cyclone storm surge generally lasts for a few hours near the region of maximum wind speeds.
- ***Intense Rainfall –*** the rain bands of a tropical cyclone can expand up to 1000km in diameter with the heaviest rainfall usually located within the eye wall.

2.6.1 Storm Surges

The potential magnitude of a storm surge is dependent on the direction and speed of the storm track, the radius to maximum wind speed and the wind strength. As described above, the storm surge comprises a direct wind set-up component and an atmospheric pressure component. In shallow continental shelf areas the pressure component of the surge can interact with the bathymetry and coastal forms and be dynamically amplified at the coastline to levels significantly greater than offshore, deepwater levels.

The combination of the meteorological storm surge and astronomical tide at any one location and point in time gives rise to an overall mean water level called the storm tide. The storm tide level can be referenced to an absolute datum such as AHD and is of particular importance when considering the design of infrastructure on the coastline.

Extensive analysis of storm tide recurrence intervals has been carried out for the majority of the Queensland coast in the Queensland Climate Change and Vulnerability to Tropical Cyclones study (Queensland Government, 2004). Keppel Bay has a generally high storm tide risk profile compared to many other locations along the Queensland coast. displays the storm surge and storm tide return period curves for Yeppoon, the closest location to Great Keppel Island reported from this study. The storm tide return period curves for Yeppoon are however considered conservatively high for Great Keppel Island for the following reasons:

- As Great Keppel Island is located offshore of the mainland, there is less potential for wind set-up to significantly increase water levels along the shorelines of Great Keppel Island.

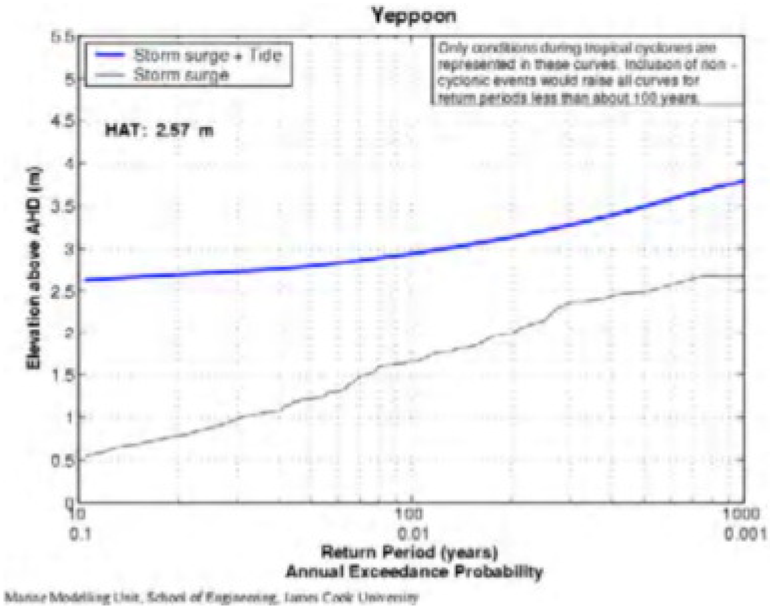

Figure 2-18 Storm Tide Recurrence Interval Curves for Yeppoon (Queensland Government, July 2004)

- The worst case track direction for storm surges at Yeppoon is a shoreward crossing of a cyclone, under this condition winds would be offshore at Putney and Fisherman's Beach.
- The worst case onshore wind conditions for Putney and Fisherman's Beach during a tropical cyclone would result in the cyclone eye being located south of Great Keppel Island. These conditions would not generate a significant pressure component of storm surge at Great Keppel Island.

In order to provide relevant estimates of the storm tide recurrence intervals at Great Keppel Island, additional analysis of cyclonic storm surge behaviour has been undertaken to relate the storm tide recurrence interval statistics that exist for Yeppoon to Putney Beach and Fisherman's Beach.

The analysis has involved the use of a parametric cyclone wind field model to develop a range of shoreward crossing cyclone scenarios. The time varying wind fields and pressures generated by this model were then simulated in the hydrodynamic model to enable the resulting storm surge at Yeppoon and Putney and Fisherman's Beach to be compared. Figure 2-19 displays an example of the wind and pressure fields produced by the parametric cyclone model for a shoreward crossing cyclone scenario in Keppel Bay. An iterative process was employed involving the calibration of the maximum wind speeds and minimum central pressures in the parametric cyclone model until peak storm surge levels produced by the hydrodynamic model matched discrete storm surge levels corresponding to the 2%, 1% and 0.2% AEP storm surges at Yeppoon determined from the Queensland Vulnerability to Tropical Cyclones study.

Figure 2-20 displays an example of the estimated 100 year ARI storm surge water level time series at Yeppoon and Putney and Fisherman's Beach generated by the calibrated parametric cyclone model coupled to the hydrodynamic model. As can be seen from Figure 2-20, the behaviour of the storm surge varies considerably between Yeppoon and Great Keppel Island under a shoreward crossing cyclone scenario, with the storm surge peak at Great Keppel Island occurring earlier and at a lower absolute level than Yeppoon. Figure 2-21 displays the peak storm surge recurrence interval estimates at Putney and Fisherman's Beach relative to Yeppoon over a range of relevant recurrence intervals developed from this analysis. Table 3-4 displays the corresponding storm tide recurrence interval estimates for Putney and Fisherman's Beach.

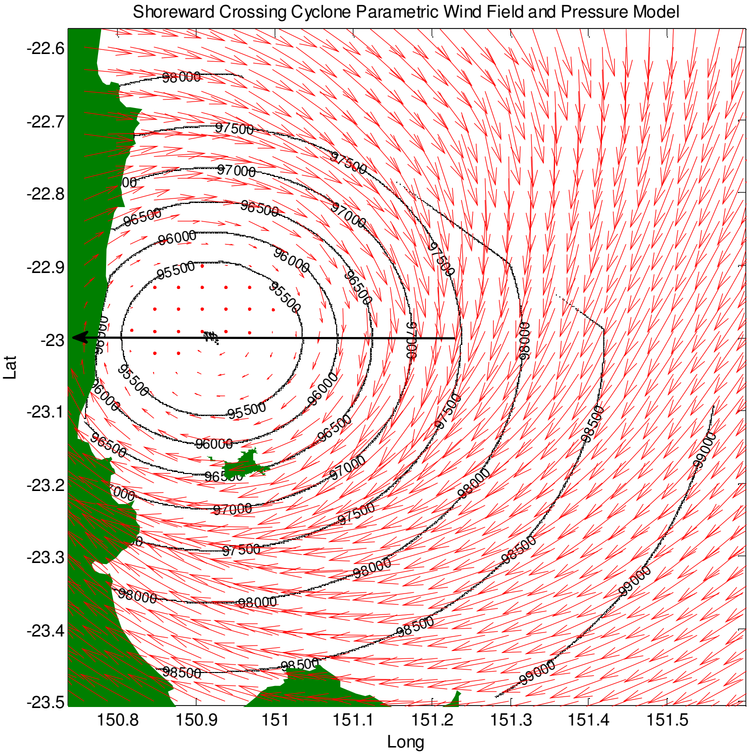

Figure 2-19 Shoreward Crossing Parametric Cyclone Wind Field

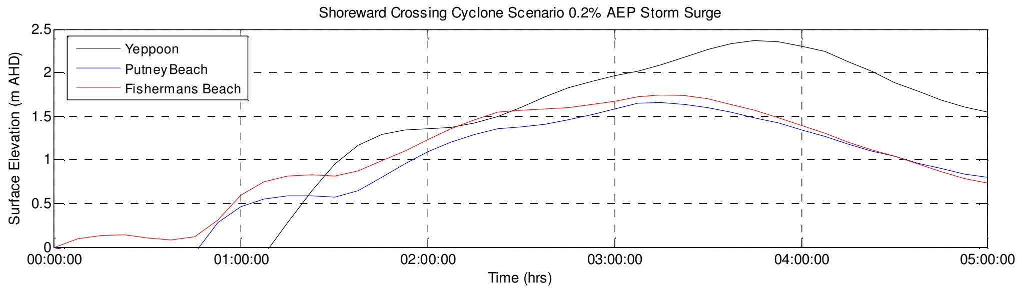

Figure 2-20 Simulated 100yr ARI Storm Surge Water Level Variations at Yeppoon, Putney and Fisherman's Beach

As can be seen from Figure 2-20, the behaviour of the storm surge varies considerably between Yeppoon and Great Keppel Island under a shoreward crossing cyclone scenario, with the storm surge peak at Great Keppel Island occurring earlier and at a lower absolute level than Yeppoon.

Figure 2-21 displays the peak storm surge recurrence interval estimates at Putney and Fisherman's Beach relative to Yeppoon over a range of relevant recurrence intervals developed from this analysis. Table 3-4 displays the corresponding storm tide recurrence interval estimates for Putney and Fisherman's Beach.

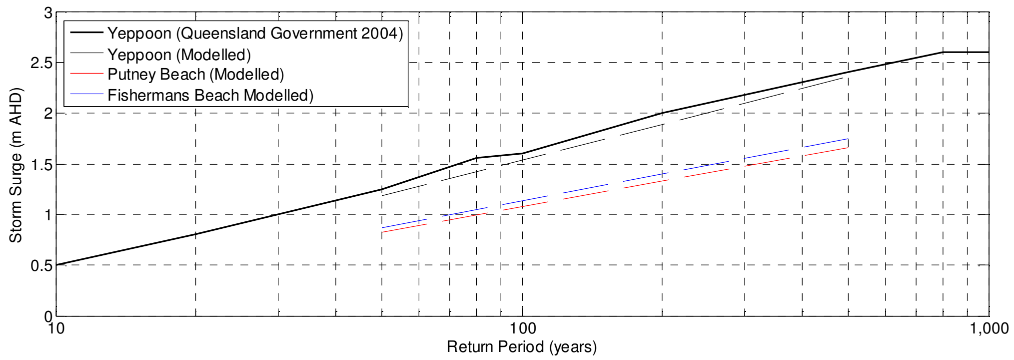

Figure 2-21 **Estimate of the Storm Surge Recurrence Intervals at Putney and Fishermans Beach Relative to Yeppoon**

Table 2-3 **Storm Tide AEP for Putney and Fishermans Beach**

AEP	Yeppoon	Putney Beach m AHD	Fishermans Beach m AHD
2%	2.75	2.32	2.37
1%	2.94	2.67	2.74
0.2%	3.49	2.75	2.83

2.6.2 Extreme Wave Conditions

The most extreme waves observed at Putney Beach are generated by tropical cyclones when the cyclone track results in northerly, through to west and southerly winds. To estimate the magnitude and recurrence intervals of extreme wave conditions at Putney Beach, the spectral wave model (Appendix B) was employed to model the generation and propagation of waves under extreme cyclonic wind conditions at Putney Beach.

Design cyclonic wind speeds representing 1, 50 and 200 year ARI wind speeds were derived from those provided for Tropical Cyclone Region C in Australian/New Zealand 1170.2:2002, Part 2: Wind Action standards. The 3 second gust wind speeds derived from these standards were converted to hourly average wind speeds by the methodology provided in the Australian/New Zealand 1170.2: 1989 "SAA Loading Code, Part 2: Wind Loads" to provide more representative wind speeds over the duration and fetches relevant to Putney Beach. The hourly average design wind speeds adopted for the design wave condition modelling are displayed in Table 2-4.

An additional important consideration in the determination of design wave conditions for Putney Beach is the relevant mean water depths to apply during the extreme wave condition model simulations. The depth assumptions are important as the depths over most of the relevant fetches to Putney Beach are relatively shallow and maximum wave heights may be depth limited at certain phases of the tide.

To provide appropriately conservative water depths for the extreme wave condition modelling, the MHWS tidal water level of 1.8m AHD was adopted for the 1 and 50 year ARI wind events. For the 200 year ARI wind event, the 1 in 100 year ARI storm tide level of 2.67m AHD was adopted. The design wind speed and water level conditions adopted for the extreme wave condition modelling are displayed in Table 2-4.

Table 2-4 Design Wind Speed and Water Level Conditions for Extreme Wave Condition Modelling

Average Recurrence Interval (Years)	Design Wind Speed (m/s)	Water Level (m AHD)
1 year	20.0	1.8
50 year	34.0	1.8
200 years	38.4	2.67

The degree of exposure to extreme wave conditions along Putney Beach is complicated by the existence of Middle Island to the immediate west. Critical wind/wave directions therefore vary considerably along Putney Beach. To provide an indication of these variations, the extreme wave condition modelling results have been returned at both a northern Putney Beach and southern Putney Beach location.

Table 2-5 summarises the 1, 50 and 200 year ARI design wave condition modelling results at both the northern Putney Beach and southern Putney Beach locations.

Table 2-5 Summary of Extreme Wave Condition Modelling Results at Putney Beach

Wind Direction	Wind Speed ARI (yr)	Hs (m)		Tp (s)		Mean Wave Direction (Deg)	
		Northern	Southern	Northern	Southern	Northern	Southern
N	1	2.8	2.1	8.1	8.3	4	350
	50	3.1	2.2	10.2	10.2	5	350
	200	3.7	2.7	11.2	11.2	7	352
NW	1	2.3	1.9	6.2	6.2	340	332
	50	2.8	2.3	8.0	7.5	345	334
	200	3.4	2.8	8.8	8.3	346	335
W	1	1.5	1.6	4.8	4.8	283	274
	50	2.0	2.0	5.3	5.3	289	279
	200	2.4	2.5	5.8	5.8	289	279
SW	1	1.7	1.8	5.1	5.1	229	231
	50	2.0	2.0	5.7	5.7	234	234
	200	2.2	2.5	7.1	6.2	216	231
S	1	1.5	1.5	5.8	5.8	218	214
	50	1.8	1.8	6.6	6.6	219	215
	200	2.4	2.2	7.1	7.1	216	212

2.7 Sediment Transport and Coastal Processes

2.7.1 Overview

The alignment of Putney and Fisherman's Beach is primarily controlled by the diffraction and refraction of north easterly and south easterly waves around the northern and southern headlands of Great Keppel Island respectively. The refracted waves approach these beaches with small oblique angles and subsequently drift sand into the westerly projecting, trailing spit formation that divides these two beaches. The alignment of the spit is therefore in dynamic equilibrium between the influence of the refracted south easterly and northerly waves and subsequent rates of sediment transport. The westward projection of the sand spit is curtailed by the increasing exposure to strong tidal current action that is generated between Middle Island and Great Keppel Island as well as increasing exposure to wave action as the end of the spit extends beyond the sheltered zone afforded by the northern and southern headlands.

Westerly, longhsore drifting of sediment along Leeke's Beach drifts past the Putney Point headland and a proportion of this sediment is transported southwards onto Putney Beach by wave and current action. The source of the sediment supply to Fisherman's Beach is not as readily apparent but is considered to be largely associated with onshore sand transport by wave and current action.

Cyclones are random, high intensity events that have the potential to supply and rearrange large quantities of sediment within the beach compartment over a very short period which, subsequently, can take many years to a decade or more to return to equilibrium.

To quantify the sediment transport processes within the vicinity of Putney and Fisherman's Beach more precisely, detailed sediment transport modelling has been carried out. The results of the analysis is described in the following sections.

2.7.2 Sediment Transport Potentials

Sediment transport in the vicinity of Putney and Fisherman's Beach is a complicated function of tidal and wind driven currents, wave action and sediment characteristics. In order to characterise the existing sediment transport potentials in the vicinity of Putney and Fisherman's Beach, the following detailed sediment transport modelling analysis has been undertaken:

- Tidal and wind driven current sediment transport analysis
- Wave driven sediment transport analysis

Current-Driven Sediment Transport

The magnitude and direction of the sediment transport potentials due to tidal and wind driven current action has been assessed in the hydrodynamic model which has been coupled to a non-cohesive sediment transport model.

Sediment transport potentials under existing conditions were estimated by simulating the hydrodynamic and sediment transport model over a representative month of summer wind and astronomical tidal conditions. The net sediment transport potential rate over the one month period was then calculated from the model results and factored to provide an estimate of the net annual sediment transport potential in terms of m^3/yr/m. Figure 2-22 displays the estimate of the predicted annual net sediment transport potentials in the vicinity of Putney and Fisherman's beach.

As can be seen from Figure 2-22, away from the non-erodable rock and reef outcrops around Middle Island, Passage Rocks and Putney Point, annual net sand transport potentials are relatively small, indicating that large sand transport fluxes are not a general feature of the region between Great Keppel Island and Middle Island under ambient (non cyclonic) conditions. The main areas of active net sediment transport under ambient, existing conditions are in general confined to the following locations:

- An area of active southward net sand transport is predicted to occur across the relatively shallow, sandy shoal that exists to the southwest of Passage Rocks. Net southerly sediment transport rates across this shoal are estimated at approximately 2-4m^3/yr/m.
- An area of minor net sediment transport is predicted to occur adjacent to the Putney and Fisherman's Beach spit head. Both flood and ebb tide currents sweep past the spit head resulting in a net offshore sand transport potential to the west. The magnitude of this sediment transport potential is estimated under existing conditions at approximately 1-2 m^3/yr/m.

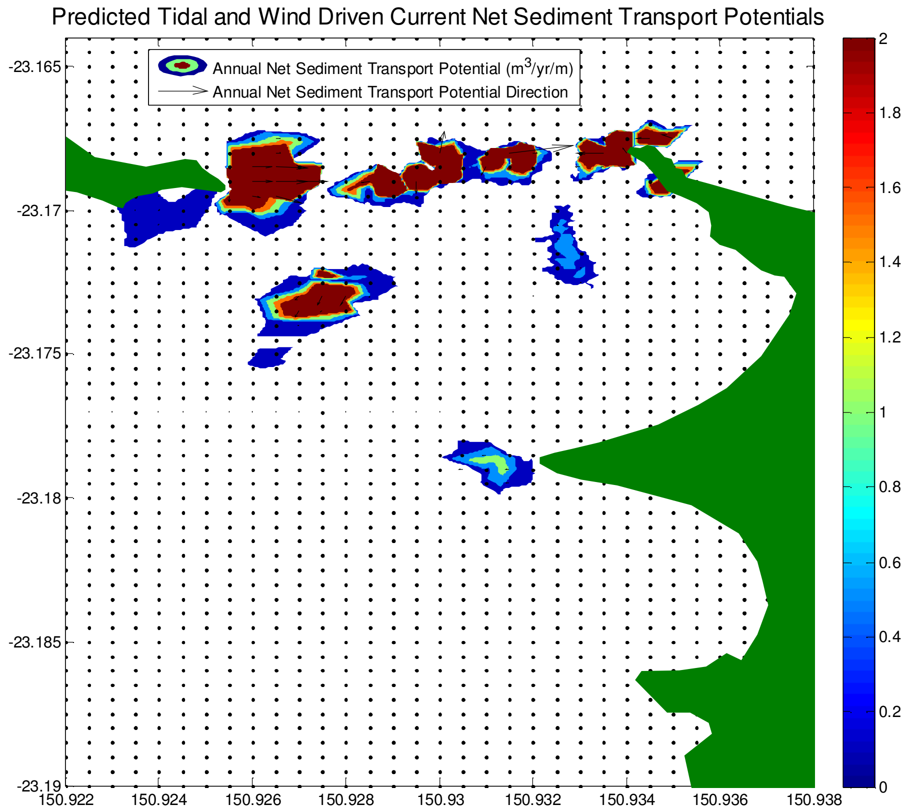

Figure 2-22 Predicted Tidal and Wind Driven Current Net Sediment Transport Potentials

To estimate the annual net sediment transport rates due to wave action on the shorelines in the vicinity of Putney and Fisherman's beach, a longshore sediment transport formulation has been applied to estimate the longshore sediment transport potentials at Fisherman's, Putney and Leeke's beach. The Kampuis formulation (Kamphuis, 1991) has been applied to estimate the alongshore sediment transport potentials. The Kamphuis formulation accounts for the impact of wave height and period, grain size, and beach slope on the rate of alongshore sediment transport and was derived from an extensive series of hydraulic model tests. The Kamphuis formulation has been applied to the 2008 hindcasted wave climate at Fisherman's, Putney and Leeke's beach to enable the net sediment transport potentials to be quantified at these locations.

Figure 2-23 provides a summary of the combined net current and wave driven sediment transport rates and directions in the vicinity of Putney and Fishermans Beach derived from the sediment transport analysis.

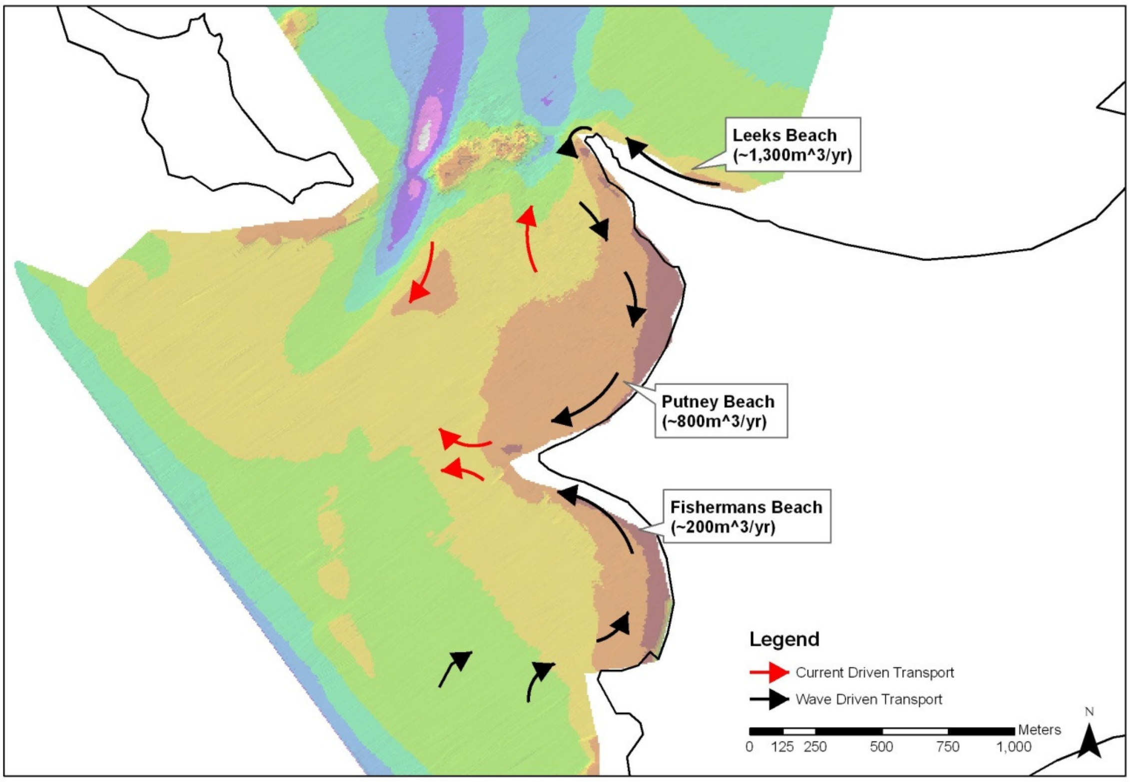

Figure 2-23 Overview of Sediment Transport and Coastal Processes

2.7.3 Chronology of Shoreline Change

To document the historical shoreline variations on Putney and Fishermans Beach, historical aerial photography of Great Keppel Island was obtained and geo-referenced to a common coordinate system and scaled to enable more precise interpretation. It should be noted that the historical photographs were captured at a variety of scales, resolutions and tidal states. The absolute accuracy of the interpretations derived from the comparisons of these photos cannot therefore be precisely verified but is considered appropriate to enable semi-quantitative estimates of coastal change to be inferred for the purposes of this assessment.

A total of 6 historical photographs were analysed spanning from 1961 – 2010, with one photo per decade providing an approximate 50 year timeseries of coastal change. To provide an indication of absolute change in the beach alignments, the vegetated dune extent from the 2010 photograph was delineated and plotted on the earlier photos to provide an indicator of beach position change. Figure 2-24 displays the timeseries of historical aerial photography of Putney and Fisherman's Beach relative to the 2010 vegetated dune extent.

The following chronology of shoreline change on Putney and Fisherman's Beach is derived from interpretation of the historical aerial photographic timeseries displayed in Figure 2-24 and the investigations undertaken by Ballantine (1996).

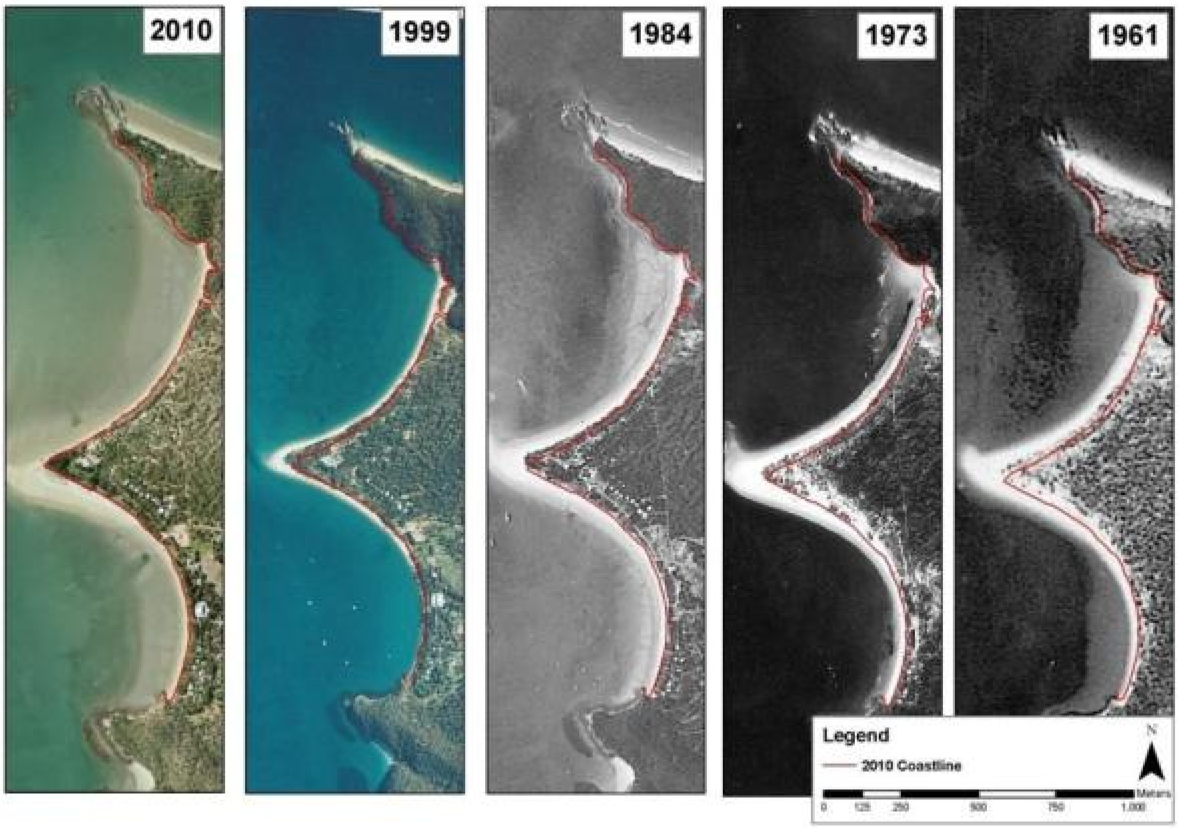

Figure 2-24 Historical Aerial Photographic Timeseries of Putney and Fisherman's Beach

1961

- Very limited human activity on the spit is apparent in the 1961 photograph. Compared to later periods, the density of vegetation on the spit is lower, with larger expanses of bare and potentially mobile sand apparent on the spit.
- Expansive meadows of seagrass are apparent offshore of Putney and Fisherman's Beach in 1961 and while difficult to interpret, it appears these meadows have largely disappeared by 1973.
- The alignment of the head of the spit is pushed towards the north indicating a relatively recent, net northward transport of sediment along Fisherman's beach.

1973

- A large lobe of sand is evident in the northern corner of Putney Beach at the mouth of Putney Creek. This sand lobe was evidently caused by flood flow scouring of the dune and beach at the mouth of Putney Creek. Between 1961 and 1973 however, no major cyclone was recorded in the vicinity of Great Keppel Island such that the flood flows that transported this sediment into Putney Beach bay must have been generated by heavy thunderstorm activity. Waves can be seen breaking along the outer edge of this sand lobe and drifting the sediment southwards along Putney Beach.
- The alignment of the head of the spit still indicates a net northward transport of sediment along Fisherman's Beach.

1984

- Between 1973 and 1984, Putney and Fisherman's Beach were impacted by Cyclone David (20 January, 1975) and Cyclone Simon (15 February, 1980). These cyclones resulted in the following impacts to Putney and Fisherman's Beach:

  - Cyclone David approached Great Keppel Island from the north and primarily impacted Putney Beach (Ballantine 1996). The combination of surge and wave action eroded sediment from Putney Beach and transported it south towards Fisherman's Beach causing the loss of many Melaleuca trees that had colonised the dune at the back of Putney Beach (Ballantine, 1996).
  - Cyclone Simon generated very strong south-south westerly winds and the resulting wave action caused severe erosion of Fisherman's Beach (Ballantine, 1996). Sediment was transported northwards towards Putney Beach and the head of the spit was pushed towards the north.
- The 1984 aerial photo shows evidence of pronounced offshore bar features, towards the headlands of both beaches, these are possibly associated with offshore sediment transport associated with cyclonic wave conditions experienced over this period
- A general reduction in beach widths along both Putney and Fisherman's Beach is apparent in the 1984 photo compared to earlier photos
- There appears to have been a marked decline in seagrass coverage and extent offshore of Putney and Fisherman's Beach since the 1961 photo.

1999

- Putney and Fisherman's Beach were severely impacted by Cyclone Fran (16 March 1992). Cyclone Fran produced very strong south-west to westerly winds at Great Keppel Island that combined with a high tide to cause severe erosion of these beaches (Ballantine, 1996).
- At some stage between 1984 and 1999 (Possibly associated with Cyclone Fran in 1992), Putney Creek breached the Putney Beach foredune inline with the main creek axis creating a more southerly entrance location. A low sandy berm still exists at this secondary entrance in the 2010 aerial photograph.
- Potential differences in tidal states between photos aside, there appears to be a consistent decline in beach widths compared to earlier periods on both Putney and Fisherman's Beach.
- The head of the spit is beginning to show a more southerly alignment compared to its position in earlier periods.

2010

- The 2010 aerial photo shows indications that the width of Putney Beach has continued to decline, particularly the southern end of the beach where significant shoreline recession has occurred since the 1999 aerial photo.
- The head of the spit is located approximately 50 metres south of the earlier spit alignments and the westward projection of the spit, as interpreted from the vegetated dune extent, has reduced by approximately 25 metres compared to earlier periods.
- A noticeable lobe of sand has accreted on the southern side of the spit on Fisherman's Beach, it is likely that this sand has come from the erosion of the Putney Beach side of the spit.

In summary, the main shoreline changes observed over the 50 year timeseries of historical aerial photographs are:

- The location of the head of the spit has shifted to the south. This change in alignment began around 2000 and has progressed through to the present day. Figure 2-25 shows the large lobe of sand that has accreted on the southern side of the spit in conjunction with the southerly migration of the spit head.
- The southern end of Putney Beach has experienced significant shoreline recession over the last decade, corresponding with the change in the spit alignment. Figure 2-26 shows the southern end of present day (November 2010) Putney Beach. Figure 2-26 shows the low beach profile, eroding dune scarp and loss of mature dune vegetation consistent with long

term shoreline recession at this location. The difference in beach profiles between the eroding (concave) and accreting (convex) of Putney and Fisherman's beach towards the head of the spit can be seen in the cross shore beach profiles displayed in Figure 2-27.

- There appears to have been a general and consistent decline in beach widths on both Putney and Fisherman's Beach since the earliest aerial photos.
- A new southerly entrance to Putney Creek was initiated sometime between 1984 and 1999, this secondary entrance shows evidence of still being active at times of high creek flows and/or elevated coastal water level conditions.

The shoreline changes observed on Putney and Fisherman's Beach over the last 50 years are considered to reflect the relatively mobile nature of this trailing spit landform and the dynamic processes operating on it. The variability observed in this landform is of the magnitude that could be expected with this type of landform, which is in a dynamic equilibrium with the physical processes operating on it. Possible causes of the shoreline changes observed over the last 50 years are considered to be the following:

- The apparent reduction in extent and coverage of seagrass offshore of Putney and Fisherman's Beach may have contributed to the general decline in beach widths by allowing more wave energy to propagate across the shallow subtidal flats and impact these beaches. Alternatively, the loss of seagrass may have allowed sand to be more readily mobilised by stronger current action offshore which has subsequently lowered the subtidal profiles in-front of these beaches and allowed greater wave action to impact these beaches.
- Longer term variations in climate such as El Nino – Southern Oscillation and the Inter-decadal Pacific Oscillation may cause long term though minor variations in the spit alignment and therefore shoreline condition.

Figure 2-25 Large Sand Lobe on Southern Side of Spit (November 2010)

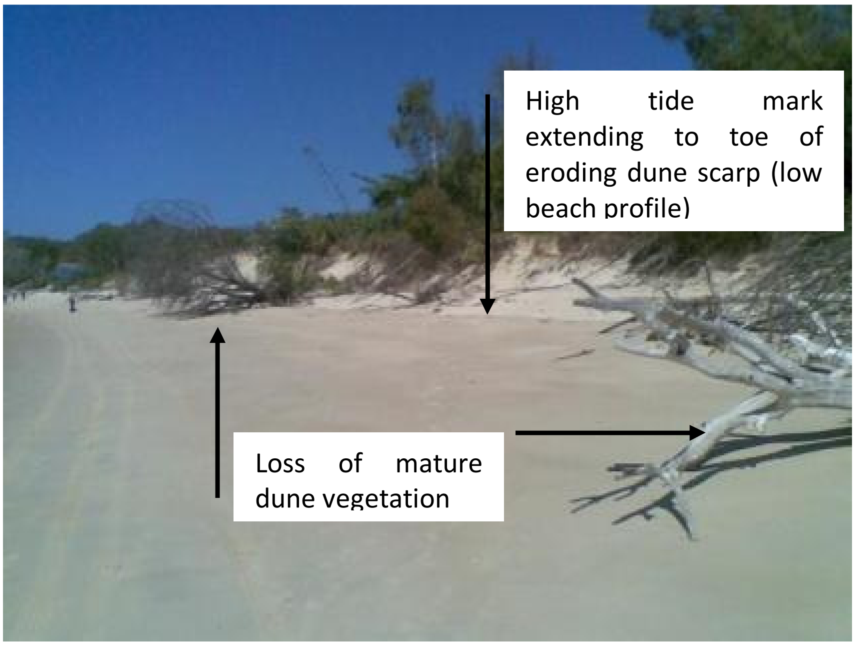

Figure 2-26 Shoreline Recession at the Southern End of Putney Beach

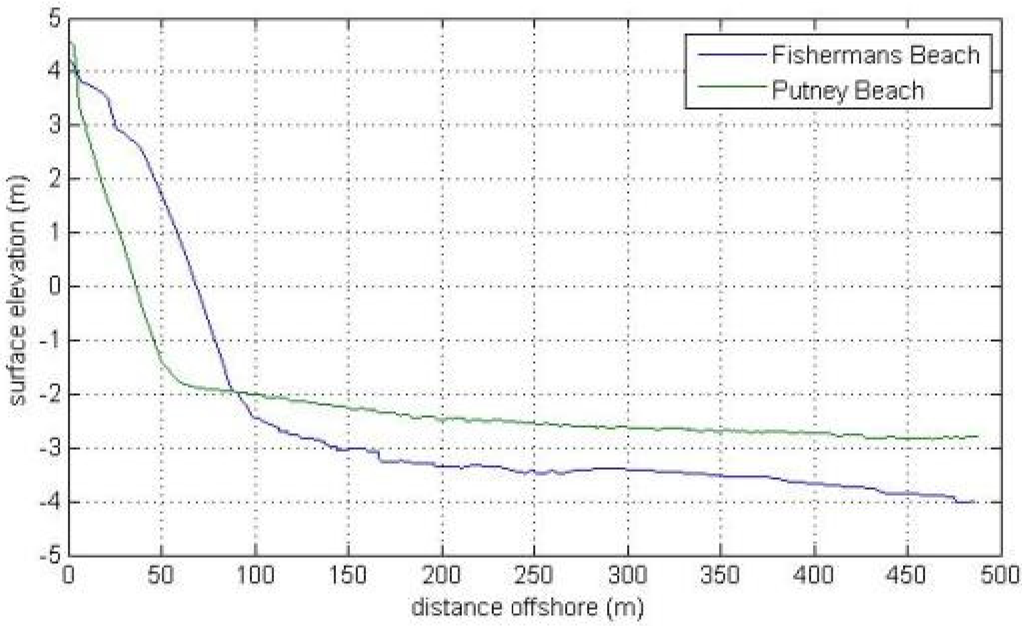

Figure 2-27 Eroding (concave) and Accreting (Convex) Beach Profiles of Putney and Fisherman's Beach towards the Spit Head

3. POTENTIAL IMPACTS AND MITIGATION

Potential impacts to hydrodynamics, coastal processes, marine water quality and sediments associated with the construction and operation of the Great Keppel Island Revitalisation Plan have been investigated and quantified. Options and methods to avoid or mitigate adverse impacts have been tested and refined with numerical models to provide recommendations for minimizing the impact of the Great Keppel Island Revitalization Plan on the coastal environment.

3.1 Proposed Marine Developments

The following two main marine components of the proposed Great Keppel Island Revitalisation Plan have been considered in the impact and mitigation assessment:

Marine Facility

A 250 berth marina facility incorporating a passenger ferry terminal, barge handling area and day boat storage is proposed to be constructed in the northern corner of Putney Beach as displayed in Figure 3-1.

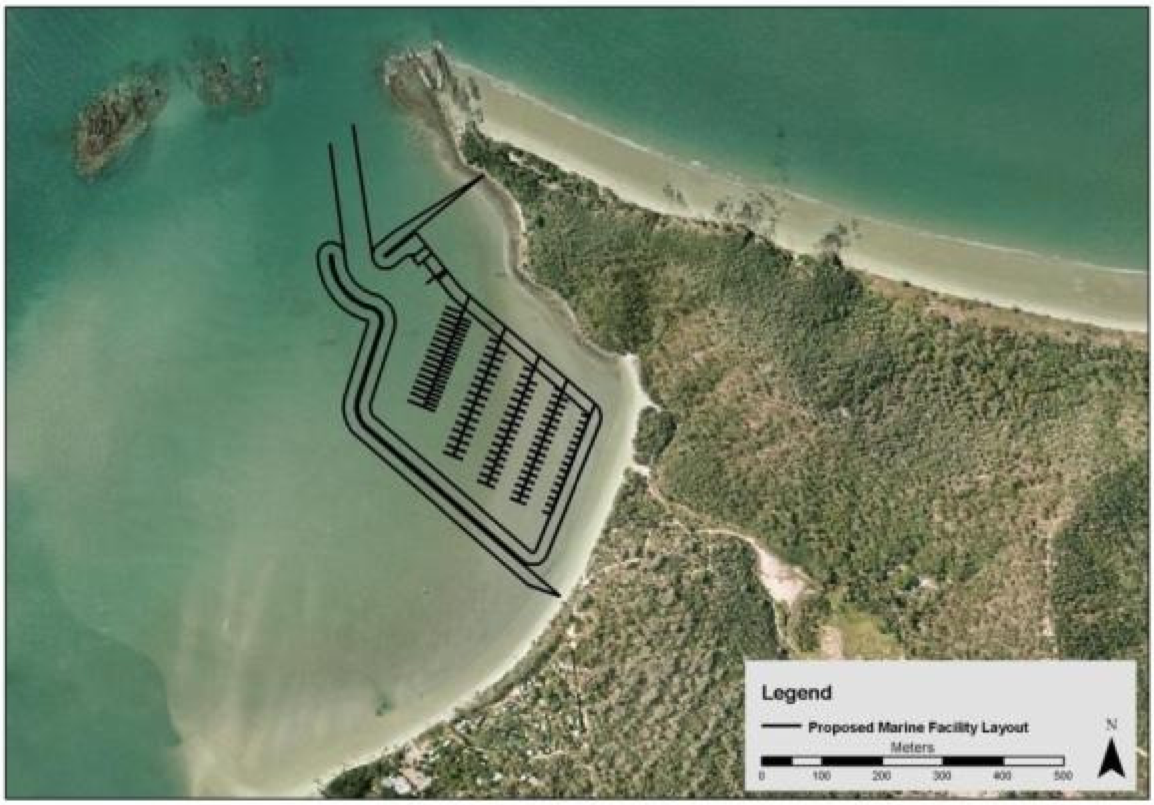

Figure 3-1 Proposed Marine Facility Layout

The main physical components of the proposed marine facility include the following:

- A 90,000m^2 marina basin that will be constructed to provide minimum depths ranging between 2.5m and 3.5m LAT.
- A western breakwater to exclude wave and current action from the marina basin
- An approximately 190m long by 45m wide access channel to the marina basin that will be maintained at a minimum depth of 3.5m LAT.

- A bunded reclamation area of approximately 46,000m^2 on the northern and eastern side of the marina basin.
- Putney Creek entrance will remain open to the marina, however a sediment and gross pollutant trap within the structure of the marina will prevent sediment from Putney Creek depositing into the marine facility.

Wet Weather Wastewater Outfall

A wet weather treated wastewater outfall is proposed as part of the project. The treated wastewater is to be discharged via an outfall diffuser approximately 1,000 meters offshore of Long Beach in approximately 11 metres of water as displayed in Figure 3-2.

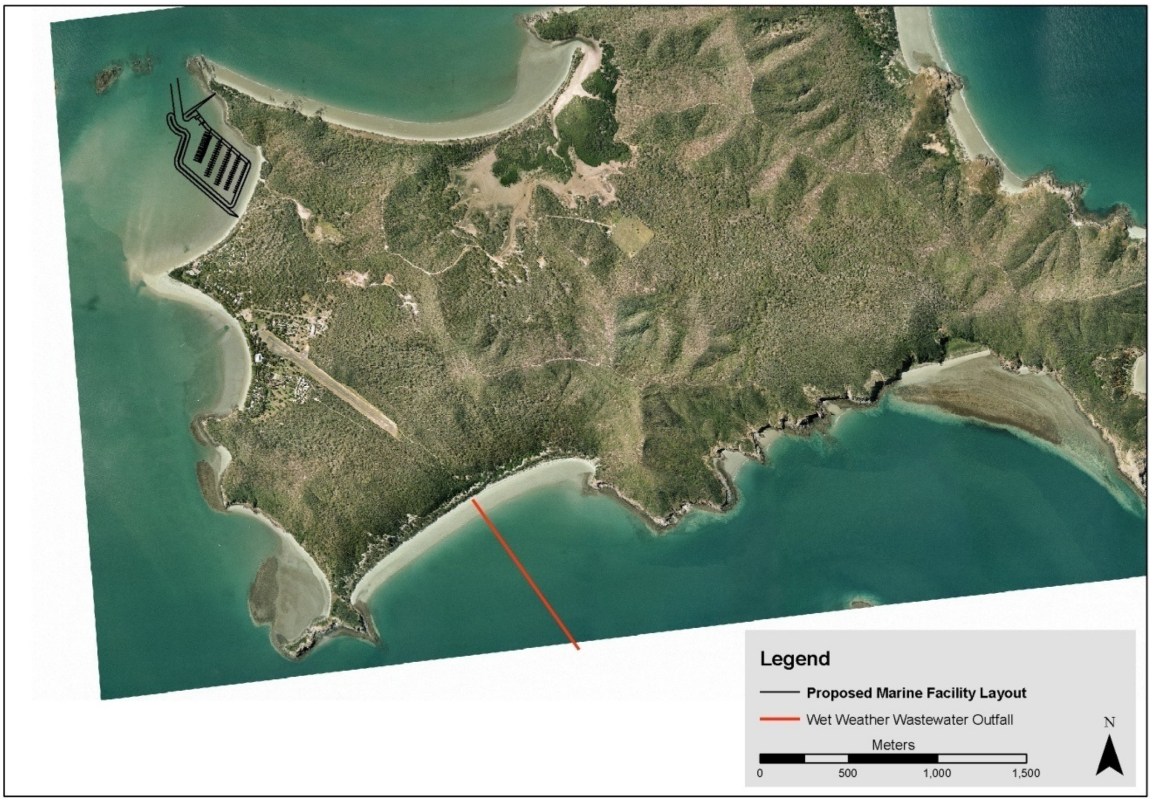

Figure 3-2 Proposed Location of Wet Weather Wastewater Ocean Outfall

The project is expected to to generate approximately 208ML/year of wastewater. This wastewater is to be treated to Class A+ standard and will comply with the nutrient levels specified by GBRMPA (Opus, 2011). The vast majority of the treated wastewater is to be reused on Great Keppel Island. A 32 ML wet weather storage facility is to be constructed to store treated effluent during periods of wet weather. It is anticipated that the capacity of this storage facility may be exceeded during an extreme wet weather event that could be expected to occur, on average, once every 10 years. Under these conditions, the excess treated effluent will be discharged via the ocean outfall.

3.2 Coastal Values

The main coastal features of Great Keppel Island impacted by the proposed marine facility include the rocky headland of Putney Point and a section of Putney Beach that is itself a component of the trailing spit landform.

Within the broader Great Barrier Reef, there are more than 600 continental bedrock islands (Smithers et al, 2007). Great Keppel Island is one of approximately 20 of these continental bedrock islands located with Keppel Bay. These islands all exhibit similar coastal morphology incorporating bold, rocky headlands, wave cut rocky shore platforms and sandy trailing spit shoreline formations.

3.2.1 Mitigation Measures

The following is considered to mitigate the impact of the marina on the coastal features and values of Great Keppel Island and the Great Barrier Reef more generally:

- The marina footprint will only impact coastal landforms that are well represented on similar continental bedrock islands located within Keppel Bay.
- The marine footprint will impact a trailing spit landform that has already been subjected to modifications/disturbance associated with human activities in comparison to more pristine examples of this type of feature on adjacent islands in Keppel Bay.
- Bypassing of sand past the marina entrance and onto Putney Beach is proposed to maintain the sediment transport continuity and therefore morphology of the trailing spit landform. This mitigation measure is discussed in more detail in Section 3.4.4

3.3 Tidal Flows and Hydrodynamics

Potential changes to tidal water levels and currents associated with the proposed marine facility were assessed in the hydrodynamic model. The hydrodynamic model geometry was changed to represent the main physical components of the marine facility including the breakwaters, reclaimed land and navigation channel and marina basin. The hydrodynamic model geometry incorporating the marine facility is displayed in Figure 3-3.

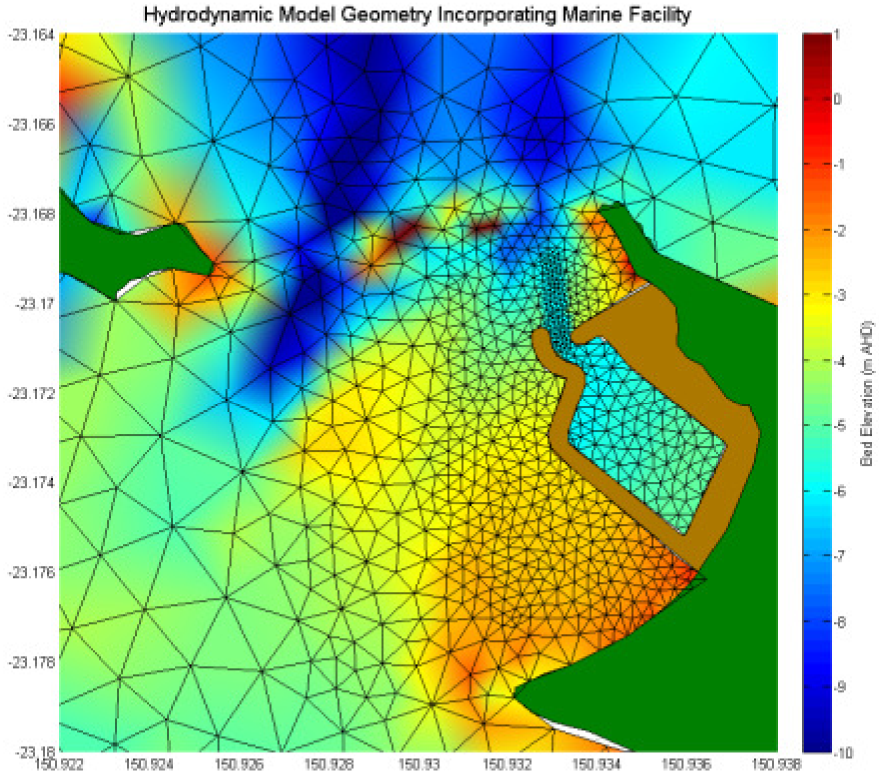

Figure 3-3 Hydrodynamic Model Geometry Incorporating Marine Facility

Hydrodynamic model simulations incorporating the marine facility were undertaken over a representative month of summer wind conditions and astronomical tides and compared to the same period under existing conditions to enable the impact of the marina to be quantified relative to existing conditions. Simulated current fields including the proposed marine facility under representative peak spring flood and ebb tidal conditions are displayed in Figure 3-4.

Comparison of the impact of the proposed marine facility on tidal current fields and water levels has been provided as follows:

- Current speed impact contour plots and vectors at peak spring flood and ebb tidal conditions relative to existing conditions have been presented in Figure 3-5. Areas where the relative current speed impact is than ± 0.02m/s have been excluded from this figure.
- Water level and current speed and direction time series plots at three locations of interest with the proposed marine facility and under existing conditions have been displayed in Figure 3-7, Figure 3-8 and Figure 3-9 respectively. The position of the three locations of interest relative to the proposed marine facility is displayed in Figure 3-6.

The tidal water level and current field impacts displayed in the following figures can be summarised as follows:

Peak Spring Flood Tidal Currents

- Flood tide currents are diverted around the western side of the marine facility resulting in acceleration of peak current speeds generally by less than 0.05m/s, compared to existing conditions.

- Peak flood tide current speeds south of the marine facility along Putney Beach are predicted to reduce by 0.05 – 0.1m/s.
- A negligible impact on water levels and tidal phase is predicted.

Peak Spring Ebb Tidal Currents

- Ebb tide currents south of the marine facility are diverted around the western edge of the marine facility resulting in a reduction in peak current speeds of approximately 0.05 – 0.075m/s south of the marine facility along Putney Beach.
- Ebb tide current speeds are accelerated around the western edge of the marine facility with local increases above existing conditions of up to 0.15m/s.
- Ebb tide current speeds between the marine facility entrance and Putney Point are reduced by 0.2m/s compared to existing conditions.
- Ebb tide current directions between Passage Rocks and Putney Point are orientated slightly more east of north than under existing conditions resulting in a minor re-distribution of current speeds and directions north of Putney Point.
- A negligible impact on water levels and tidal phase is predicted.

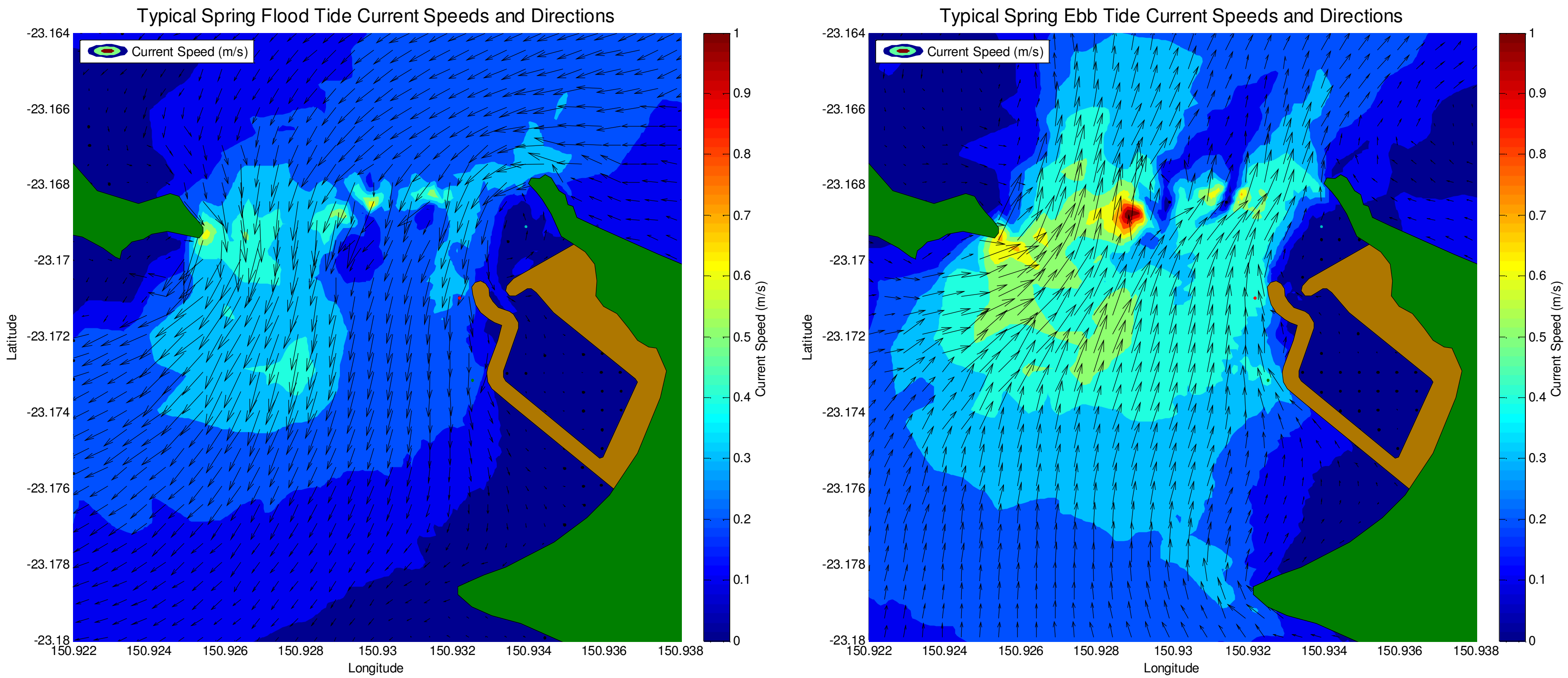

Figure 3-4 Predicted Peak Spring Flood and Ebb Tide Current Velocity Fields in the Vicinity of the Proposed Marine Facility

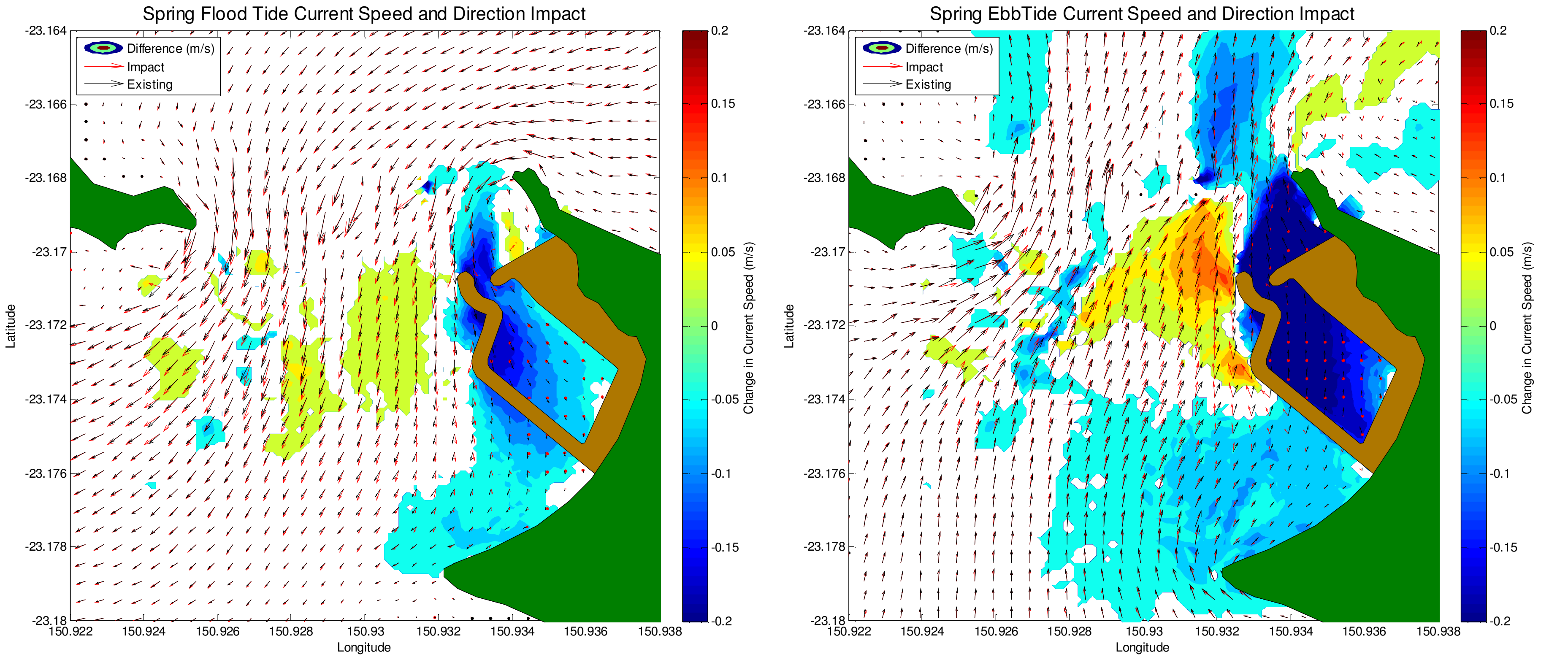

Figure 3-5 Predicted Peak Spring Flood and Ebb Tide Current Velocity Impact Relative to Existing Conditions

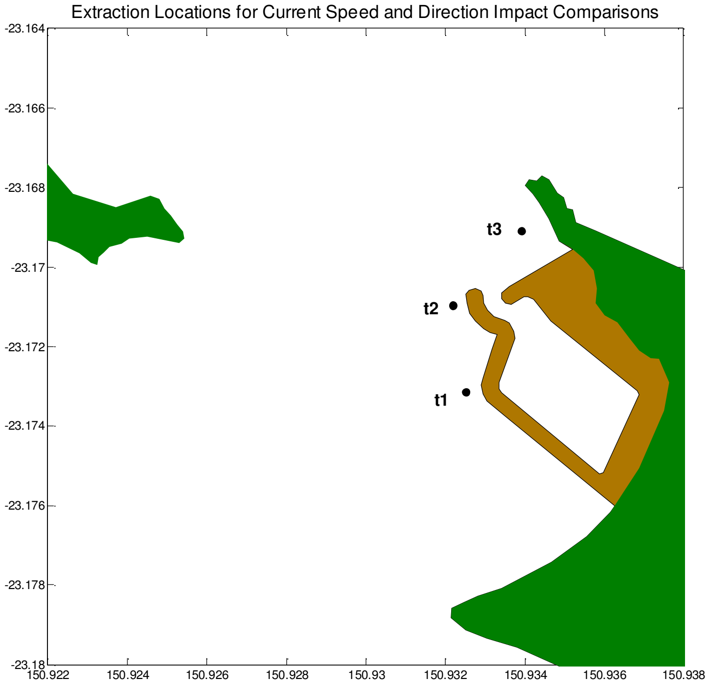

Figure 3-6 Locations of Water Level and Current Speed and Direction Impacts Time Series

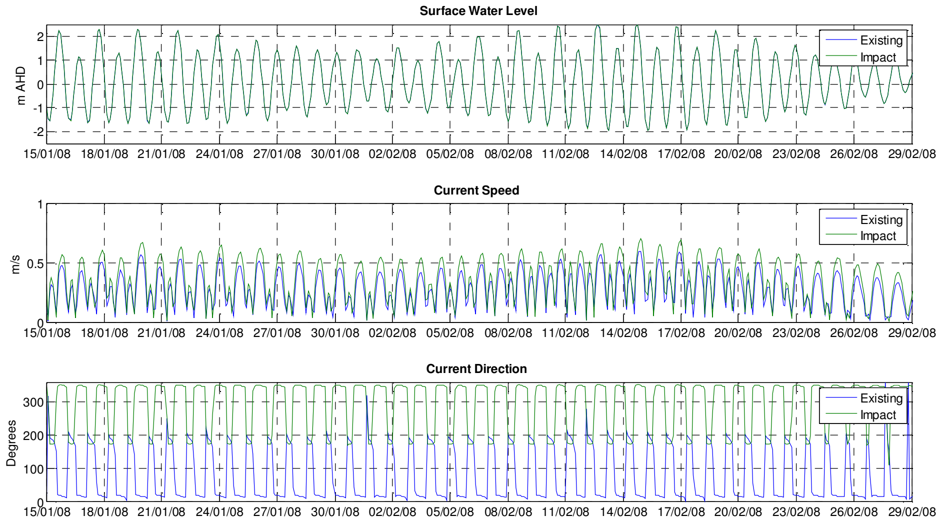

Figure 3-7 t1 - Water Level, Current Speed and Direction Impact

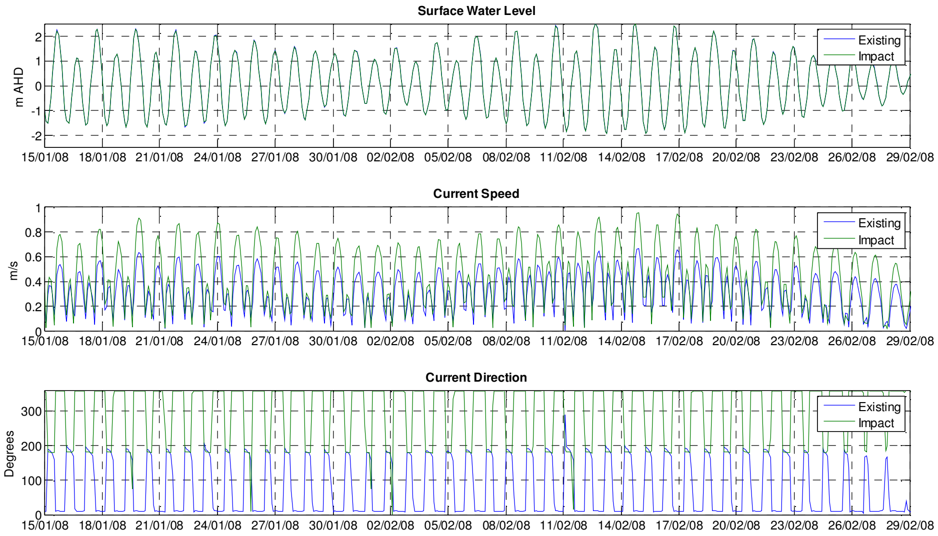

Figure 3-8 **t2 - Water Level, Current Speed and Direction Impact**

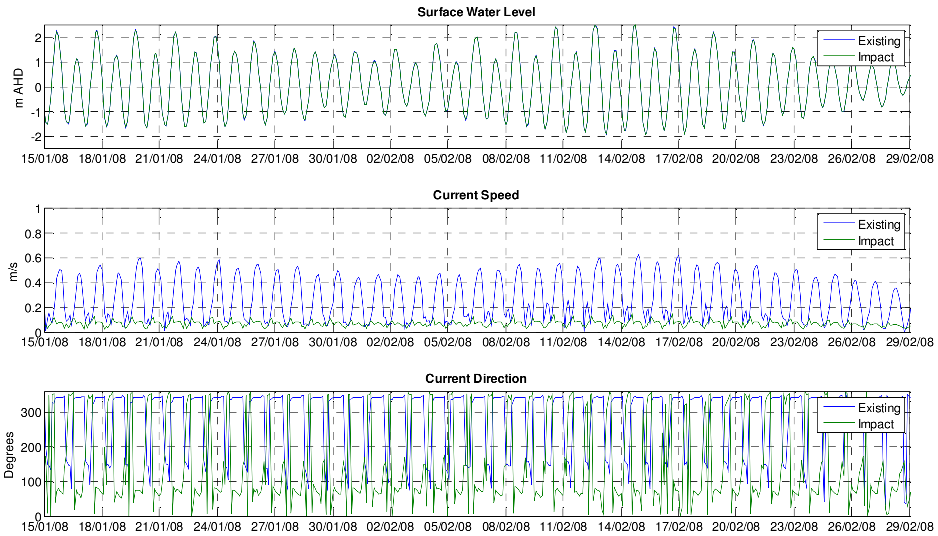

Figure 3-9 **t3 - Water Level, Current Speed and Direction Impact**

3.3.1 Mitigation Measures

The local and relatively minor changes to current speeds and directions predicted to arise from the construction of the marina are not considered to result in direct environmental impacts requiring mitigation.

3.4 Sediment Transport and Coastal Processes

Potential impacts of the marina development on sediment transport and siltation have been assessed. This assessment has considered the impact on sediment transport and siltation due to changes to tidal and wind driven currents and waves from the marina development discussed in Section 3.2. The assessment has been undertaken to identify the magnitude of any morphological changes caused by the proposed marina development and to enable the requirements, or otherwise for maintenance dredging of the channel entrance and marina basin to be determined.

3.4.1 Sand Transport Potential

To facilitate the assessment of the potential impact of the marina development on net sand transport potentials due to tidal and wind driven currents, the hydrodynamic and sediment transport model was simulated over a month of summer wind and tidal conditions under existing conditions and incorporating the main structural features of the marina to enable the impact on net sediment transport potentials due to tidal and wind driven currents in the area to be quantified. Figure 3-10 displays the predicted difference in the net tidal and wind driven current sediment transport rates in the vicinity of the marina. The following impacts on the net sediment transport rates are predicted:

- Net sediment transport rates around the western edge of Putney Point are predicted to decrease. Construction of the marina will deflect the ebb and flood tidal currents away from the western edge of Putney Point and create an area between the marina and Putney Point that is relatively sheltered from strong current action and sediment transport.
- Construction of the marina will slightly reduce the flood and ebb tide current velocities that sweep past the spit head and therefore the rate at which sediment is mobilised and transported away from the spit head.
- The western breakwater of the marina will cause an acceleration of the currents around the seaward edge of the breakwater. This is predicted to cause a slight increase in the sand transport potentials at these locations and a corresponding reduction in transport potentials immediately adjacent to the breakwater where current velocities are lower.
- The predicted increases in flood tide velocities across the sandy shoal to the south west of Passage Rocks is predicted to increase the rate of southward sediment transport in this area.

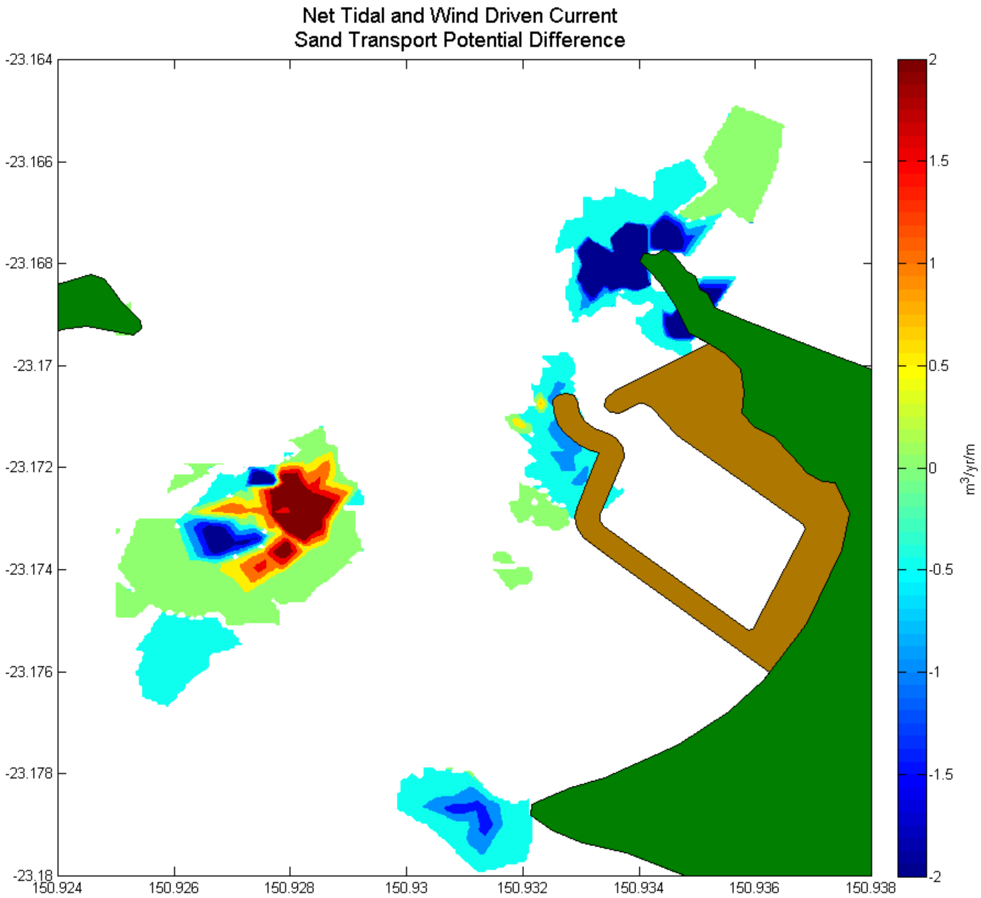

Figure 3-10 Tidal and Wind Driven Current Sediment Transport Impact

3.4.2 Putney and Fishermans Beach Coastal Processes

Potential impacts to incident wave energy and directions and subsequent sediment transport potential along Putney Beach associated with the proposed marine facility have been assessed. The spectral wave model geometry was altered to represent the main physical components of the marine facility and the wave conditions at Putney Beach were hindcast based on representative 2008 wind, ocean swell boundary conditions and tidal water level variations. The wave hindcast results have been compared to the wave hindcast results simulated under existing conditions over the same hindcast period. Figure 3-11 displays an example of the predicted impact of the marine facility on wave heights and directions at Putney Beach under prevailing northerly wave conditions.

Figure 3-11 is considered to show the following impacts:

- Under northerly wave conditions and with the proposed marine facility, northerly waves diffract around the western edge of the marine facility breakwater and approach Putney Beach with directions almost shore normal. Under existing conditions, northerly waves diffract around Putney Point and approach Putney Beach with small oblique angles.
- Under northerly wave conditions, wave heights along Putney Beach are predicted to be slightly lower than existing conditions due to the sheltering effect of the marine facility and the reduction in wave heights caused by the diffraction of waves around the western edge of the breakwater.

To integrate the predicted changes in wave heights and directions displayed in Figure 3-11 on sediment transport processes occurring on Putney Beach over the longer term, the Kampuis formulation (Kamphuis, 1991) has been applied to estimate the alongshore sediment transport potentials on Putney Beach. The Kamphuis formulation has been applied to the 2008 hindcasted wave climate for Putney Beach with the proposed marine facility and under existing conditions to enable the impact on sediment transport potentials to be quantified. The results of the longshore sediment transport potentials are displayed in Figure 3-12 in terms of the following:

- Instantaneous longshore sediment transport potentials
- Cumulative gross longshore sediment transport potentials
- Cumulative net longshore sediment transport potentials

(Positive transport rates correspond to southerly transport. Negative transport rates correspond to northerly transport.)

The following impacts on longshore sediment transport rates on Putney Beach are predicted from the comparisons displayed in Figure 3-12:

- The gross longshore sediment transport potential (i.e. the total volume of sediment potentially moved both north and south along Putney Beach) is predicted to be approximately half the potential predicted under existing conditions, reducing from approximately 1,200m^3/yr to 600m^3/yr. This change is considered primarily due to the reduction in wave heights and smaller incident wave angles caused by diffraction of northerly waves around the breakwater which causes less longshore sediment transport potential than under existing conditions.
- Under existing conditions, the net longshore sediment transport potential (i.e. the net volume of sand moved along Putney Beach) has been estimated at approximately 800m^3/yr towards the spit head (southerly transport). The impact of the marine facility is predicted to reduce the longshore sediment transport potentials along Putney Beach to close to zero and potentially result in a small reversal of the net sediment transport towards the north. Over time, the change in net longshore transport potentials is expected to slowly transfer sand from the spit head back along Putney Beach.

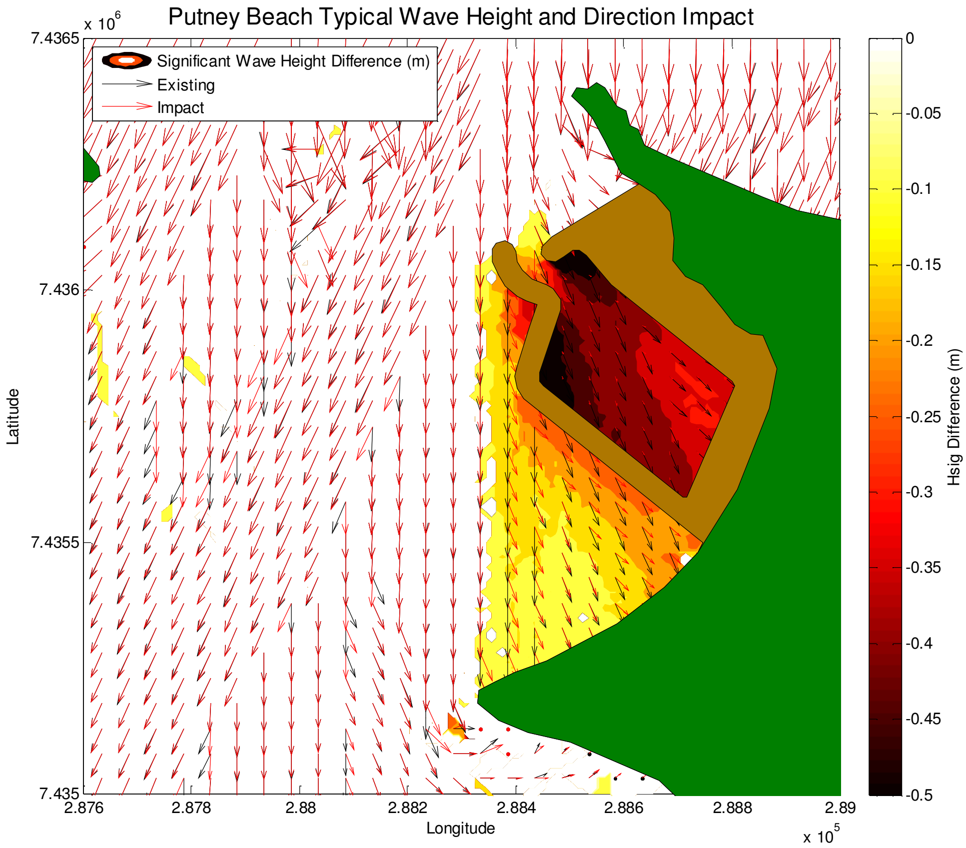

Figure 3-11 Example of the Predicted Impact of the Marine Facility on Wave Heights and Directions on Putney Beach under Prevailing Northerly Wave Conditions

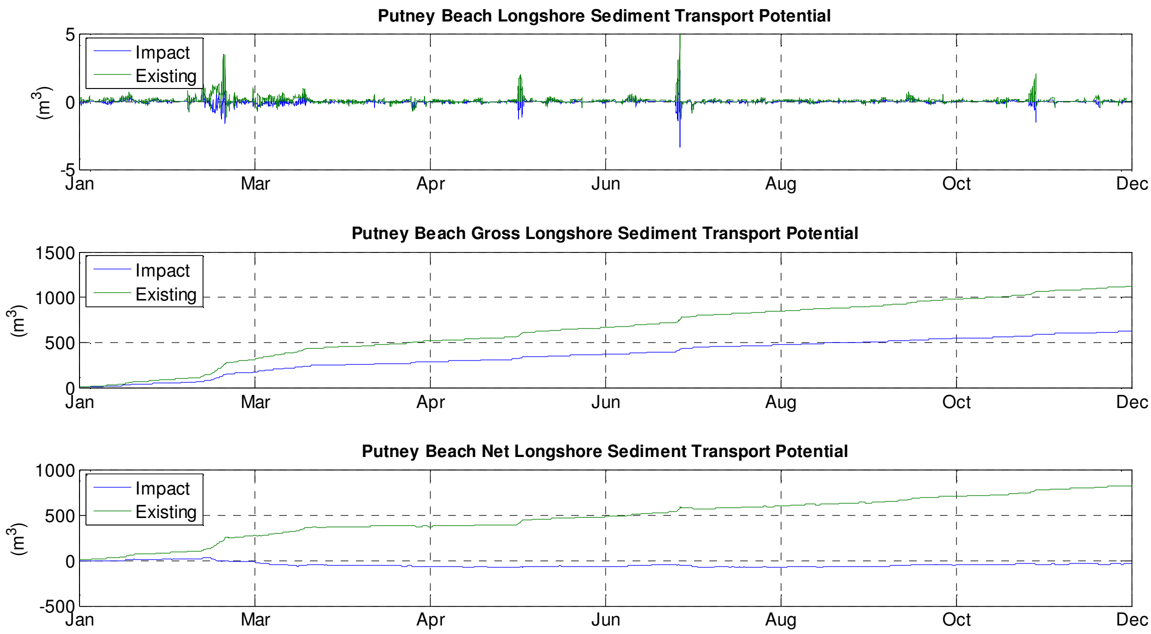

Figure 3-12 Putney Beach Longshore Sediment Transport Potential Impact

3.4.3 Siltation

The development of the marina has the potential to create areas both within and adjacent to the marina that are subjected to limited tidal current or wave action. Bed shear stresses in these quiescent areas may be low enough that fine silts can be deposited and are unable to be resuspended leading to a gradual accumulation of fine, cohesive sediments on the seabed in these areas.

Bed shear stresses less than approximately 0.1N/m^2 are conservatively estimated as generally resulting in fine silt deposition. To identify areas within and adjacent to the marina that may not experience bed shear stresses large enough to resuspend fine silts, the hydrodynamic model simulation results over a month of representative summer wind and tide conditions have been processed to calculate the maximum bed shear stresses over this period. Figure 3-13 displays the areas in which maximum bed shear stresses are not predicted to exceed 0.1N/m^2. From Figure 3-13, the following comments on the potential extent of fine silt deposition can be made:

- The potential extent of the area of fine silt deposition is largely confined to within the marina basin.
- A small area immediately adjacent to the breakwater on Putney Beach is also predicted to experience bed shear stresses low enough to allow fine silt deposition. However, wave action on Putney Beach is expected to be significant enough at times to resuspend fine silts in this area such that long term accretion of fine silts is not expected at this location.

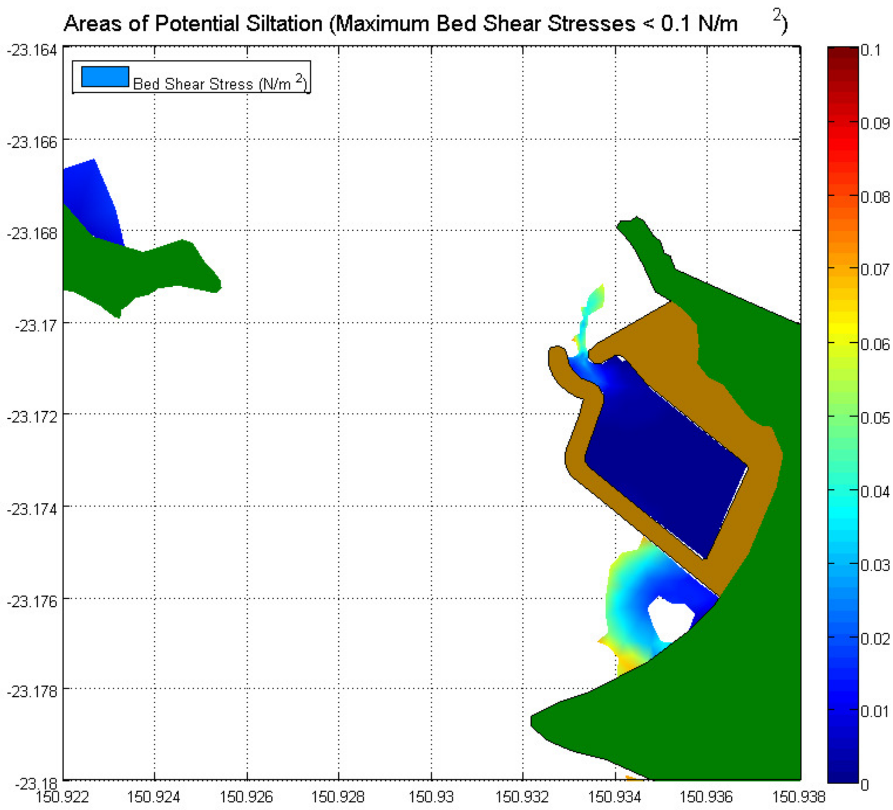

Figure 3-13 Areas of Potential Siltation

3.4.4 Mitigation Measures

The following measures are proposed to mitigate the impact of the marina on the local sediment transport processes and to maintain the operational functionality of the marina over the longterm.

Maintenance Dredging

Maintenance dredging is likely to be required periodically over the course of the marina's operation to maintain the minimum navigable depths required in the entrance channel. The sediment transport modelling predictions provide only very small rates of sediment transport across the entrance channel under ambient conditions. Maintenance dredging of the entrance channel is therefore only expected to be required occasionally (i.e, approximately greater than 5 years on average) or following a severe cyclone.

Initially, following construction of the marina, local acceleration of the ebb tidal currents around the outer edge of the marina breakwaters are predicted to result in some localised scour, as the bed morphology immediately adjacent to the toes of the breakwaters adjusts. The sediment transport modelling predicts that this is likely to result in an initial and relatively small flux of sediment in a northerly direction towards the entrance channel.

To accommodate this initial flux of sediment past the entrance following the breakwater construction and to minimise the frequency in which maintenance dredging is required generally, it is proposed that the entrance channel is overdredged and/or a sediment trap is established. The sediment trap would limit the impact of siltation of the entrance channel in the first years of the operation of the marina and to limit the potential impact on navigability of the marina entrance following a severe cyclone.

Bed shear stresses within the marina basin are predicted to allow for the deposition of fine silts. Overtime, gradual accumulation of fine, cohesive sediments on the seabed within the marina basin is expected. The relatively low ambient suspended sediment concentrations are such that the rate of siltation of the marina from this process is unlikely to be significant to the marinas operation. Fluxes of sediment into the marina basin during large floods in Putney Creek are to be mitigated with sediment traps constructed on the landward side of the marina.

Sediment Bypassing

An estimated 1,500m^3/yr of net westerly sediment transport is predicted along Leeke's Beach. At the end of Leeke's Beach, this sediment spills around Putney Point. Under existing conditions, a proportion of this sediment is transported northward by relatively strong ebb tidal currents that sweep past Putney Point. The remainder of the Leeke's Beach net sediment transport is likely to be transported southward and along Putney Beach by flood tide currents and wave action.

Construction of the marina will deflect the ebb tidal currents away from Putney Point and sediment transport modelling indicates that the sediment transport potentials in this area will be reduced. The marina will also prevent the onshore migration of sediment towards Putney Beach by wave action. Overtime, the net sediment transport along Leeke's Beach would be expected to accrete in the sheltered zone that will exist between the marina and Putney Point. To prevent siltation of the entrance channel by this accreting sand and to maintain the long term sand transport continuity on Putney Beach, periodic bypassing/maintenance dredging of sand from the area between the marina entrance and Putney Point is proposed.

Initial sediment transport estimates suggest the rate of sand accretion between the marina and Putney Point is likely to be of the order of 1,000-1,500m^3/yr. Periodic bypassing of approximately 5,000 – 7,000m^3 of sand every five years would maintain the sediment transport continuity to Putney Beach and result in no net sand accretion between the marina and Putney point. The frequency of sand bypassing/maintenance dredging operations and the impact of the accreting sand could be minimised by the establishing a dredged sediment trap at this location during the initial capital dredging works.

Putney Beach

Construction of the marina will result in changes to the size and incident angles of waves on Putney Beach relative to existing conditions. Changes to the incident wave climate on Putney Beach will in turn impact the potential sediment transport rates along Putney Beach.

Under existing conditions, the net sediment transport potential along Putney Beach has been estimated as approximately $800m^3$/yr towards the spit head. This net sediment transport potential is currently transporting sand from Putney Beach to the spit head, resulting in long term shoreline recession on Putney Beach.

Construction of the marina is expected to reduce the net sediment transport potential along Putney Beach to close to zero, or potentially, a minor reversal in the net transport back towards Putney Point. The impact of the change in the net sediment transport potentials is expected to be a reduction in the rate of shoreline recession along Putney Beach and over the long term, gradual accretion of sand along Putney Beach and progradation of the Putney Beach shoreline between the spit head and the western breakwater of the marina.

The periodic bypassing of sand from Putney Point to Putney Beach will also serve to increase the beach volumes and widths and improve the amenity of this beach.

Sand will continue to be slowly lost from the spit head by the action of waves and tidal currents sweeping past the spit head. Construction of the marina is however predicted to slightly reduce current velocities and therefore sediment transport potential rates at the spit head. Periodic bypassing of sand from Putney Point to Putney Beach and out to the spit head will be required to maintain the long term sediment transport continuity of this system and prevent long term decline in the projection of the spit head or impacts to Fishermans Beach.

3.5 Marina Wave Climate

Protection for vessels moored within the marina from waves generated in Keppel Bay is provided by breakwaters such that waves may only propagate into the marina through the marina entrance. The orientation of the marina entrance to the north results in worst case wave penetration into the marina being associated with wave conditions from the north- east through north-west directions.

The Australian Standards AS 3962-2001 *Guidelines for Design of Marinas* recommends wave heights at berths for 1 and 50 year ARI design wave conditions. Table 3-1 summarises these guidelines.

Table 3-1 Guidelines for Marina Wave Conditions (AS 3962-2001)

Wave Direction at Berth	1 Year Wave Conditions (m)			50 Year Wave Conditions (m)		
	Excellent	Good	Moderate	Excellent	Good	Moderate
Head-on Seas	<0.225	<0.3	<0.375	<0.45	<0.6	<0.75
Beam-on Seas	<0.125	<0.15	<0.1875	<0.1875	<0.25	<0.3125
Oblique Seas	<0.225	<0.3	<0.375	<0.3	<0.4	<0.5

To assess the marina wave climate and degree of protection afforded by the breakwaters in relation to the Australian Standards, the spectral wave model geometry was modified to represent the main structural features of the marina. The spectral wave model has then been simulated under the 1 and 50 year ARI design wave conditions previously developed and summarised in Table 2-5 to predict the resultant wave climate inside the marina basin. Figure 3-14 displays the spectral wave model layout and predicted wave heights under the worst case 50 year ARI north-westerly wave conditions. From

Figure 3-14 it can be seen that wave heights are significantly attenuated through the marina entrance, even under worst case north-westerly wave conditions. Table 3-2 summarises the significant wave heights predicted at the most exposed berth location (Figure 3-14) inside the marina basin for all relevant wave directions and recurrence intervals. The following comments are provided in relation to the predicted marina wave climate and the Australian Standards for marina design:

- The design wave conditions developed for the marina wave climate assessment are conservatively high, providing worst case wave climate conditions in the marina.
- The orientation of the berths within the marina is such that incident waves will be close to head-on to the berthed vessels. Wave height guidelines for head-on wave conditions are larger than beam-on conditions.
- For all design wave directions from the south through to west, all berth locations in the marina are predicted to experience an 'excellent' wave climate.
- For worst case design wave conditions from the north to north-west, a relatively small number of berths immediately adjacent to the marina entrance could experience wave heights that would be considered to provide a 'good - moderate' climate. The remainder of the berths would all experience wave heights consistent with 'excellent' conditions.
- Minor optimisation of the entrance alignment and overlap during the detailed design of the marina breakwaters will provide an opportunity to further reduce wave heights in the marina under worst case north to north-westerly design wave conditions.

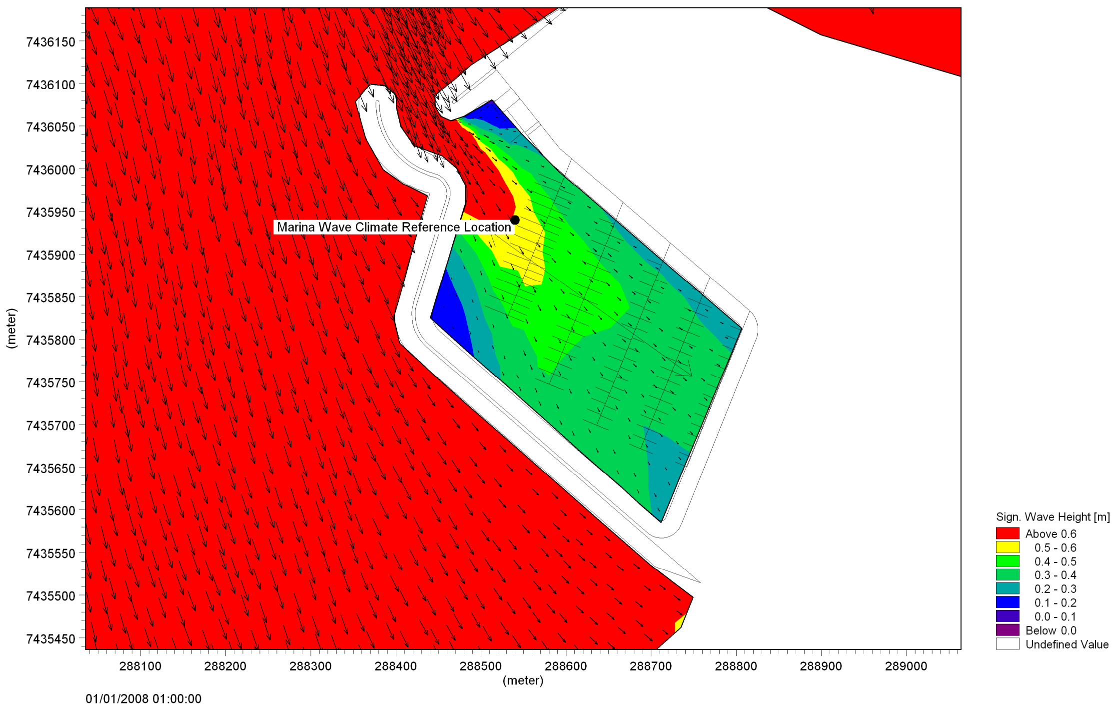

Figure 3-14 Predicted Marina Wave Heights Under 50 year ARI NW Design Waves

Table 3-2 Summary of Marina Wave Climate Results at Most Exposed Berths Location

Design Wave Direction	Design Wave ARI (Yrs)	Significant Wave Height (m)
North	1	0.39
	50	0.44
North West	1	0.40
	50	0.59
West	1	0.2
	50	0.3
South West	1	0.1
	50	0.08
South	1	0.04
	50	0.08

3.6 Climate Change Risk Assessment

3.6.1 Background

Increased concentrations of greenhouse gases in the earth's atmosphere are projected to cause a warming of the atmosphere and oceans which in turn are projected to drive a range of other changes to the earth's climate and the climate variability.

To assess the potential impact of climate change on the coastal environment and the coastal infrastructure proposed as part of the Great Keppel Island Revitalisation Project, a risk assessment methodology has been adopted. The main steps of the risk assessment process are as follows:

- Identification of the relevant threats associated with climate change to the coastal environment
- Determination of the aspects of the development that could potentially be exposes to these threats
- Assessment of the overall risk of this exposure

For the purposes of the risk assessment process *Risk* is defined as the product of the *Likelihood* of the occurrence of the various *Threats* associated with climate change times the *Consequences* of their occurrence.

To accommodate the likely effects of climate change current best management practice requires an adaptive approach towards planning and design in the coastal zone. In this respect, it is noted that the National Committee of Coastal and Ocean Engineering (Engineers Australia, 2004) discusses 3 main options for managing the threats of climate change to coasts and coastal infrastructure. These are:

Retreat: allow the coastline to retreat and prevent development in areas near threatened coastlines through conditional approvals and phasing-out of development.

Accommodate: accommodate coastal recession to avoid the worst impacts through advanced planning and modification of land use, building codes, etc.

Protect: protect the coastline through hard structural options including, dykes, sea walls, revetments and groynes of soft structural options such as beach nourishment, wetland creation and littoral drift make-up.

3.6.2 Threat Identification

Relevant climate change impacts on the physical processes operating on coastal environment are considered the following:

- Sea Level Rise
- Seasonal Distribution of Wind Speeds and Directions
- Tropical Cyclone Intensity and Frequency

The projected changes to the above physical processes have been gathered from the relative authoritative sources and are discussed below.

Sea Level Rise

Global average sea level rose by approximately 0.17m during the 20th Century. The average global rate of sea level rise between 1950 and 2000 was 1.8 ± 0.3mm/yr. Rosslyn Bay to the west of Great Keppel Island is one of the National Tide Centre's array of sixteen high accuracy sea level measurement stations. The net relative sea level trend since installation in June 1992 is 2.0mm/yr at Rosslyn Bay (NTC, 2010). The Intergovernmental Panel on Climate Change (IPCC) is the authoritative source on projections of future sea-level rise due to climate change. Table 3-3 displays the sea level rise projections relative to late 20th century mean sea levels for the A1F1 high emission scenario.

Table 3-3 IPCC 2007 A1F1 Projected Sea Level Rise

Sea Level Rise Scenario	2030	2070	2100
IPCC 2007 A1F1	0.15m	0.47m	0.82m

The main impacts associated with increase in mean sea level are considered:

- Shoreline Recession
- Increase in Storm Tide Elevations

Seasonal Distribution of Wind Speeds and Directions

The south-east trade wind circulations dominate the wind/wave climate of Keppel Bay. Projections of climate change impacts on wind speeds in the region have been provided by the CSIRO (2007).

While significant variation in the projections between climate models exists, the 50th percentile results suggest a potential increase in wind speeds of between 5-10% along the Central Queensland Coast and Keppel Bay by 2070 under high emission scenarios. A strengthening in the prevailing south-east trade winds would result in a corresponding increase in the predominance and magnitude of east to south easterly waves in Keppel Bay.

The main impacts associated with changes to the seasonal distribution of wind speeds and directions are associated with corresponding changes incident wave energy and rates and directions of sediment transport along sandy shorelines on Great Keppel Island.

Tropical Cyclone Intensity

Current projections on the impact of climate change on tropical cyclones suggests that a warming atmosphere will produce more intense cyclones as measured by maximum wind speeds and rainfall (Lough, 2007). The spatial and seasonal distribution of occurrence is however expected to remain approximately similar to present whilst the frequency of tropical cyclone formation may actually decline under climate change (Lough 2007).

The main impacts associated with increases in tropical cyclone intensity are considered the following;

- Higher maximum wind speeds generating larger waves and associated wave set-up on the coastline
- Higher maximum wind speeds and lower central pressures generating large storm surges

To assess the combined threat posed by increases in cyclone intensity and mean sea level rise, the storm surge analysis undertaken in Section 2.6.1 has been undertaken for projected 2100 conditions incorporating 0.82m of mean sea level rise and 5% increase in maximum tropical cyclone wind speeds and a 5% decrease in central pressure. Predicted annual exceedance probability storm tides at 2100 for Putney and Fisherman's Beach from this analysis are summarised relative to existing conditions in Table 3-4. Table 3-4 shows increases in predicted storm tide elevations at Putney and Fisherman's Beach of generally between 1.0 and 1.1m. This increase is comprised of 0.82m of mean sea level rise and an additional meteorologically induced component of between 0.2-0.3m.

Table 3-4 Predicted 2100 Storm Tide AEP for Putney and Fishermans Beach

AEP	Yeppoon Exs (m AHD)	Yeppoon 2100 (m AHD)	Putney Beach Exs (m AHD)	Putney Beach 2100 (m AHD)	Fishermans Beach Exs (m AHD)	Fishermans Beach 2100 (m AHD)
2%	2.75	3.74	2.32	3.34	2.37	3.39
1%	2.94	4.33	2.67	3.74	2.74	3.82
0.2%	3.49	4.62	2.75	3.87	2.83	3.97

3.6.3 Exposure to Risk

The main components of the coastal environment and the Great Keppel Island Resort Revitalisation Plan that are exposed to the climate change threats identified previously are considered to belong the following four main categories:

- Putney and Fisherman's Beaches
- Marina Breakwaters
- Marina Infrastructure and Reclamation
- Foreshore Development

Putney and Fisherman's Beaches

Threats

General models of sandy shoreline profile response to increases in mean sea level predict that sandy shoreline profiles could be expected to be translated shoreward and upward to maintain an equilibrium form. This implies the transfer of sand from the upper beach profile offshore to the seaward profile. The ratio of shoreline translation to sea level rise is generally predicted to be within 50 to 100:1. At Putney and Fisherman's Beach this could be expected to result in long term shoreline recession as the shoreline profiles on these beaches adjust to a new equilibrium with mean sea level. Based on a projected increase in mean sea level of 0.82m, approximately 40 – 80m of shoreline recession could be observed.

It is noted that inner regions of the continental shelf such as Keppel Bay have experienced a relative sea level fall of approximately one meter since the Holocene sea level maximum approximately 6000 years ago (Smithers et al 2007). The relative sea level fall has been caused by minor flexure of the continental shelf in response to the loading of seawater (hydro-isostasy). This has resulted in the upward flexure of the inner margins of the continental shelf such as Keppel Bay and a corresponding relative fall in sea level. This implies that major coastal landforms in Keppel Bay were formed under relatively higher sea level conditions and would suggest that a degree of resilience to projected 21st century sea level rise exists such that large modifications to trailing spit landforms and associated beaches is not to be expected (Smithers et al 2007).

The impact of the projected changes to seasonal distribution of wind speeds and directions resulting in an increase in east to south easterly waves on the coastal processes of Putney and Fisherman's Beach is considered to be mitigated by the fact that these beaches face west and are only impacted by east to south easterly waves that have had to undergo significant refraction. Therefore, changes in the distribution of wave energy along Putney and Fisherman's Beach are expected to be relatively minor and are not expected to result in changes to these shoreline alignments significantly greater than the current degree of variability observed.

Increases in the intensity of tropical cyclones due to climate change, resulting in higher maximum wind speeds, in combination with increased mean depths due to sea level rise may potentially allow slightly larger waves to impact Putney Beach during the passage of a tropical cyclone. However, the significance of these changes will be mitigated by the limited fetches and shallow depths of water that exist over the applicable fetches to Putney Beach. These factors currently limit the size and period of the waves that can impact Putney Beach during a cyclone.

Reductions to tropical cyclone frequency due to climate change are potentially significant as the greater the period between subsequent tropical cyclone impacts on Putney Beach, the greater the period for natural recovery of the beaches to occur.

Consequences

The consequences of shoreline recession on Putney and Fishermans Beach would include loss of beach amenity as the eroding shoreline could be expected to result in a low and narrow beach. Beach access can also be impeded as a high and steep dune scarp is likely to exist along these shorelines.

Mitigation

Mitigation of shoreline recession hazards and loss of beach amenity can be mitigated by nourishment of beaches

Marina Breakwaters

Threats

The main threats to the marina breakwaters are considered:

- Increases in mean sea level and storm tide heights and increases in the size of extreme waves could potentially lead to increased rates of overtopping of the breakwaters
- Increased structural damage of the breakwaters could also occur due to increases in storm tide heights and extreme waves

Consequences

The consequences of increased overtopping of the breakwaters could lead to increase wave action within the harbour which could ultimately become unacceptable and result in damage to berthed vessels in the marina under design storm conditions.

The consequence of structural damage to the breakwaters is considered to generally relate to increased long term maintenance costs.

Mitigation

The risks posed by climate change to the marina breakwaters can be accommodated during the detailed design of the breakwaters by the following:

- Increasing or adapting breakwater crest heights to limit the extent of wave overtopping under design water level and wave conditions to 2100.
- Increasing the primary armour unit weights during detailed design to limit the potential for structural damage to occur to the breakwaters under design water level and wave conditions to 2100.

Marina Infrastructure and Reclamation

Threats

Marina infrastructure and the reclamation area are protected from wave action by the breakwaters. As a result, the main threats to these components will be associated with inundation due to increases in mean sea level and storm tides.

Consequences

The consequences of inundation to marina infrastructure and reclamation would include water damage costs and inconvenience.

Mitigation

The risk posed by climate change to marina infrastructure and reclamation area can be accommodated by constructing finished surface levels and floor levels above the relevant design storm tide inundation levels to 2100.

Foreshore Development

Threats

Development associated with the project adjacent to or near the existing shoreline of Putney and Fisherman's beaches could potentially be exposed to threats associated with shoreline recession. The majority of the proposed development is located at a distance greater than 100m from the existing shoreline and is therefore not expected to be impacted by shoreline recession by 2100.

The majority of the land proposed to be developed as part of the project is located at an elevation of approximately 4.0m AHD or greater and is therefore not expected to be subjected to storm tide inundation to 2100. Some minor areas of the development are however located at an elevation of between 3.5-4.0m AHD and could potentially be subjected to inundation during an extreme storm tide by 2100.

Consequences

Areas of the development located at an elevation of between 3.5 -4.0m AHD and could potentially be inundated to depths less than 0.5m in an extreme storm tide event by 2100. The consequences of this inundation include water damage costs and inconvenience

Some minor components of the development located within 100 meters of the existing shoreline could potentially be impinged upon by shoreline recession hazards by 2100. The consequences of exposure to this risk include potential exposure to more significant inundation by storm tides and wave action and foundation instability.

Mitigation

The impact on minor areas of the development that could potentially be subjected to relatively shallow storm tide inundation under extreme 2100 storm tide conditions can be mitigated by raising floor levels in these areas and/or landscaping to prevent storm tides penetrating into these areas.

3.7 Marina Water Quality

3.7.1 Marina Residence Times

Residence times within the marina are expected to be very low due to the relatively small marina basin volume and large tidal range which will result in a very significant exchange of water between the marina and Keppel Bay each tidal cycle. The marina basin volume at mean sea level is approximately 500,000m^3. The volume change in the marina between MLWS and MHWS is over 330,000m^3. Therefore, greater than 50% of the average marina volume will be exchanged over a single spring tidal cycle. Practical measures of residence times such as the e-folding time are therefore likely to no greater than 1 – 2 days for all locations within the marina basin.

3.7.2 Antifouling

Copper concentrations in the waters of the marina are likely to be elevated due to the presence of copper in antifouling paints. The concentration of copper in the marina is dependent on a number of factors including:

- Leaching rate from vessel hull
- Number of vessels
- Hydraulic flushing
- Background concentration

The marina has berthing facilities for up to 250 vessels with an average length of around 17.5m, providing an estimated typical wet hull area of approximately 27m^2 per vessel. Crecelius *et a*l (2003) report leach rates for copper in two Puget Sound marinas at 0.093kg/day for a 450 berth marina (0.21g/boat/day) and 0.5kg/day for a 950 berth marina (0.52g/boat/day). Schiff *et a*l (2003) reported in-situ leach rates for copper based antifouling paint at 3.7-4.35 µg/cm^2/day and that leech rates decline exponentially from the time of application. Significant variations in leech rates in the marina will occur depending on the anti fouling maintenance regime of the vessels within the marina. For the purposes of this assessment, an appropriately conservative average copper leach rate of 4 µg/cm^2/day has been adopted.

Hydrodynamic model simulations have been undertaken to determine the resulting concentrations and fate of the copper leached from antifouling paint for a fully berthed marina. A conservative numerical tracer was released evenly over the berth area of the marina at a rate equivalent to the leeching of 263g/day of copper. The hydrodynamic model was simulated over a one month period of typical summer wind and astronomical tidal conditions and the fate and transport of the numerical tracer was tracked over the simulation period. The copper concentration in the model relates to the total amount of copper released from the antifouling paints rather than the bio-available copper and is therefore conservative. Studies have shown that if only total copper is determined, the toxicity will be overestimated by a factor of 4 on average (Dürr, Simone, 2010).

The highest protection trigger level (99%) for copper in high conservation value marine aquatic ecosystems is provided by the ANZECC (2000) guidelines as 0.3ug/L, this level is considered for outside of the marine. For within the marina, this environment is representative of a slightly to moderately disturbed system, the trigger level of copper in a slightly –moderately disturbed system is provided by ANZECC (2000) guidelines as 1.3 ug/L.

Figure 3-15 shows the predicted 90%ile exceedance copper concentrations above background for a fully berthed marina and conservative copper leach rate of 4 μg/cm^2/day. The model simulation results presented in Figure 3-15 are considered to show slightly elevated copper concentrations are generally confined to the marina basin, however these levels are considered to slightly exceed the ANZECC (2000) guidelines of 1.3 ug/L for slightly to moderately disturbed systems. Figure 3-15 also shows that the 90%ile exceedance concentration of copper rapidly decrease outside of the marina basin, these levels are predicted to be generally at or below the ANZECC (2000) guidelines of 0.3 ug/L for pristine environments.

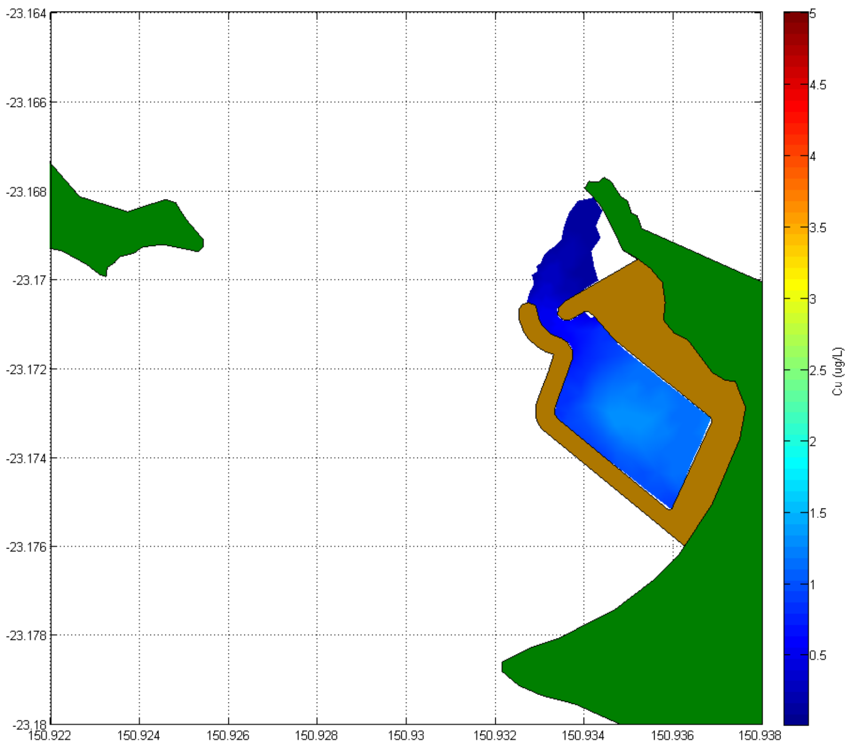

Figure 3-15 Predicted 90%ile Exceedance Copper Concentrations from Antifouling Leaching

3.7.3 Mitigation Measures

No mitigation measures are proposed as the copper concentrations are considered to only slightly exceed the specified thresholds as outlined in the ANZECC (2000) guidelines. There are also considered to be no practical options for mitigating the rate of antifouling leachate.

3.8 Sediment Quality and Dredging

3.8.1 Overview

During construction, dredging will be required to create the marine facility basin, approach channel and to provide material for reclamation and breakwater construction. The volume of material to be dredged including an allowance for over-dredging has been determined as approximately 300,000m^3. Figure 3-16 displays the spatial variation in the depth of material to be dredged based on existing bed elevations to create the marine facility basin and approach channel. As can be seen from Figure 3-16, the depth of dredging required is generally of the order 2.5 - 3.0m.The assessment of marine sediments and dredging has been undertaken in accordance with the National Assessment Guidelines for Dredging 2009 (Department of the Environment, Water, Heritage and the Arts, 2009).

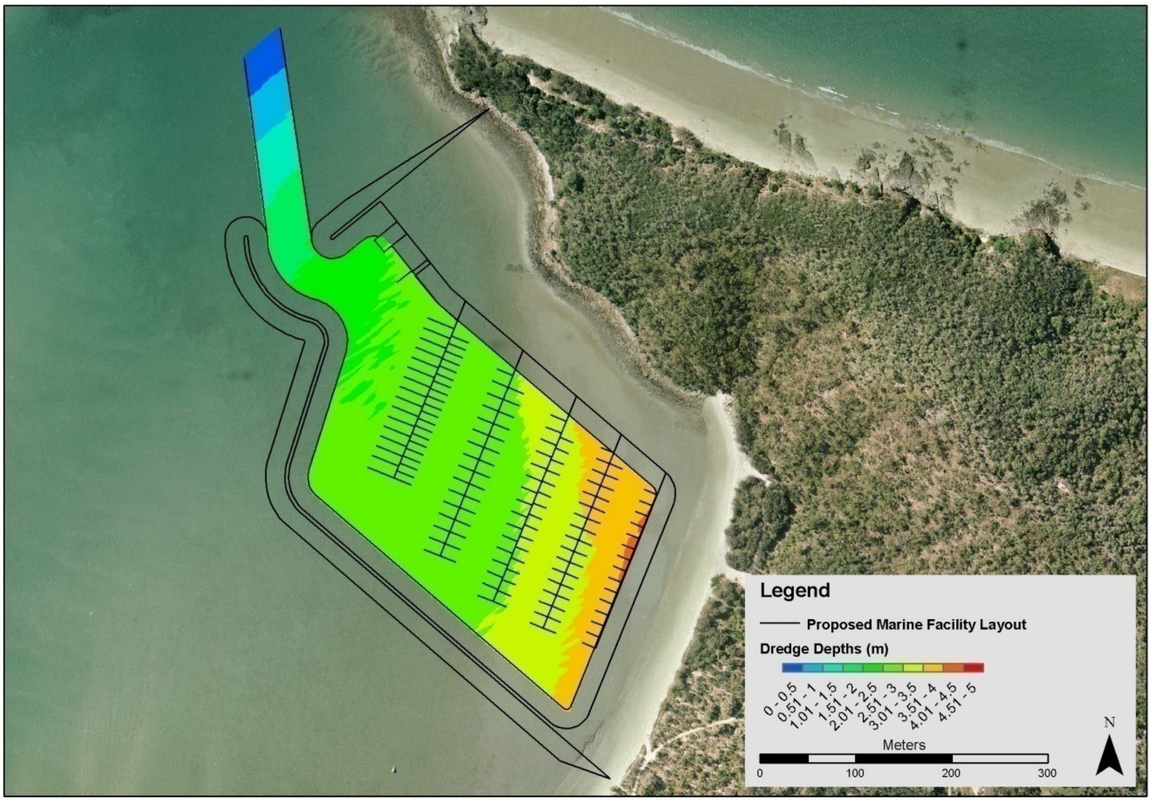

Figure 3-16 Dredged Depths for Construction of the Marine Facility

3.8.2 Dredge Sediment Characteristics

Seismic refraction survey was undertaken over the area encompassing the marina footprint by Marine & Earth Sciences. The survey was undertaken to characterise the nature of the sediments existing beneath the seabed in the areas proposed to be dredged. In particular, the geophysical survey was undertaken to map the depth of unconsolidated material and identify any bedrock surfaces within the dredge footprint to assess marina construction and dredging feasibility. The geophysical survey identified a continuous reflector across the marina footprint that was interpreted as a bedrock surface. This reflector deepens rapidly southward from the northern eastern boundary of the marina with minimum depths below the seabed to this reflector greater than approximately 10m. Overlying the interpreted bedrock surface reflector is a series of horizontal reflectors that are consistent with horizontally layered unconsolidated material. Penetration levels through the unconsolidated material were considered very good and indicative of generally soft, loose material (Marine & Earth Sciences, 2011).

Figure 3-17 displays a cross section of the seismic reflector survey from the north to south through the marina footprint showing the interpreted bedrock surface lying below horizontally layered, unconsolidated material.

Figure 3-18 displays contours of the unconsolidated sediment depths to bedrock surface over the dredge footprint interpreted from the geophysical survey.

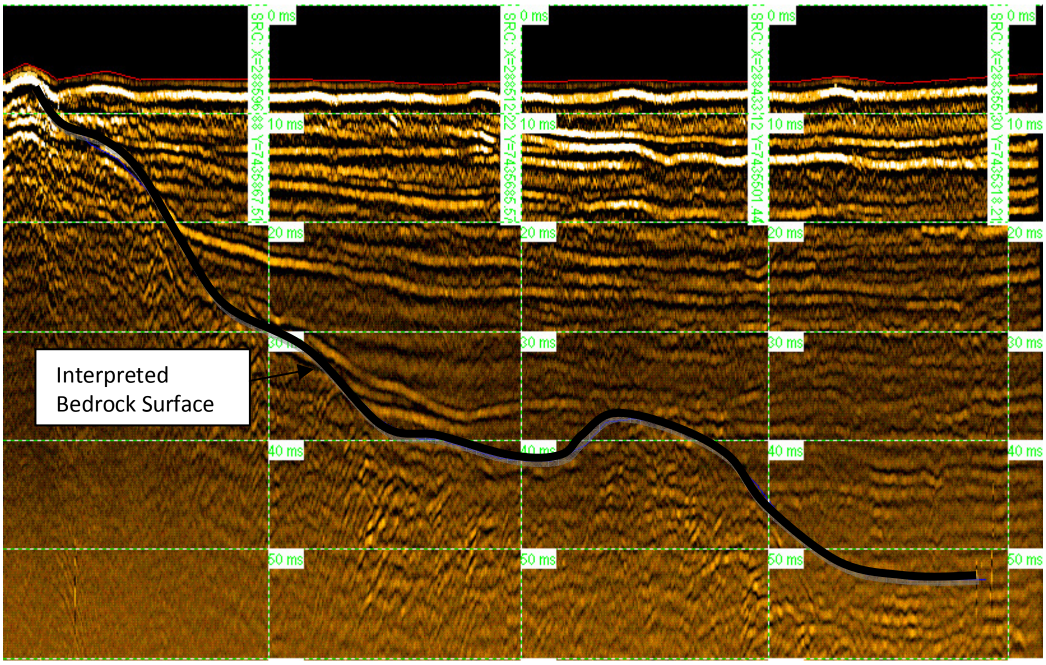

Figure 3-17 North-South Seismic Reflection Survey Cross Section through Marina Basin (Marine & Earth Sciences, 2011)

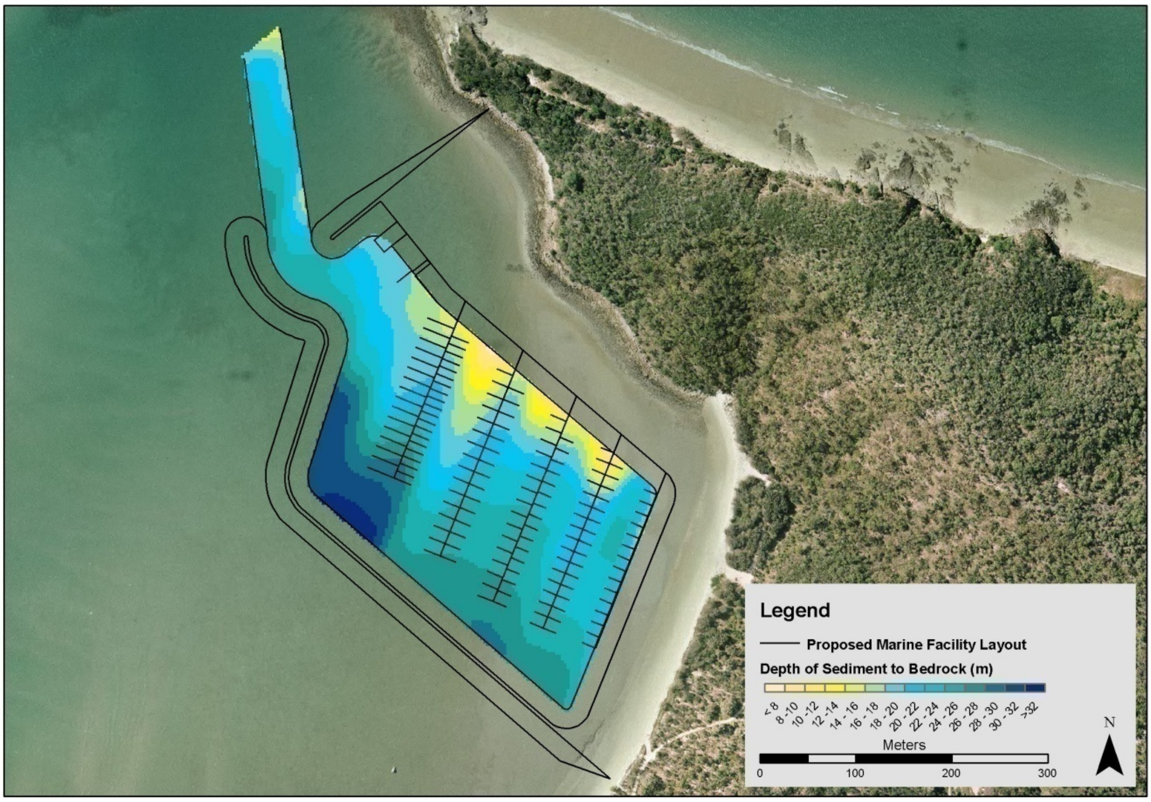

Figure 3-18 Depth of Unconsolidated Sediment to Bed Rock over the Dredge Area

Sediment cores were undertaken from 12 locations within the dredge area footprint. The sediment sampling and analysis plan for the sediment sampling is discussed in detail in frc Environmental Technical Report of the EIS (frc, 2011).

A relatively small number of cores were not able to penetrate to the full dredge depth without damaging the coring equipment. At these locations coral rubble or clay was encountered. Some variations in the stratigraphy of the sediments within the marina basin determined from the sediment coring is consistent with the geophysical survey results which showed a series of horizontal reflectors indicative of variations in sediment composition. The minor, localised variations in sediment composition identified from the sediment coring are not considered to be significant to the choice of dredge plant or the turbidity that may be generated during dredging of these sediments.

The settling characteristics of the sediment when disturbed are an important parameter for assessing the fate of turbid plumes generated during dredging. For the fine cohesive fractions of the sediment, flocculation of the fine particles results in the rate that the sediment in suspension settles being itself a function of the concentration of suspended sediment. Settling tests undertaken on the samples of the sediment cores have been undertaken to determine the concentration dependent settling velocity of the sediment. Table 3-5 summarises the median characteristics of the dredge sediment

As can be seen from Table 3-5, the dredge sediment is overwhelming comprised of sand sized or greater fractions. Only approximately 5% of the material to be dredged has particle sizes in the silt or clay fraction. Only the silt and clay fractions of the dredge material would remain in suspension when disturbed by dredging, as the sand sized or greater particles settle out relatively quickly. Therefore, the capacity to generate very large suspended sediment loads during dredging of the sediment is limited by the relatively minor percentage of fine particles which can be suspended during dredging of the sediment.

Table 3-5 Summary of Dredge Sediment Characteristics

Fraction	Grain Size (mm)	Median Percentage (%)	Settling Velocity (m/s)
Gravel	+2.0	2	1.2
Sand	2.0 - 0.06	93	0.02
Silt/Clay	<0.06	5	0.001

3.8.3 Marina Construction Methodology

The proposed construction method for the marine facility has been developed in consideration of the following:

- Limited access to major local sources of quarry material on Great Keppel Island to enable the construction of traditional rubble mound breakwaters or to provide material for land reclamation
- The desire to prevent the need for sea disposal of dredge spoil as part of the construction of the marina

To overcome the above, it is proposed that all the spoil from the marina basin dredging will be utilised to form the core of the breakwaters and to provide the majority of the material required for land reclamation. The proposed construction method therefore requires the breakwater cores to be constructed of a number of large geotextile tubes filled with sediment excavated from the marina basin. Figure 3-19 displays a schematic design of the western breakwater design incorporating the use of sand filled geotextile tubes to form the core of the breakwater. Figure 3-20 displays examples of the geotextile tube breakwater core construction technique.

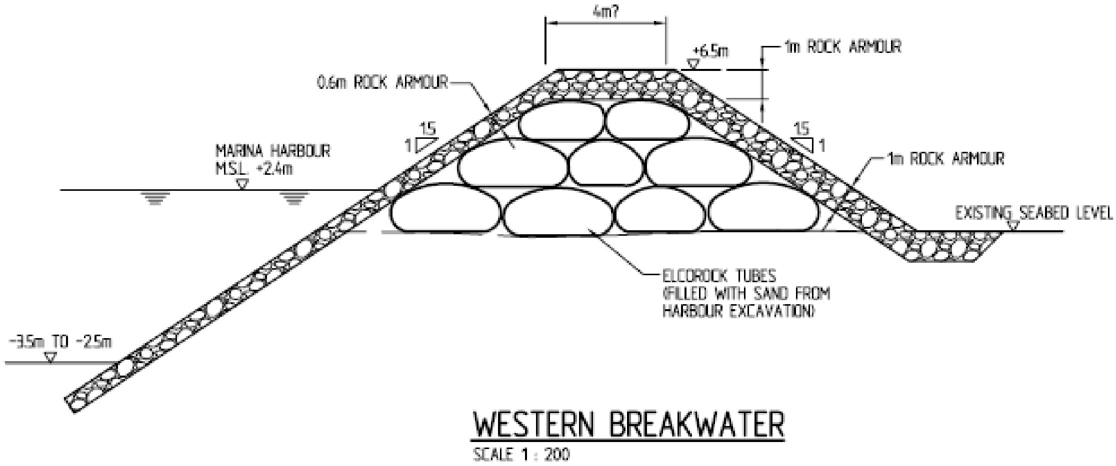

Figure 3-19 Schematic Design of Western Breakwater Cross Section (IMC, 2011)

Figure 3-20 Example of Geotextile Breakwater Core Construction (Anwaj Is, Bahrain (Bergado, 2005))

Construction of the marine facility is proposed to be undertaken in four main stages. The four stages are illustrated conceptually in Figure 3-21 and the details of each stage are discussed below:

Marine Facility Stage 1 - Western Breakwater Construction and Basin Dredging

The western breakwater component of the marine facility is proposed to be constructed in Stage 1. Construction of the western breakwater will eliminate the majority of the current and wave action from the marine facility basin and minimise weather related downtime and risks for the remainder of the marine facility construction. Construction of the western breakwater first will also help to contain the extent of any turbid plumes, generated during construction, within the marine facility footprint.

Stage 1 will require approximately 57,000m^3 of sediment to be dredged from the marina basin to fill the geotextile tubes to create the core of the western breakwater. It is expected that a small cutter suction dredge (CSD) will be able to achieve a dredging rate of 120m^3/hr, enabling a 20m long by 16m circumference tube to be filled within approximately 3 hours. Assuming 3 tubes a day can be filled at this rate for 7 days a week and including some contingency, it is estimated that the western breakwater core construction can be completed in 12 weeks with this method.

Construction will commence at the shoreward end of the western breakwater. A small-medium CSD will begin dredging the marine facility basin. The dredge spoil will be pumped directly into geotextile tubes and the tubes will be hydraulically filled with the dredge spoil. The core of the western breakwater will be progressively constructed seaward in this way with the CSD positioned in its lee to minimise weather related downtime.

Due to the large tidal range, filling of the geotextile bags will be required to be sequenced with the phase of the tide in shallow areas. In deeper areas, the geotextile bags may be filled and positioned through the use of a bottom dump barge.

Marine Facility Stage 2 – Marina Basin Revetment and Basin Dredging

Marine Facility Stage 2 will involve the construction of the marina basin revetments. Stage 2 will require a total of approximately 40,000m^3 of sediment to be dredged from the marina basin to fill the geotextile tubes to create the marina revetments. Based on a similar dredging and geotextile tube fill rates as adopted for the western breakwater core construction, a total 12 weeks is expected to be required to construct the marina revetments.

To construct the marina revetments, the CSD will be positioned in the lee of the newly constructed western breakwater core and it is anticipated that much of the turbidity generated by the dredging and filling of the geotextile bags can be contained within the marina basin footprint.

Marine Facility Stage 3 – Northern Reclamation

Marine Facility Stage 3 will require the remainder of the marina basin excavation and approach channel dredging to be completed. The total remaining volume of material to be dredged in Stage 3 has been determined as approximately 185,000m^3. It expected that a medium sized cutter dredge, achieving a dredge rate of approximately 500m^3/hr and operating 8 hours a day, 7 days a week could complete the dredging within 8 weeks.

Dredge spoil will be pumped directly into the reclamation area to the north of the marina basin. The reclamation area will be designed with a number of settling basins to allow fines to settle out of suspension before the decant overflow is allowed to return to the marina basin.

Marine Facility Stage 4 – Placement of Breakwater Armour and Marina Basin Rip Rap

Following completion of the geotextile core, armour rock will be placed over the breakwaters and marina revetments. The placement of the armour rock is likely to be undertaken from a barge mounted excavator, with the armour rock barged from sources on the mainland. The placement of the armour rock is not expected to constitute a significant source of turbidity in relation to the dredging stages of construction and has not been considered further in this assessment.

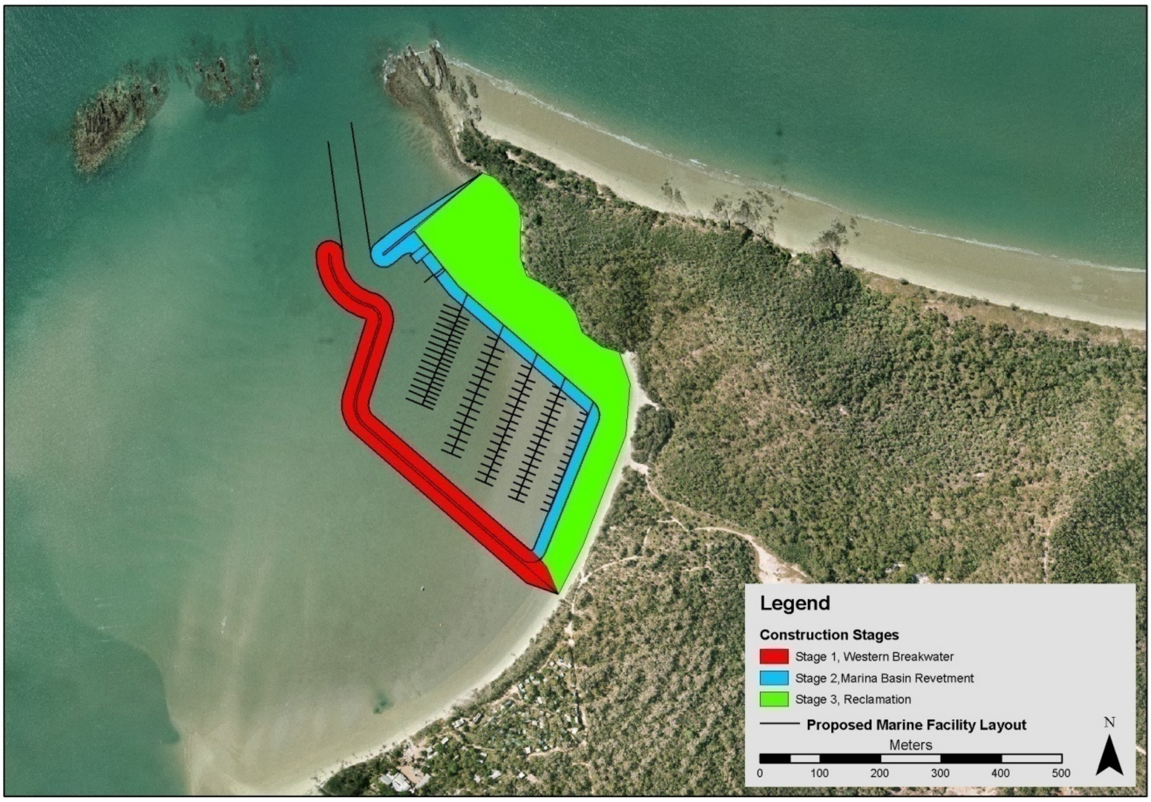

Figure 3-21 Overview of Marine Facility Construction Stages

3.8.4 Total Suspended Solids Generation Rates and Loadings

Construction and associated dredging of the marine facility will generate plumes of suspended sediment. The following potential sources of suspended sediment have been identified during construction of the marine facility:

- At the head of the cutter suction dredge (CSD)
- Discharges from the overflow ports on the geotextile tubes during filling
- Decant discharges from the reclamation

The mechanism of suspended sediment production and rates of suspended sediment generation for the identified suspended sediment sources are discussed below.

Cutter Suction Dredge

A CSD is usually mounted on a barge and consists of a rotating cutter head with adjacent vacuum pump and pipeline which transports the dredge material as a slurry to the disposal site. The vacuum pump at the cutter head means that the majority of sediment disturbed by the dredging action is removed from the dredging site rather than going into suspension around the dredge head.

Suspended sediment generation rates at the dredge head vary considerably depending on the proportion of fines in the bed material, the size and type of dredge plant and skill and experience of the dredge plant operator. A very conservative approach is to assume approximately 5% of excavated material goes into suspension. Assuming a small CSD with a 120m^3/h capacity, this corresponds to a suspended sediment generation rate of approximately 3kg/s. Of this suspended sediment the overwhelming majority will be sand sized fractions which will settle out almost instantly around the dredge head. The remaining 5% of fines will however remain is suspension producing a suspended sediment generation rate of 0.15kg/sec or 4.4kg/m^3.

Nakai (1978) gives suspended sediment generation rates for "hydraulic cutterheads" in sand between 0.1 and 0.3kg/m^3. Suspended sediment generation rates however quickly rise above 10kg/m^3 as the proportion of silts and clays in the bed material increases. Given the low proportion of fines in the sediment to be dredged, the suspended sediment generation rates for the CSD are therefore considered to be conservative.

Geotextile Tube Overflow Discharges

The filling of the geotextile tubes with dredged material will result in the generation of some suspended sediment. To enable water, pumped as a slurry into the geotextile bags, during filling to exit the bags, the bags are designed with a number of ports where water is able to flow out of the bag as it is pumped full of sediment.

The water flowing from the geotextile ports is likely to contain a high proportion of fine material which has not settled within the tube and will go into suspension once it is discharged from the geotextile tube ports. It has been assumed very conservatively that 100% of the fine faction in the dredged sediment will be discharged through the geotextile ports. This is considered to be a conservative assumption as in practice a proportion of the fines will be captured within the geotextile tubes as they are filled.

Assuming a 250mm pipe and 100l/s pumping rate, turbidity generated at the overflow ports during the geotextile tube filling was estimated as 1.9kg/s or 57.7kg/m^3.

Decant Discharges from Reclamation

Use of the dredged material for fill in the reclamation area will require dewatering to be carried out. The reclamation area will be arranged to ensure settling time is optimised to reduce the concentration of fines in the decant outfall. Conservative estimates of suspended sediment loads from the decant outfall from the reclamation area have been adopted. It is estimated that 99% of the dredge material will settle out of suspension whilst in the detention area.

Total TSS loads generated at each stage of construction and from each of the identified suspended sediment sources where relevant have been estimated from turbidity generation rates and from the average dredge rates and schedule discussed previously.

A summary of the TSS generation rates and total loads used for the dredge plume impact assessment are provided in Table 3-6. Downtime was removed from the model simulation to ensure the scenarios represented the conservative case of more continuous dredging and suspended sediment discharge than may occur in practice.

Table 3-6 Summary of TSS Loadings during Construction and Dredging of the Marine Facility

Stage	Dredge Volume (m^3)	Source Description	Operation	TSS Generation Rate (kg/s)	Total TSS Load (× 10^3 kg)
1	58,000	Small CSD dredging marina basin	9 hrs/d, 7 days a week, 8 weeks	0.15	270
		Geotextile overflow port discharge		1.92	3500
2	40,000	Small CSD dredging	9 hrs/d, 7 days	0.15	205

		marina basin	a week, 6 weeks		
		Geotextile overflow port discharge		1.92	2600
3	185,000	Medium CSD dredging marina basin and approach channel	10 hrs, 7 days a week, 6 weeks	0.4	830
		Decant overflow from reclamation		0.004	6

3.8.5 Suspended Sediment Plume Impact Assessment

To assess the likely magnitude and extent of suspended sediment plumes generated during construction of the marine facility, the hydrodynamic model was coupled with a suspended sediment transport model. The suspended sediment transport model enables the simulation of suspended sediment sources and their transport, deposition and erosion under the action of currents and/or waves.

Suspended sediment plume impacts during construction have been assessed separately for each construction stage. The results of the suspended sediment plume simulations have been summarised for each stage as follows:

- Median and 90%ile exceedance TSS spatial plans
- TSS timeseries at the key reporting locations displayed in Figure 3-22
- TSS deposition thickness spatial plans

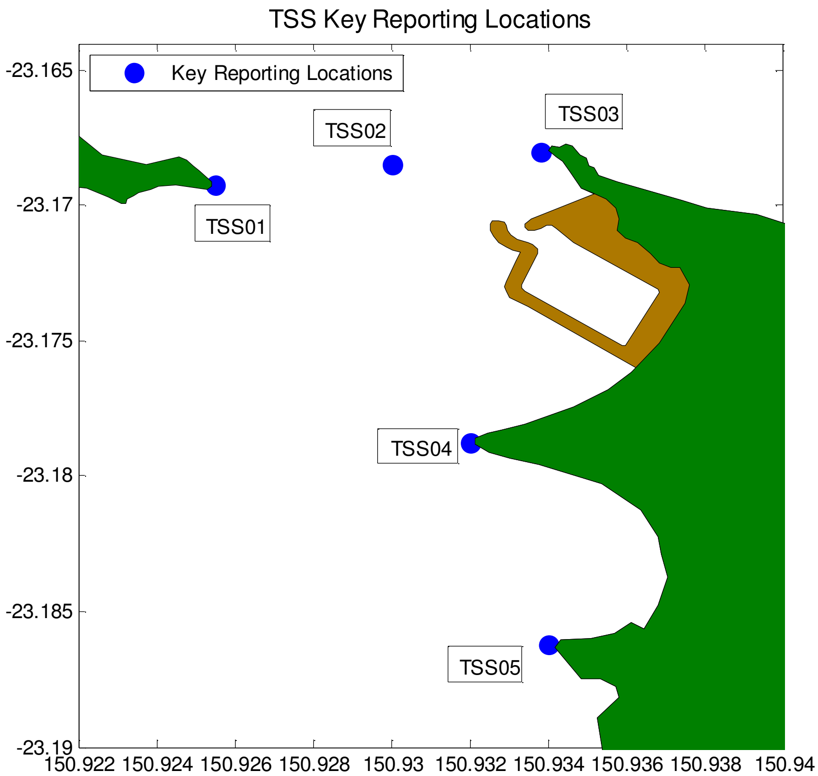

Figure 3-22 TSS Key Reporting Locations

Stage 1

Stage 1 involves the construction of the western breakwater. Over the course of Stage 1, the western breakwater would gradually extend seaward until completed. For the purposes of the dredge plume impact assessment however, Stage 1 has been represented by a partially constructed western breakwater as displayed in Figure 3-23. Figure 3-23 also displays the location of the CSD source points for the marina excavation and the source point representing overflow from the geotextile bag filling. The hydrodynamic model has been simulated over the 8 week Stage 1 construction period (assuming no downtime) with the suspended sediment generation rates and loads summarised in Figure 3-23.

The dredge plume simulation results for Stage 1 construction have been summarised as follows:

- Figure 3-24 displays the predicted median TSS results over the duration of Stage 1 construction.
- Figure 3-25 displays the predicted 90%ile TSS results over the duration of Stage 1 construction.
- **Figure** 3-26 displays the predicted TSS timeseries at the key reporting locations over the duration of Stage 1 construction.
- Figure 3-27 displays the predicted TSS deposition thickness over the duration of Stage 1 construction.

The impacts from the analysis of the dredge plume simulations for Stage 1 construction are considered as follows:

- Median TSS above 5mg/L are restricted to the immediate dredging and geotextile filling area. Median TSS less than 5mg/L may occur within a relatively localised area around the dredging and construction operations.
- Sediment plumes with concentration above 30mg/L may briefly extend to Spithead to the south and Putney Point to the north as tidal currents sweep along Putney Beach.
- All other TSS reporting locations are predicted to experience only infrequent increases in TSS of less than 10mg/L.
- Localised suspended sediment deposition of up to 0.1m is predicted adjacent to the western breakwater and within the marina basin as is the western breakwater is being constructed.

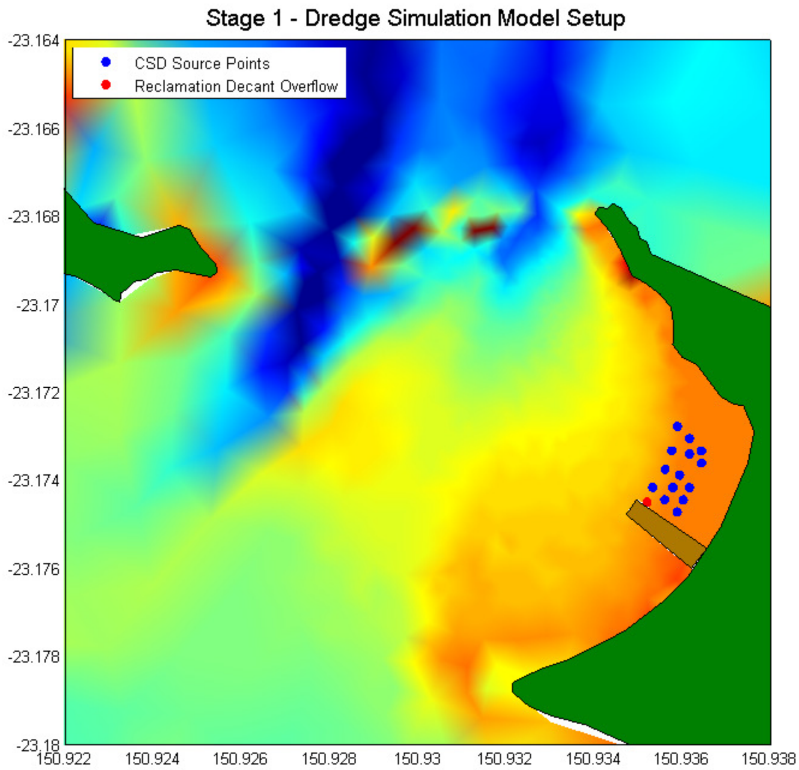

Figure 3-23 Stage 1 – Dredge Simulation Model Setup

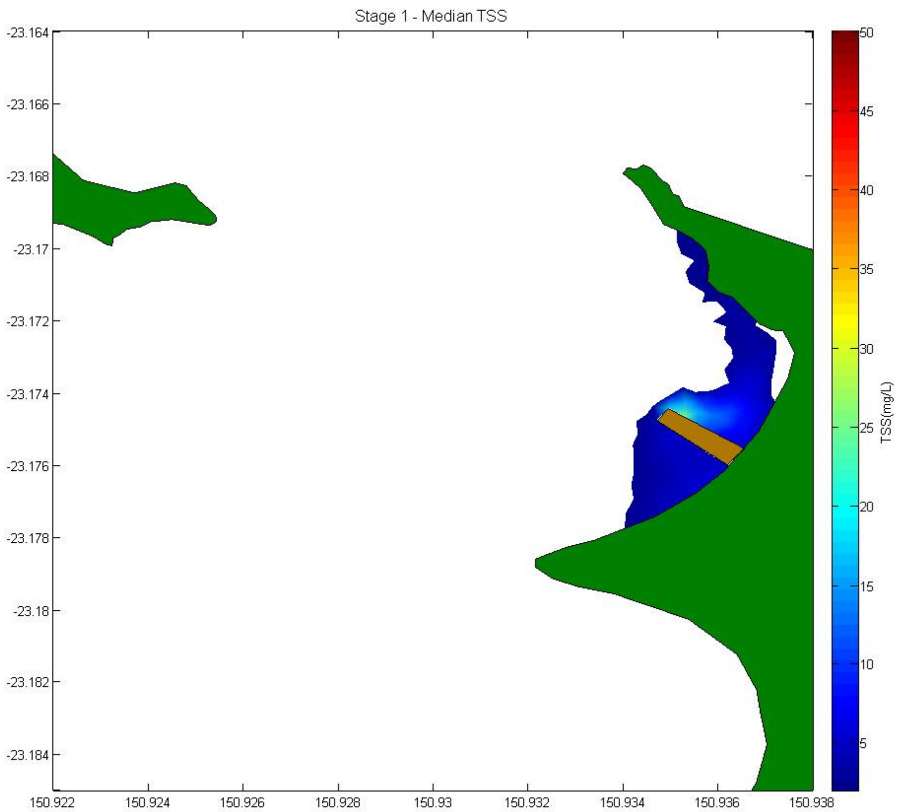

Figure 3-24 Stage 1 – Median TSS Results

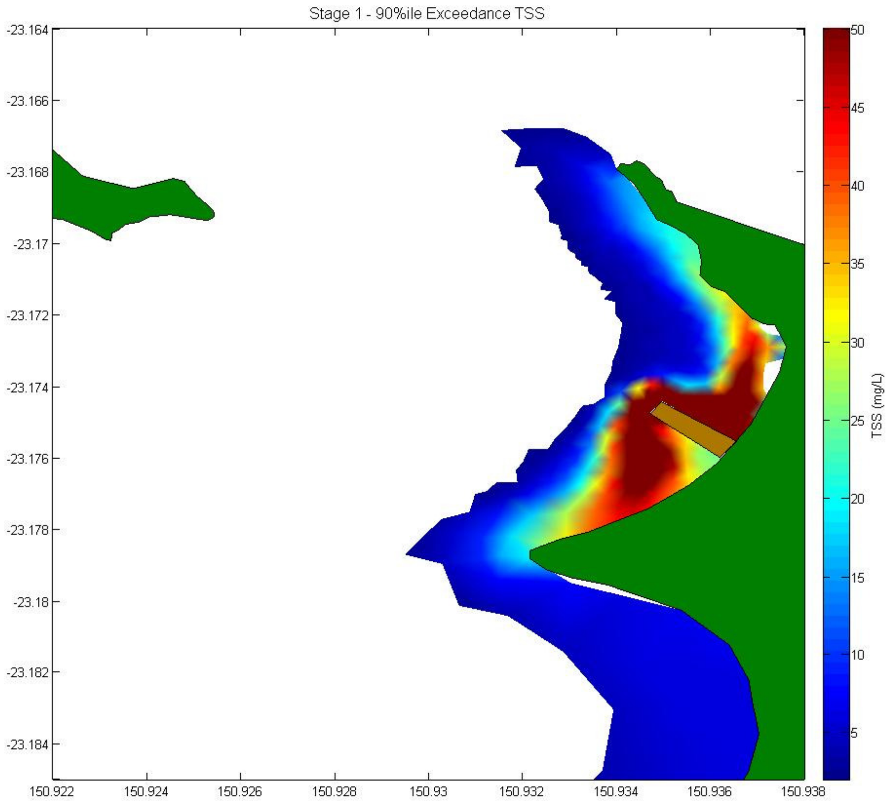

Figure 3-25 Stage 1 – 90%ile Exceedance TSS Results

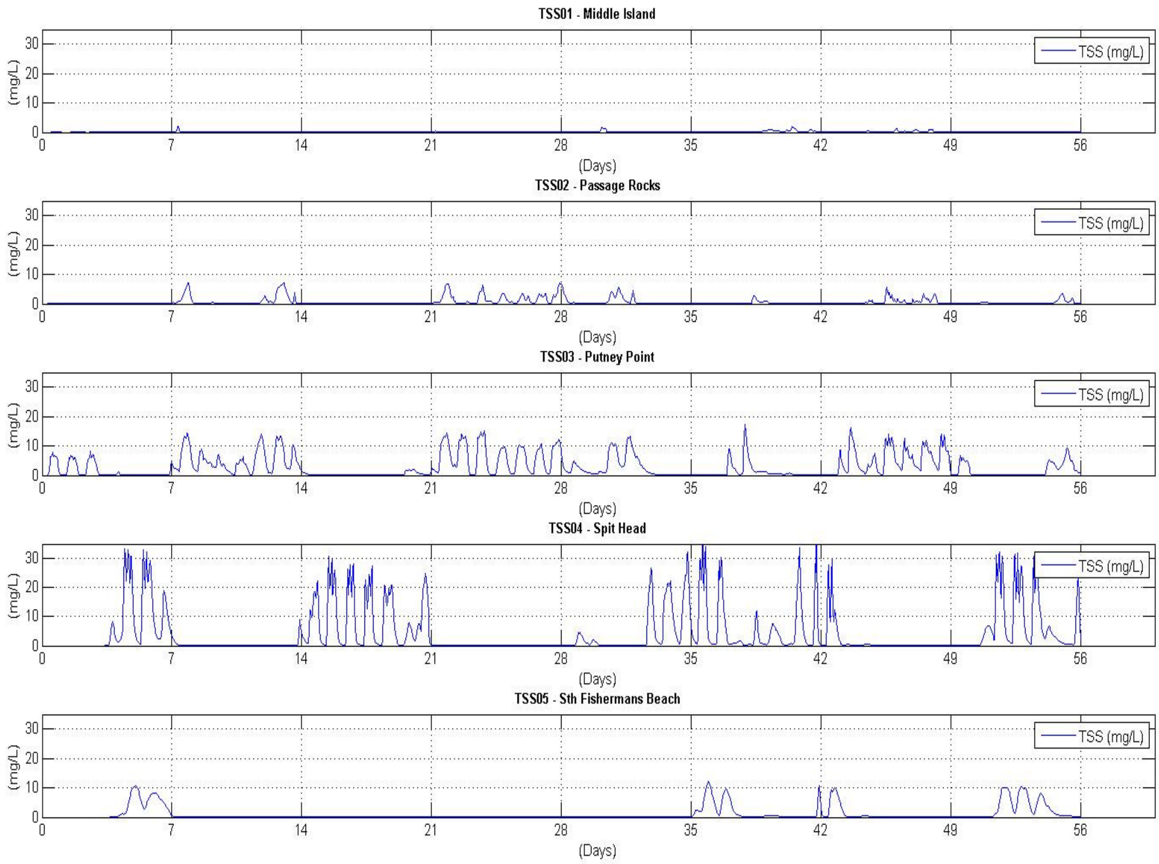

Figure 3-26 Stage 1 - TSS Timeseries at Key Reporting Locations

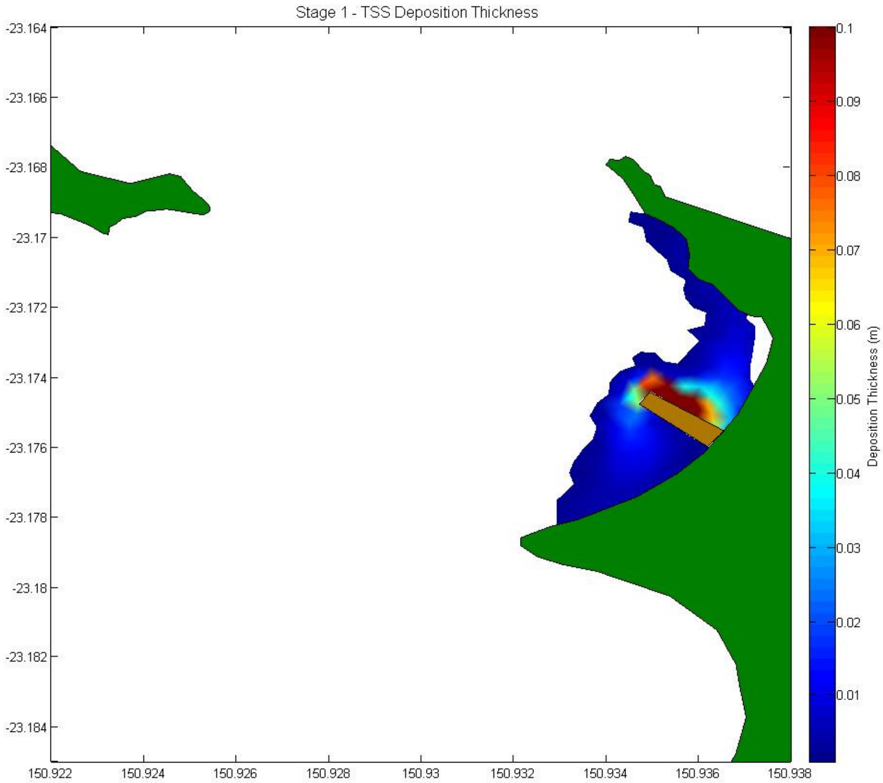

Figure 3-27 Stage 1 – TSS Deposition Thickness

Stage 2

Following the construction of the western breakwater, Stage 2 involves the construction of the marina basin revetments. Figure 3-28 displays the location of the CSD source points for the marina excavation and the source points representing overflow from the geotextile bag filling. The hydrodynamic model has been simulated over the 6 week Stage 2 construction period (assuming no downtime) with the suspended sediment generation rates and loads summarised in Figure 3-28.

The dredge plume simulation results for Stage 2 construction have been summarised as follows:

- Figure 3-29 displays the predicted median TSS results over the duration of Stage 2 construction.
- Figure 3-30 displays the predicted 90%ile TSS results over the duration of Stage 2 construction.
- **Figure** 3-31 displays the predicted TSS timeseries at the key reporting locations over the duration of Stage 2 construction.
- Figure 3-32 displays the predicted TSS deposition thickness over the duration of Stage 2 construction.

The impacts from the analysis of the dredge plume simulations for Stage 2 construction are considered as follows:

- Suspended sediment plumes are predicted to be largely contained within the marina basin.
- Sediment plumes outside of the dredging area will be minimal with concentrations less than 5mg/L modelled at Putney Point (TSS03).
- Suspended sediment deposition is predicted to be essentially confined to within the marina basin.

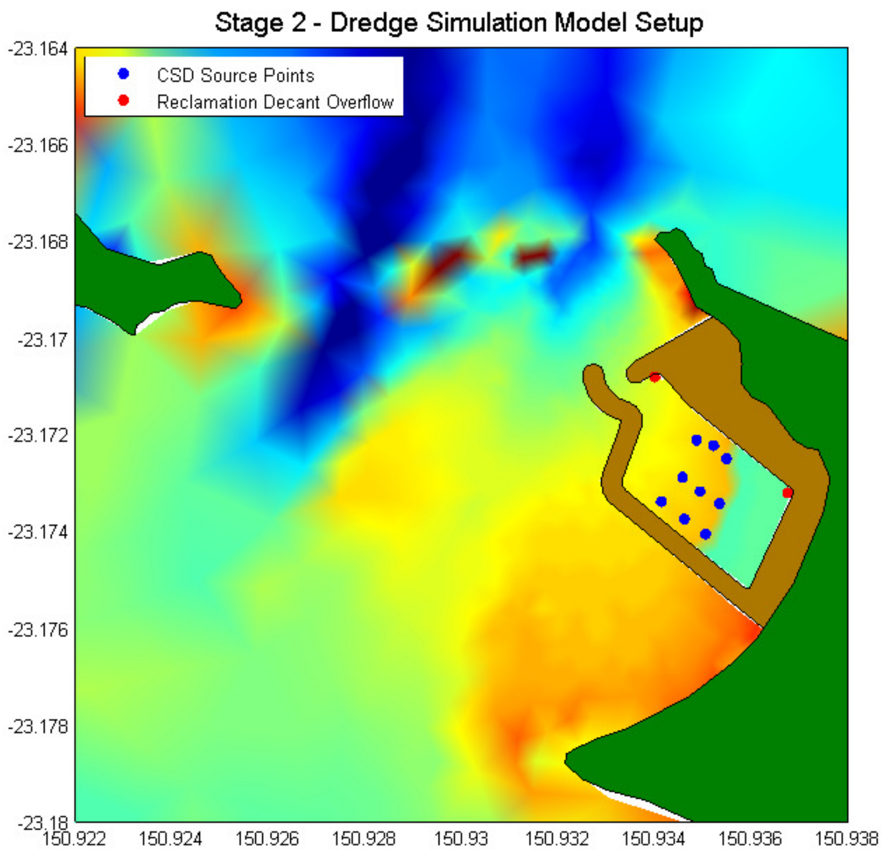

Figure 3-28 Stage 2 – Dredge Simulation Model Setup

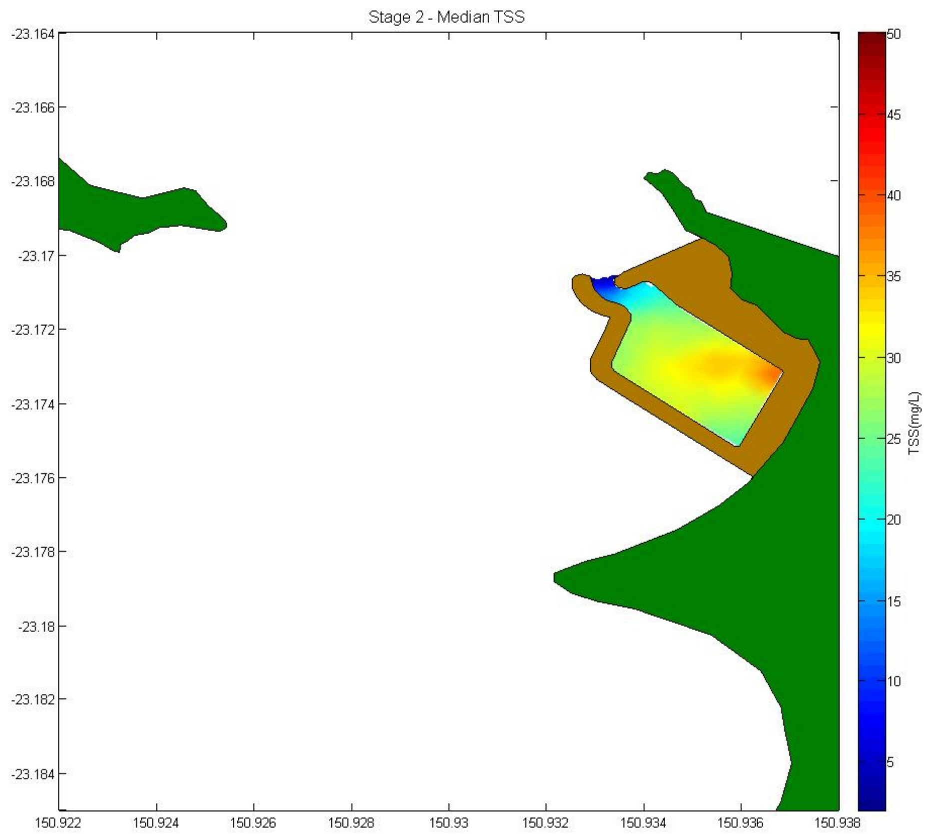

Figure 3-29 Stage 2 – Median TSS Results

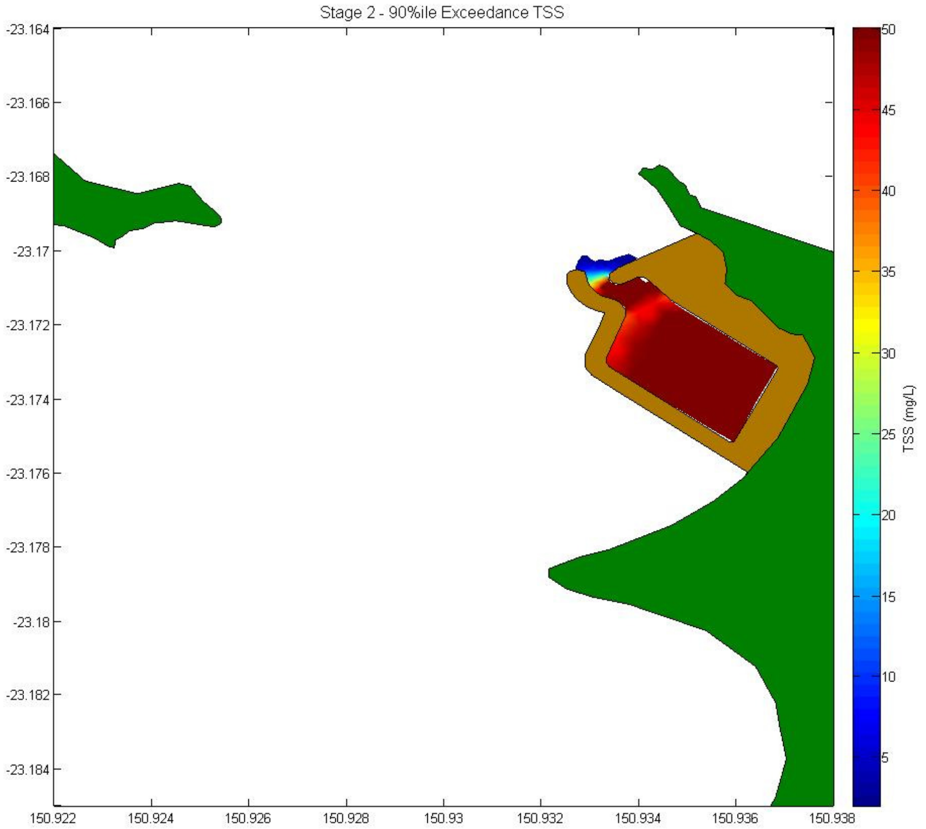

Figure 3-30 Stage 2 – 90%ile Exceedance TSS Results

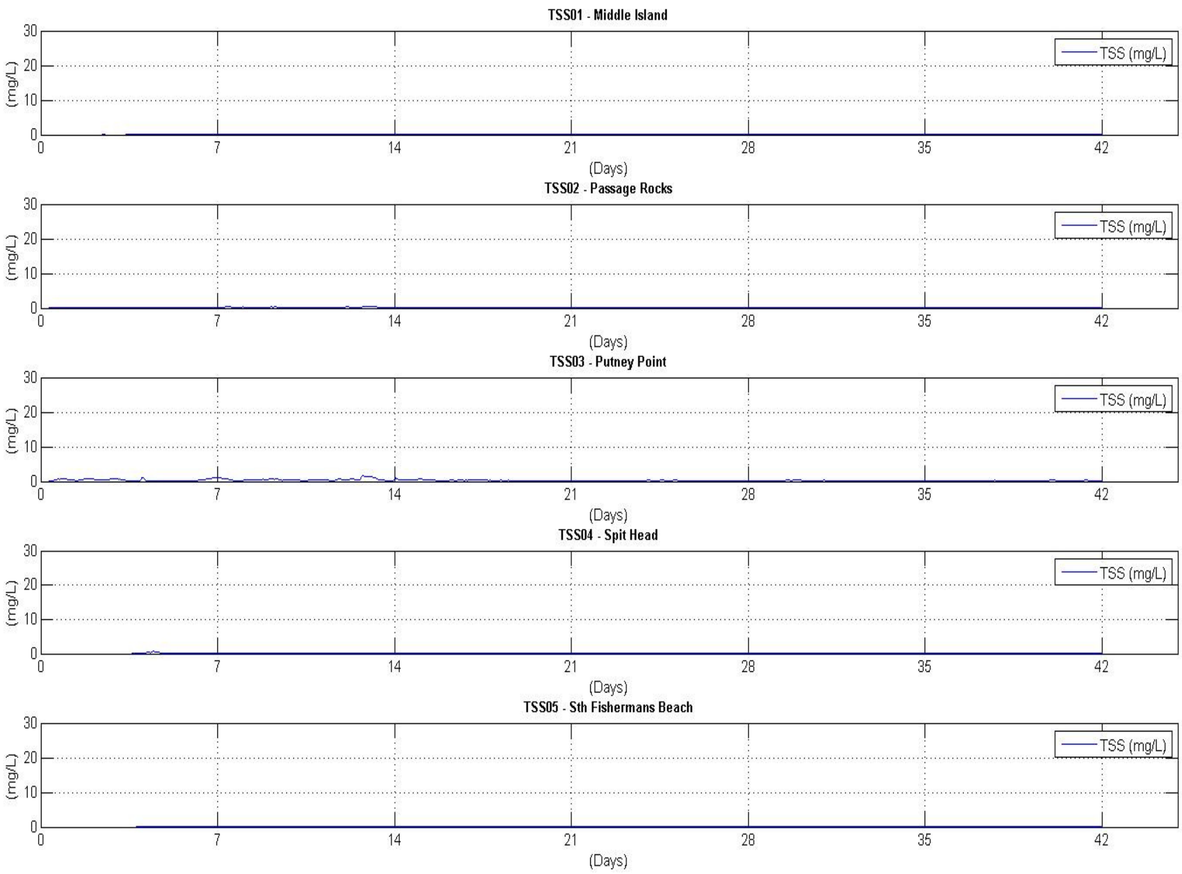

Figure 3-31 Stage 2 - TSS Timeseries at Key Reporting Locations

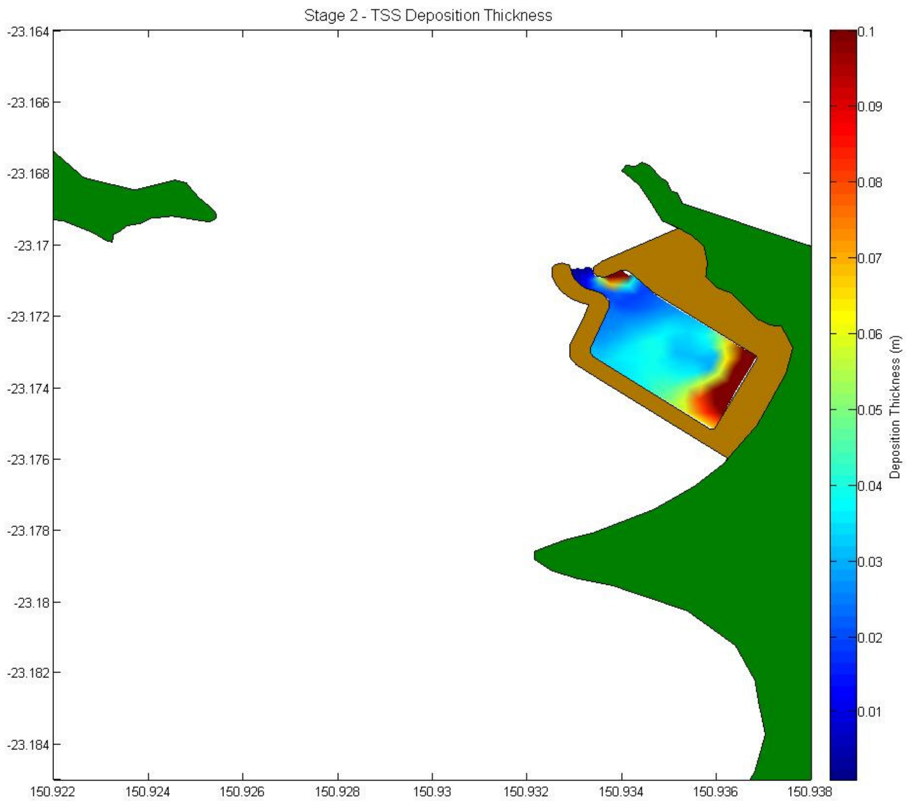

Figure 3-32 Stage 2 – TSS Deposition Thickness

Stage 3

Stage 3 involves dredging of the remainder of the marina basin and approach channel and reclamation of the area to the north of the marina basin. Modelling has assumed the dredging will be completed using a medium sized dredger to complete the works. Figure 3-33 displays the location of the CSD source points for the marina excavation and the source points representing decant overflow from the reclamation. The hydrodynamic model has been simulated over the 6 week Stage 3 construction period (assuming no downtime) with the suspended sediment generation rates and total loads summarised in Figure 3-33. The dredge plume simulation results for Stage 3 construction have been summarised as follows:

- Figure 3-34 displays the predicted median TSS results over the duration of Stage 3 construction.
- Figure 3-35 displays the predicted 90%ile TSS results over the duration of Stage 3 construction.
- Figure 3-36 displays the predicted TSS timeseries at the key reporting locations over the duration of Stage 3 construction.
- Figure 3-37 displays the predicted TSS deposition thickness over the duration of Stage 3 construction.

The impacts from the analysis of the dredge plume simulations for Stage 3 construction are considered as follows:

- Suspended sediment plumes are predicted to be largely contained within the marina basin with the exception of the final stages of the approach channel dredging outside the marina breakwater.
- Elevated levels of suspended sediment are predicted to occur during the dredging of the approach channel with levels up to 30mg/L briefly occurring at Putney Point (TS003).
- Suspended sediment deposition is predicted to be essentially confined to the marina basin and in the vicinity of the decant overflow from the reclamation.

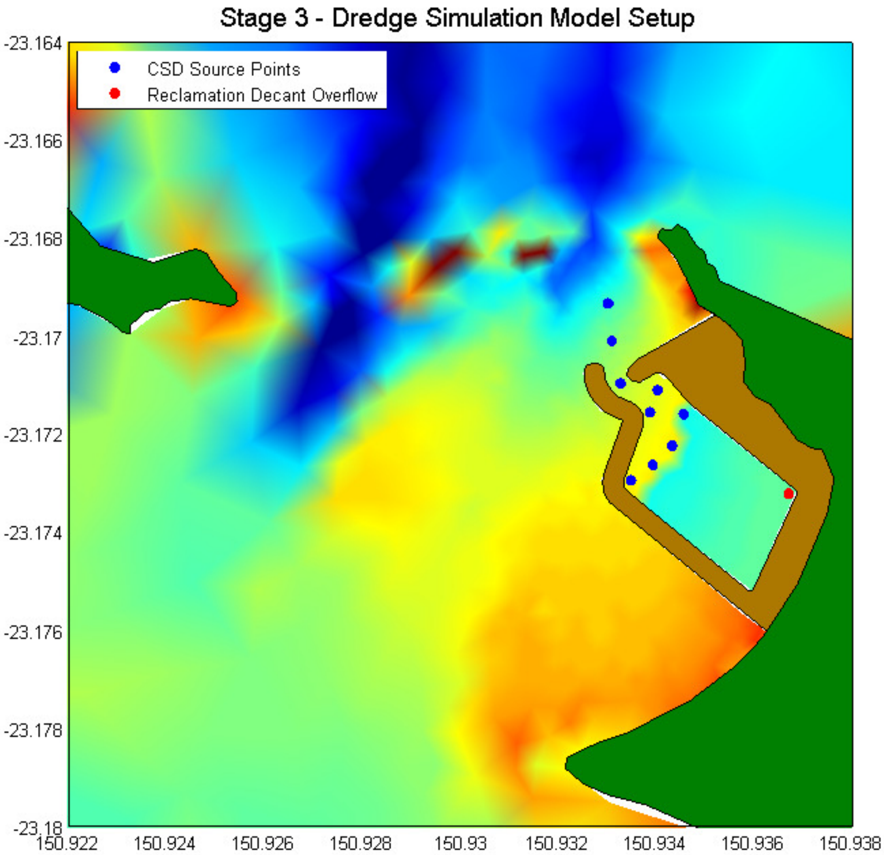

Figure 3-33 Stage 3 – Dredge Simulation Model Setup

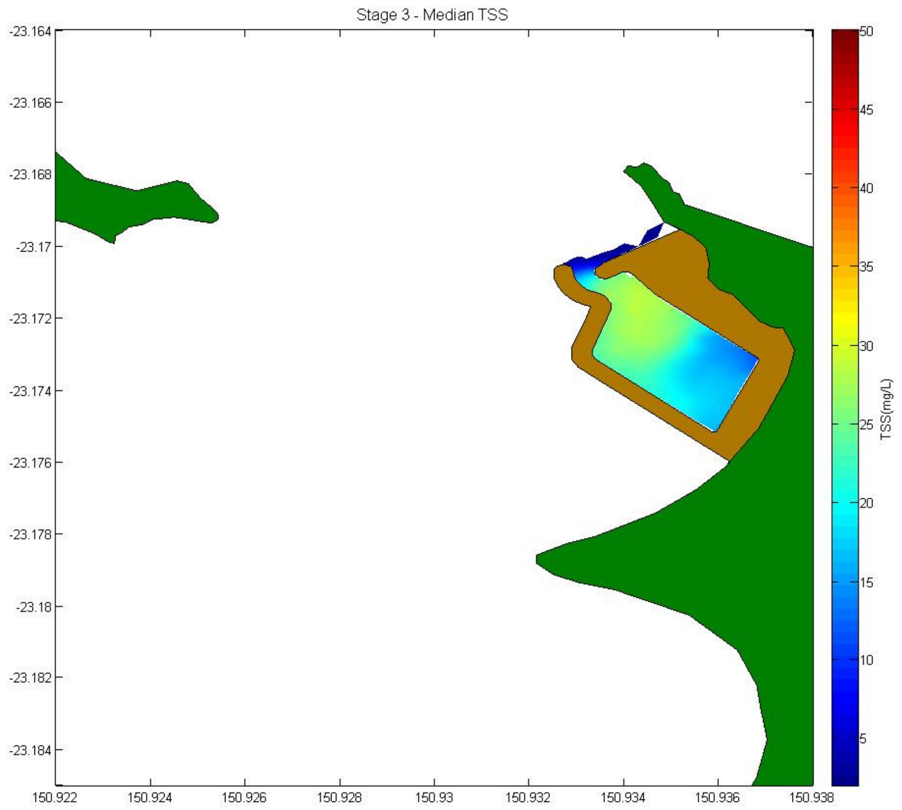

Figure 3-34 Stage 3 – Median TSS Results

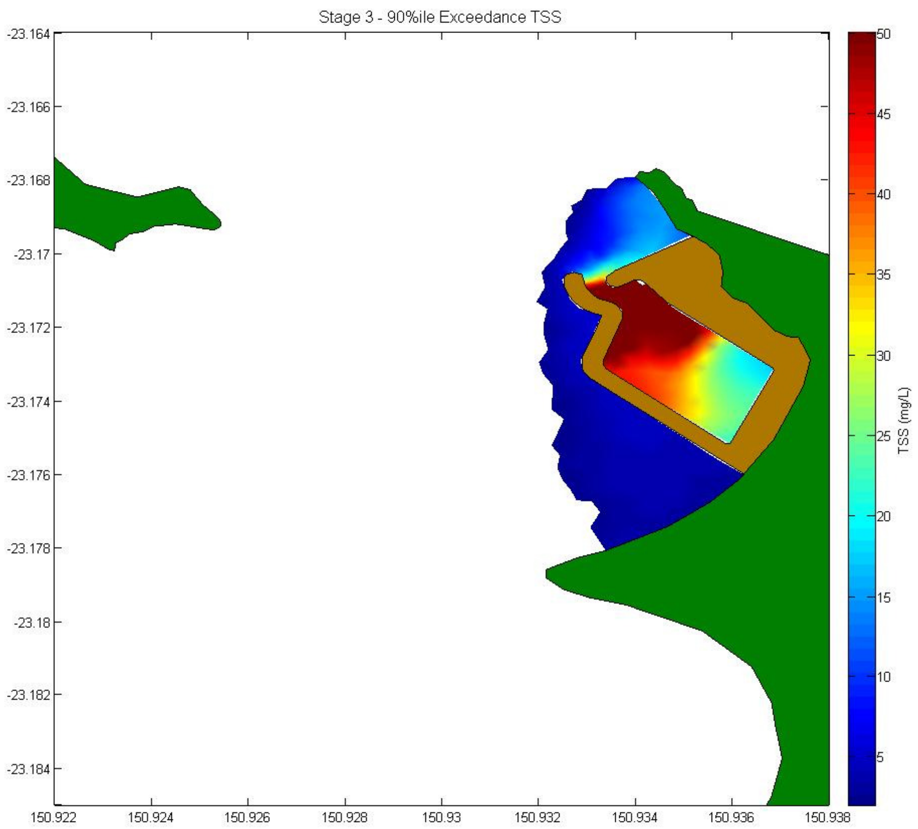

Figure 3-35 Stage 3 – 90%ile Exceedance TSS Results

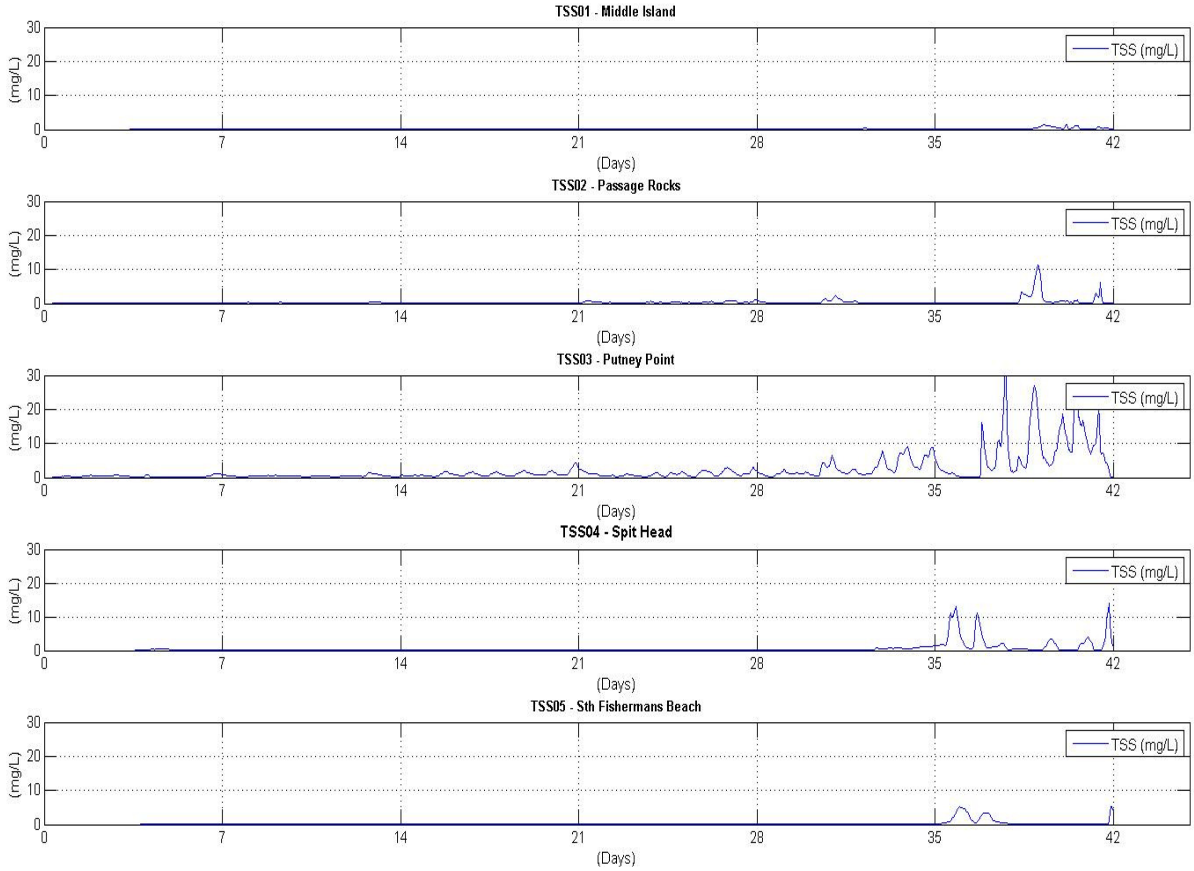

Figure 3-36 Stage 3 - TSS Timeseries at Key Reporting Locations

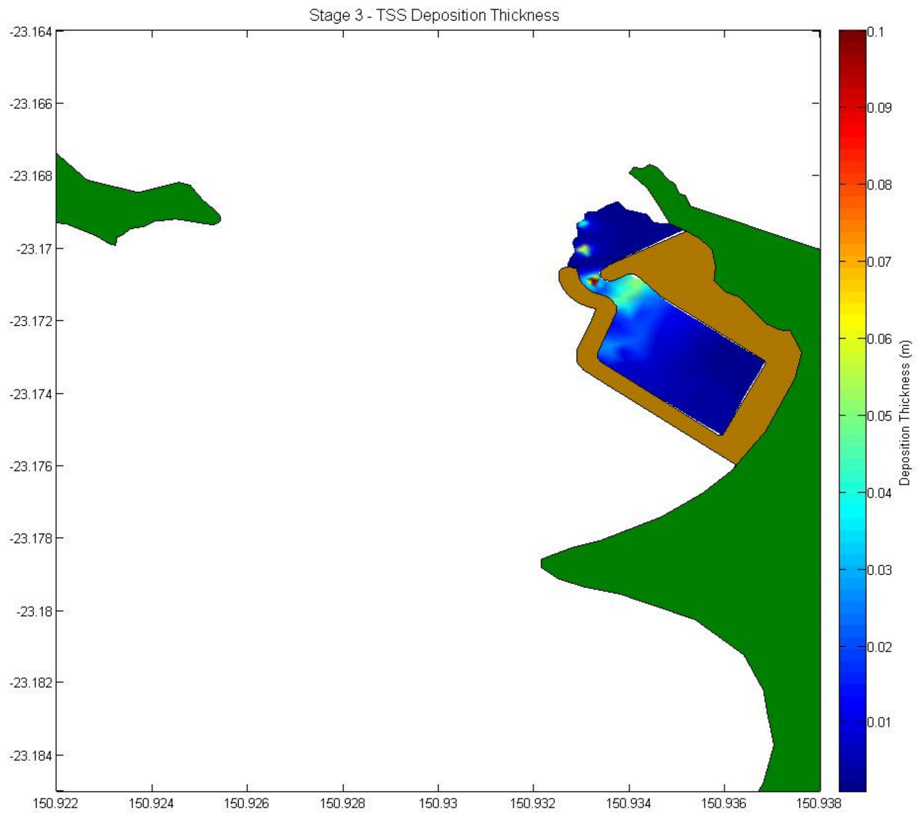

Figure 3-37 Stage 3 – TSS Deposition Thickness

3.8.6 Mitigation Measures

The proposed construction and dredge methodology are considered to constitute significant mitigation measures in their own right, as they have been specifically designed to limit the magnitude and extent of the turbid plumes generated during construction of the marina. The following key features of the construction and dredge methodology are considered to significantly mitigate the potential magnitude and extent of the turbid plumes generated during construction:

- The use of small to medium CSD will limit the amount of suspended sediment generation during excavation in relation to other dredge plant options.
- The use of the dredge spoil to fill geotextile bags to provide the core of the breakwater and marina revetments will prevent the need for ocean disposal of the spoil and assist in filtering and settling out a significant amount of the fines that would have otherwise gone into suspension during sea disposal of the spoil.
- Construction of the western breakwater in Stage 1 will assist in eliminating the majority of the current and wave action from the marine facility basin and significantly assist to contain the extent of the turbid plumes generated during construction to within the marine facility footprint.

The following additional measures are proposed to be developed to mitigate the impact of the dredge plumes predicted to occur during construction:

- Investigation into the potential application of silt screens at the entrance to the marina, following the construction of the western breakwater in Stage 1 will be undertaken. The presence of silt screens across the entrance will potentially further reduce the extent that the turbid plumes may impact areas outside the marina basin.
- The reclamation area will be designed with multiple cells to maximise the length of time over which fine sediments may settle out of suspension before the decant flows back to the marina basin.
- A Dredge Management Plan will be developed incorporating real time turbidity monitoring at key locations and trigger levels for instigating mitigation measures, including reducing the rate, or even cessation of dredging.

3.9 Wet Weather Wastewater Outfall

An assessment of the potential impact of discharges via the wet weather wastewater outfall on the water quality of the receiving environment has been undertaken.

As discussed in Section 3.1, the vast majority of the wastewater from the development is to be reused on Great Keppel Island. The wastewater is to be treated to be equivalent to Class A+ standards and will comply with the nutrient levels specified by GBRMPA (Opus Pty Ltd, 2011).

A 32 ML wet weather storage facility is to be constructed to store treated effluent during periods of wet weather. It is anticipated that the capacity of this storage facility may be exceeded during extreme wet weather events and that, under these circumstances, discharge via the ocean outfall will be required. Modelling using the last 53 years of rainfall data indicates that the wet weather storage would have reached capacity and discharge via ocean outfall would have occurred on approximately 5-6 occasions (each event may have been 1 or more consecutive days) (Opus, 2011).

The worst case discharge scenario has been assessed corresponding to three consecutive wet weather days resulting in a total discharge via the outfall of 5.1ML at a rate of 23.6L/s for 20 hours per day. The wastewater discharges would contain approximately 20mg/L Total Nitrogen and 7mg/L Total Phosphorus.

Initial Dilution

The wastewater outfall diffuser is proposed to be located at a mean water depth of approximately 11.0m. This would provide a minimum water depth above the diffuser at LAT of 8.6m. Wastewater discharges from the outfall would exit the outfall via a tee shaped diffuser comprising two ports approximately 75mm in diameter. This would result in port exit velocities of approximately 2.7m/s at a discharge rate of 23.6L/s. High port exit velocities will increase the initial dilution of the wastewater discharges.

The application of empirically derived relationships (e.g., Cederwall, 1966, or Fan and Brooks, 1969) for the dilution of buoyant plumes under quiescent current conditions from this diffuser port configuration has provided estimated minimum dilutions by the time the buoyant plume reaches the surface of in excess of 70:1 and 100:1 at mean low water and mean high water, respectively. This would correspond to Total Nitrogen and Total Phosphorus concentrations of 0.20-0.28mg/L and 0.07-0.10mg/L respectively at the surface.

The assumption of quiescent conditions is considered to be conservative, as current action is relatively strong and slack water conditions only occur briefly at the top and bottom of the tide at the outfall location. Mixing of the wastewater discharges would significantly increase in the presence of cross currents and an initial dilution well in excess of 100:1 would be expected on average.

Far Field Mixing

Far field modelling of the wastewater outfall discharges has been undertaken in the hydrodynamic model. The modelling has adopted low dispersion coefficients to provide a conservative (worst case) wastewater constituent concentrations around the outfall. Turbulent dispersion associated with wind induced overturning and wave mixing has not been included and would result in wastewater constituent concentrations below those identified in the modelling.

A conservative numerical tracer has been used to assess the advection and dispersion characteristics of the wastewater discharges from the outfall. The numerical tracer has been applied to the model at the location of the wastewater outfall at a constant concentration of 1000units/m^3 and rate of 23.6L/s for 20 hours over a total of 3 days. The hydrodynamic model has been simulated over a representative period of tide and wind driven current conditions over this period. The advection and dispersion of the initial tracer concentration from the outfall has been used to calculate the relative concentrations of Total Nitrogen and Total Phosphorus in the receiving environment around the outfall. Figure 3-38 and Figure 3-39 display the predicted maximum instantaneous Total Nitrogen and Total Phosphorus concentrations respectively above background over the worst case 3 day wet weather outfall scenario.

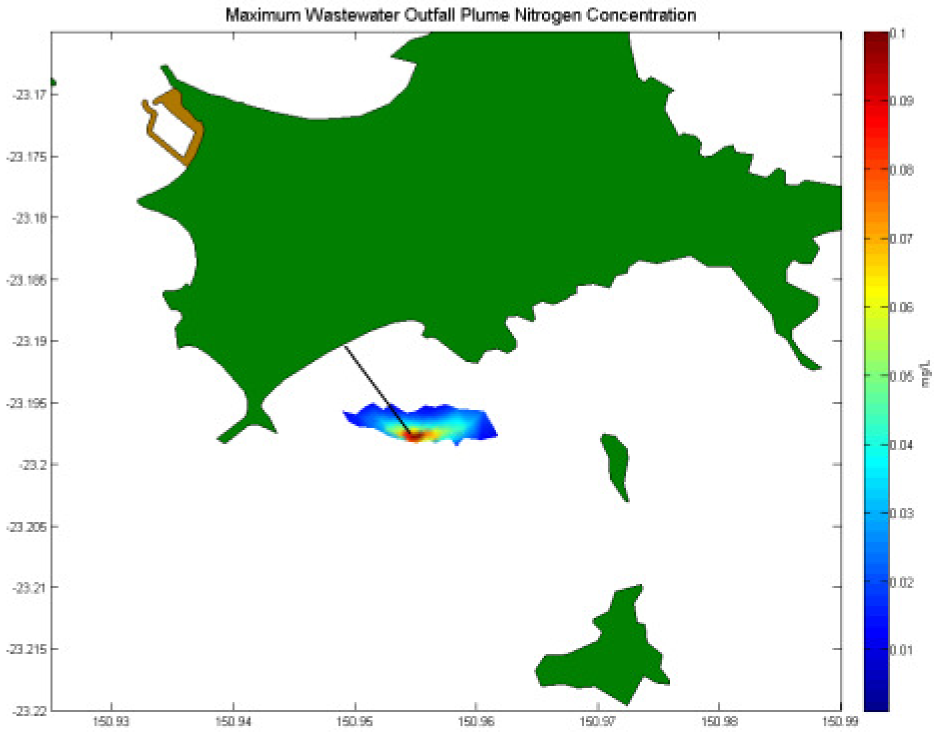

Figure 3-38 Predicted Maximum Total Nitrogen Concentrations from Wastewater Outfall

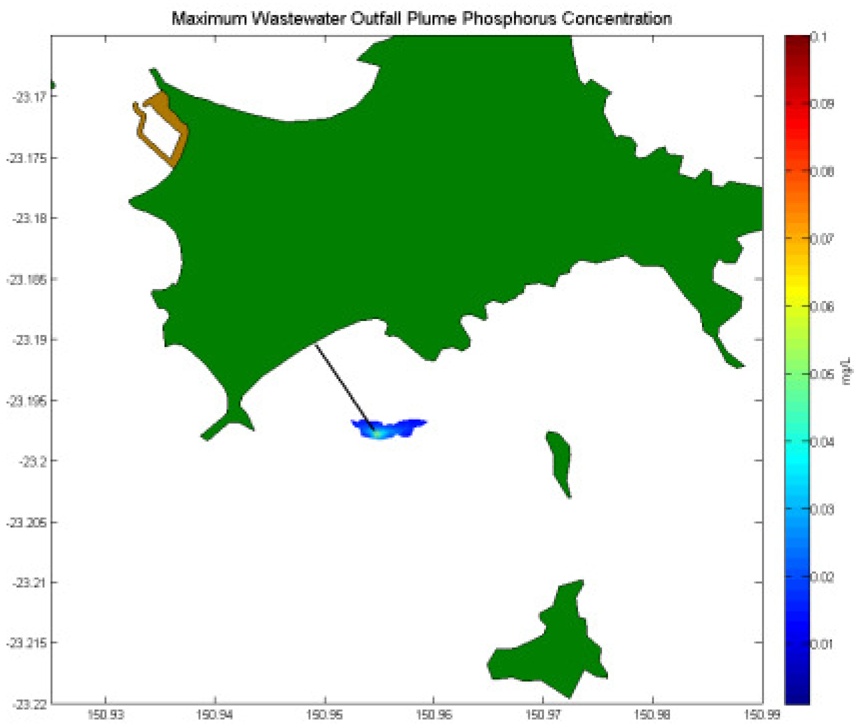

Figure 3-39 Predicted Maximum Total Phosphorus Concentrations from Wastewater Outfall

4. CONCLUSION

To assess the risk posed to the marine physical environment by activities undertaken as part of the proposed project a risk assessment has been undertaken. This risk assessment addresses the potential impacts and consequences of the construction and operational phases of the project described in the above sections along with residual risk following implementation of the proposed mitigation measures. A standard risk assessment matrix as presented in Table 4-1 below. The risk assessment of the marine physical environment impacts of the project are provided in Table 4-2.

Table 4-1 Risk Assessment Matrix

Probability	Consequence				
	1 Insignificant	2 Minor	3 Moderate	4 Major	5 Catastrophic
1 Rare	1 Low	2 Low	3 Low	4 Low	5 Medium
2 Unlikely	2 Low	4 Low	6 Medium	8 Medium	10 Medium
3 Moderate	3 Low	6 Medium	9 Medium	12 High	15 High
4 Likely	4 Low	8 Medium	12 High	16 High	20 Extreme
5 Almost Certain	5 Medium	10 Medium	15 High	20 Extreme	25 Extreme

Table 4-2 Risk Assessment

Activity Description	Potential Impacts and their Consequences	Preliminary Risk Assessment (C,L) Score	Additional Control Strategy	Residual Risk with Control Strategies Adopted (C,L) Score
Tidal Flows and Hydrodynamics	• Minor changes to ebb and flood tide currently around the marina, along Putney Beach and between Putney Point and Passage Rocks • A negligible impact on water levels and tidal phase is predicted	**(1,3) Low**	• The tidal flow and hydrodynamic impacts are considered negligible.	**(1,3) Low**
Tidal and Wind Driven Current Sediment Transport Potential	• Net sediment transport rates around the western edge of Putney Point are predicted to decrease • Rate at which sediment is mobilised and transported away from the spit head will be reduced • Small increase in sand transport potentials at the seaward edge of the western breakwater • Flood tide velocities across the sandy shoal to the south west of Passage Rocks is predicted to increase the rate of southward sediment transport in this area	**(3,3)Medium**	• Maintenance dredging of the entrance channel expected to be required every 5 years on average	**(2,2) Low**
Putney and Fishermans Beach Coastal Processes	• The gross longshore sediment transport potential is likely to reducing from approximately 1,200m^3/yr to 600m^3/yr • The net longshore sediment transport potential is likely to be reduced to close to zero and potentially result in a small reversal towards the north	**(3,3)Medium**	• The periodic bypassing of sand from Putney Point to Putney Beach will be required to maintain the long term sediment continuity along Putney Beach	**(2,2) Low**
Siltation	• The potential extent of the area of fine silt deposition is largely confined to within the marina basin • A small area immediately adjacent to the breakwater on Putney Beach is predicted to experience bed shear		• The rate of siltation is in general expected to be very low. • A sediment trap will be constructed to prevent sediment	

	stresses low enough to allow fine silt deposition. Wave action on Putney Beach is expected to be significant enough at times to resuspend fine silts in this area such that long term accretion of fine silts is not expected • Flood flows from Putney Creek may transport sediment into the marina	(3,3)Medium	from Putney Creek being transported into the marina basin during flood flows	(2,2) Low
Marine Wave Climate	• All berth locations in the marina are predicted to experience a 'good' to 'excellent' wave climate under worst case design wave conditions	(2,2) Low	• No additional mitigation measures are considered necessary	(2,2) Low
Climate Change – Shoreline Recession	• At Putney and Fisherman's Beach approximately 40 – 80m of shoreline recession could be observed, resulting in a loss of beach amenity and beach access	(3,3) Medium	• Infrastructure will be located a sufficient buffer distance from existing shorelines	(2,2) Low
Climate Change - Increase in Storm Tide Elevations	• Increased overtopping of the breakwaters resulting in increased wave action within the marina, resulting in damage to berthed vessels under design storm conditions	(3,3) Medium	• Increasing/adapting breakwater crest heights to limit the extent of wave overtopping under design water level and wave conditions to 2100 • Increasing the primary armour unit weights during detailed design to limit the potential for structural damage to occur to the breakwaters under design water level and wave conditions to 2100	(2,2) Low
Climate Change – Coastal Inundation	• Inundation to marina infrastructure and reclamation would include water damage costs and inconvenience	(3,3) Medium	• Constructing finished surface levels and floor levels above the relevant design storm tide inundation levels to 2100	(2,2) Low
Marine Water Quality – Marine Residence Times	• Practical measures of residence times are likely to be no greater than 1 – 2 days for all locations within the marina basin	(1,1) Low	• No additional mitigation measures are considered necessary	(1,1) Low
Marine Water Quality –	• Copper concentrations from antifouling leachate are		• There is not considered any	

Antifouling	predicted to slightly exceed relevant guidelines within the marina basin	**(3,3)Medium**	practical mitigation measures available for this impact	**(3,3)Medium**
Sediment Quality and Dredging –Stage 1 Suspended Sediment Plume	***Stage 1* -** Localised suspended sediment deposition of up to 0.1m is predicted adjacent to the western breakwater, within the marina basin, as it is being constructed	**(3,3)Medium**	• The use of small to medium CSD will limit the amount of suspended sediment generation during excavation • The use of the dredge spoil to fill geotextile bags to provide the core of the breakwater and marina revetments will prevent the need for ocean disposal of the spoil and assist in filtering and settling out a significant amount of the fines that would have otherwise gone into suspension during sea disposal of the spoil • • A Dredge Management Plan will be developed incorporating real time turbidity monitoring at key locations and trigger levels for cessation of dredging	**(2,2) Low**
Sediment Quality and Dredging –Stage 2 Suspended Sediment Plume	***Stage 2* -** Suspended sediment plumes are predicted to be largely contained within the marina basin - Putney Point will be occasionally exposed to brief periods of elevated TSS of up to approximately 30mg/L on ebb tides - The Spit Head is predicted to experience occasional spikes in TSS of less than 10mg/L - Suspended sediment deposition is predicted to be essentially confined to the marina basin	**(3,3) Medium**	• Construction of the western breakwater in Stage 1 will significantly assist to contain the extent of the turbid plumes generated to within the marine facility • Investigation into the potential application of silt screens at the entrance to the marina, following Stage 1 will be undertaken • A Dredge Management Plan will be developed incorporating real time turbidity monitoring at key	**(2,2)Low**

			locations and trigger levels for cessation of dredging	
Sediment Quality and Dredging –Stage 3 Suspended Sediment Plume	***Stage 3*** **-** Suspended sediment plumes are predicted to be largely contained within the marina basin - Putney Point will be occasionally exposed to brief periods of elevated TSS of less than approximately 10mg/L, particularly while the approach channel dredging is occurring - Suspended sediment deposition is predicted to be essentially confined to the marina basin and in the vicinity of the decant overflow from the reclamation	**(3,3) Medium**	• The reclamation area will be designed with multiple cells to maximise the length of time over which fine sediments may settle out of suspension before the decant flows back to the marina basin • A Dredge Management Plan will be developed incorporating real time turbidity monitoring at key locations and trigger levels for cessation of dredging	**(2,2)Low**

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APPENDIX A OCEANOGRAPHIC DATA COLLECTION PROGRAM

An oceanographic data collection program was conducted between February and March 2011. The data collection program was undertaken to improve the understanding of the hydrodynamics of the study area and to provide measurement data to enable verification of numerical models.

Measurements of currents, water levels and wave spectra were obtained using a bed mounted Acoustic Current Doppler Profiler (ADCP) instrument. The instrument was deployed at the location displayed in Figure A-1 at the following coordinates -23 10.937S; 150 55.238 E. The instrument was deployed in approximately 7.5m depth between 11 February and 13 March 2011.

The ADCP recorded current velocities in 0.5m depth bins every 10 minutes. The wave spectra was burst sampled for 20 minutes every 1 hour.

Figure A-2 displays the water surface elevations and depth averaged current speeds and directions measured by the ADCP over the duration of the 1 month deployment.

Figure A-3 displays the significant wave heights, spectral peak periods and significant wave directions measured by the ADCP over the duration of the 1 month deployment.

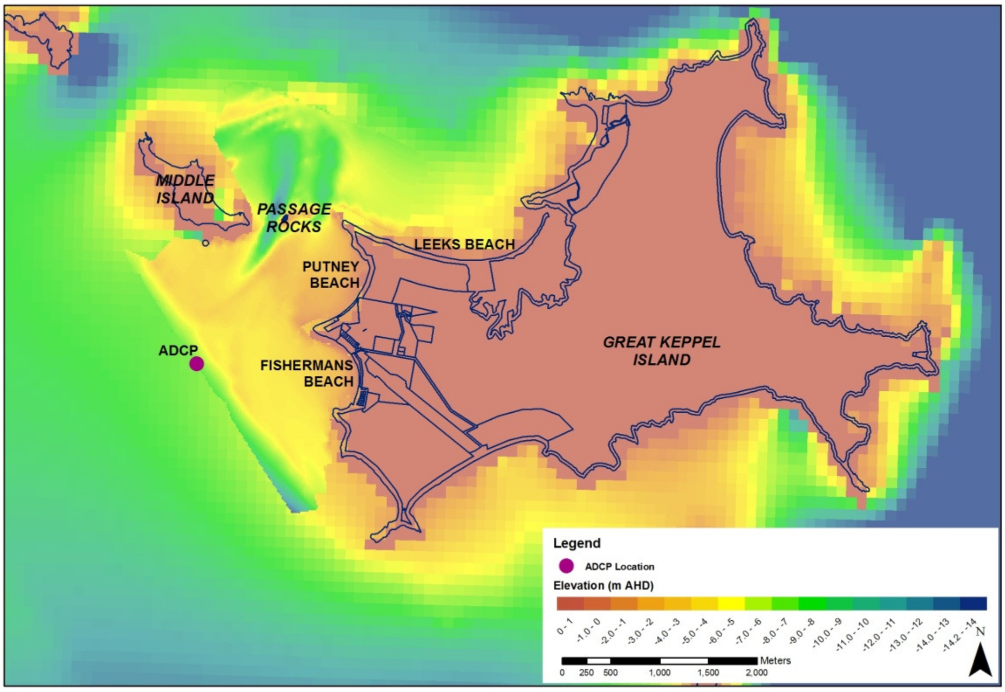

Figure A- 1 Location of ADCP deployment

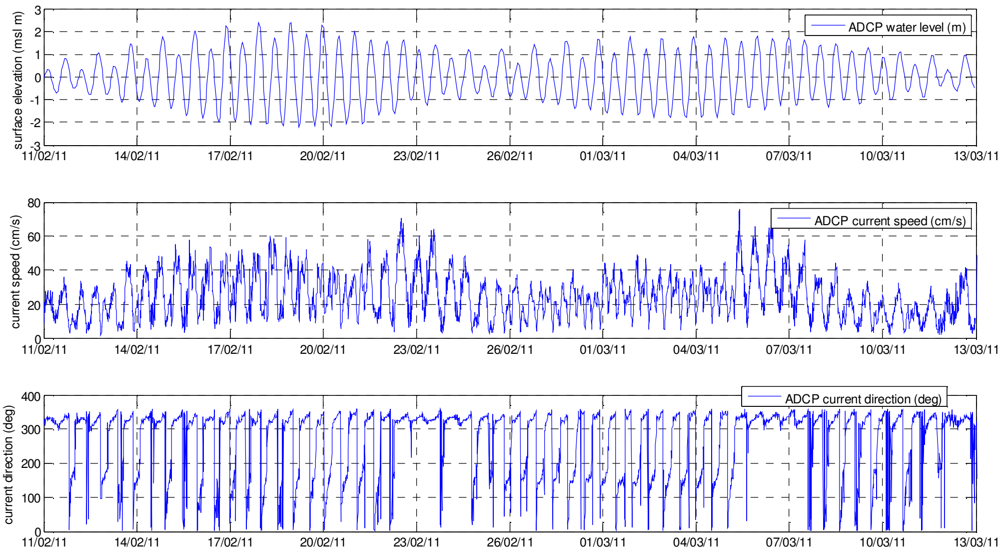

Figure A- 2 ADCP recorded surface water elevations and depth averaged currents speeds and directions

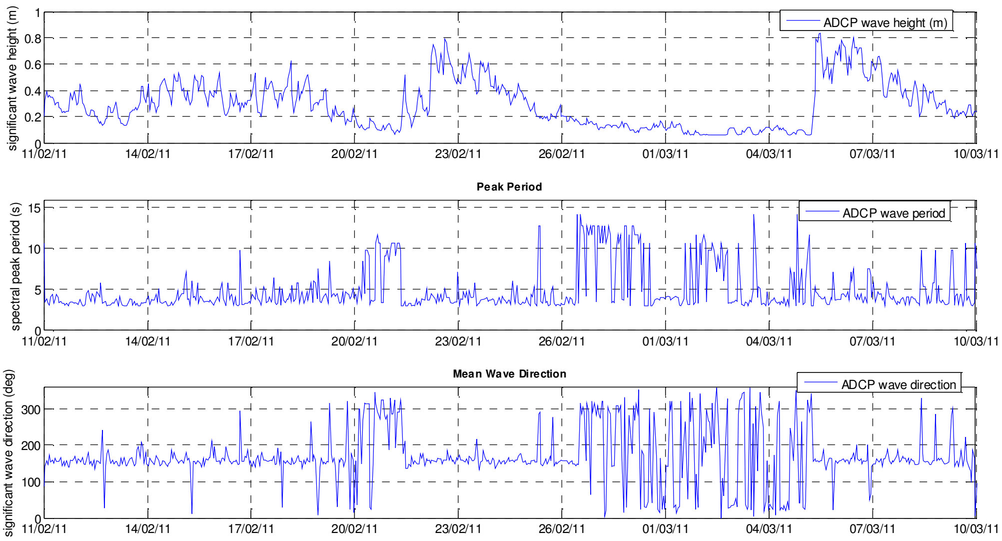

Figure A- 3 ADCP recorded significant wave heights, peak periods and wave directions

APPENDIX B DESCRIPTION OF NUMERICAL MODELS

To ensure a sound understanding and rigorous analysis of the dominant physical forces and processes operating in the coastal area of interest is undertaken, a series of numerical coastal modelling tools have been developed. The numerical models, once validated, are capable of providing a quantitative description of the hydrodynamic, sediment transport and water quality characteristics of the area of interest under a variety of boundary forcing scenarios.

The following numerical models have been developed to assist in the definition of the existing condition and impact assessment components of the EIS:

- Finite Volume Spectral Wave Model
- Finite Volume Hydrodynamic Model

The hydrodynamic and spectral wave models can be coupled with transport modules to investigate flushing, the fate of dredge plumes, discharges and sediment with the study area.

The numerical models have undergone extensive calibration involving comparisons of model predictions to measured water levels, currents and waves. Details of the model development, boundary conditions specifications and calibration of these models are provided in the following sections.

Spectral Wave Model

The Danish Hydraulic Institutes (DHI), MIKE 21 Spectral Wave (SW) model has been employed for this study. MIKE 21 SW is a 3rd generation spectral wind-wave model capable of simulating wave growth by action of wind, non-linear wave-wave interaction, dissipation by white-capping, wave breaking and bottom friction, refraction due to depth variations, and wave-current interaction. The spectral wave action balance equation is spherical co-ordinates. The discretisation of the governing equations is performed using a cell-centred finite volume method with an unstructured mesh in the geographical domain. An explicit method is applied for the time integration.

Domain Schematisation

The bathymetric mesh of the MIKE 21 SW model was primarily derived from the 3DGBBR Project DEM. The bathymetry in the vicinity of Putney Beach was derived from the project specific hydrographic survey discussed in Section 2.2. The model domain and bathymetry is shown in Figure B-1. The spectral wave model covers a rectangular extent from 19 30’ to 25 30’S and 150 30’ to 158 30’E.

The resolution of the computational mesh was varied to improve the description of the wave transformations in the vicinity of Putney Beach. Figure B-2 displays the mesh resolution and bathymetry of the spectral wave model in the vicinity of Putney Beach.

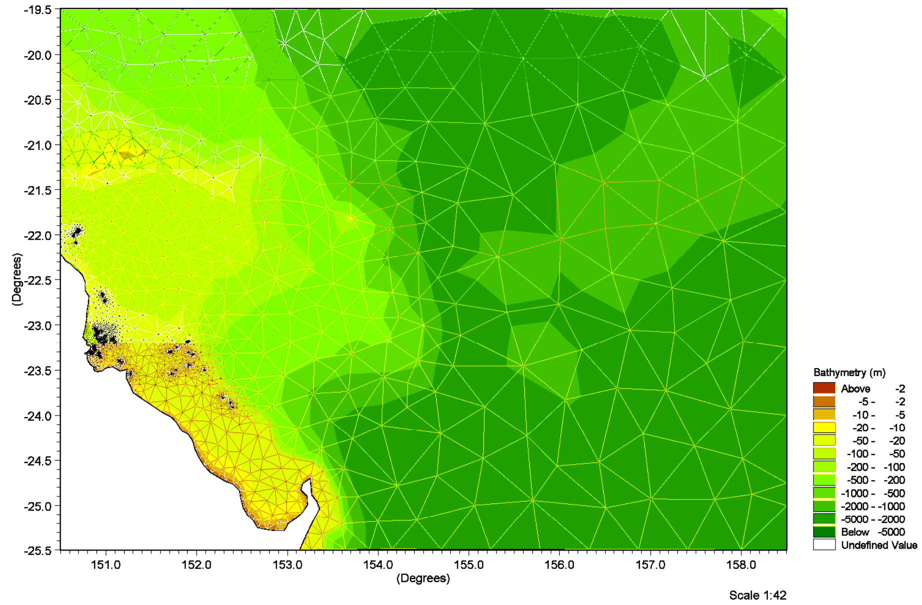

Figure B- 1 Spectral Wave Model Domain and Computational Mesh Schematisation

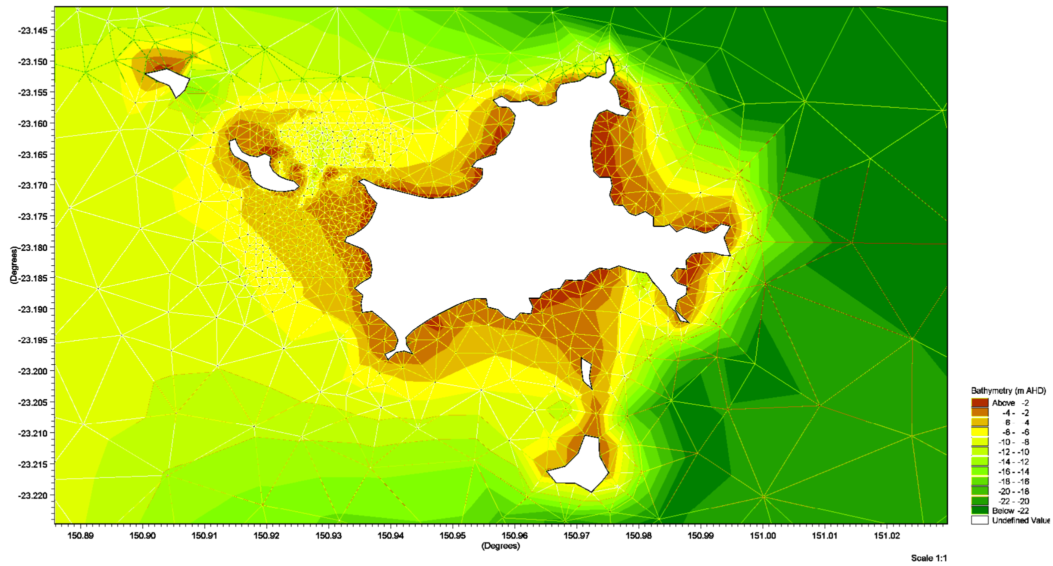

Figure B- 2 Spectral Wave Model– Great Keppel Island Detailed Bathymetry

Boundary Conditions

Boundary conditions for the calibration of the spectral wave model have been derived from the outputs of the NOAA Wave Watch 3 global hindcast model. The NOAA Wave Watch 3 global hindcast model runs from 1997 to present. The wave model results are provided on a rectangular grid 0.750 degree N and 1.25 degree E grid. The results from this hindcast model are extensively validated with buoy and satellite measurements at a global scale and are considered very reliable at exposed, deep water locations.

The 10 meter, u and v vector wind velocity outputs from the NOAA hindcast model were extracted and lineally interpolated to 0.250degree spatially and 3 hourly temporally varying grid of u and v wind velocity components to force the spectral wave model.

Wave energy propagating from outside the model domain was incorporated via open wave boundary conditions. The open wave boundary conditions were extracted from the NOAA wave model to provide spatially and temporally varying wave boundary conditions along the North, South and East model boundaries.

Model Calibration

The calibration process consists of systematically comparing observed key wave height, period and direction behaviour within the study area against the spectral wave models reproduction of that behaviour. Where the model does not adequately represent the observed behaviour, reasons for the discrepancies are identified and inputs to the model adjusted.

The spectral wave model has been calibrated to measured wave data at the following two locations and periods:

- A two month period (1 Jan – 1 March 2008) of wave measurements obtained from the Emu Park wave rider buoy located approximately 20 kilometres to the south east of Great Keppel Island.
- A one month period (11 February - 13 March 2011) of wave measurements from the ADCP deployment in the vicinity of Putney Beach discussed in Appendix A.

Comparisons of the level of agreement achieved between the modelled and observed key spectral wave parameters at the Emu Park wave rider buoy have been displayed in Figure B-3. Comparisons of the level of agreement achieved between the modelled and observed key spectral wave parameters at the location of the ADCP instrument deployment have been displayed in Figure B-4.

Figure B-3 and Figure B-4 are considered to illustrate the high level of agreement between modelled and observed wave conditions that has been achieved as part of the spectral wave model calibration. The level of agreement achieved is considered appropriate for investigating the long term wave climate conditions in the study area.

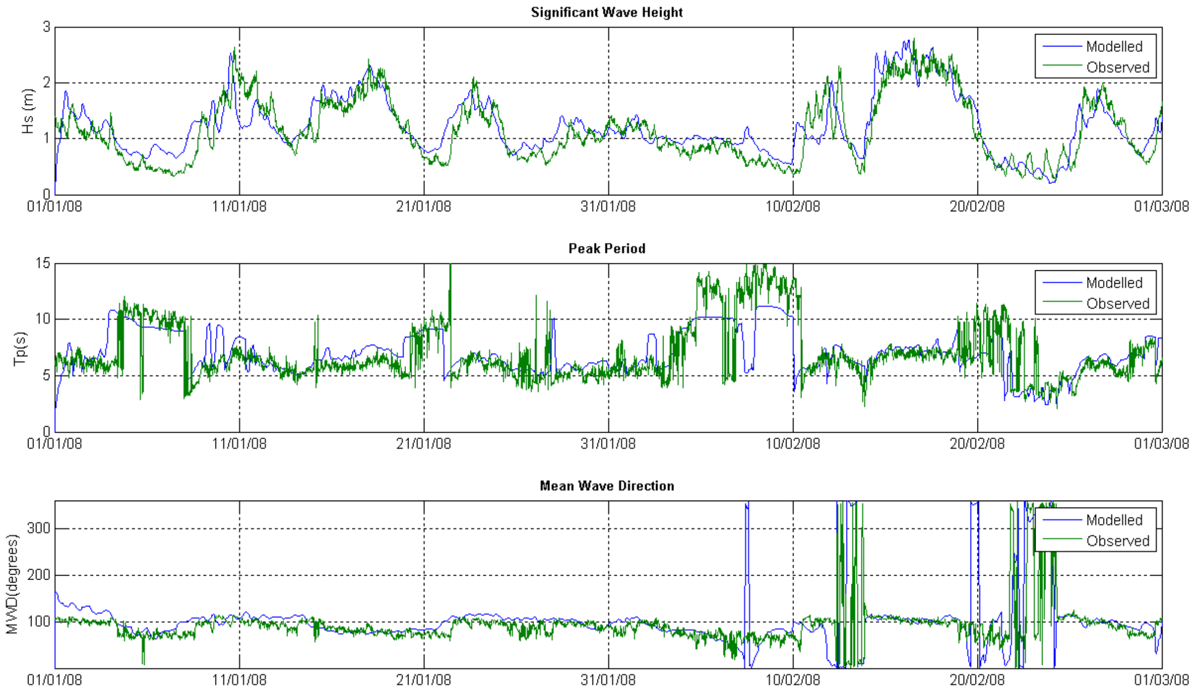

Figure B- 3 Comparison of modelled and observed key statistical wave parameters at Emu Park wave rider buoy for period 1 January – 1 March 2008.

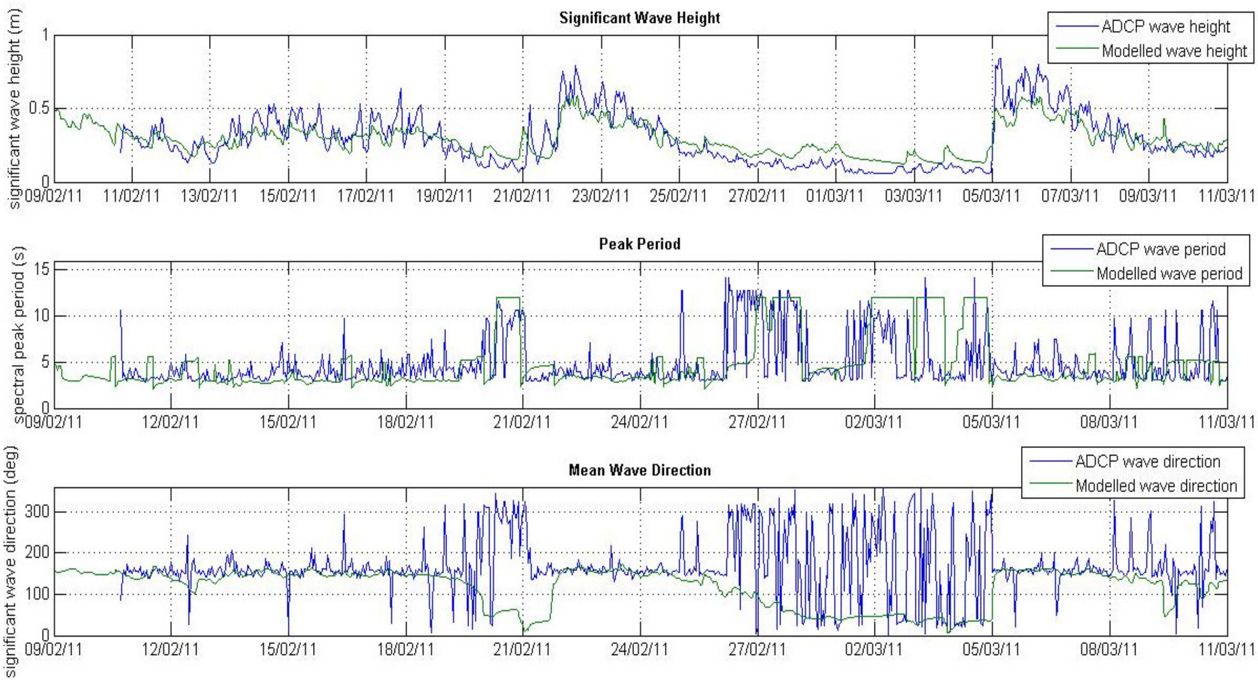

Figure B- 4 **Comparison of modelled and observed key statistical wave parameters at ADCP for period 11 February – 13 March 2011.**

Hydrodynamic Model

The Danish Hydraulic Institutes (DHI), MIKE 21 Flexible Mesh (FM) hydrodynamic model has been employed to assess the hydrodynamic conditions within the study area. MIKE21 FM is two dimensional finite volume model that solves the unsteady incompressible flow equations. The model consists of continuity and momentum equations and a turbulent closure scheme.

The discretisation of the governing equations is performed using a cell-centred finite volume method with an unstructured mesh in the geographical domain. An explicit method is applied for the time integration.

The application of a two dimensional (depth averaged) hydrodynamic model for the impact assessment at Great Keppel Island is considered appropriate for the following reasons:

- The macro tidal regime is highly energetic and well mixed in he vicinity of Great Keppel Island
- Three dimensional current data returned from the ADCP indicated a high uniformity in current directions across the profile and current magnitudes were consistent with the logarithmic velocity profile and boundary layer approximation of the depth averaged model solution
- In the specific areas of interest, depths are relatively shallow at generally less than five metres and there are significant areas of wetting and drying.
- There was no indication of significant stratification in temperature and salinity profiles collected as part of the water quality assessments.

Domain Schematisation

The extent of the MIKE 21 FM model is shown in Figure B-5. The bathymetric mesh of the MIKE 21 FM model was primarily derived from the 3DGBBR Project DEM. The bathymetry in the vicinity of Putney Beach was derived from the project specific hydrographic survey discussed in Section 2.2.

The resolution of the computational mesh was varied to improve the description of the tide and current fields in the vicinity of Putney Beach. Figure B-6 displays the mesh resolution and bathymetry of the hydrodynamic model in the vicinity of Putney Beach.

The model consists of 4032 triangular elements with a maximum time step of 30 seconds, critical CFL number of 0.8, a Manning's roughness coefficient of 0.03 and a Smagorinsky eddy viscosity formulation.

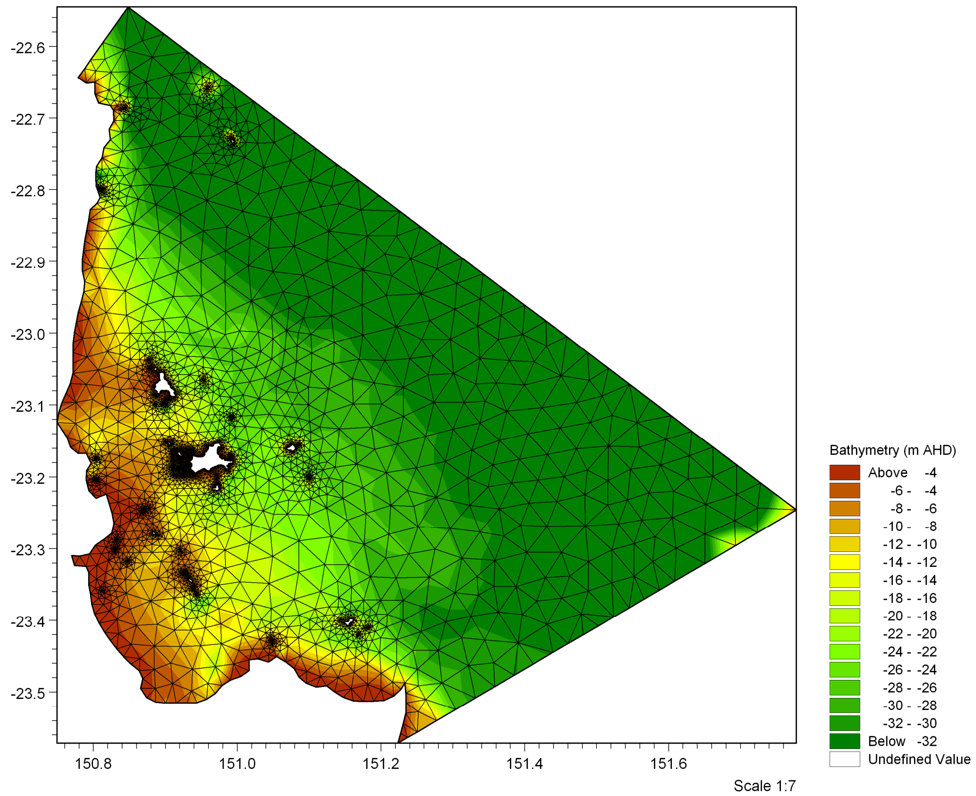

Figure B- 5 Keppel Bay Hydrodynamic Model Domain and Computational Mesh Schematisation

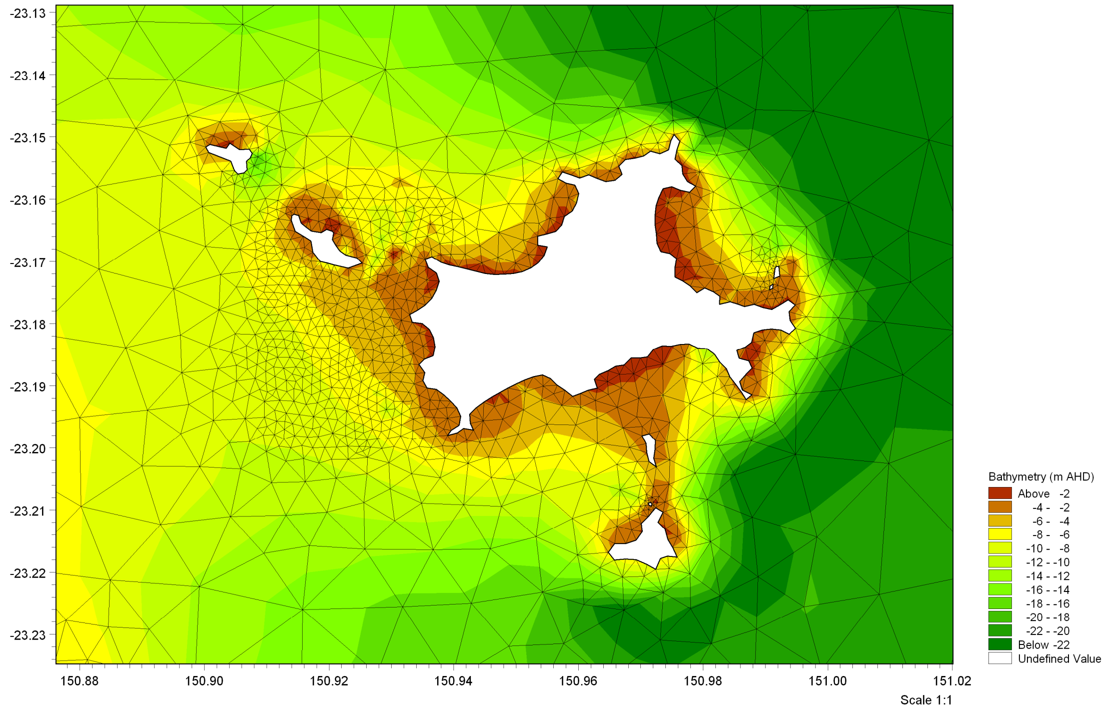

Figure B- 6 Hydrodynamic Model – Great Keppel Island Detailed Bathymetry

Boundary Conditions

Open boundary conditions are defined on the south eastern and north eastern and northern extents of the model. The open boundary conditions are driven by a combination of tidal constituent information from Standard Ports located on or near the model boundaries. The following Standard Port tidal constituent information was utilized for the model boundaries:

- South eastern boundary extending from Cape Capricorn (59691) to Tryon Islet (59720)
- North eastern boundary extending from Tryon Islet to Peaked Island (59658)
- Northern boundary extending from Peaked Island to Cliff Point on the mainland

The definition of the astronomical tidal boundary conditions in the model formed part of the model calibration process, and is described in more detail in Section 0.

Wind shear on the water surface drives secondary circulations within Keppel Bay. These were modelled by the development of spatially and temporally varying wind fields for Keppel Bay. These wind fields were derived from wind measurements from the Bureau of Meteorology (BOM) weather stations at Yeppoon and Rundle Island.

Model Calibration

Calibration of the hydrodynamic model has been undertaken in two parts. The first part consisted of calibration of the model's capability to reproduce astronomical tidal water level variations throughout Keppel Bay. The second part consisted of calibrating the model to astronomical and meteorologically driven currents observed by the ADCP in the vicinity of Putney Beach.

Calibration of Astronomical Tidal Water Level Variations in Keppel Bay

The hydrodynamic model was calibrated against predicted astronomical tides at the following four Standard Port locations in Keppel Bay:

- NW of Johnson Patch (59668)
- Middle Island., Keppel Island (59672)
- Rossyln Bay (59670)
- Port Alma (59690)

The locations of the Standard Ports employed in the hydrodynamic model calibration are displayed in Figure B-7.

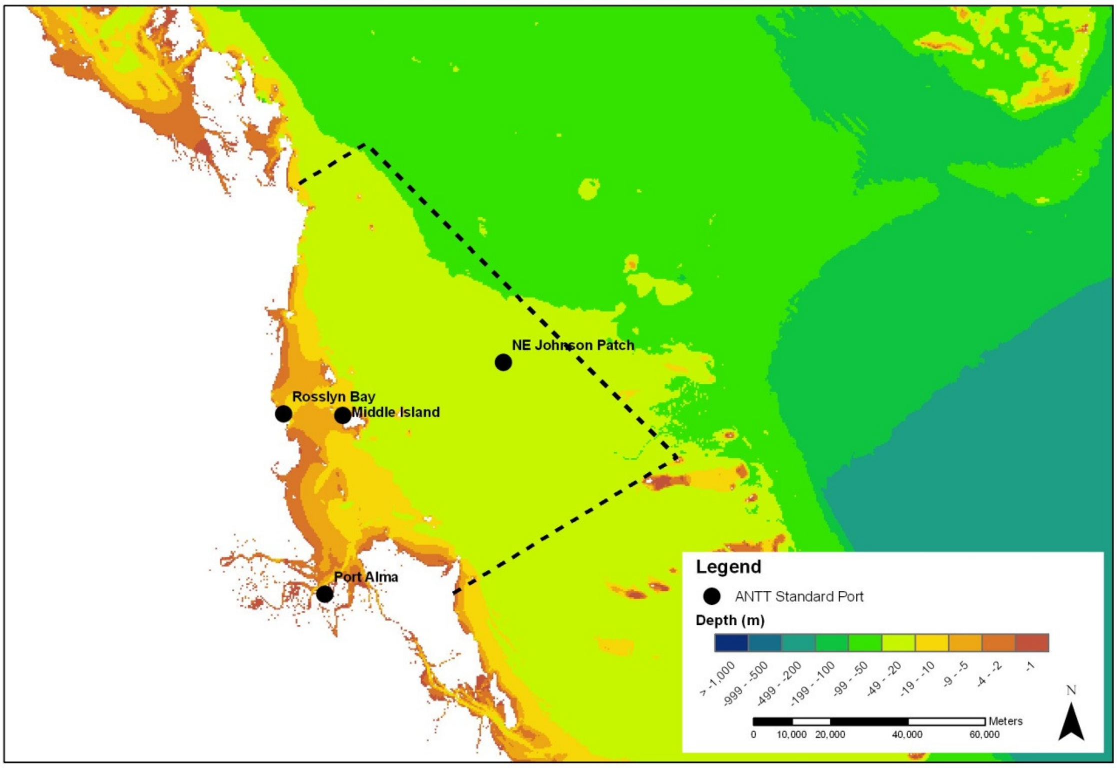

Figure B- 7 Locations of Standard Ports used in the Hydrodynamic Model Calibration

The calibration process consisted of applying predicted tidal water level elevations at the model boundaries, simulating the model over several spring-neap tidal cycles, and comparing the model results against the predicted tidal water levels at the Standard Port locations. Fine tuning of the model results was achieved by making relatively minor alternations to the amplitude, phase and/or interpolation of the predicted water levels along the model boundaries as well as minor adjustments to bed friction coefficient.

Comparisons of predicted and model astronomical tidal variations at the four Standard Port locations are presented in Figure B-8. These comparisons are given for the same 30 day period. When compared with the corresponding predicted water levels at the four Standard Port locations in Keppel Bay, the results show that the model is capable of providing a good reproduction of the main features of the astronomical tide within Keppel Bay, including:

- The amplification of the tide from offshore to onshore as the tide resonates within the Southern Great Barrier Reef lagoon.
- Changes in phase as the tide propagates from south to north in Keppel Bay.

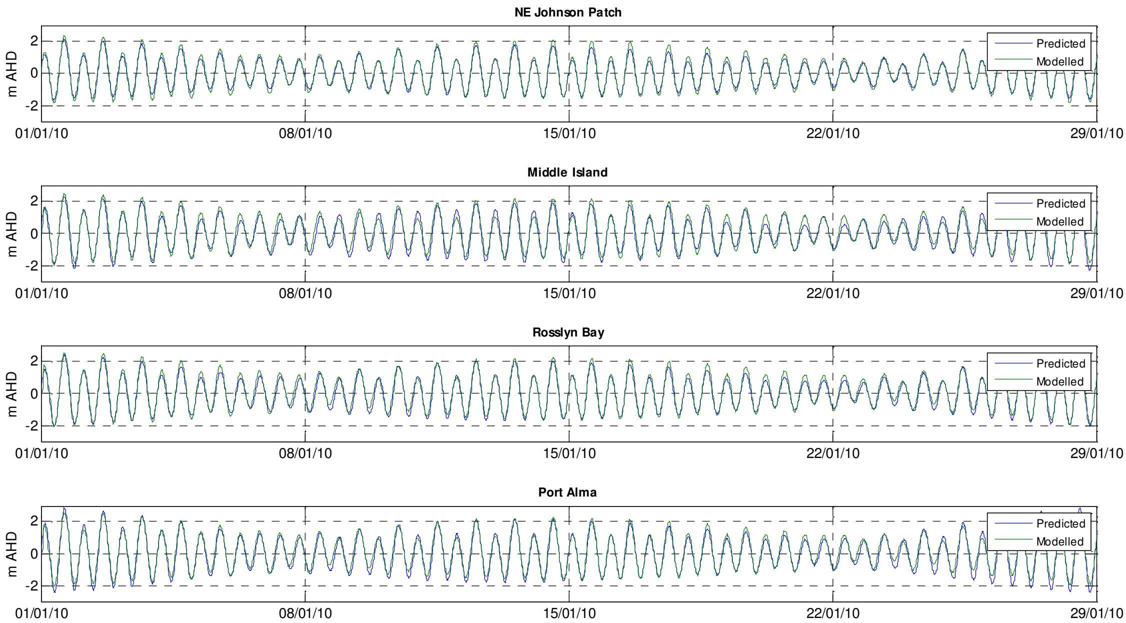

Figure B-8 Comparison of Modelled and Predicted Astronomical Tides in Keppel Bay

Calibration of Tidal and Wind Driven Current Variations at Great Keppel Island

Tidal and wind driven current fields at Great Keppel Island, in the vicinity of Putney Beach, have been calibrated in the model by comparison of the depth averaged ADCP current observations and the modelled results over the ADCP deployment period from 11 February – 13 March 2011.

Wind observations at Yeppoon and Rundle Island were combined to provide a spatially varying estimate of the wind conditions over the entire model domain. Figure B-9 displays a comparison of modelled and observed water levels, U (east-west) and V (north-south) depth averaged current velocities as well as the wind speed and directions at the Rundle Island wind station. Figure B-9 shows the influence that periods of strong south easterly wind conditions have on north going tidal current velocities at Great Keppel Island.

The level of agreement achieved by the model is considered adequate considering the following limitations and qualifications:

- The hydrodynamic model was forced only by astronomical tidal boundaries and the effects of wind within the model domain. The ADCP current measurements contain other sources of water level and current variability originating from outside the model domain but which cannot be accurately defined on the model boundaries.
- Wind conditions over the model domain were generalised by combining wind data from two land based wind stations.
- The two dimensional hydrodynamic model results were compared to measured currents that were averaged over the water column.

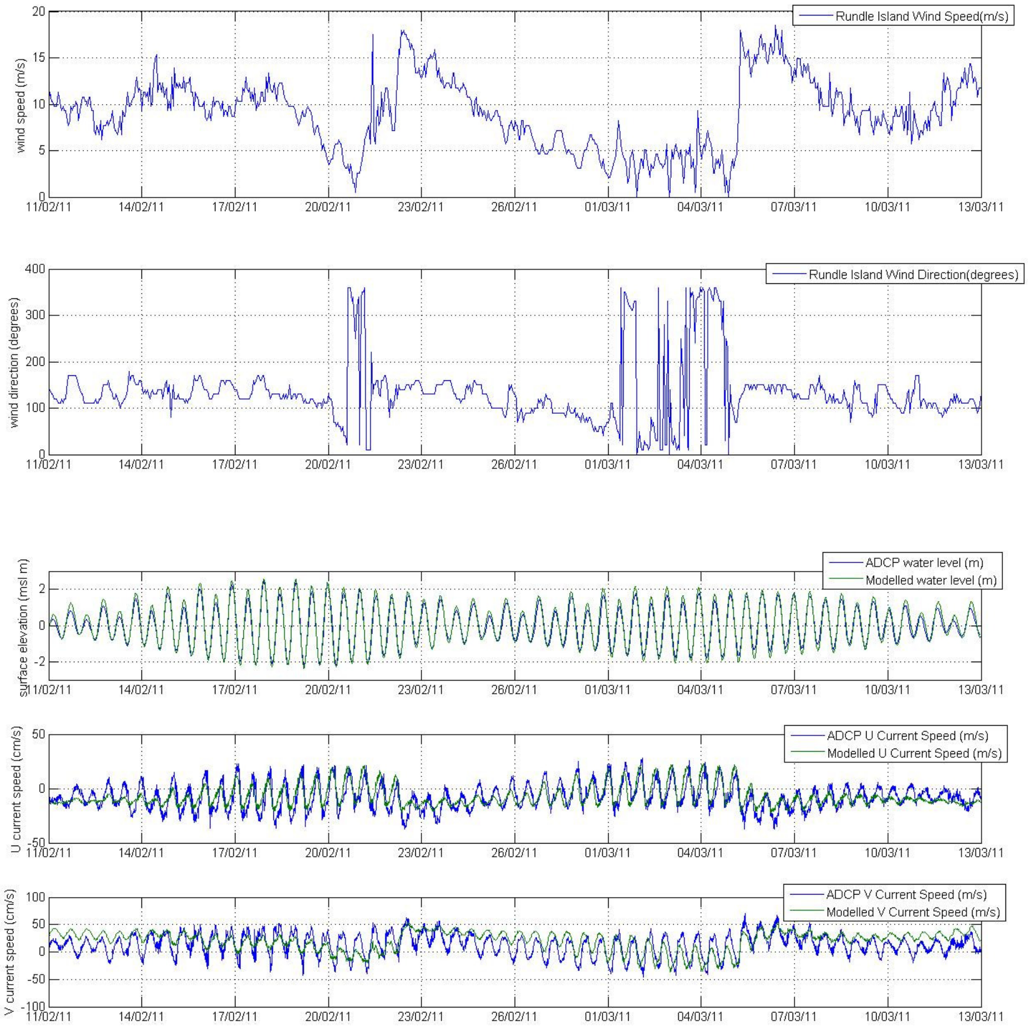

Figure B- 9 Comparison Modelled and Observed Water Levels and Currents in the Vicinity of Great Keppel Island