Great Keppel Island Resort Revitalisation EIS

Aquatic Ecology

Prepared for:

Tower Holdings Pty Ltd

frc environmental

PO Box 2363
Wellington Point Qld 4160

Telephone: + 61 7 3286 3850
Facsimile: + 61 7 3821 7936

frc Ref: 100705

Document Control Summary

Project No.:	100705
Status:	Report
Project Director:	John Thorogood
Project Manager:	Kylie McPherson
Title:	Great Keppel Island Resort Revitalisation EIS – Aquatic Ecology
Project Team:	C. Chargulaf, C. Conacher, C. Forward, D. Holzheimer, M. Langridge, A. Mallo, K. McPherson, L. Thorburn J. Thorogood
Client:	Tower Holdings Pty Ltd
Client Contact:	Anthony Aiossa
Date:	June 2012
Edition:	100705Rvi
Checked by:	________________
Issued by:	________________

Distribution Record

Tower Holdings Pty Ltd 1 pdf via e-mail

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Executive Summary

Tower Holdings Pty Ltd have proposed a Revitalisation Plan for Great Keppel Island, which will provide a low-rise, low-impact and environmentally focused resort on Great Keppel Island. This report presents the findings of field surveys and associated studies of the Great Keppel Island aquatic environment (marine and freshwater) and of a nominal 'infrastructure corridor' between the island and the mainland, and our assessment of the likely impacts of the proposed development on aquatic ecosystem health and biodiversity.

Existing Environment

Marine Ecosystems

Physicochemical water quality was typical of inshore waters. The concentration of total suspended solids was high in Leeke's and Putney creeks and at both mainland sites. High concentrations are likely to be related to sediment-laden run-off associated with heavy rain. The concentrations of total nitrogen and total phosphorus were also high at most sites. The concentrations of total copper and zinc exceeded the relevant guideline values at several sites.

Surface sediments were largely composed of sands and were uncontaminated within the marina footprint. Concentrations of metals in the sediment were generally higher at Leeke's Creek mouth, near the underwater observatory on Middle Island and at the mainland sites. The concentration of total lead exceeded the relevant guideline value at Leeke's Creek mouth during the post-wet survey.

Ten species of mangrove were recorded on Great Keppel Island and seven species at Kinka Beach. Six species of saltmarsh were recorded on Great Keppel Island and at Kinka Beach. Mangrove forests ranged from poor to good ecological health. Most trees showed few signs of stress; the major exceptions to this were at Putney Creek, where the community was assessed as being in poor health. Most of the mangrove communities provide good to very good fisheries habitat

Four species of seagrass were recorded around Great Keppel Island. Communities were dominated by *Halophila ovalis* and *Halodule uninervis.* Seagrass communities typically had an overall cover of <5% with sparse, patchy distribution. There has been a substantial decrease in the cover and the extent of seagrass since the 1970s. This is likely to be related to cyclone activity, sedimentation and / or elevated nutrient levels.

Coral communities were dominated by branching and massive growth forms, together with some plate / foliose, soft, mushroom and encrusting growth forms. The corals of Putney Beach were dominated by *Turbinaria* sp. and the soft coral *Sarcophyton* sp.. Coral cover was highest at Middle Island and Passage Rocks. Severely bleached corals were most abundant at Clam Bay during the wet season survey.

The intertidal rocky shore at Putney and Fishermans beaches supported a diverse invertebrate community, including oysters, barnacles, gastropods, limpets, chitons, anemones and crabs. Polychaeta and malacostracan crustaceans were the most common and abundant benthic infaunal taxa. The abundance of benthic infauna was highly variable at Fishermans Beach and Putney Beach; this may reflect 'boom and bust' cycles often associated with nutrient enrichment, due to sewage input from Putney Creek and moored vessels at Fishermans Beach.

The coral, seagrass and mangrove communities of the project area provide habitat for a variety of fish. Fish were most abundant within coral communities; few fish were recorded in seagrass meadow. Several species of sharks and rays were recorded.

Three species of marine turtle were recorded during the surveys; the flatback, green and hawksbill. A total of 29 nesting activities were recorded on Leeke's, Putney and Long beaches during the 2010–11 nesting season; three nesting events were recorded at Putney Beach.

Freshwater Ecosystems

Water quality at the freshwater site was variable. The pH was low in the upper reaches of Leeke's Creek, whilst electrical conductivity was high in the upper reaches of Putney Creek. The concentration of total nitrogen and phosphorus was above the relevant guideline value at almost all freshwater sites. Freshwater communities were characterised by a range of aquatic floral species with low cover. Aquatic macroinvertebrate communities were dominated by families that are tolerant of a wide range of environmental conditions and are often found in moderately disturbed ecosystems. Only one freshwater fish was caught at freshwater sites. No freshwater turtles were recorded.

Impacts and Mitigation

Marine Ecosystems

Construction and operation of the proposed development may impact marine ecosystems. Impacts may be both direct (for example, loss of habitat to dredging) and indirect (for example altered community structure in response to altered water quality), and either irreversible or temporary. Potential impacts to marine ecosystems include loss and / or gain of habitat, increased turbidity and sediment deposition, spills of hydrocarbons and other contaminants, copper contamination, nutrient enrichment, artificial lighting, human activities, introduction of marine pests, waste / litter, and acid sulphate or potential acid sulphate sediments

'Best practice' assessment and engineering practices are proposed to minimise the impacts associated with both construction and operation of the proposed development.

Whilst dredging will result in the loss of approximately 9.60 ha of substrate supporting patchy seagrass (patches of <15% cover over <10% of that area) and approximately 20 ha of unvegetated soft sediment, this loss represents less than 0.1% of the seagrass, and significantly less of the shallow subtidal unvegetated sediment, of the central Queensland region. Installation of the submarine cables and pipes from the island to the mainland are planned to avoid significant areas of seagrass, coral and mangrove, and is likely to result in the further disturbance of approximately 0.004 ha of sparse seagrass (regrowth can be expected). Disturbance of up to 0.04 ha of mangroves at Kinka Beach may be required.

Modelling has shown that it is likely that the dredge plume will be contained within the marina footprint; it may extend beyond the footprint for short periods. Consequently, floral and faunal communities beyond the marina footprint are highly unlikely to be significantly impacted: only a very small area of seagrass to the south of the marina (> 1 ha) may potentially be significantly, but temporarily, impacted by deposited silt. The coral communities in the vicinity of the proposed marina are likely to be largely unaffected by increased suspended solid concentration and sediment deposition. Fishes, turtles and marine mammals are highly unlikely to be significantly impacted. During dredging / sediment disturbance, the extent and density of the turbidity plume will be monitored, and the results of monitoring will inform the implementation of a dredging Environmental Monitoring Plan.

Construction of the marina will result in the loss of approximately 0.98 ha of rocky intertidal habitat, whilst providing a greater extent of hard surfaces (breakwalls, piles, pontoons, etc.), able to support algae, hard and soft coral, sponges and associated fauna.

Opening the mouth of Putney Creek will result in improved water quality within the creek and consequently enhanced ecosystem heath and productivity.

Fuel and oil spills together with waste and litter are potential impacts than may be effectively managed.

Monitoring of seagrass, mangroves, coral communities and soft-sediment macrobenthic communities will also take place during the construction phase. Annual monitoring of seagrass, mangrove, coral and soft-sediment macrobenthos health is proposed following completion of the development. Monitoring will focus on the community structure and health of communities in the vicinity of the development footprint (including around the island and adjacent to the mainland), and in areas where altered hydrodynamics may impact on habitat characteristics.

Offsets for marine habitat include fish habitat enhancement, restoration, creation or exchange and contribution of an offset amount constituting financial support for research, education, acquisition or exchange. In addition, the construction of a Research Centre and the establishment of a biodiversity fund have been proposed.

Operation of the marina and of the golf course have the potential to contribute nutrients and other contaminants to coastal waters, whilst lighting and increased vessel activity have the potential to impact on fish, turtles, dugong and other marine mammals. Tried-and-tested infrastructure and processes are proposed to effectively manage contaminant export and light-spillage. Increased vessel activity is to be countered through, responsive engineering design, opportunities for regulation of speed and importantly education.

The proposed development is sufficiently distant from other proposed major developments (at Balaclava Island, Curtis Island and Port of Gladstone) to be unlikely to contribute to significant cumulative impacts.

Freshwater Ecosystems

Construction and operation activities have the potential to impact on surface water quality, sediment quality and freshwater ecosystems through vegetation clearing and earthworks, increased turbidity and subsequent sedimentation, impacts to aquatic fauna passage, hydrocarbon contamination, litter / waste and nutrient enrichment.

'Best practice' engineering design and implementation will be employed to effectively manage the impacts associated with both construction and operation of the proposed development. The minimal habitat loss proposed is unlikely to impact ecosystem function or health. Erosion and sediment control measures will be employed to manage the necessary clearing and stormwater runoff: predicted impacts to water quality are insignificant. Appropriately designed fish-passage will be provided for where waterways crossings are required.

Monitoring of turbidity levels in the creeks will be undertaken when constructing permanent or temporary creek crossings during the wet season. Water quality in the water supply dam will be monitored regularly to confirm the suitability of the water for irrigation (including monitoring of blue green algae), and to confirm water quality in the event of release to the receiving environment.

Conclusions

Great Keppel Island is surrounded by waters of significant ecological and conservation value, whilst the island's freshwaters are of lesser conservation significance. The major drivers of coastal ecosystem health are broad-scale climate and flood flows of mainland river systems.

The proposed development, through carefully considered siting, scale and design has been modelled to show remarkably minor impacts on the ecosystem health and biodiversity of both coastal and fresh- waters.

Development of the marina and infrastructure connection with the mainland will result in the loss of small areas of seagrass and intertidal rocky shore, and a larger area of unvegetated soft sediment. Loss of mangroves and coral-associated communities will be negligible. These losses will be offset by the gain of hard substrate habitat and improved water quality and productivity within Putney Creek, in addition to the provision of substantial, funded research and education facilities.

Rigorous monitoring of both construction and operations are proposed. This monitoring will serve to inform the implementation of an equally rigorous environmental management plan.

The proponent's approach to this development represent world's best practice in respect of impact avoidance, minimisation and mitigation. The offsets proposed are of significant benefit to the ongoing effective management of the region.

1 Introduction

This report presents the findings of field surveys and associated studies of the Great Keppel Island aquatic environment (marine and freshwater) and of a nominal 'infrastructure corridor' between the island and the mainland, on behalf of Tower Holdings Pty Ltd. It contributes to both the Australian Government *Guidelines for an Environmental Impact Statement for the Great Keppel Island Tourism and Marina Development* (EPBC 2010/5521/GBRMPA G33552.1) and the Queensland Government *Terms of Reference (ToR) for an Environmental Impact Statement (EIS) – Great Keppel Island Resort Project*. Table 1.1 outlines the specific Sections of these ToR that are addressed in this report.

This report provides a description of the marine and freshwater communities within the footprint of the proposed Great Keppel Island Resort Revitalisation Project, and in adjacent waters (Figure 1.1). An assessment of the potential and likely impacts of the proposed marina on these communities has also been undertaken, and opportunities for impact mitigation are discussed.

Table 1.1 State and national Terms of Reference for an environmental impact statement for the Great Keppel Island Revitalisation project.

Terms of Reference		Section/s of this Report
	QUEENSLAND GOVERNMENT[1]	
3.3.4	**Aquatic ecology**	
3.3.4.1	Description of environmental values	
	Flora	5.2, 7.2, Appendix E
	Fauna – turtles	6.2, Appendix F
	Benthic macroinvertebrates	6.2, Appendix F
	Fish Habitat	5.2, Appendix E
3.3.4.2	Potential impacts	8.2, 8.2
3.3.4.3	Mitigation measures	8.3, 9.3
3.5.2	**Water quality**	
3.5.2.1	Description of environmental values	Appendix C
	• Baseline information on water quality of coastal waters	3.1, 3.3
	• Values identified in the Environmental Protection (Water) Policy	3.1
3.5.3	**Sediment quality and dredging**	Appendix D
	• Baseline information on marine sediments and sediment quantity in the area likely to be disturbed by dredging or vessel movements	4.2
	• Assessment of marine sediments in accordance with the *National Assessment Guidelines for Dredging 2009* (Department of the Environment, Water, Heritage and the Arts 2009)	4.2
	AUSTRALIAN GOVERNMENT[2]	
5.5	**Matters of National Environmental Significance**	
	a) World Heritage Properties	Appendix B
	b) National Heritage Places	Appendix B
	c) Great Barrier Reef Marine Park	Appendix B

Terms of Reference		Section/s of this Report
	d) Listed threatened species and ecological communities	Appendix B
	e) Listed migratory species	Appendix B
	f) Commonwealth marine areas	Appendix B
5.8	**Existing Environment**	
5.8.1	Bio-physical Environment	
	g) Provide a description of biota/biotic habitats, including a map of marine/intertidal habitats (including information on seasonal fluctuations e.g. seagrass prevalence), likely to be affected by the proposed development	5, 7, Appendix E & F
	h) Provide the results of surveys and relevant research and a detailed map displaying the location of an regional ecosystems listed under Queensland's *Vegetation Management Act 1999*, ecological communities listed as threatened under the EPBC Act, and the location of any flora species of national, regional and conservation significance.	5, 7, Appendix B & E
	i) Include a summary of the location, size and breeding status of terrestrial and marine threatened and migratory species listed under the EPBC Act, which are likely to occur in the area affected by the proposal.	Appendix B
	j) Include a summary of the location and size of threatened ecological communities listed under the EPBC Act, which are likely to occur in the area surrounding the proposal.	Appendix B
	k) Identify, describe and map environments important to the health of the Great Barrier Reef Marine Park, including terrestrial and intertidal habitats and Island watercourses that are likely to be affected by the proposed development.	5, 7
	l) Identify, describe and map reef[3] communities (e.g. infauna, benthic invertebrates) in areas likely to be affected by the proposal development, including information on species diversity, seasonality and abundance.	6

Terms of Reference		Section/s of this Report
	q) Provide a description of the biodiversity and biogeography of the receiving environment. Sensitive environments and species must be identified along with: i) Key ecological relationships and interdependencies (e.g. species aggregations, flora and fauna relationships etc) with particular attention to the receiving environment in the Great Barrier Reef Marine Park, and ii) A description of the relative importance of the sensitive species and/or environment and the role it plays in overall ecosystems functioning and the functional redundancy of that species and/or environment.	5, 6, 7, Appendix F
	r) Identification of any existing or proposed reserves in or adjacent to the project and their status.	Appendix B
	s) Identification of the World Heritage and National Heritage values expressed in the vicinity of the proposed development, including an evaluation of the contribution that the values expressed at this location make the overall values for the Great Barrier Reef World Heritage Area and National Heritage Place	Appendix B
	t) Identification of those aspects of the Commonwealth marine area potentially affected by the proposal, including but not limited to baseline data on listed threatened, migratory and marine species and any other species of conservation significance, including cetaceans.	8, Appendix B, Appendix F
5.9	**Impacts of the Proposed Development**	
5.9.1	General Impacts	
	d) A discussion of potential impacts which may arise from the introduction of pest species on the terrestrial and marine environment	8.2, 9.2
	f) In discussing potential impacts, consider how the interaction of extreme environmental events (e.g. cyclones, coral bleaching, flood events) and any related cumulative impacts may impact on the proposal and the environment (both independently and cumulatively)	8.2
5.9.2	Impacts to Listed Migratory Species, Threatened Species and Ecological Communities	
	Assessment of all potential and likely impacts to listed migratory species, threatened species and ecological communities from the construction and on-going operation of the development, including but not limited to impacts on:	

Terms of Reference		Section/s of this Report
	a) Marine turtles	8.2
	b) Cetaceans	8.2
	c) Dugongs	8.2
	d) Elasmobranchs	8.28.2
5.9.5	Impacts to the Environment of the Great Barrier Reef Marine Park	
	a) Direct impacts of the proposal (including marina construction/operation and installation of sub-sea utilities) on water quality, including salinity, turbidity, suspended sediments, colour, odour, dissolved oxygen, nutrient levels, concentrations of heavy metals, pH, hydrocarbon spills, and other relevant parameters or dissolved substances.	8.2, 9.2, Appendix C
	i) Impacts to marine flora and fauna species and biotic habitats, including sensitive environments such as coral reefs and seagrasses. The assessment must consider changes to species composition and abundance, community type and functionality, propagation of species and potential barriers to species movement or gene flow.	8.2, 9.2
	j) Impacts to macrobenthic species, fish, seasnakes and larger marine fauna species (composition and population densities) including changes to communities' breeding success, habitat, potential barriers or disturbances to migration or migratory patterns and other wildlife movements	8.2
	k) Impact of anticipated illumination on seabirds, marine turtles and other migratory species, including impacts on nesting and disorientation	8.2
	l) Impacts of increased visitor use on turtle nesting and hatchings on Great Keppel Island and the Keppel Group.	8.2
	m) Impact on cetaceans, dugongs, and marine turtles from increased vessel movement from the proposed marina and potential for boat strike.	8.2
5.9.7	Impacts to the Commonwealth Marine Environment	
	a) Impacts resulting from an increase in vessel movement from the proposed marina, and the potential for boat strike on marine fauna in the Commonwealth marine area	8.2
	c) Potential of pest species becoming established in the Commonwealth marine area	8.2
5.9.8	Physical and Biodiversity Impacts due to Proposed Development	

Terms of Reference		Section/s of this Report
	a) Likely impacts to the ecological integrity of wetland areas	8.2
	b) Likely impacts to the ecological integrity of ecosystems important to maintaining the health of Great Barrier Reef ecosystems	8.2
	2. Consider potential impacts to fauna and flora species and communities (composition and population densities)	8.2
	3. Consider potential impacts arising from the introduction and/or spread of exotic pest species	8.2
5.10	**Safeguards, Mitigation Measures and Monitoring, Offsets**	
5.10.1	Mitigation Measures	8.3, 9.3
5.10.2	Offsets	8.3, 9.3
5.11	Monitoring and Reporting	8.4, 9.4

[1] The Coordinator-General (October 2010) *Terms of reference for an environmental impact statement (EIS): Great Keppel Island Resort Project*. Department of Infrastructure and Planning, Queensland Government

[2] Department of Sustainability, Environment, Water, Population and Communities, and Great Barrier Reef Marine Park Authority (February 2011) *Guidelines for an Environmental Impact Statement for the Great Keppel Island Tourism and Marina Development, Queensland*. Australian Government

[3] A reference to reef communities includes all Great Barrier Reef ecosystems components including corals, algae, mangroves, soft sediment habitats etc (as per the Great Barrier Reef Outlook Report 2009)

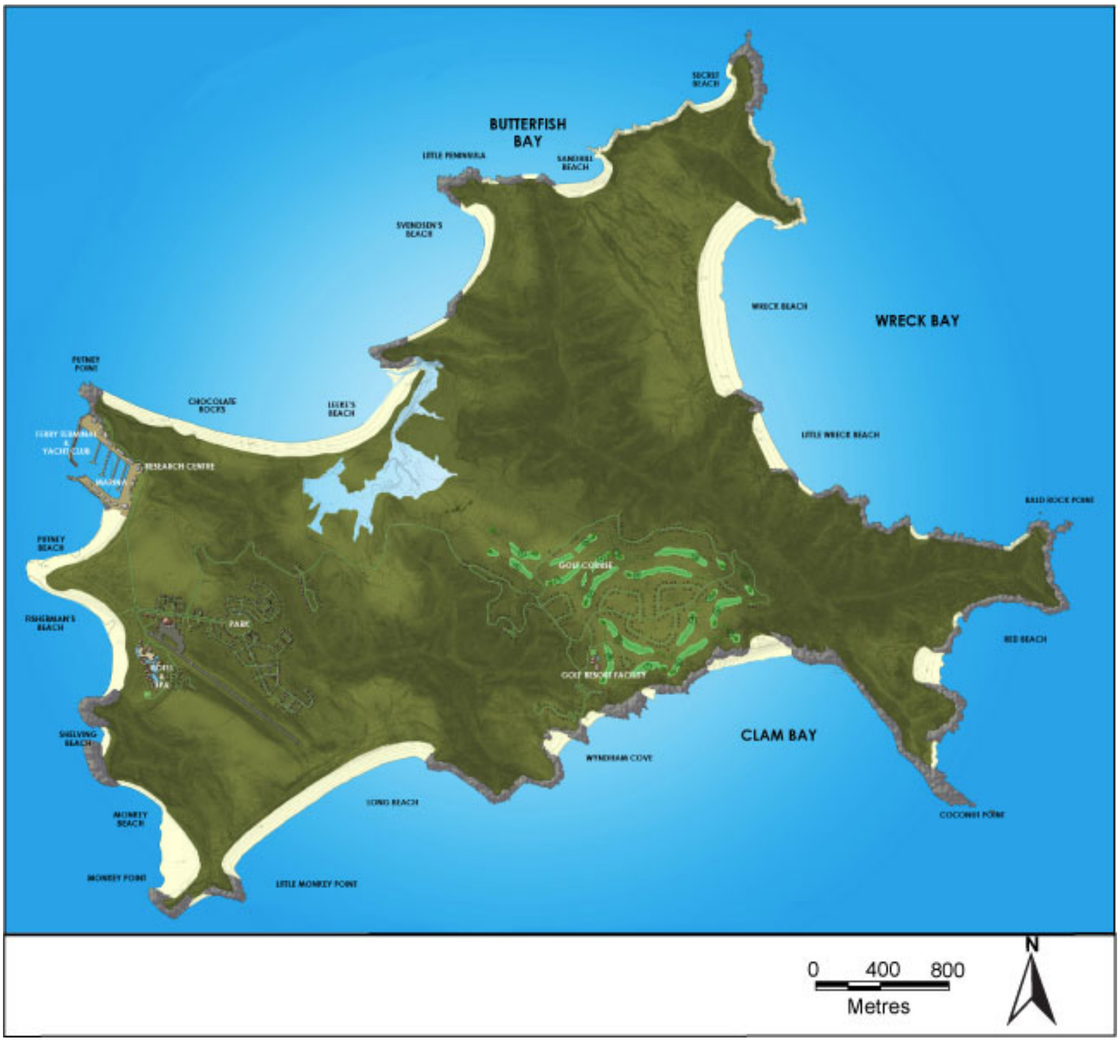

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	Figure 1.1 Footprint of the proposed Great Keppel Island Revitalisation Project	
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2 Project Background

2.1 Description of the Site

2.2 Project Description

Tower Holdings Pty Ltd have proposed a Revitalisation Plan for Great Keppel Island, which will provide a low-rise, low-impact and environmentally focused resort on Great Keppel Island.

On 28 August 2009 the Coordinator-General declared the 'Great Keppel Island Resort Project' to be a 'significant project'. Tower Holdings Pty Ltd subsequently submitted an *Environmental and Biodiversity Conservation Act 1999* (EPBC Act) referral to the Minister of the Department of Environment, Water, Heritage and the Arts (DEWHA). On 28 October 2009, the Minister decided that the proposed action would have unacceptable impacts in accordance with Part 3 of the EPBC Act.

In response to DEWHA's rejection of the proposal, Tower Holdings Pty Ltd submitted a 2010 EPBC Act referral, which included a revised and substantially reduced Revitalisation Plan for Great Keppel Island. On 4 July 2010, the Minister declared the revised plan was to undergo appropriate assessment and approval under the EPBC Act, prior to proceeding.

The revised proposal for the Great Keppel Island Resort Revitalisation Plan 2010 (Figure 1.1) includes the:

- designation of the majority of Lot 21 (approximately 62% or 545 ha) as an Environmental Protection Area, with the footprint to be chosen through collaboration with conservation groups and the Queensland Parks and Wildlife Service (QPWS)
- demolition of the old resort and construction of a new hotel at Fisherman's Beach comprising 250 suites and a day spa
- dredging of Putney Beach for construction of the marina and re-nourishment of Putney Beach using dredge spoil
- development of a marina at Putney Beach comprising 250 berths, emergency services facilities, ferry terminal, yacht club and dry dock storage
- development of a retail area with a mix of cafes, restaurants and clothing stores around the marina

- development of an 18-hole golf course, integrated with essential habitats and ecological corridors, and located on previously disturbed grazing lands
- replacement of the existing airstrip runway
- development of 750 eco-tourism villas incorporating sustainable building design, rooftop solar panels and water tanks
- development of 300 eco-tourism apartments incorporating sustainable building design, rooftop solar panels and water tanks
- development of associated service facilities and utilities (e.g. waste collection area, fire-fighting and emergency services hub, fuel storage, solar panels and wastewater treatment plant and a water desalination plant)
- establishment of buffer zones to ensure protection of habitats and to provide fauna corridors
- establishment of constructed wetlands and a Water Management Plan to mitigate effects of stormwater run-off and golf course run-off into the Great Barrier Reef Marine Park (GBRMP)
- establishment of the Great Keppel Island Research Centre and Biodiversity Conservation Fund (BCF), which will aim to deliver a better understanding of the surrounding environments, and to actively undertake conservation works to enhance the natural environment
- development of a sporting park which can be used by resort guests and other Great Keppel Island residents and visitors
- preservation of indigenous sites of significance (in consultation with the traditional owners)
- restoration of the original Leeke's Homestead, and
- installation of a submarine connection of services (e.g. power, water, telecommunications, wastewater and gas) between Great Keppel Island and Kinka Beach on the mainland.

2.3 Survey Area

The survey area included marine and freshwater communities on and surrounding Great Keppel Island, and marine communities near Kinka Beach and Tanby Beach on the mainland (Figure 2.1).

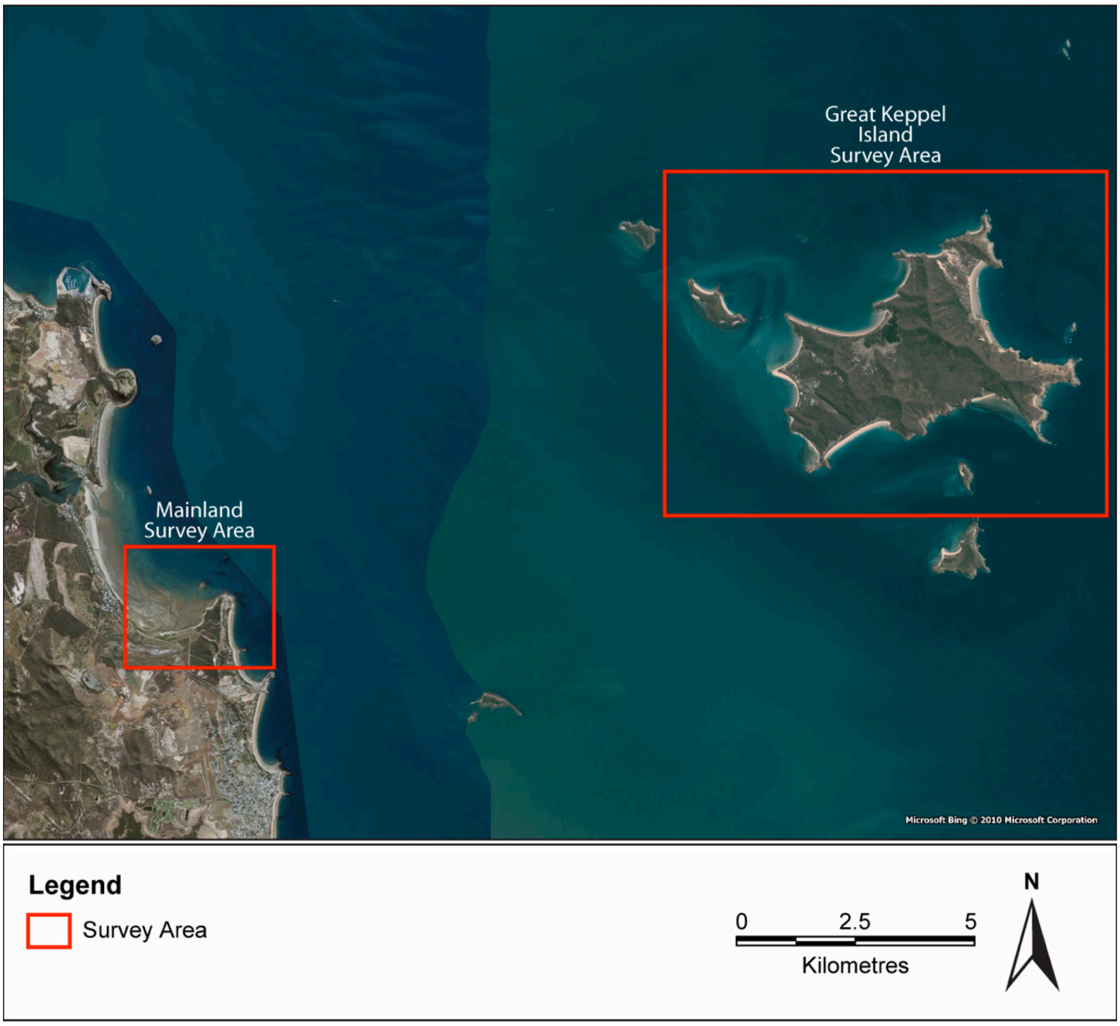

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	Figure 2.1 Great Keppel Island and mainland survey areas.	
	Microsoft Bing © 2010	June 2011

Spatial and temporal replication was determined adequate to describe the existing environment and ***predict an impact***, as opposed to ***future assessment of the extent of impact***. Water quality monitoring was not designed to set local water quality guidelines. Additional replicated sampling to inform post-development impact assessment and local water quality guidelines will be addressed at the Environmental Management Plan (EMP) and / or conditions of approval stage.

Great Keppel Island

Great Keppel Island is part of a group of 16 continental islands called the Keppel Island Group that covers an area of 14.5 km^2. It is located in the southern reaches of the Great Barrier Reef, approximately 15 km offshore of Yeppoon in northern Queensland and more than 200 km inshore of the Outer Barrier Reef and the Swain Reef complex.

The Keppel Bay Island Group is a designated National Park that includes 15 islands (Great Keppel Island is not part of the National Park). The Great Barrier Reef Marine Park surrounds the Keppel Island Group and together they form the Great Barrier Reef World Heritage Area, the world's largest reef and island archipelago.

The Keppel Island Group is located directly offshore of the Fitzroy Basin, which is the largest basin draining into the Great Barrier Reef. The islands lie in a shallow basin north of Keppel Bay, and are surrounded by a patchwork of fringing reefs (GBRMPA 2007). The Keppel Island Group is managed by the Rockhampton Regional Council (RRC).

Great Keppel Island is the largest island (1 454 ha) of the Keppel Island Group. There are 17 beaches on Great Keppel Island and its natural environment offers a range of popular tourist activities including swimming, diving, snorkelling and bushwalking. Until recently, Great Keppel Island had a number of different commercial accommodation facilities ranging from camping to resort accommodation. The Great Keppel Island Resort was the main tourism resort on the island, until it closed in early 2008. There are two backpacker facilities and approximately 20 residential / commercial premises currently on the island.

Mainland

Kinka Beach and Tanby Beach are a part of a small coastal settlement about 15 km west of Great Keppel Island, 3 km north of Emu Park and 7 km south of Yeppoon. The land was originally part of a pastoral lease, until a small residential development began in the 1930s. The area is residential, except for one shop, a caravan park and three motels. In the 2006 census, the local settlement had a population of 621.

2.4 Survey Timing

Surveys were undertaken during the following seasons:

- pre-wet – 15 to 19 November 2010
- wet – 17 to 21 January 2011
- post-wet – 30 March to 2 April 2011 (March/April), and 30 April to 2 May 2011 (April/May), and
- winter (to quantify marine community 'recovery' post-flooding) – 11 to 14 July 2011.

The design tree for the marine assessment is provided in Appendix A. Sites were surveyed at different times of the year, due to restrictions associated with rough weather (the March/April 2011 survey was cut short by strong winds and large swell and could not resume until April/May 2011) and boat availability and permits (delays in sourcing commercial vessel and permits to green zones meant that the November 2010 survey could not be completed until January 2011), together with the addition of new sites as potential locations for project elements were refined (e.g. the location for wastewater release at Long Beach was advised at the post-wet season stage).

2.5 Marine Surveys

The following marine communities, together with water and sediment quality, were assessed at sites around Great Keppel Island:

- mangroves
- seagrass meadows
- coral outcrops
- soft sediment macroinvertebrate communities
- rocky shore communities, and
- marine vertebrates.

The following marine communities were assessed at sites near the mainland:

- mangroves, and
- soft sediment macroinvertebrate communities.

2.6 Freshwater Surveys

Freshwater surveys were undertaken at eight sites on Great Keppel Island during the post-wet season. Freshwater surveys included assessments of:

- water quality
- sediment quality
- aquatic habitat
- macrophytes
- aquatic macroinvertebrates, and
- fish.

The design tree for the freshwater assessment is provided in Appendix A. Sites were surveyed at different times of the year, but within the post-wet season, in response to water levels and as information about new waterbodies became available. Natural channel sites (non-dam sites) are ephemeral and dry throughout most of the year.

Further details on the survey design are provided in Appendix A. Details of relevant legislation is provided in Appendix B.

3 Marine Water Quality

3.1 Water Quality Objectives

Water quality objectives (WQOs) have been defined based on published guidelines (Appendix B) including the *Water Quality Guidelines for the Great Barrier Reef Marine Park* (GBRMPA 2009) and the *Queensland Water Quality Guidelines* (QWQG) for coastal / inshore waters in the central Queensland region (QWQG; DERM 2009a). For parameters not specified in these guidelines, the WQOs have been based on the *Australian and New Zealand Water Quality Guidelines for Fresh and Marine Waters* (the national guidelines) (ANZECC & ARMCANZ 2000) for tropical Australia (see Appendix C for further details).

These published guidelines are considered sufficient to protect the described environmental values of the proposed development area, with the exception of visual recreation and cultural heritage, to which the following guidelines apply:

- visual recreation – water should be free of: floating debris; oil and grease; substances that produce undesirable colour, odour, taste or foaming; and undesirable aquatic life such as algae or dense growth of attached plants or insects, and
- cultural heritage – protect or restore indigenous and non-indigenous cultural heritage, consistent with relevant policies and plans.

3.2 Methods

Sites Surveyed

Surveys were undertaken during the following seasons:

- pre-wet – 15 to 19 November 2010
- wet – 17 to 21 January 2011, and
- post-wet – 30 March to 2 April 2011, and 30 April to 2 May 2011.

Water quality assessments included *in situ* physicochemical measurements at 30 sites around Great Keppel Island (Figure 3.1):

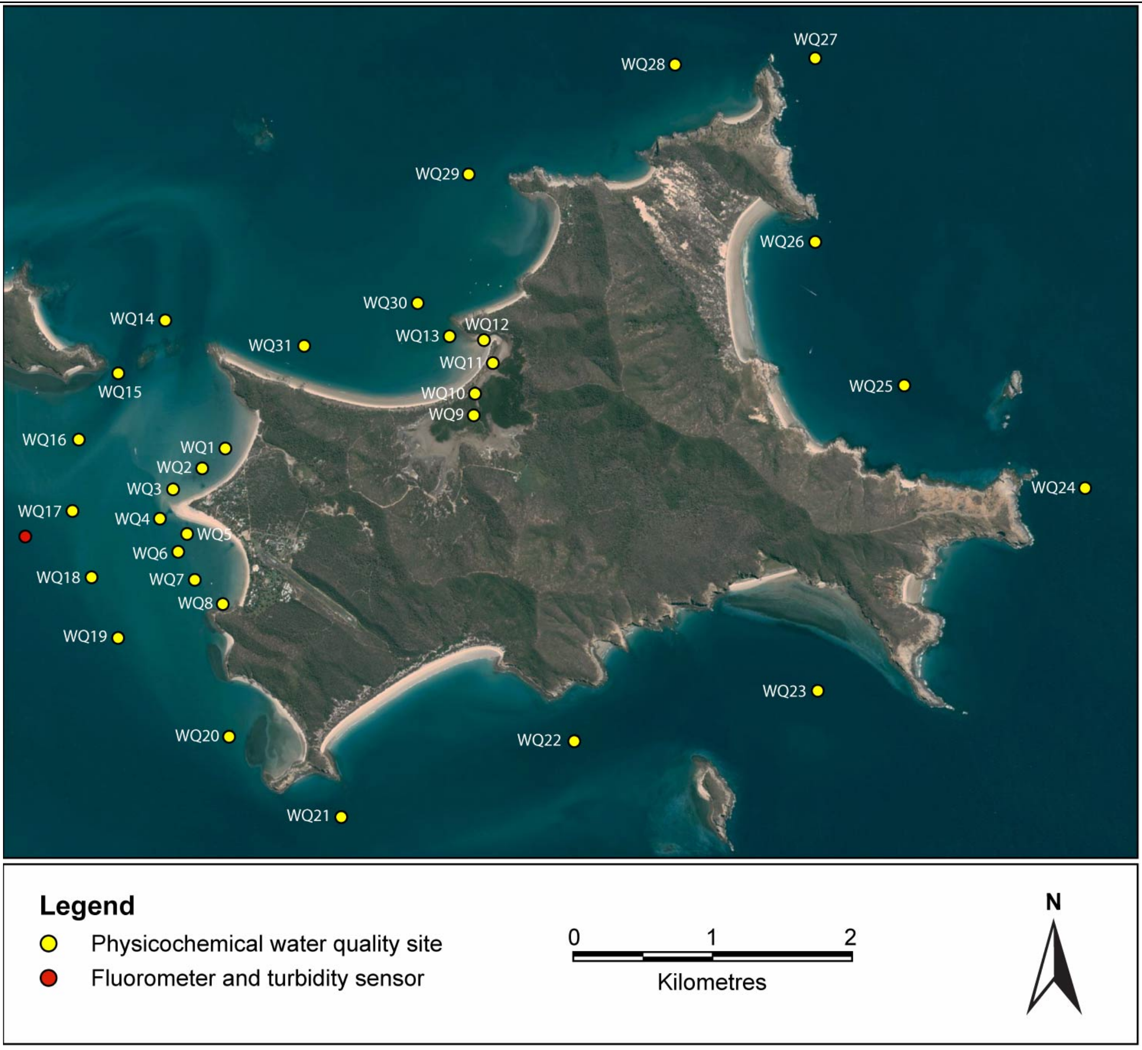
- Putney Point to Putney Beach (WQ1–8) (near the proposed marina)
- the Leeke's Creek area (WQ 9–13) (downstream of the proposed golf course), and
- offshore[1] (WQ14–30) (around the entire island, approximately 500 m from the shore).

Water samples were collected at 12 sites surrounding Great Keppel Island (Figure 3.2) and two sites near the mainland (Figure 3.3) for laboratory analysis of potential contaminants.

A combination fluorometer and turbidity logger was placed offshore of The Spit (site TS; located between Putney and Fishermans beaches) by Water Technology from 11 February to 13 March 2011 to measure chlorophyll-a concentration and turbidity (Figure 3.1).

Further details are provided in Appendix C.

[1] Only offshore sites were surveyed during the wet season due to time-constraints.



Great Keppel Island Revitalisation EIS

Figure 3.1 Great Keppel Island physicochemical water quality sites.

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June 2011

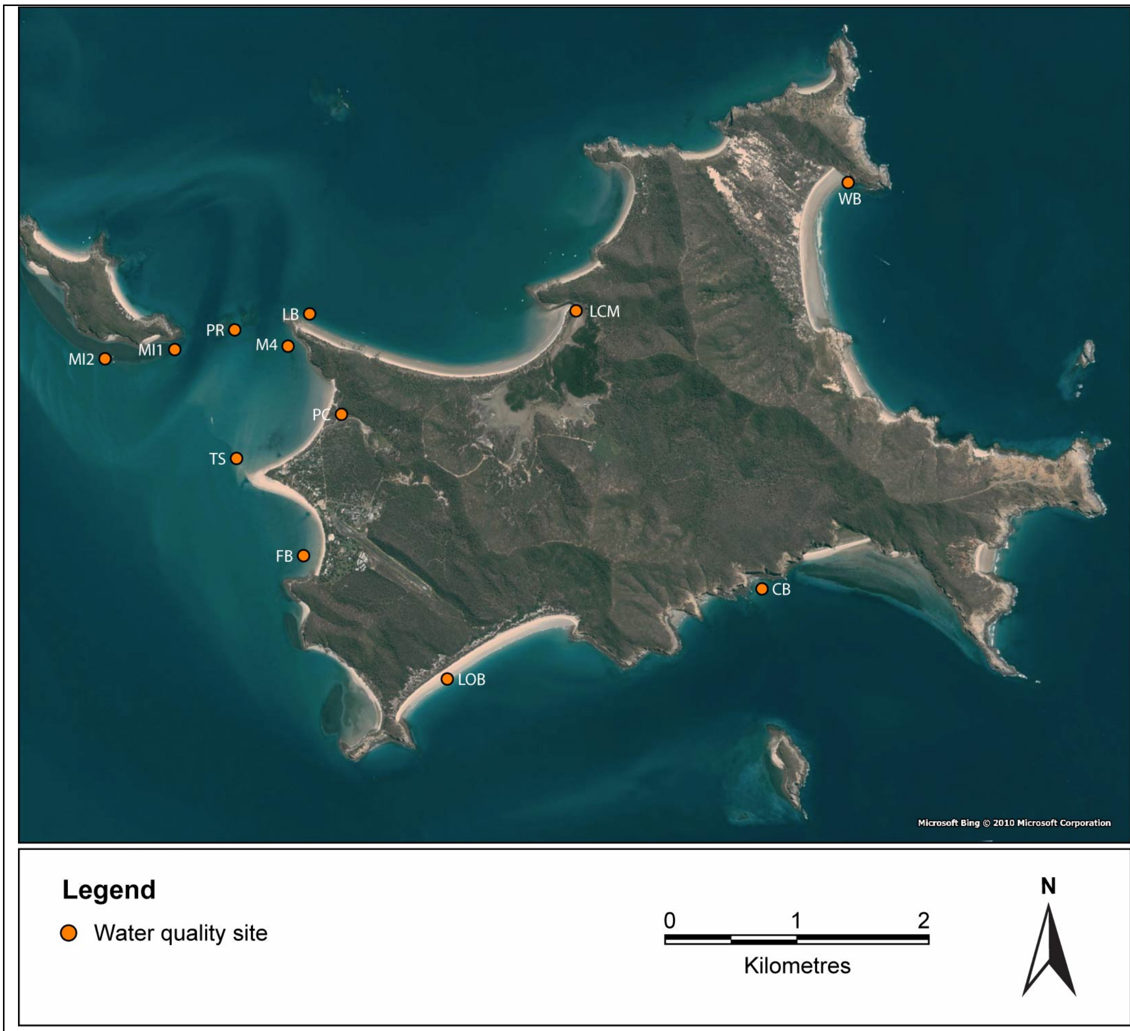

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	Figure 3.2 Great Keppel Island water quality sites for laboratory analysis of contaminants.	
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Legend

Survey site

0 0.4 0.8
Kilometres

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	Figure 3.3 Mainland water quality sites for laboratory analysis of contaminants.	
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3.3 Results

Physicochemical

Salinity of the survey area was typical of inshore waters. During the post-wet survey, salinity was typically lower near the surface than at depth. During the wet survey, salinity was lower on an outgoing tide than on an incoming tide. This is likely to reflect tidal movement of freshwater run-off (floodwaters) and stratification of fresh and marine waters.

Dissolved oxygen concentrations were typically higher near the surface than at depth, and were highest during the wet survey. Concentrations near the surface were often above the relevant QWQG trigger value range whereas concentrations at depth were often below the relevant range. Leeke's Creek tended to have lower dissolved oxygen concentrations than other sites. These patterns are likely to reflect wind- and wave-driven water movement that mixes the water column with oxygen in the atmosphere (strong winds and large waves characterised the wet survey); together with primary production and microbial activity.

Turbidity was typically higher during the post-wet survey than other surveys, and higher at depth than near the surface. Turbidity at several sites exceeded the relevant QWQG trigger value during the wet and post-wet survey; turbidity tended to be highest in Leeke's Creek but was also relatively high near Passage Rocks and Putney Point. Turbidity offshore of The Spit (collected by the *in situ* logger) also exceeded the QWQG trigger value on several occasions and often for an extended duration (more than five days). High turbidity reflects sediment-laden run-off associated with rainfall and / or disturbance of the substrate due to wind, wave and tidal action; all of which introduce suspended particles into the water column.

The concentration of total suspended solids exceeded the relevant QWQG trigger value in Leeke's and Putney creeks and at both mainland sites. Concentrations were generally highest in the post-wet survey. High concentrations are likely to be related to sediment-laden run-off associated with heavy rain.

Laboratory Analyses

The concentrations of total nitrogen and total phosphorus exceeded the relevant QWQG trigger values at most sites, and were particularly high in Putney Creek during the pre-wet survey (Figure 3.4). The concentration of total phosphorus was relatively high at the mainland sites (Figure 3.5). The concentration of chlorophyll-a offshore of The Spit was above the QWQG upper trigger value for much of the fluorometer logging duration (Figure 3.6). This is likely to be related to the concentration of nitrogen in nearby waters exceeding the QWQG upper trigger value prior to the survey, and the concentration of phosphorus exceeding the QWQG upper trigger value both before and after the survey.

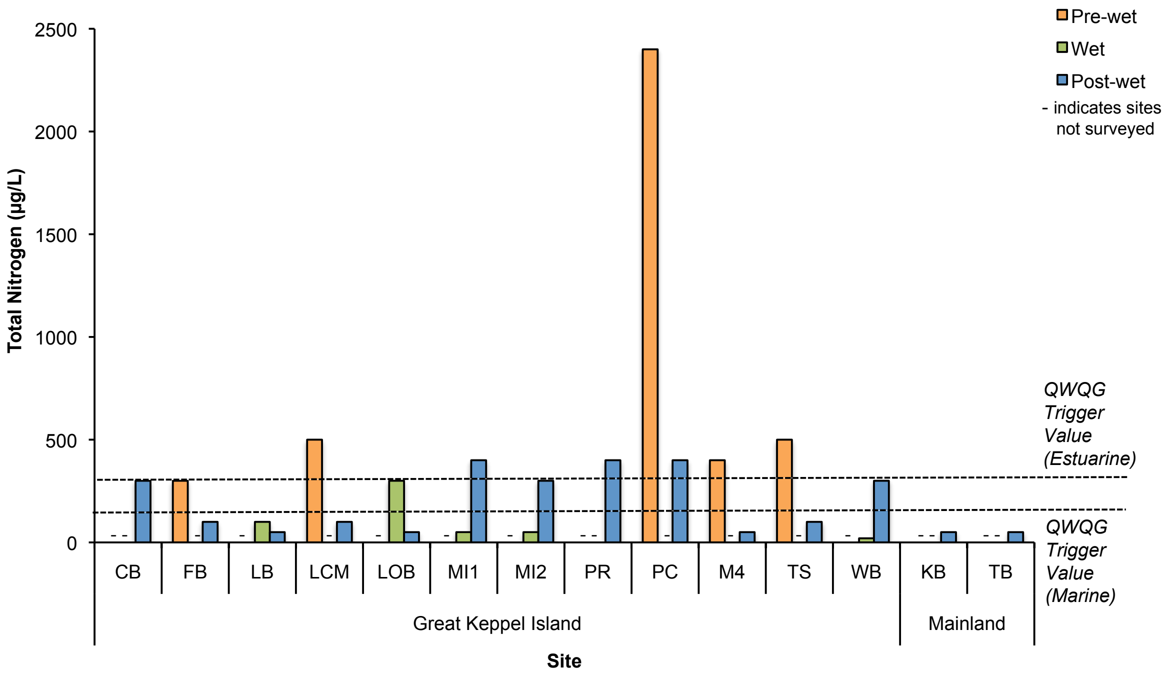

Figure 3.4 Total nitrogen concentration in surface waters at each site in each survey.

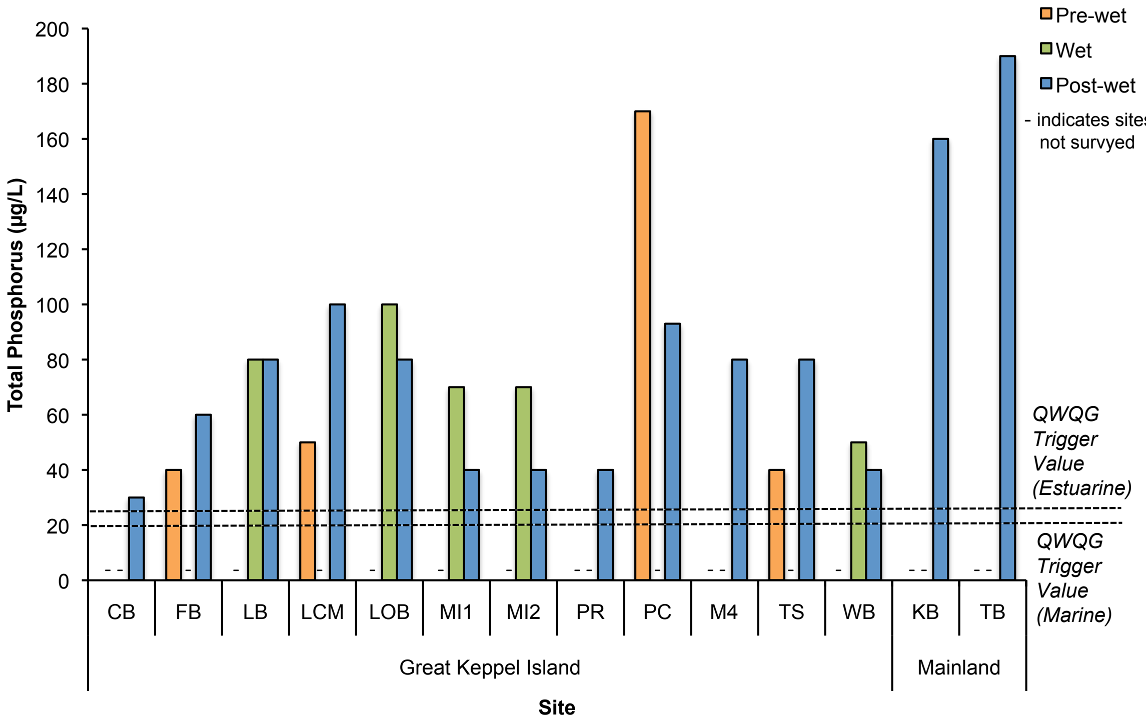

Figure 3.5 Total phosphorus concentration in surface waters at each site in each survey.

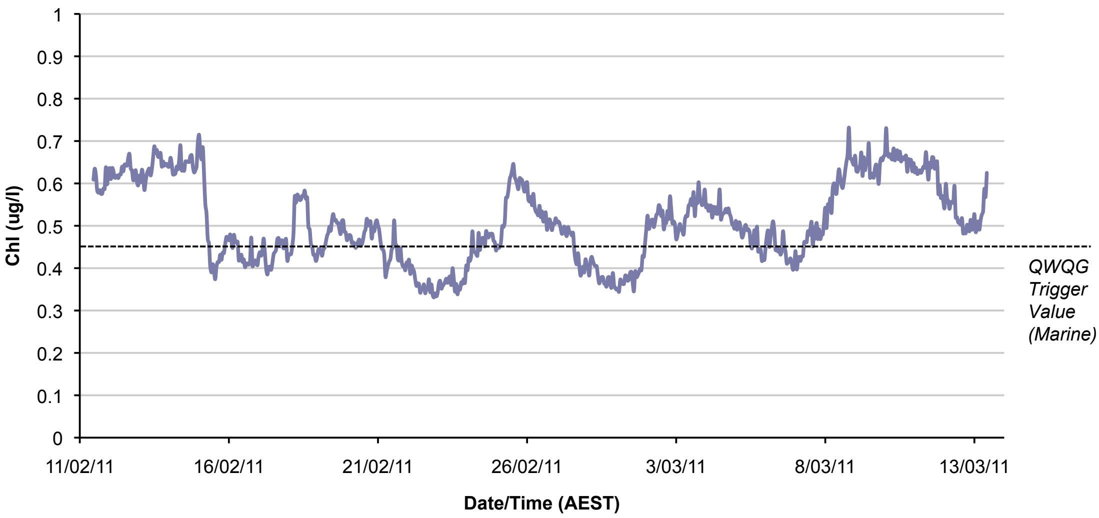

Figure 3.6 Concentration of chlorophyll-a in waters offshore of The Spit from 11 February 2011 to 13 March 2011.

The concentration of total arsenic was below the laboratory detection limit at all sites during all surveys, except in Putney Creek during the pre-wet survey. There are no trigger values for arsenic in estuarine or marine waters.

The concentration of total copper exceeded the relevant ANZECC & ARMCANZ trigger value in Putney Creek and at the mainland sites in the post-wet survey (Figure 3.7).

The concentration of total zinc exceeded the relevant ANZECC & ARMCANZ trigger value at most sites in the post-wet survey, and was particularly high near The Spit and to a lesser extent in Putney Creek and at Kinka Beach (Figure 3.8).

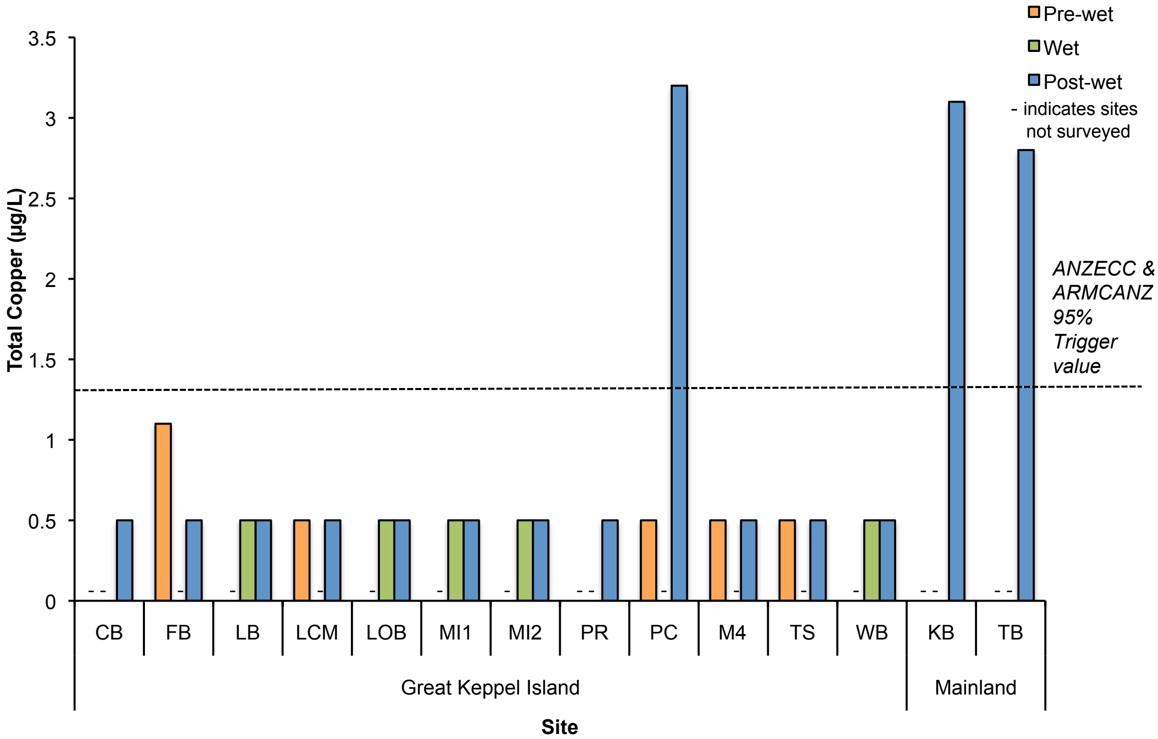

Figure 3.7 Total copper concentration in surface waters at each site in each survey.

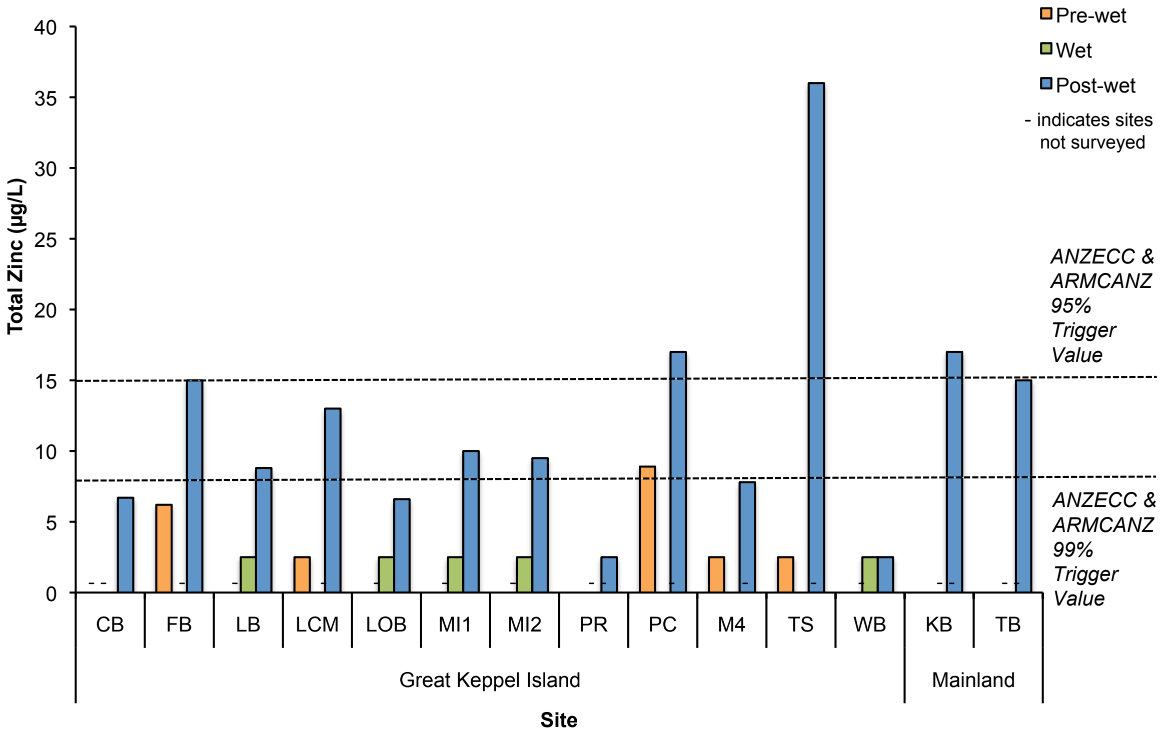

Figure 3.8 Total zinc concentration in surface waters at each site in each survey.

The concentration of other metals and metalloids (cadmium, chromium, nickel, lead and mercury), total petroleum hydrocarbons, aromatic hydrocarbons and organochloride pesticides were below laboratory detection limits and / or relevant trigger values at all sites in all surveys.

Regional Context

Concern regarding the trend of decline in water quality in the water draining to the Great Barrier Reef, as well as its lagoon, is well documented. Located approximately 40 km off the mouth of the Fitzroy River, the waters surrounding Great Keppel Island have a seasonal input of fresh and turbid waters that can result in episodes of poor water quality. Land use in the Fitzroy Basin is dominated by grazing and agriculture, together with mining and forestry.

The main sources of nutrients in the project area are derived from river and land run-off, particularly during floods. Nutrients (nitrogen and phosphorous) are mostly derived from diffuse sources, however point sources are locally significant in the upper estuary during extended periods of very low flow (as nutrients remain for a long time). There is little evidence to indicate that nutrient loads from the Fitzroy Basin are having a major impact on the ecology of the Fitzroy River estuary and offshore waters.

There are significant concentrations of several herbicides (atrazine, tebuthiuron and diuron) and lower concentrations of additional herbicides entering the Fitzroy River estuary in summer flows, with the potential to flow into coastal waters.

Coastal water quality of the region and of Great Keppel Island in particular, is highly variable, responding to flood discharge from the Fitzroy River and less frequently cyclonic conditions. It is these event-based ‘drivers’ of coastal water quality that have the greatest ecological significance (and within which the potential impacts of the proposed marina should be viewed).

Further details are provided in Appendix C.

4 Marine Sediment Quality

4.1 Methods

Surface Sediments

Sites Surveyed

Surface sediment sampling was undertaken during the following seasons:

- pre-wet – 15 to 19 November 2010
- wet – 17 to 21 January 2011, and
- post-wet – 30 March to 2 April 2011, and 30 April to 2 May 2011.

Sediment samples were collected at 12 sites around Great Keppel Island (Figure 4.1) and two sites near the mainland (Figure 4.2) for laboratory analysis of potential contaminants. Sediment was collected from the top 0.3 m of seabed using a stainless steel trowel, and transferred directly into the sampling containers provided by the analytical laboratory.

Replicate sediment samples were collected at one site during the pre-wet and wet season survey, and at two sites during the post-wet season survey to provide an indication of within-site variation. In addition, replicate subsamples of two sediment samples were analysed to provide an estimate of variation due to laboratory analysis.

The *Australian and New Zealand Water Quality Guidelines for Fresh and Marine Waters* (the national guidelines) (ANZECC & ARMCANZ 2000) interim sediment quality guideline (ISQG) values were used as the guidelines, as regional guidelines have not been set for the project area. Surface sediment quality data was compared to the ISQG-low trigger value (where available). The ISQG-low trigger value is referenced in the ANZECC & ARMCANZ (2000) guidelines as the most conservative trigger value for comparison.

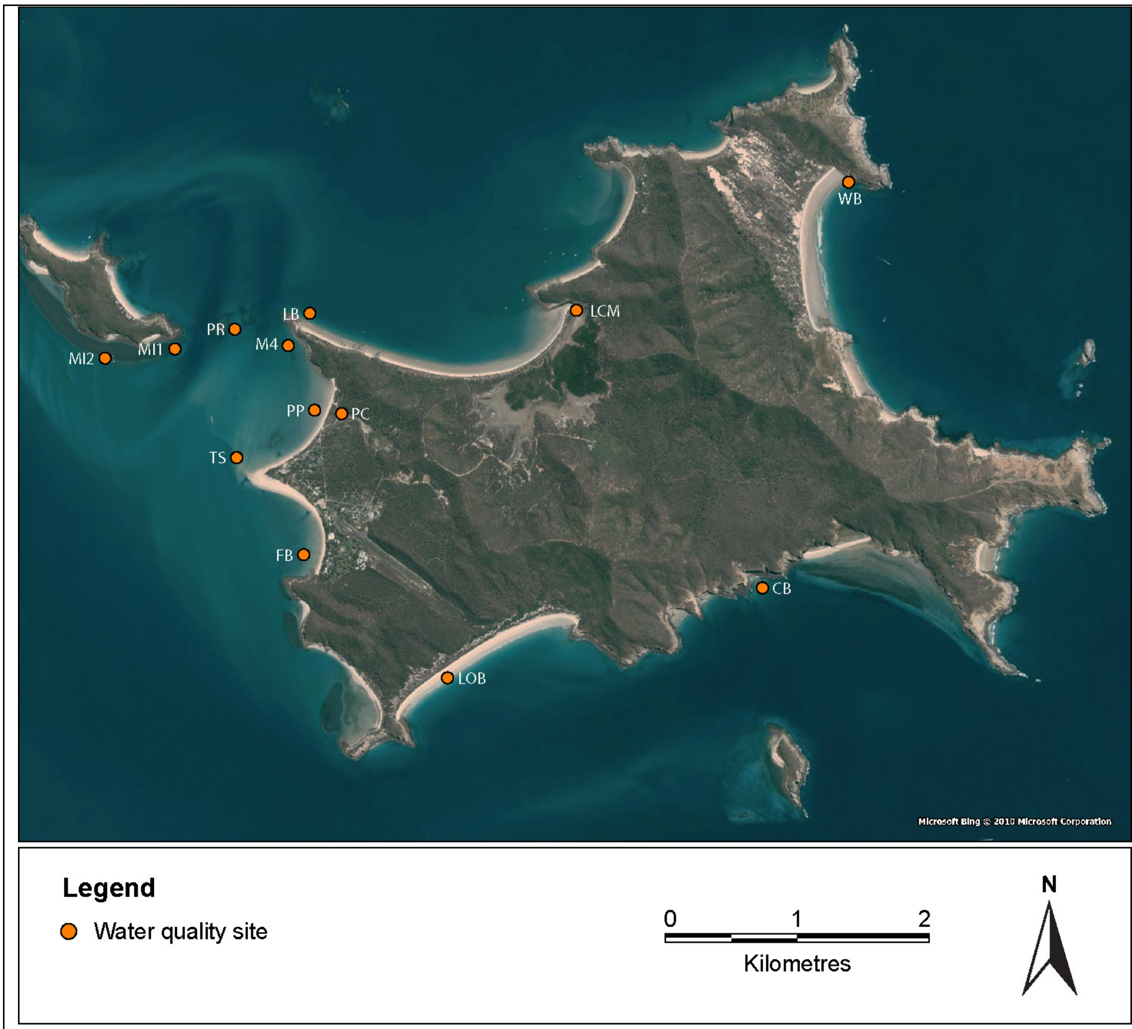

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	Figure 4.1 Great Keppel Island surface sediment quality sites.	
	Microsoft Bing © 2010 Microsoft Corporation	June 2011

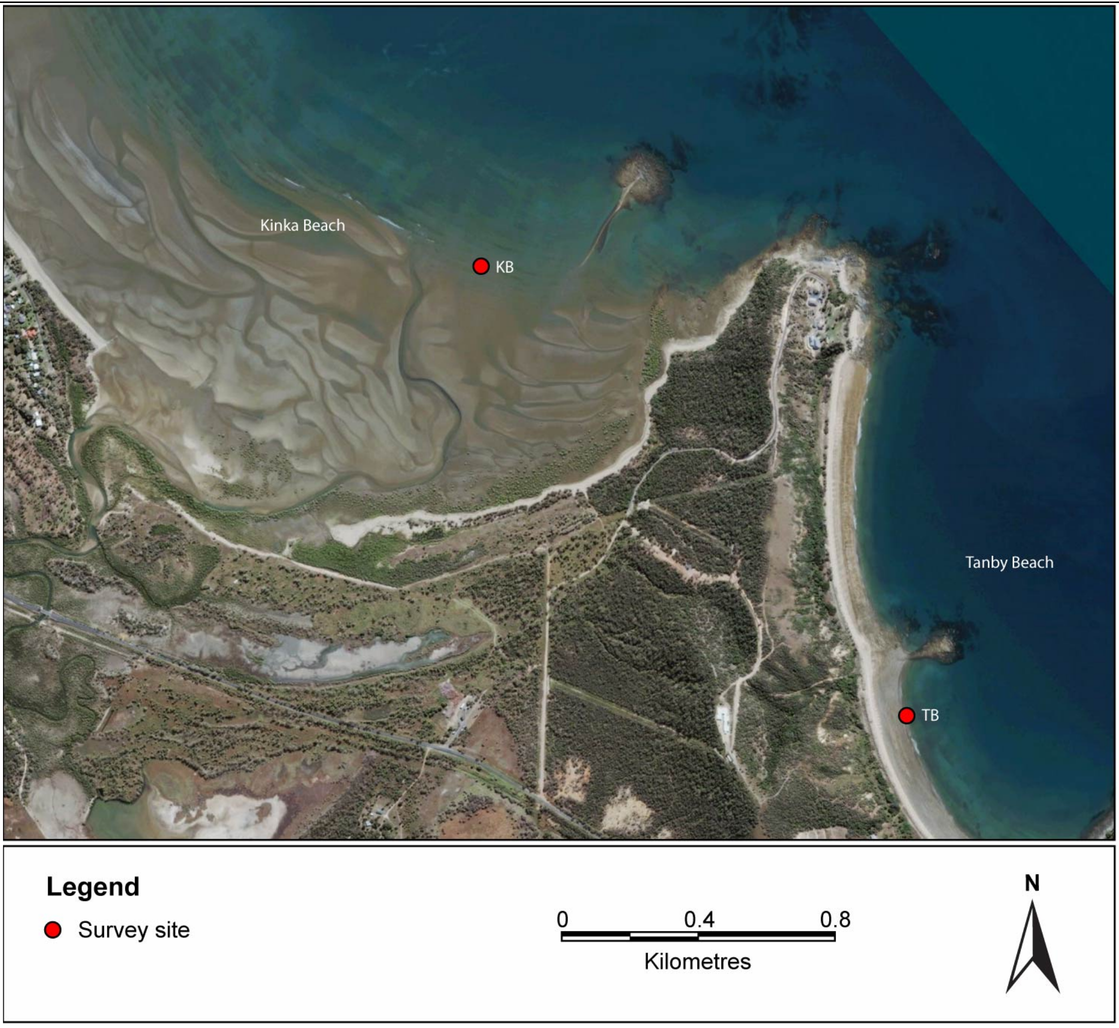

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	Figure 4.2 Mainland surface sediment quality sites.	
	Microsoft Bing © 2010 Microsoft Corporation	June 2011

Sediments of the Marina Footprint

Sediment sampling was undertaken in the proposed marina and channel footprint at Putney Beach from 15 to 18 June 2011 (Figure 4.3). This sediment sampling and analysis plan (SAP) for dredging was designed in accordance with the *National Assessment Guidelines for Dredging* (NAGD) (DEWHA 2009), the *Guidelines for Sampling and Analysis Procedure for Lowland Acid Sulphate Soils (ASS) in Queensland 1998* (the ASS guidelines) (Ahern et al. 1998) and the *State Planning Policy 2/02 Guideline: Acid Sulphate Soils*. Further details are provided in Appendix J.

Sites Surveyed

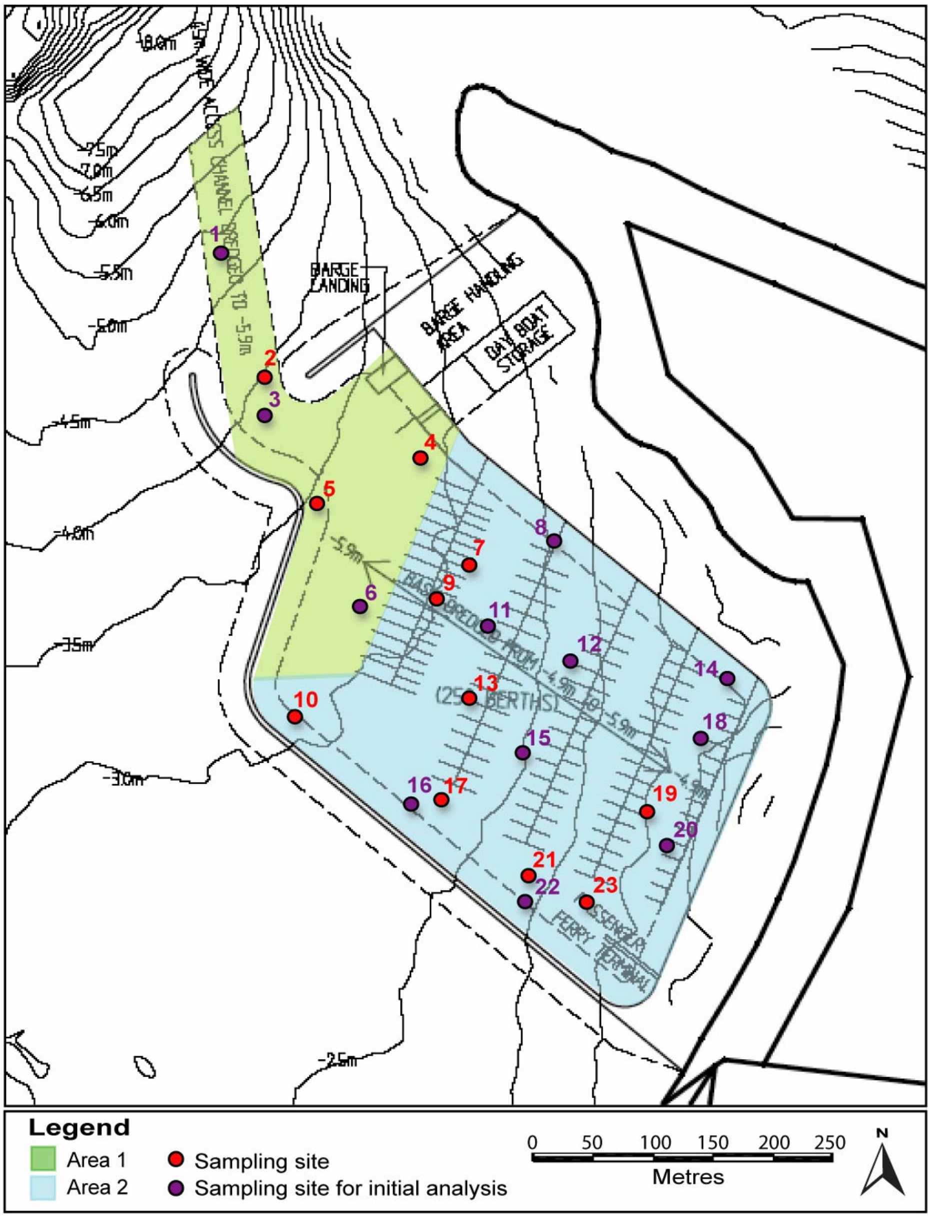
Samples were collected from 23 sites in accordance with Appendix A of the NAGD: sites 1 to 6 were located in the proposed entrance channel (Area 1), and the remaining sites were in the proposed marina basin (Area 2).

Approximately half of these sites (12) were assessed, as preliminary surface sediment sampling indicated that sediments were 'probably clean'. The 12 sites initially analysed represent the spatial extent of the dredge area and the range of sediment depths to be dredged.

The assessment of sediment quality in the marine footprint followed the approach outlined in Section 4.2 of the NAGD.

Any results less than the practical quantification limit (PQL) were entered as half the PQL, for statistical and analytical purposes (DEWHA 2009). The concentration of detected organic compounds was normalised to total organic carbon (TOC) content, as outlined in Section 4.2.3 of the NAGD.

Further details are provided in Appendix D.



Great Keppel Island Revitalisation EIS	
Figure 4.3 Sampling sites within the marina footprint.	
Source: International Marina Consultants	May 2011

4.2 Results

Surface Sediments

Surface sediments were largely composed of sands.

The concentration of total nitrogen was variable between sites and surveys. The highest concentration of total nitrogen was in Putney Creek during the pre-wet survey and at Fishermans Beach during in the post-wet survey (Figure 4.4).

The concentration of total phosphorus was highest at Middle Island during both surveys, and also relatively high at the mainland sites during both wet and post-wet surveys; the concentration of total phosphorus was generally similar at each site during each survey (Figure 4.5).

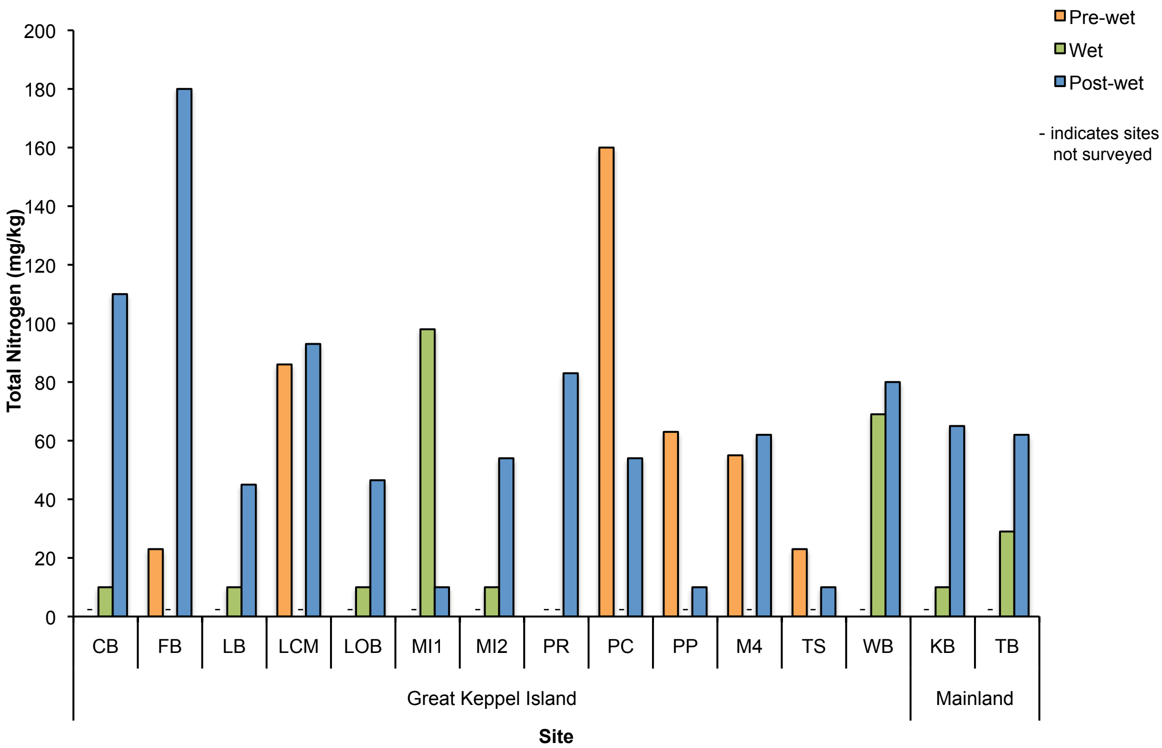


Figure 4.4 Total nitrogen concentration in surface sediment at each site in each survey.

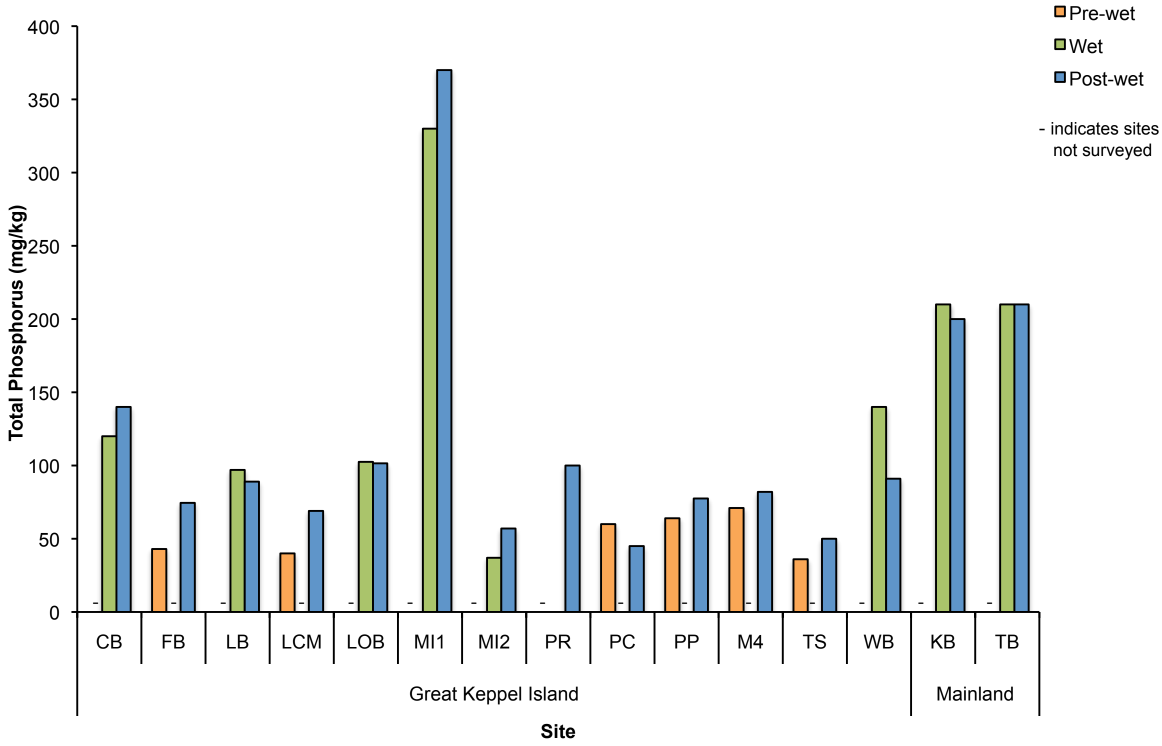


Figure 4.5 Total phosphorus concentration in surface sediment at each site in each survey.

The concentration of total arsenic, chromium, copper, mercury and zinc was below the ISQG-low trigger value at all sites during all surveys. The concentration of total lead at the Leeke's Creek mouth exceeded the ISQG-low trigger value during the post-wet survey; all other sites were substantially lower than the trigger value in all surveys (Figure 4.6).

Overall, concentrations of metals and metalloids were higher at Leeke's Creek mouth, near the underwater observatory on Middle Island and at the mainland sites. Relatively high levels could be related to the (decommissioned) underwater observatory, boating activity in Leeke's Creek and terrestrial run-off (e.g. fertilisers and mining activities) at the mainland sites.

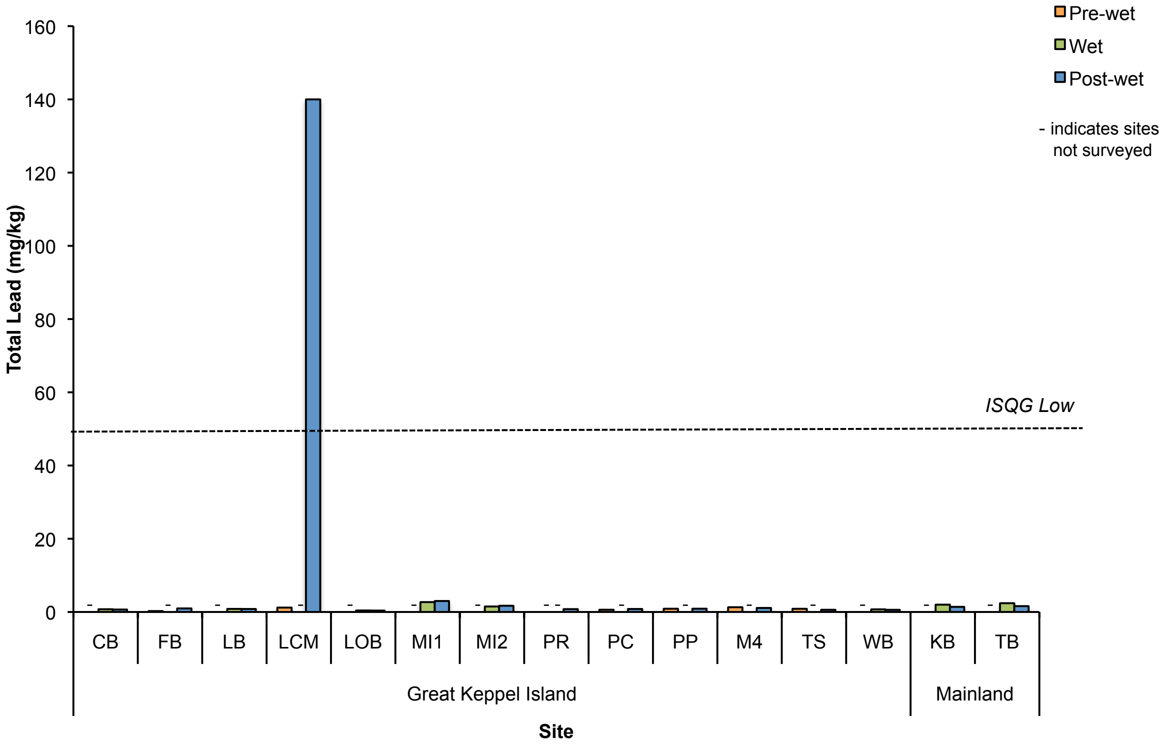


Figure 4.6 Total lead concentration in surface sediment at each site in each survey.

Sediments of the Marina Footprint

Sediments of the marina footprint were largely composed of sands. The concentration of nutrients in the sediments was substantially lower than other locations in Queensland. The concentrations of all contaminants were below the laboratory LORs and NAGD screening levels (where available). The sediments are therefore considered to be uncontaminated.

No treatment of acid sulphate soils is likely to be required during dredging activities, as net acidity (including acid neutralising capacity) was low and mostly below the laboratory limits of reporting.

The results of quality assurance / quality control analyses were generally acceptable, with the exception of the laboratory replicates of silver and field replicates of phosphate, nitrate and copper. Given that there are no screening levels for phosphate and nitrate, and that concentrations of copper in all samples were below the screening level, this does not affect the interpretation of the results.

Regional Context

Keppel Bay has been shaped through macrotidal currents, and wind and wave regimes, with continental islands, relict seabed morphology, and sediment input from terrestrial and marine sources. Terrestrial sediment from the Fitzroy Basin mostly accumulates in the mouth of the Fitzroy River estuary, with river sediment reaching the offshore reefs of the Keppel Islands during major flood events.

Agricultural and mining activities throughout the Fitzroy Basin introduce contaminants to waterways and ultimately to the offshore areas during flood events. Contaminants include fertilisers which can contain nutrients and metals as phosphate salts (particularly cadmium), 'cattle dip' which can contain arsenic compounds for parasite control, and mining activities which can introduce metals such as copper, gold and coal compounds.

Metal contamination in the sediment of the region appears to be low. The data, for the concentration of metal in sediment, indicates that the concentration of most metals in the Fitzroy River estuary is consistent with the concentration of metals in other Queensland estuaries that are not so heavily impacted by agricultural and mining activities. However elevated concentrations have been recorded for nickel, chromium and antimony, which are likely to reflect the geology of the central Queensland region rather than anthropogenic influences (particularly for nickel and chromium). High nickel and mercury concentrations have been reported throughout the estuary, suggesting possible diffuse anthropogenic sources. High antimony and gold concentrations have been reported in Keppel Bay, suggesting some historical accumulation of these metals.

The Fitzroy River estuary and inshore coastal waters of the region contain weathered sediments that are naturally nutrient-rich. Dissolved and particulate nutrients reach Keppel Bay via the Fitzroy River plume during flood events, or during the dry season by tidal flows when fine sediments and water are exchanged within the Fitzroy River estuary.

Further details are provided in Appendix D.

5 Marine Flora

5.1 Methods

Mangrove Forest and Saltmarsh

Survey Details

Mangrove communities were surveyed during the following seasons [2]:

- pre-wet – 15 to 19 November 2010
- wet – 17 to 21 January 2011, and
- post-wet – 30 to 31 March and 30 April 2011 and 30 April to 2 May 2011.

Mangroves were surveyed at two sites on Great Keppel Island and at one mainland site, which were, respectively (Figure 5.1 to Figure 5.5):

- Leeke's Creek
- Putney Creek, and
- Kinka Beach.

The boundaries of different mangrove and saltmarsh communities were marked using a GPS (accurate to ±4 m). Survey points were established at regular intervals, or when a change in mangrove community structure or ecological health (condition) was noted. At each survey point, species composition (% cover of each species), canopy height (m), canopy cover (%), and the structural formation of the mangroves were recorded. Structural formation followed the classification system used by the Queensland Herbarium (Dowling & Stephens 2001). Data points and field survey data were superimposed onto rectified aerial photographs using GIS software (MapInfo). Maps of the vegetation communities were created from the data, and from interpretation of aerial photography.

[2] Great Keppel Island mangroves communities were surveyed in the pre-wet and post-wet season surveys. Kinka Beach mangrove communities were surveyed during the wet survey (as they were added to the project area after the pre-wet survey, to consider impacts of the submarine cable crossing) and post-wet survey.

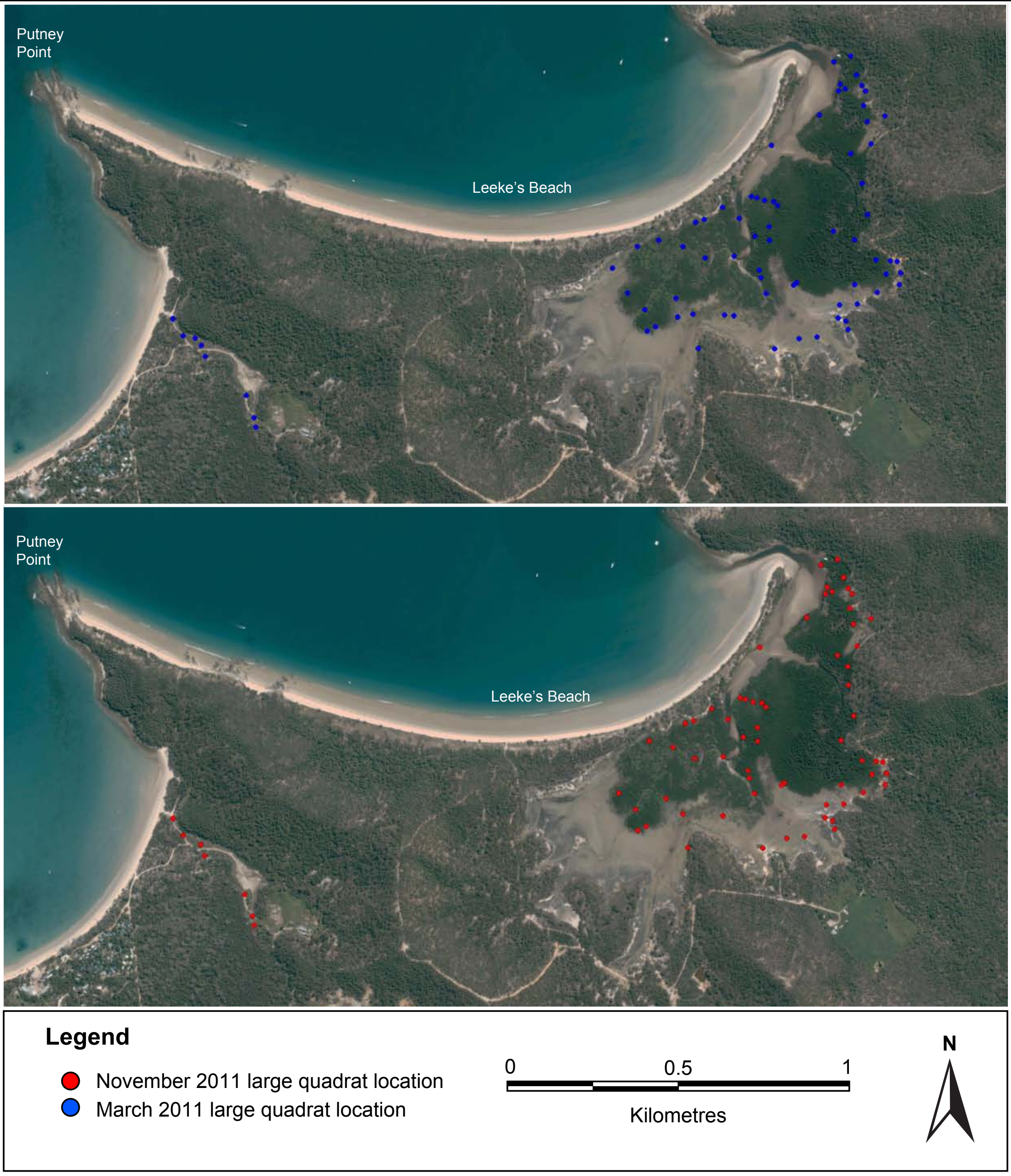


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Figure 5.1 Quadrat locations for assessment of mangrove distribution, community composition and condition in Leeke's and Putney creeks.

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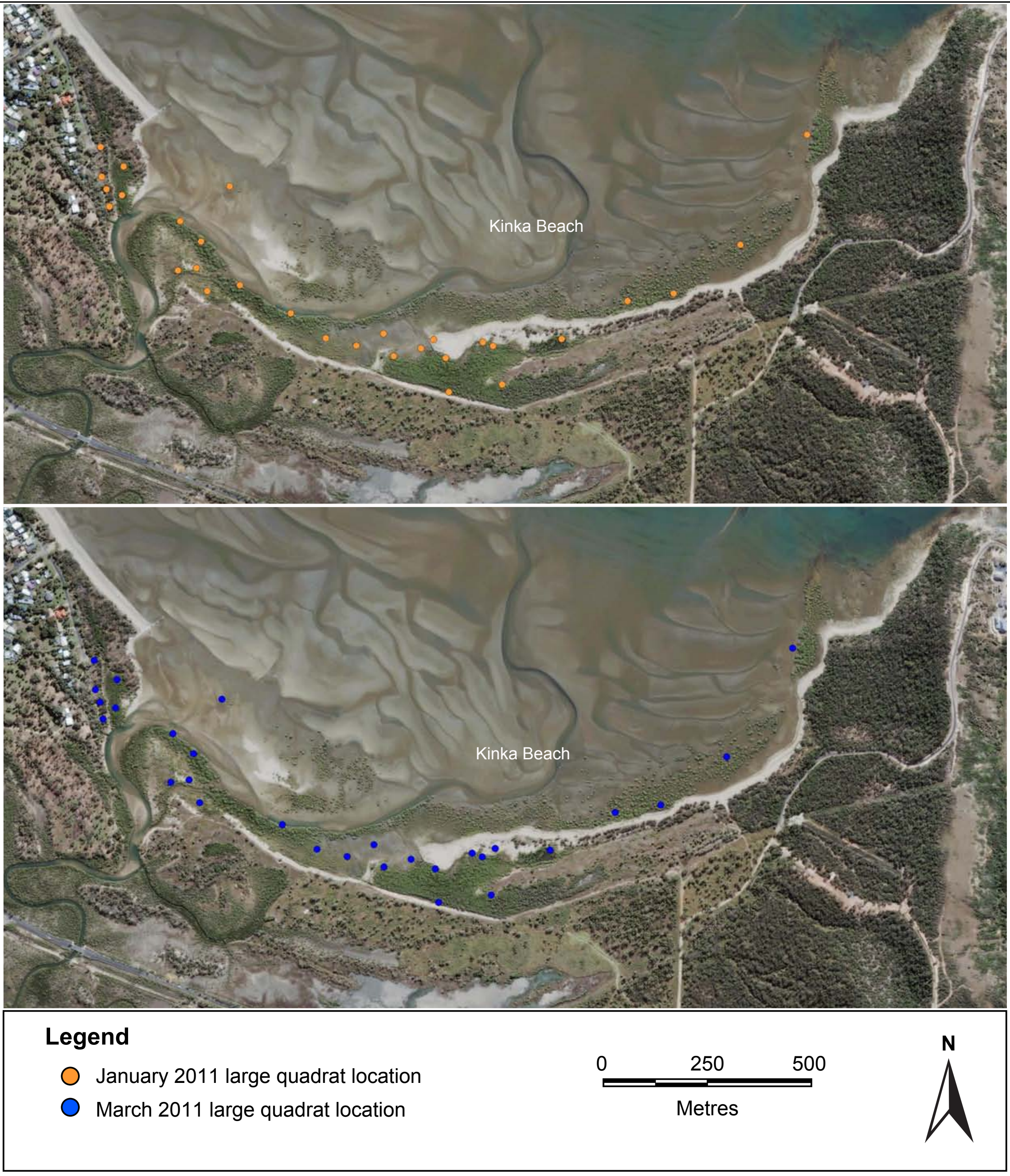

Great Keppel Island Revitalisation EIS	
Figure 5.2	Quadrat locations for assessment of mangrove distribution, community composition and condition at Kinka Beach.
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Great Keppel Island Revitalisation EIS	
Figure 5.3	Quadrat locations for quantitative assessment of mangrove values to fisheries in Putney Creek.
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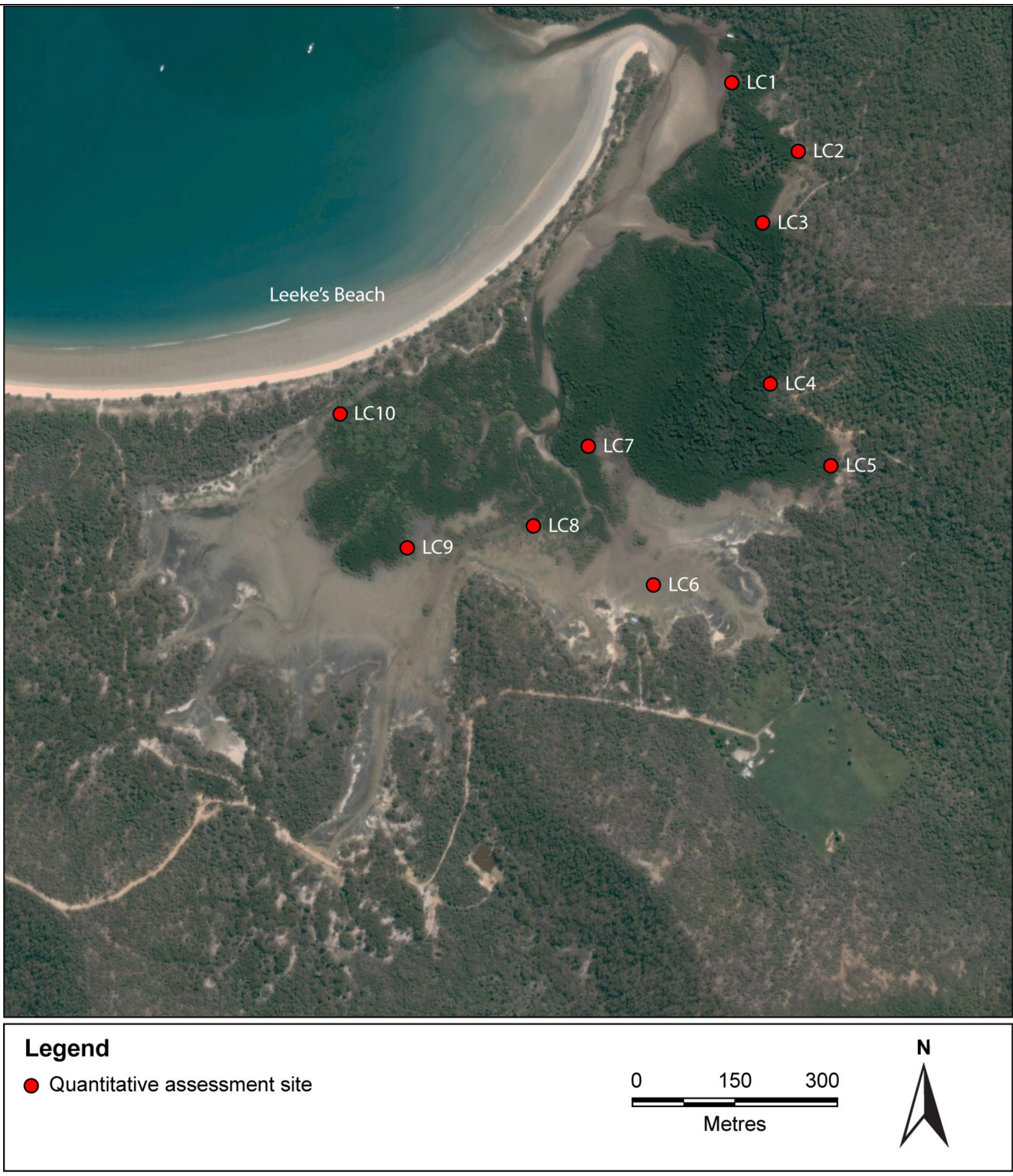

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Great Keppel Island Revitalisation EIS

Figure 5.4 Quadrat locations for quantitative assessment of mangrove values to fisheries in Leeke's Creek.

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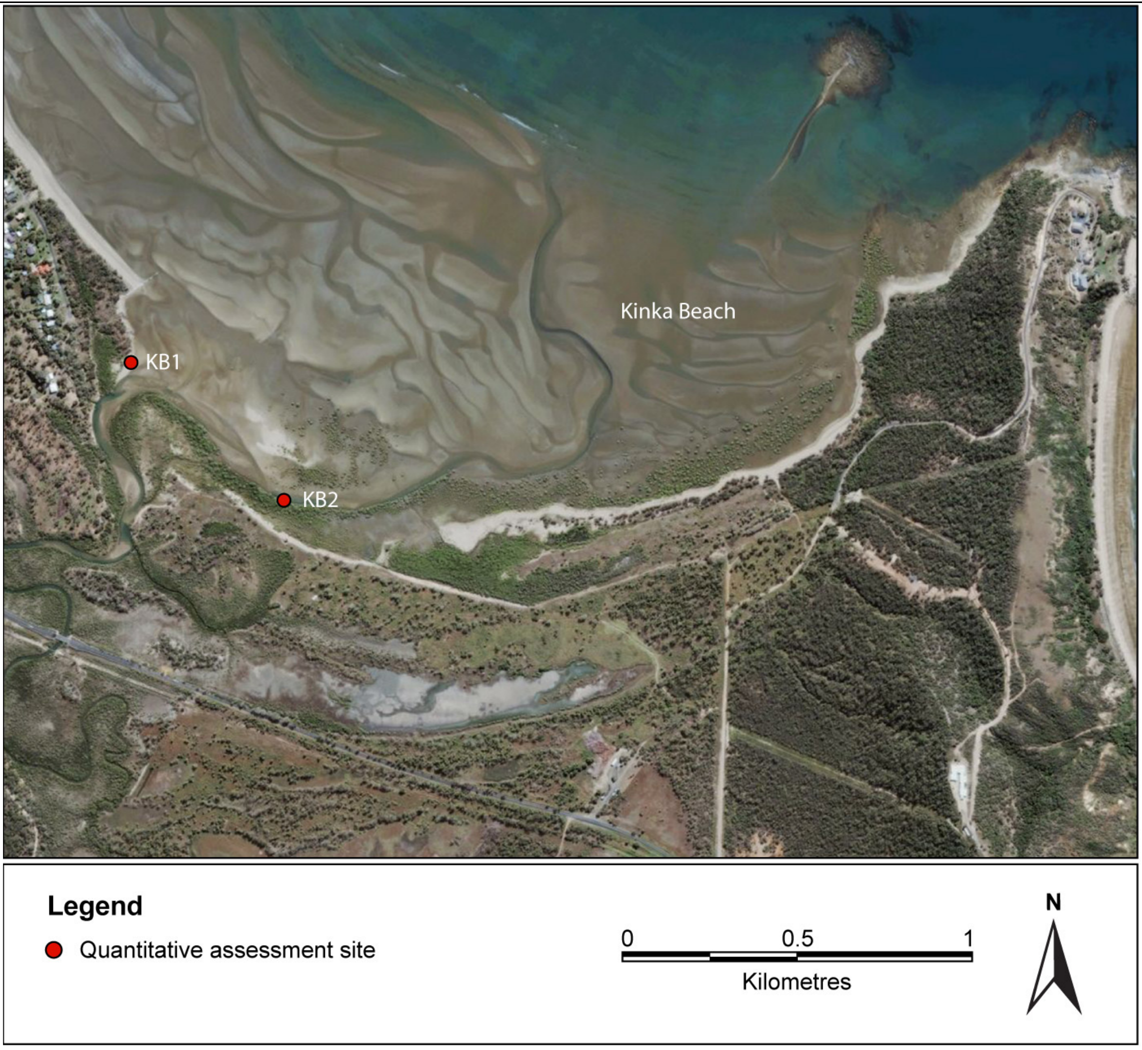


Great Keppel Island Revitalisation EIS	
Figure 5.5 Quadrat locations for quantitative assessment of mangrove values to fisheries at Kinka Beach.	
Microsoft Bing © 2010 Microsoft Corporation	July 2011

At each survey point, ecological health (condition) was assessed within a 10 x 10 m quadrat. The value of the mangrove forests to fisheries was assessed in three randomly placed 1 x 1 m quadrats in selected larger (10 x 10 m) quadrats, at:

- three sites in Putney Creek,
- ten sites in Leeke's Creek and
- two sites at Kinka Beach.

Seagrass Meadows and Macroalgae

Survey Details

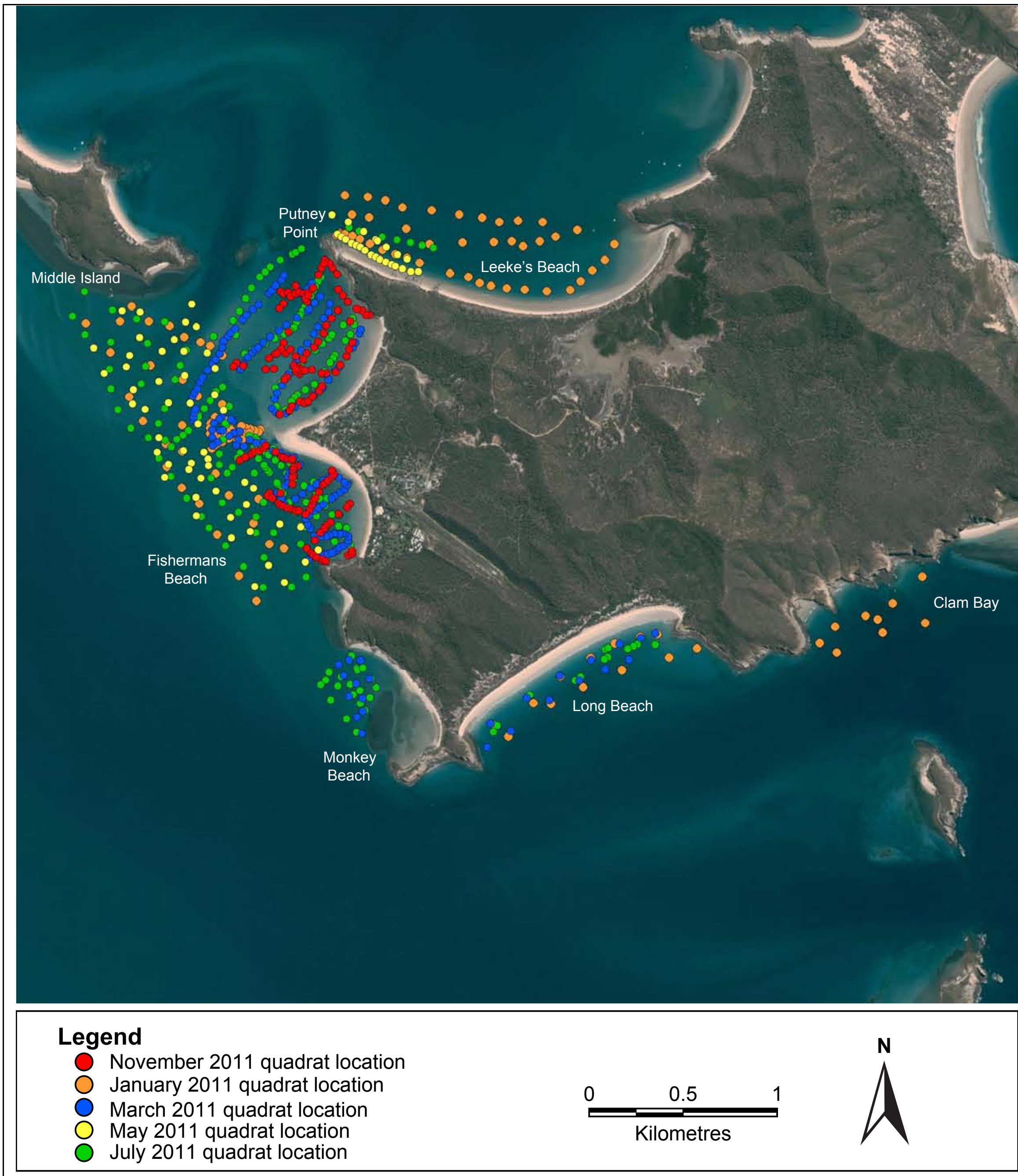
Seagrass communities were surveyed during the following seasons[3]:

- pre-wet – 15 to 19 November 2010
- wet – 17 to 21 January 2011
- post-wet – 30 to 31 March and 30 April 2011 and 30 April to 2 May 2011, and
- winter (to quantify community 'recovery' following flooding) – 11 to 14 July 2011.

Seagrass communities were surveyed at nine locations around Great Keppel Island (Figure 5.6):

- Putney Beach
- Fishermans Beach
- Leeke's Beach
- Leeke's Creek Mouth
- The Spit
- Middle Island
- Long Beach
- Clam Bay, and
- Monkey Beach.

[3] Seagrass meadows of Putney Beach, Fishermans Beach and The Spit were surveyed during the pre-wet, post-wet and winter season surveys. Seagrass meadows of Long Beach, Middle Island, Leeke's Beach and Monkey Beach were surveyed during the wet survey (as they were not accessible during the pre-wet survey), post-wet and winter surveys. Leeke's Creek mouth and Clam Bay was surveyed during the wet survey; there was no seagrass and these locations were not re-surveyed.



Great Keppel Island Revitalisation EIS	
Figure 5.6	Quadrat locations for assessment of seagrass meadows around Great Keppel Island.
Microsoft Bing © 2010 Microsoft Corporation	May 2012

Seagrass communities of the submarine cable alignment were surveyed by Marine & Earth Sciences Pty Ltd, from 1 to 3 March 2011 (as organised by Water Technology).

The distribution and community composition of seagrass meadows were recorded during surveys undertaken on snorkel.

Above-ground biomass was determined by visually estimating biomass and correlating this with data from collected samples (Mellors 1991).

A description of the historical changes to the seagrass meadows of Putney Beach was based on available aerial photos and information sourced from government agencies, local residents, community-based groups (e.g. Seagrass Watch) and researchers (where available).

Further details are provided in Appendix E.

5.2 Results

Mangrove Forests and Saltmarsh

The estimated area of mangrove forest and saltmarsh at Putney Creek was 1 ha and 12 ha, respectively (Figure 5.7). The estimated area of mangrove forest and saltmarsh at Leeke's Creek was 30 ha and 19 ha, respectively (Figure 5.8). The estimated area of mangrove forest at Kinka Beach was 31 ha (Figure 5.9).

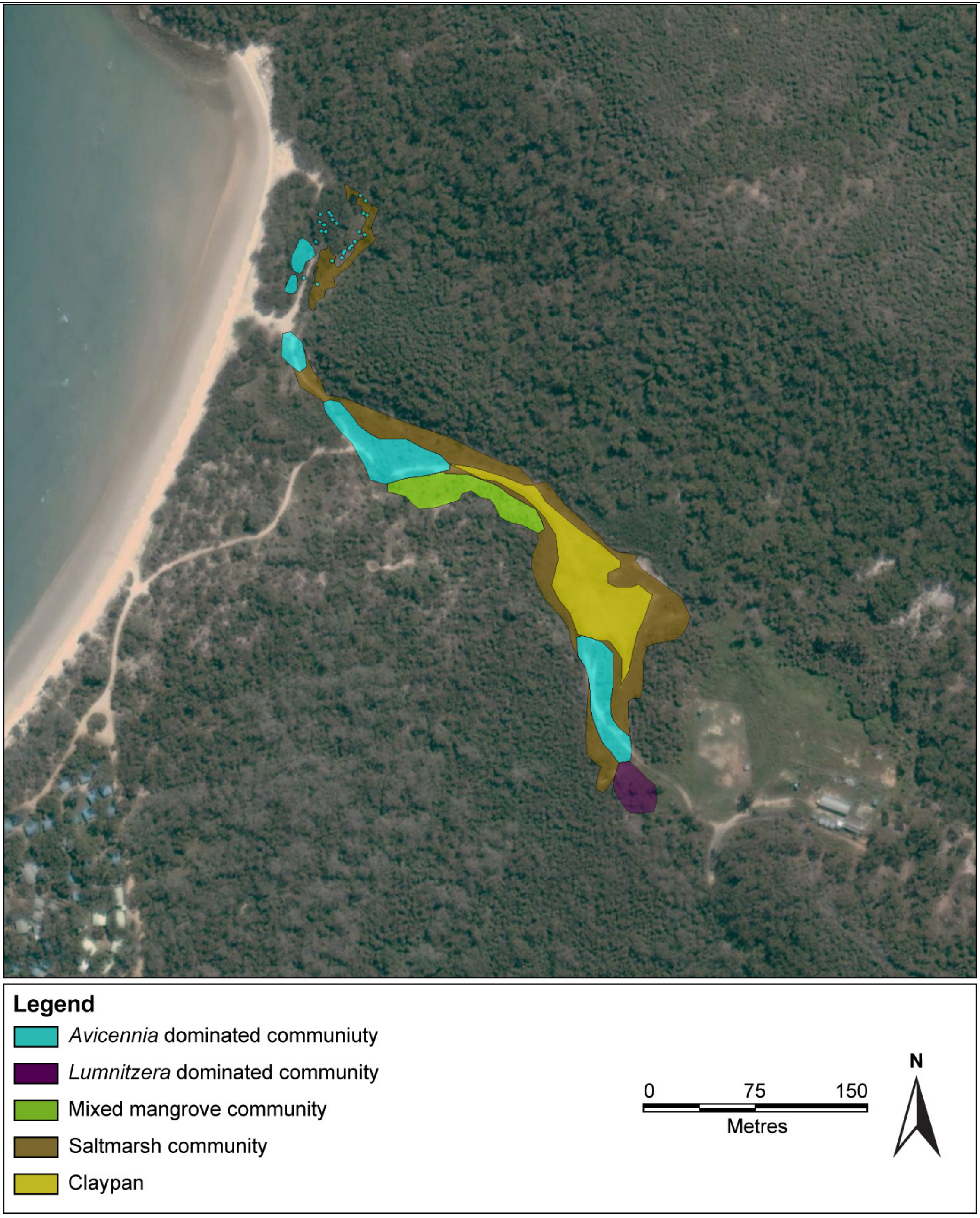


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Figure 5.7 Mangrove and saltmarsh communities at Putney Creek.

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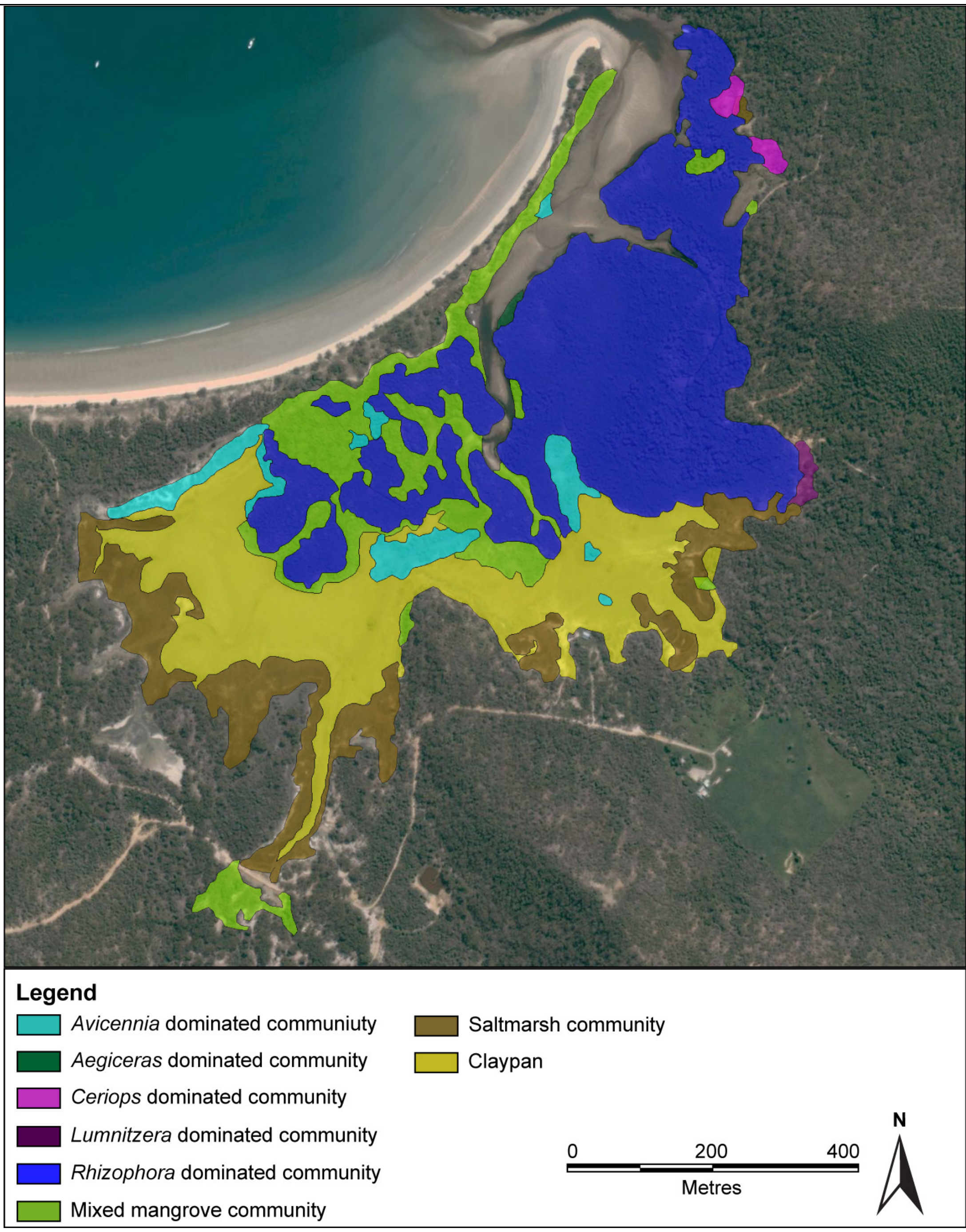

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Figure 5.8 Mangrove and saltmarsh communities at Leeke's Creek.

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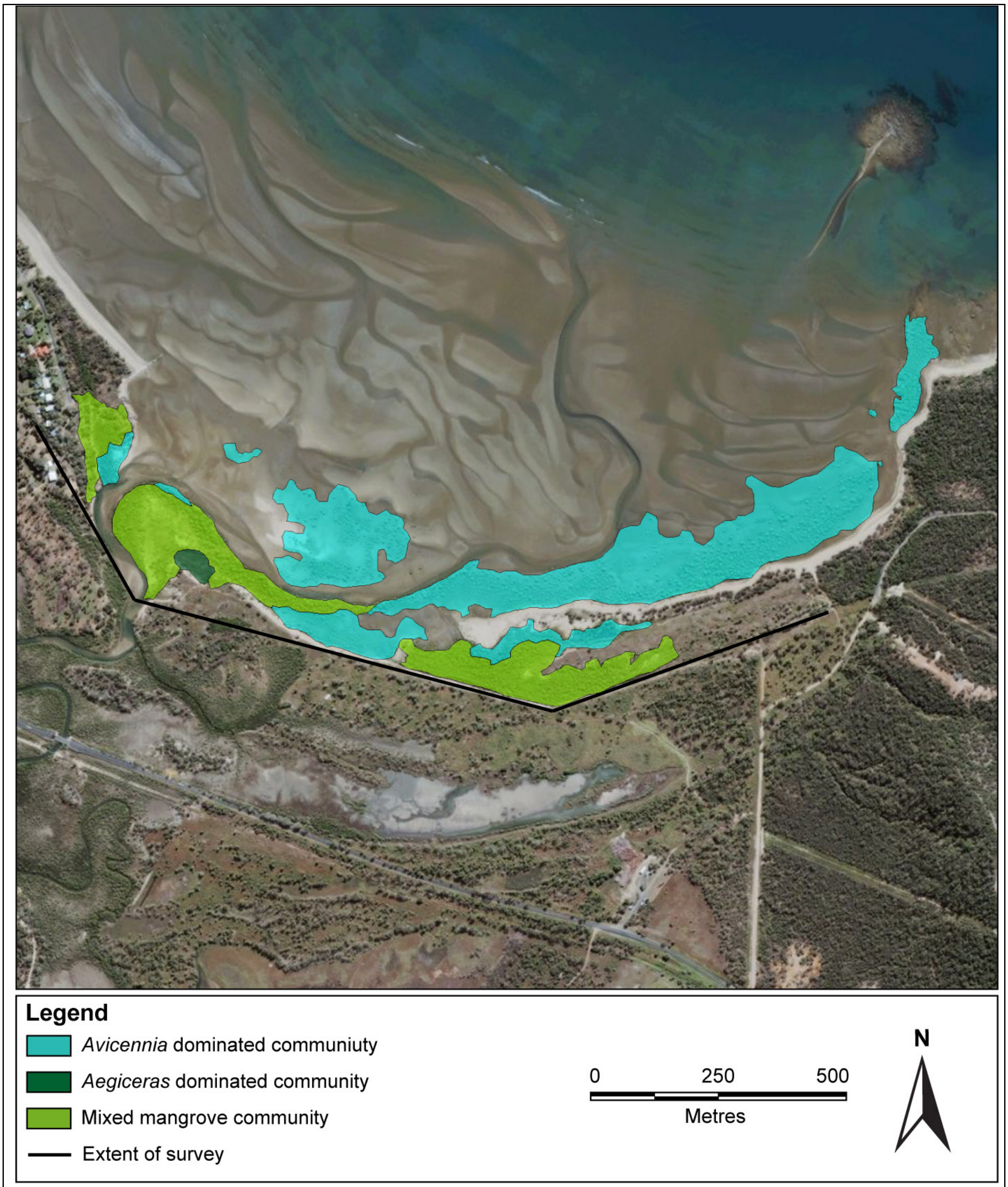

Great Keppel Island Revitalisation EIS	
Figure 5.9 Mangrove communities at Kinka Beach.	
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Ten species of mangrove were recorded on Great Keppel Island and seven species at Kinka Beach (Table 5.1). Mangrove communities were dominated by:

- *Rhizophora spp.* (predominantly *Rhizophora stylosa* and *Rhizophora apiculata*, Figure 5.10)
- *Avicennia marina*
- *Aegiceras corniculatum*
- *Lumnitzera racemosa*, and
- *Ceriops australis*.

Table 5.1 Mangrove species on Great Keppel Island and at Kinka Beach.

Family	**Scientific Name**	**Common Name**	**Great Keppel Island**	**Kinka Beach**
Plumbaginaceae	*Aegialitis annulata*	club mangrove	–	✓
Myrsinaceae	*Aegiceras corniculatum*	river mangrove	✓	✓
Acanthaceae	*Avicennia marina*	grey mangrove	✓	✓
Rhizophoraceae	*Bruguiera gymnorrhiza*	large-leafed orange mangrove	✓	–
Rhizophoraceae	*Ceriops australis*	smooth-fruited yellow mangrove	✓	✓
Euphorbioideae	*Excoecaria agallocha*	milky mangrove	✓	–
Combretaceae	*Lumnitzera racemosa*	white-flowered black mangrove	✓	✓
Myrtaceae	*Osbornia octodonta*	myrtle mangrove	✓	✓
Rhizophoraceae	*Rhizophora* spp.	stilt mangrove	✓	✓
Meliaceae	*Xylocarpus granatum*	cannonnball mangrove	✓	–

Figure 5.10

Rhizophora dominated community at Leeke's Creek.

Six species of saltmarsh were recorded on Great Keppel Island and at Kinka Beach (Table 5.2); only two of these species were recorded in both areas. Saltmarsh communities were dominated by *Sporobolus virginicus* (Figure 5.11), *Sarcocornia quinqueflora* and *Suaeda australis*. Several sedge species, including *Fimbristylis* sp. and *Juncus* sp., grew next to the mangrove and saltmarsh communities at Leeke's Creek.

Table 5.2 Saltmarsh species on Great Keppel Island and Kinka Beach.

Family	**Scientific Name**	**Common Name**	**Great Keppel Island**	**Kinka Beach**
Aizoaceae	*Sesuvium portulacastrum*	sea purslane	–	✓
Amaranthaceae	*Suaeda australis*	Austral seablite	✓	✓
Chenopodiaceae	*Enchylaena tomentosa*	ruby saltbush	–	✓
Chenopodiaceae	*Sarcocornia quinqueflora*	bead weed	✓	–
Plumbaginaceae	*Limonium austral*	sea lavender	✓	–
Phocaea	*Sporobolus virginicus*	marine couch	✓	✓

Figure 5.11

Sporobolus virginicus dominated community at Leeke's Creek.

Mangrove forests were in poor to good ecological health. Most trees showed few signs of stress; the major exceptions to this were at Putney Creek, where the community was assessed as being in poor health, exhibiting:

- reduced canopy cover (generally <15%)
- a relatively high percentage of dead branches (generally >20%), and
- dead mangroves.

Most of the mangrove communities provide good to very good fisheries habitat, and had reasonable amounts of structural habitat for fauna, and frequent tidal inundation. Fisheries habitat values were generally higher at Leeke's Creek, than Putney Creek and Kinka Beach.

Seagrass Meadows and Macroalgae

Four species of seagrass were recorded around Great Keppel Island (Table 5.3). Communities were dominated by *Halophila ovalis* and *Halodule uninervis* (Figure 5.12). *Halophila ovalis* was less widespread than *H. uninervis*, which is likely to be related to environmental conditions such as turbidity and sedimentation. *Halophila spinulosa* and *Syringodium isoetifolium* were least widespread and not evident during the winter recovery survey. Seagrass communities typically had an overall cover of <5% with sparse, patchy distribution (Figure 5.12). The sediment was dominated by sand. These results are consistent with the most recent (pre-wet season 2009) Seagrass Watch survey, which recorded <4% cover of mostly *H. uninervis* at the Great Keppel Island site of Monkey Beach (Seagrass Watch 2011).

Table 5.3 Seagrass species around Great Keppel Island.

Family	Scientific Name	Common Name
Cymodoceaceae	*Halodule uninervis*	narrowleaf seagrass
Hydrocharitaceae	*Halophila ovalis*	paddle weed
Hydrocharitaceae	*Halophila spinulosa*	fern seagrass
Potamogetonaceae	*Syringodium isoetifolium*	noodle seagrass

Figure 5.12

Typical cover of *Halodule uninervis*.

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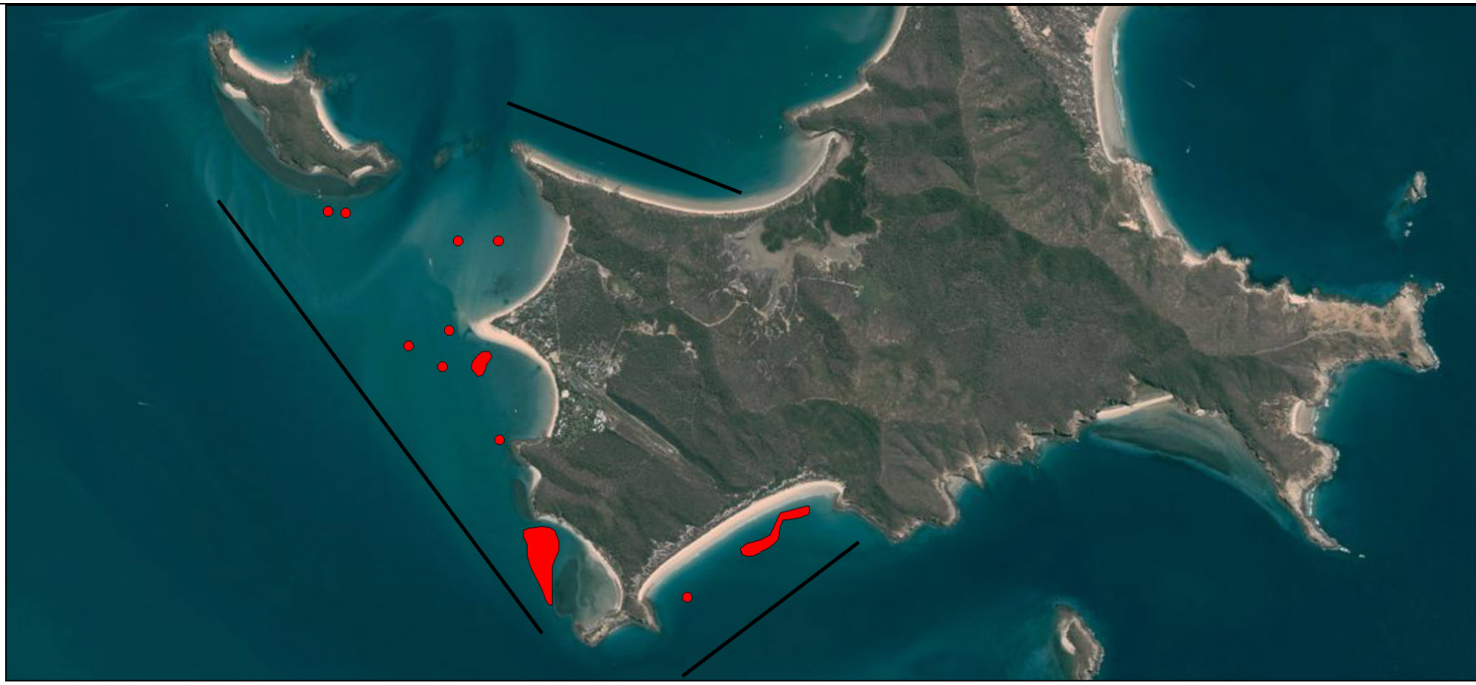
	Figure 5.13 Seagrass meadows during the pre-wet season survey.
	Microsoft Bing © 2010 Microsoft Corporation — July 2011



Legend
Seagrass
Extent of survey

0 1 2
Kilometres
N

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Figure 5.14 Seagrass meadows during the post-wet season survey.

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Figure 5.15 Seagrass meadows during the winter recovery survey.

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July 2011

There were few algal or faunal epiphytes on the seagrasses meadows. The cyanobacteria, *Lyngbya majuscula*, was recorded on the seagrass at several locations in each survey, with dense cover at some locations (Figure 5.16). The macroalgae, *Caulerpa taxifolia*, was relatively common, growing in small isolated patches at all locations. *Laurencia* sp., *Halimeda* sp., *Hypnea* sp. and *Padina* sp. grew in small, isolated patches at some locations.

Benthic epifaunal communities were dominated by echinoderms (e.g. sea stars *Protoreaster* spp. and crinoids), acorn worms (*Balanoglossus carnosus*), obese sea pens (*Cavernularia obesa*) and moon snails (*Polinices lewisssi*). Stingrays, and their feedings pits, were recorded during all surveys, including the blue-spotted stingray (*Dasyatis kuhlii*), cowtail stingray (*Taeniura melanospila*) and common shovel-nosed ray (*Rhinobatos batillum*).

Figure 5.16

Dense *Lyngbya majuscula* growing on sparse seagrass.

Overall, seagrass meadows had lower cover and covered a smaller area in the post-wet and winter recovery surveys than the pre-wet / wet survey (Table 5.4). Diversity was also lower in the winter survey, with only two species recorded (*H. ovalis* and *H. uninervis*). These types of changes are typical of inshore seagrass meadows of the region following large rainfall events.

There has been a substantial decrease in the cover and the extent of seagrass since the 1970s. This is likely to be related to cyclone activity, sedimentation and / or elevated nutrient levels.

Table 5.4 Overall cover, extent and diversity of each seagrass meadow in each survey.

Survey / Site	Percent Cover (%)	Approximate Area (ha)	Species Present [a]			
			Hu	Ho	Hs	Si
Pre-wet and wet season survey						
Putney Beach	5	24	✓	✓	✓	✓
Fishermans Beach	10	23	✓	✓	–	✓
Leeke's Beach	<5	<1	–	–	–	✓
The Spit	5	30	✓	✓	✓	✓
Middle Island	5	5	✓	✓	✓	–
Long Beach	5	14	✓	✓	✓	–
Clam Bay	0	0	–	–	–	–
Leeke's Creek Mouth	0	0	–	–	–	–
Monkey Beach	NS	NS	NS	NS	NS	NS
Post-wet season survey						
Putney Beach	<5	<1	✓	–	–	–
Fishermans Beach	<5	2	✓	✓	✓	–
Leeke's Beach	0	0	–	–	–	–
The Spit	0	0	–	–	–	–
Middle Island	<5	<1	✓	–	–	✓
Long Beach	<5	4	✓	✓	✓	–
Clam Bay	NS	NS	NS	NS	NS	NS
Leeke's Creek Mouth	NS	NS	NS	NS	NS	NS
Monkey Beach	<5	8	✓	✓	✓	–
Winter recovery survey						
Putney Beach	<5	10	✓	✓	–	–
Fishermans Beach	<5	7	✓	✓	–	–
Leeke's Beach	0	0	–	–	–	–
The Spit	0	0	–	–	–	–
Middle Island	<5	<1	–	✓	–	–
Long Beach	<5	2	✓	✓	–	–
Clam Bay	NS	NS	NS	NS	NS	NS
Leeke's Creek Mouth	NS	NS	NS	NS	NS	NS
Monkey Beach	<5	2	✓	✓	–	–

a Hu (Halodule uninervis), Ho (Halophila ovalis), Hs (Halophila spinulosa) and Si (Syringodium isoetifolium)

NS site not surveyed

Regional and Ecological Context

Mangrove Forests and Saltmarsh

Twenty species of mangroves have been reported within the region (from the Keppel Islands in the north to Rodd's Bay in the south). Regionally, between Shoalwater Bay and Hervey Bay, there are approximately 3875 patches of mangroves covering an area of 20 300 ha.

Mangrove communities grow on a diverse range of sediments from rocky outcrops and coarse sand, to fine silts and mud. However, they develop best in sheltered, depositional environments on fine silts and clays. Drainage and aeration depend on sediment characteristics, frequency and period of fresh and saltwater inundation and elevation. Mangrove species differ in their ability to withstand poorly drained or poorly aerated soils. Saltmarshes cannot remain vigorous on waterlogged, anaerobic soils, and this is likely to be a major factor limiting their seaward distribution.

Estuarine wetlands, including mangrove and saltmarsh communities, provide valuable habitat and food sources for a variety of vertebrate and invertebrate species. Some of these are of conservational significance (e.g. marine turtles and the water mouse), while others are recreationally and / or commercially important. The majority of commercially and recreationally important fish species from eastern Australia depend upon estuarine environments. Shallow water and intertidal habitats are among the most productive environments for fisheries.

Seagrass Meadows

Nine species of seagrass have been recorded in the region. There are approximately 4 600 000 ha of seagrass in the Great Barrier Reef, with 45 910 ha in Central Queensland from Mackay to Gladstone (including Rodds Bay), 17 940 ha from Shoalwater Bay to the Fitzroy River mouth (inclusive) and 40 ha around the islands of the Keppel Group.

The extent and condition (e.g. reproductive health) of seagrass in the region is highly variable; species composition of meadows differs between habitats. In general, inshore coastal meadows are dominated by *Zostera muelleri* [4] with some *Halodule uninervis*, estuarine meadows are dominated by *Z. muelleri* and coral reef-associated meadows are dominated by *H. uninervis.* Variability between habitats is likely to be related to light and nutrient levels. Epiphyte coverage on seagrass is generally seasonal, with macroalgal cover typically lower on inshore coastal and reef meadows, and highly variable in

[4] This species was previously described as *Zostera capricorni.*

estuarine environments. Dominant seagrass species in the area (*H. uninervis* and *Z. muelleri*) are characterised by abundant seed production, fast growth rates, and the ability to rapidly recolonise areas. This suggests that these species may be able to rapidly colonise following a disturbance.

Macroalgae are a commonly overlooked component of the marine environment, which may significantly contribute to an area's ability to support marine life, particularly fish and crustacea. While the distribution of macroalgae is variable and has not been mapped, it is expected to occur throughout the project area, with the greatest diversity and biomass near the mouths of creeks and rivers.

Cyanobacteria Lyngbya

Lyngbya majuscula is a naturally-occurring, toxic, filamentous, cyanobacteria (blue-green algae), that is found worldwide in tropical and subtropical estuarine and coastal habitats. *Lyngbya* growth has resulted in the loss of seagrass meadows, and may have reduced turtle and dugong feeding grounds in Moreton Bay. *Lyngbya* can cause severe eye and skin irritations to humans, as well as asthma-like symptoms. *Lyngbya* can affect the economics of commercial and recreational fisheries and tourism.

There is commonly an association between *Lyngbya* blooms and development of coastal catchments. Changes in catchment land use can lead to alterations of the inputs of dissolved organics, iron, and phosphorus into a system, which can lead to *Lyngbya* blooms. Nuisance *Lyngbya* blooms have been recorded on coral outcrops near Great Keppel Island by others.

Further details are provided in Appendix E.

6 Marine Fauna

6.1 Methods

Coral communities and benthic macroinvertebrate communities were surveyed in the following seasons[5]:

- pre-wet – 16 to 19 November 2010
- wet – 17 to 21 January 2011
- post-wet – 28 March to 1 April 2011 and 30 April to 2 May 2011, and
- winter (to quantify community ‘recovery’ following flooding) – 12 to 14 July 2011.

Coral communities were surveyed at ten sites around Great Keppel Island (Figure 6.1):

- Clam Bay West (CBW)
- Clam Bay Centre (CBC)
- Fishermans Beach (FB)
- Monkey Beach (MB)
- Long Beach (LOB)
- Middle Island (MI1)
- Middle Island Observatory (MI2)
- Passage Rocks (PR)
- Putney Beach (PB), and
- Wreck Beach (WB).

[5] Faunal communities of Fishermans Beach, Passage Rocks and Putney Beach were surveyed during the pre-wet, post-wet and winter surveys. Faunal communities of Clam Bay, Monkey Beach, Long Beach, Middle Island and Wreck Beach were surveyed during the wet survey (as they were not accessible during the pre-wet season due to permit and boat constraints), post-wet and winter surveys. Coral was surveyed at Clam Bay east during the wet survey; there was no live coral and this site was not re-surveyed. Invertebrate communities of the mainland were surveyed during the wet survey (as they were added to the project area after the pre-wet survey, to consider impacts of the submarine cable crossing), post-wet and winter survey.

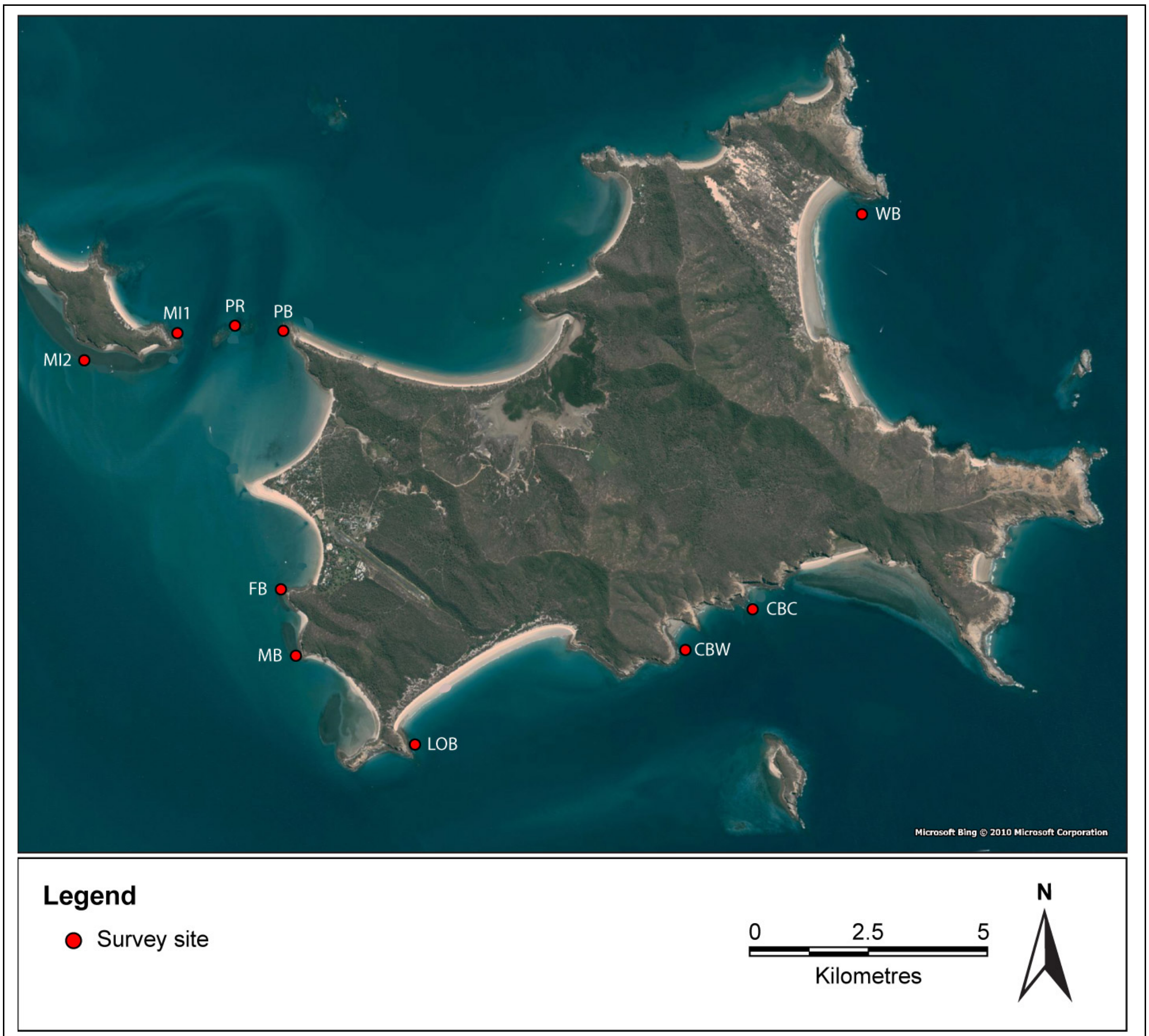

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	Figure 6.1 Coral survey sites.
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Benthic infaunal invertebrate communities were surveyed at eleven sites around Great Keppel Island (Figure 6.2):

- Clam Bay (CB)
- Fisherman's Beach (FB)
- Leeke's Beach (LB)
- Leeke's Creek Mouth (LCM)
- Long Beach (LOB)
- Putney Beach (PB1, PB2, PB3 and PB4)
- The Spit (TS),
- Wreck Beach (WB), and

at two mainland sites (Figure 6.3):

- Tanby Beach (TB), and
- Kinka Beach (KB).

The intertidal rocky shores were surveyed at Putney and Fishermans beaches during the pre-wet survey.

Macrocrustaceans, fishes, marine reptiles and marine mammals were opportunistically recorded during all surveys.

Marine turtle nesting was surveyed at Putney, Fishermans and Long beaches during the 2010-11 nesting season.

Further details are provided in Appendix F.

Legend

Marine infaunal benthic invertebrate sampling sites

0 1 2
Kilometres

N

frc environmental AQUATIC ECOLOGISTS deep thinking. science.	Great Keppel Island Revitalisation EIS	
	Figure 6.2 Great Keppel Island benthic infaunal invertebrate sites.	
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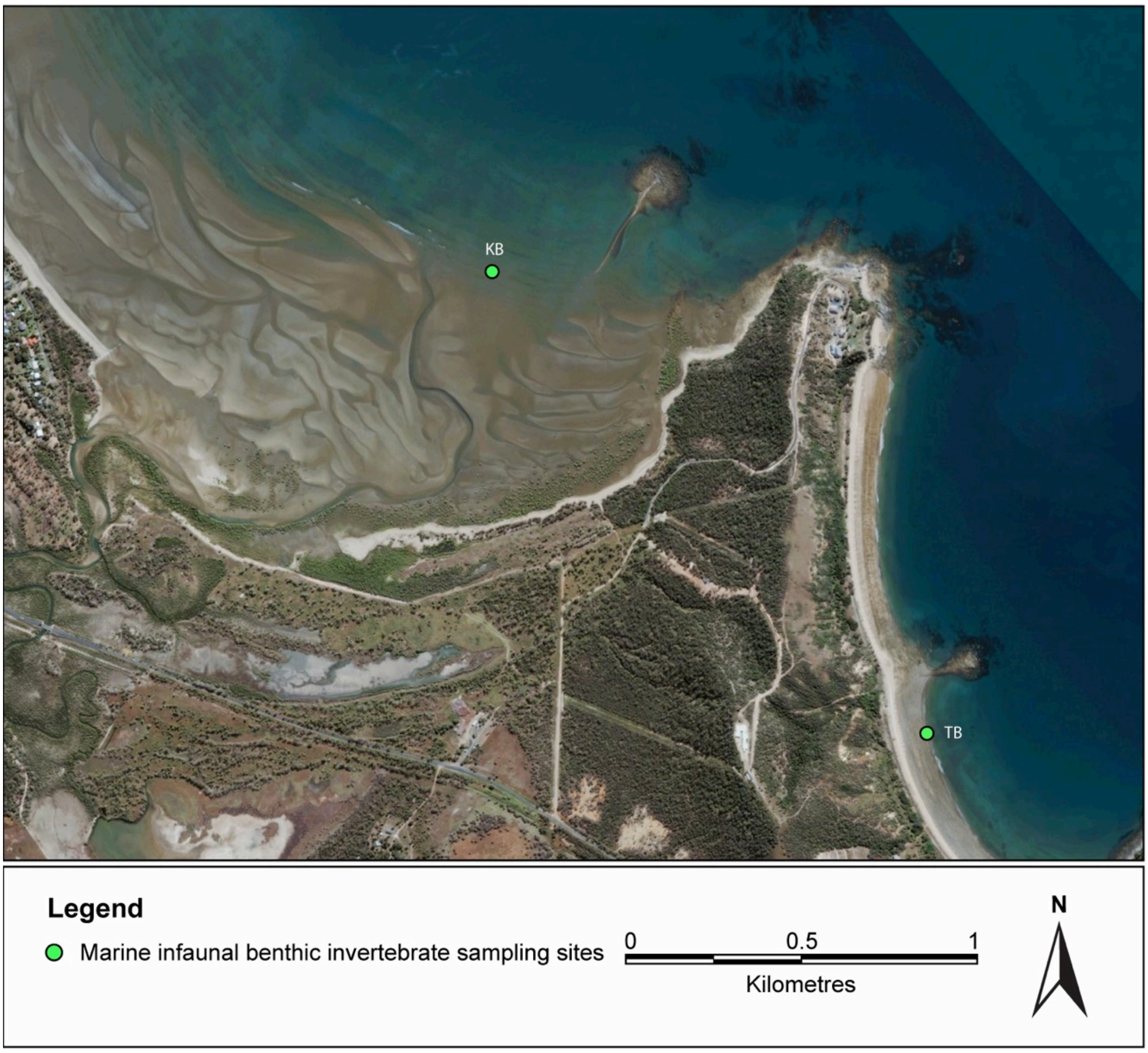

frc environmental AQUATIC ECOLOGISTS deep thinking. science.	Great Keppel Island Revitalisation EIS
	Figure 6.3 Mainland benthic infaunal invertebrate sites.
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6.2 Results

Coral Communities

Coral cover was high (>41%) at one Middle Island site and low (<16%) at the site near the observatory at Middle Island. Cover was relatively high at Passage Rocks.

Communities were dominated by branching growth forms from the family Acroporidea (mostly *Montipora* spp and *Acropora* spp., Figure 6.4) and massive growth forms from the families Faviidae (mostly *Favia* spp. [Figure 6.5], *Favites* spp., *Gonisterea* spp. and *Platygyra* spp.) and Poritidae (mostly *Porites* spp.), together with some plate / foliose, soft, mushroom and encrusting growth forms. The corals of Putney Beach were dominated by *Turbinaria* sp. and the soft coral *Sarcophyton* sp..

Severely bleached corals were most abundant at Clam Bay during the wet season survey (up to 17% cover). Coral disease was not observed.

Coral-associated epifauna (e.g. ascidians, barnacles, bivalves, echinoderms, polychaetes and zoanthids) were not abundant, covering <10% of the substrate at any one site.

Turf algae dominated the macroalgal communities, and typically grew on dead branching corals (Figure 6.6). There was low (typically <10%) cover of crustose coralline algae and larger growth forms from the genera *Lobophora*, *Padina* and *Halimeda* at most sites during most surveys.

Cover of sediment (rubble, sand and fine sediment) varied between sites and within most sites. Cover was consistently high (>47%) at Fishermans Beach and Putney Beach, and consistently low (<3%) at Middle Island sites and to a lesser extent (<13%) at Passage Rocks and Wreck Bay.

Coral communities of the project area were consistent with those reported by other studies of the area, and typical of the region.

Figure 6.4

Branching (*Acropora* sp.) coral at Middle Island.

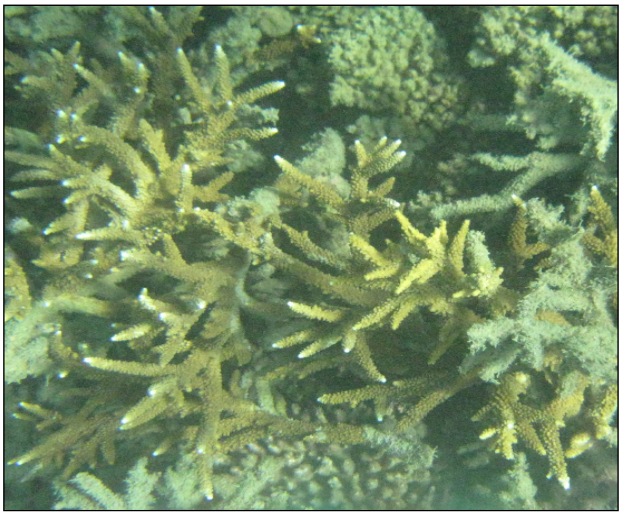
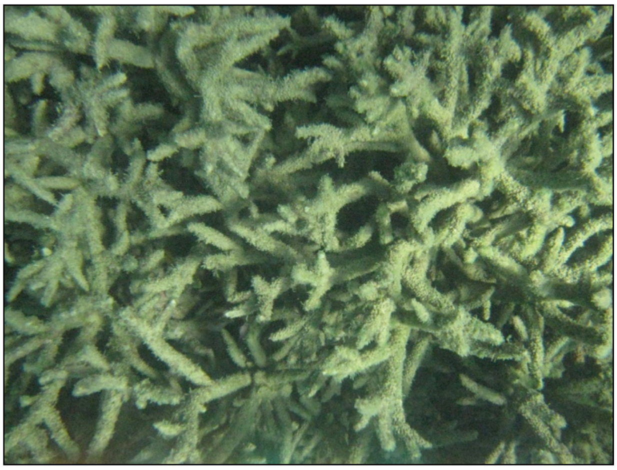


Figure 6.5

Massive (Favia sp.) coral at site Long Beach

Figure 6.6

Turf algae on dead coral near the Middle Island Observatory.



Intertidal Rocky Shore

The intertidal rocky shore at Putney and Fishermans beaches supported a diverse invertebrate community, including oysters, barnacles, gastropods, limpets, chitons, anemones and crabs. Rock oysters (*Saccotrea* sp.) dominated the upper intertidal zone at both Putney and Fishermans beaches (Figure 6.7).

Figure 6.7

Rock oysters (*Saccostrea* sp.) dominate the intertidal zone.

Benthic Infaunal Invertebrate Communities

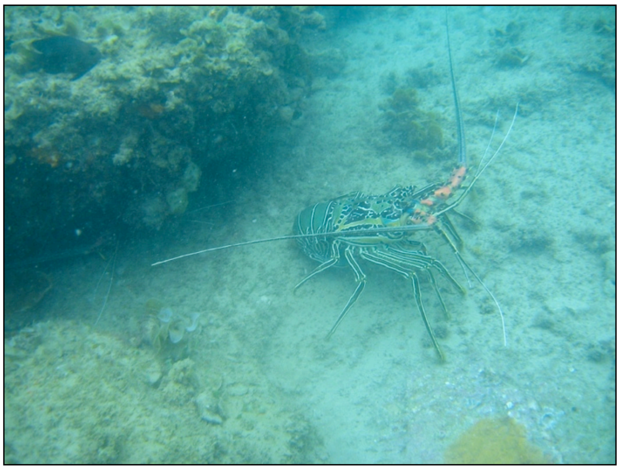
Polychaeta (worms) and malacostracan crustaceans (amphipods, isopods and decapods) were the most common and abundant benthic infaunal taxa, recorded at all sites during all of the surveys. Taxonomic richness was relatively high but variable between surveys at Putney Beach, and consistently low (<2 taxa) at Clam Bay, Long Beach and the mainland sites. Abundance was relatively low (<7 individuals) at most sites during most surveys. Abundance was highly variable at Fishermans Beach and Putney Beach; this may reflect 'boom and bust' cycles often associated with nutrient enrichment, due to sewage input from Putney Creek and moored vessels at Fishermans Beach.

Decapod Macrocrustaceans

A range of macrocrustaceans were recorded in, or are likely to inhabit, the project area including the ornate spiny lobster (Figure 6.8) and crabs such as the mud, blue swimmer, orange-clawed fiddler, ghost, soldier, grapsid and hermit crabs.

Figure 6.8

Ornate spiny lobster (Panulirus ornatus) at Putney Beach.



Fishes

The coral, seagrass and mangrove communities of the project area provide habitat for a variety of fish.

Coral-associated fin-fish communities were generally dominated by damselfish (Pomacentridae), wrasse (Labridae), sweetlip (Haemulidae) and fusiliers (Caesionidae), together with rabbitfish (*Siganus* spp.), butterflyfish (Chaetodontidae), emperors (Lethrinidae), seaperch (*Lutjanus* spp.), cardinalfish (Apogonidae), drummers (Monodactlidae), fusiliers (Caesionidae), angelfish (Pomacanthidae), emperors (*Lethrinus* spp.), goatfish (Mullidae), puffers (Tetradontidae), cod (Serranidae), surgeonfish (Acanthuridae) and parrotfish (Scaridae).

Few adult fish were recorded in the seagrass meadows; several blenny and goby burrows were observed. These species are a food source for commercially and recreationally important fish species. Ray feeding-pits were relatively common in the seagrass meadows, suggesting that the blue-spotted, cowtail and shovelnose rays commonly fed on benthic infaunal invertebrates within the sediment of the meadows.

Fish communities associated with the Leeke's Creek mangrove forest were characterised by mobile, transient species with little direct commercial or recreational value, in particular hardyheads and silverbiddies. Estuarine and blue-spotted rays were regularly observed feeding in Leeke's Creek in relatively large numbers (up to ten individuals observed near the creek mouth with tens of feeding-pits evident).

Elasmobranchs recorded during the surveys included the epaulette shark, blue-spotted stingray (Figure 6.9), cowtail stingray, estuarine stingray, common shovel-nosed ray, and spotted eagle ray.

Figure 6.9

Blue-spotted stingray (*Dasyatis kuhlii*) at Putney Beach.

Marine Reptiles

Marine turtles are relatively widespread in the project area. Three species of marine turtle were recorded during the surveys, the flatback (*Natator depressus*), green (*Chelonia mydas*) and hawksbill (*Eretmochelys imbricata*).

A total of 29 nesting activities were recorded on Leeke's, Putney and Long beaches during the 2010–11 nesting season. Twenty of these activities were recorded on Leeke's Beach, while six were recorded on Long Beach and three were recorded on Putney Beach. These results are consistent with observations made by island resident Lyndie Svendsen, who recorded a small number of flatback and green (*Chelonia mydas*) turtles nesting on the beaches of Great Keppel Island. Of the beaches observed, most nesting activity has been reported from Leeke's Beach, Long Beach, Second Beach and Butterfish Bay. Over the period 2005 to 2009, four turtle nesting activities were reported for Putney Beach.

A seasnake (unidentified) was recorded off Leeke's Beach over sandy substrate. Seasnakes, including the olive (*Aipysurus laevis*) and stokes (*Astrotia stokesii*), are likely to inhabit the project area.

Marine Mammals

A small pod of bottlenose dolphins (*Tursiops* sp.), of approximately six to eight individuals, was recorded near Fishermans Beach during the pre-wet survey. The pod consisted of adults and juveniles that appeared to be feeding.

Regional and Ecological Context

Coral Communities

The coastal waters of the project area are within the 'high nutrient coastal strip' bioregion of the Great Barrier Reef. This bioregion is characterised by terrigenous mud, high levels of nutrients from the adjoining land, seagrass in sheltered waters and a wet tropic climate. Within this area, there are scattered coastal fringing reefs that generally develop around the mainland and high continental islands, and which have high coverage of hard coral, soft coral and macroalgae, but low coral diversity.

The coral communities of this bioregion generally have a high cover of coral and microalgae, a good capacity to recover following disturbance (e.g. coral bleaching), a high (but often variable) spat settlement (recruitment), and low juvenile coral densities. Coral reefs of the region have been repeatedly affected by bleaching, with substantial declines in coral coverage observed in 1998, 2002 and 2006[6]; in January 2006, 100% of corals in Keppel Bay were bleached with approximately 40% mortality by May 2006. However, rapid recovery has also been documented and some reefs in southern Keppel Bay (Humpy, Middle, Halfway and Pumpkin islands, and the reef surrounding Passage and Outer rocks) may be coral 'refuges' due to high diversity and connectivity to sites with lower diversity and coral cover.

After a major flood event in January 1991, large freshwater input from the Fitzroy River resulted in reduced coral cover and increased bleaching. Approximately 85% of coral in the area died and was overgrown by turf algae; shallow areas were most affected. Mortality was greatest for acroporids and pocilloporids, with survival in shallow habitats most apparent for faviids, *Turbinaria* spp., *Porites* spp., *Psammocora* sp. and *Coscinaraea* sp..

The distribution of coral-associated flora and fauna is determined principally by exposure to wave action, and water quality (in particular turbidity).

[6] And most likely 2010-11, although the effect of the recent Fitzroy River flooding on coral reef communities is yet to be confirmed.

Intertidal Rocky Shores

There is limited information available regarding intertidal rocky shores of the region. Communities of the nearby Port Curtis region, approximately 75 km south of the project area, support diverse floral and faunal communities, including gastropods, sponges, ascidians, soft and hard coral and macroalgae. Artificial structures, such as jetties, seawalls and pipes, are also likely to provide hard surfaces for sessile marine communities. The diverse habitats of these rocky environments often support diverse ecological communities that include fishes, reptiles (such as sea snakes and turtles), echinoderms, polychaetes and crustaceans. Rocky habitats are of importance to many species that require hard substrate for colonisation.

Benthic Infaunal Invertebrate Communities

Benthic infaunal invertebrate communities of the region are typically dominated by filter feeders. Species richness and abundance are typically lowest in fine muddy substrates of intertidal areas, and highest in coarse sandy sediments. Abundance typically increases with regional rainfall and freshwater inflow. Infaunal invertebrate communities in the Port Curtis region include 129 taxa, and are dominated by polychaetes, molluscs and crustaceans. The highest mean abundance and highest taxonomic richness values recorded for Port Curtis are higher than those recorded during this study. This is likely to be related to the finer sediments of the Port Curtis area (as finer sediments typically support more diverse and abundant infaunal communities).

Decapod Crustaceans

There is limited information available regarding macrocrustacean communities of the region. Communities are expected to be typical of other Queensland reefs, which include prawns and shrimps (from the genera *Penaeus, Periclimenes, Stenopus* and *Thor*), mantis shrimps (from the genus *Odontodactylus*), lobsters and crayfish (from the genera *Allogalathea, Callianassa*, *Ibacus, Neaxius, Panulirus* and *Thenus*), hermit crabs (from the genera *Cilianarius* and *Dardanus),* and crabs (from the several genera including *Uca, Mictyris, Trapezia, Charybdis, Portunus, Scylla* and *Ocypode*).

Fishes

There is limited information available regarding fish communities of the region. Fish assemblages of Keppel Bay are typical of inshore waters. The rock and reef habitat at nearby Port Curtis is used by a range of adult and juvenile fish species, such as yellowfin bream (*Acanthopargus australis*), sweetlip (*Lethrinus* spp.), and estuary cod (*Epinephelus coioide*).

Marine Reptiles

Five of Australia's six species of marine turtles are likely to occur in the project area. This includes resident populations of flatback (*Natator depressus*) and green (*Chelonia mydas*) turtles, and occasional occurrence of loggerhead (*Caretta caretta*) hawksbill (*Eretmochelys imbricata*) and olive Ridley (*Lepidochelys olivacea*) turtles. Marine turtles are protected under the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) and Queensland Nature Conservation (Wildlife) Regulation 2006 (NCWR).

Seasnakes are listed under the 'marine' schedule of the EPBC Act, and are consequently protected within Commonwealth Marine waters such as the GBRMP. Seasnakes inhabit a range of habitats, including sandy bottom habitats, reef habitats and pelagic habitats (*Pelamis* sp. only). Seasnakes inhabit the project area; the olive (*Aipysurus laevis*) and stokes (*Astrotia stokesii*) seasnake are relatively abundant at Passage Rocks and Middle Island.

Marine Mammals

Several cetaceans (whales, dolphins and porpoises) are listed under the 'cetaceans' schedule of the EPBC Act. Several species are also listed under the 'threatened' schedule of the EPBC Act and NCWR, and in the IUCN Red List. Species likely to use habitats in the project area include the Indo-Pacific humpback dolphin (*Sousa chinensis*), bottlenose dolphin (*Tursiops* spp.), common dolphin (*Delphinus delphis*), dugong (*Dugong dugon*) and water mouse (*Xeromys myoides*). Several other species may occur in nearby waters, including the humpback whale (*Megaptera novaeangliae*), minke whale (*Balaenoptera acutorostrata*), Bryde's whale (*Balaenoptera edeni*), Australian snubfin dolphin (*Orcaella heinsohni*) and Risso's dolphin (*Grampus griseus*).

Exotic Marine Fauna

No introduced marine species have been reported outside of designated ports in the Great Barrier Reef. Although nine introduced marine species have been recorded in the Port Curtis region, including bryozoans (*Amathia distans*, *Bugula neritina*, *Cryptosula pallasiana*, and *Watersporia subtoraquata*), ascidians (*Botrylloides leachi* and *Styela plicata*), isopod crustaceans (*Paracerceis sculpta*), hydrozoans (*Obelia longissima*), and dinoflagellates (*Alexandrium* sp.).

Further details are provided in Appendix F.

7 Freshwater Ecosystems

7.1 Methods

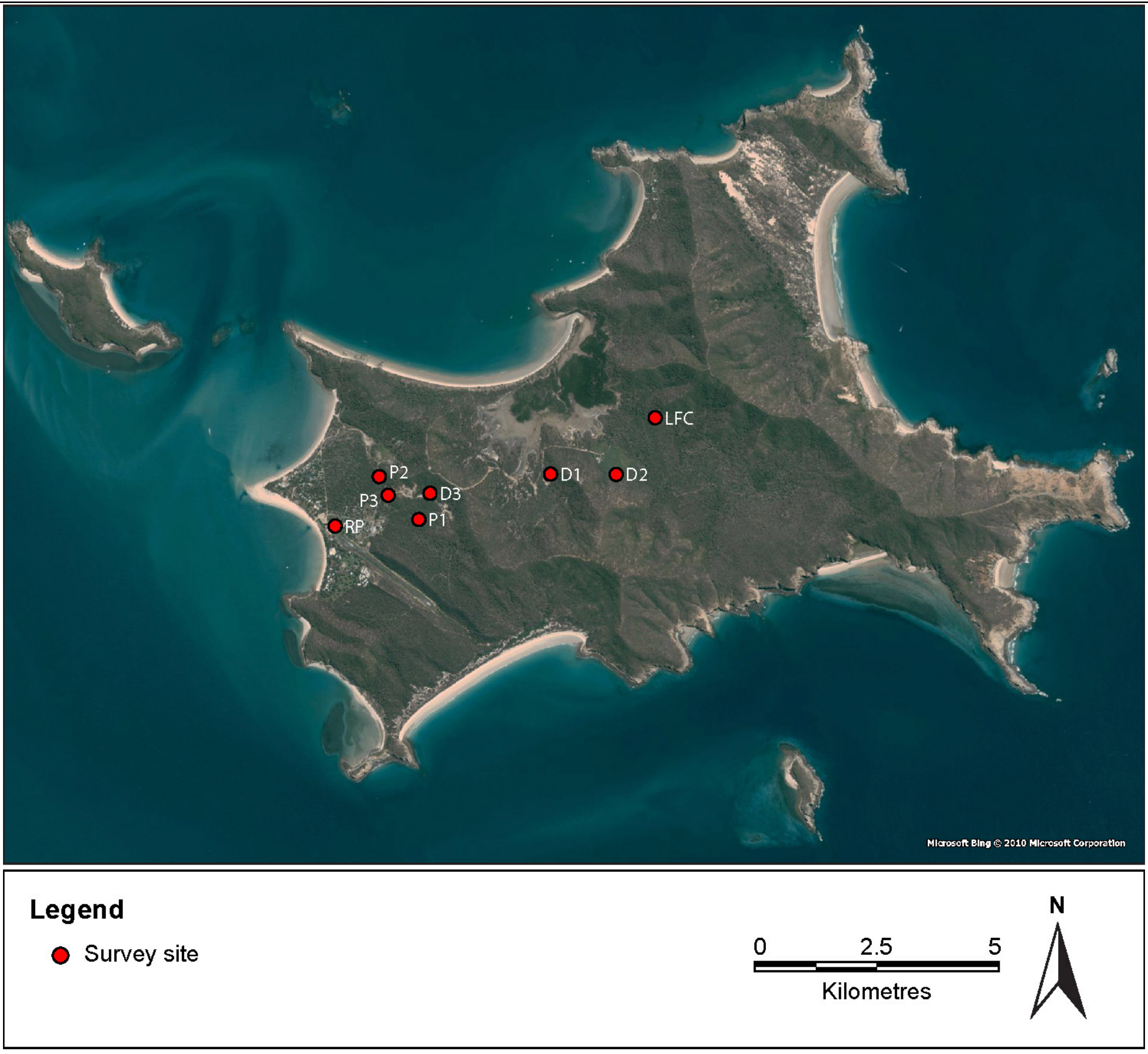
Eight freshwater sites on Great Keppel Island were surveyed in the post-wet season (on 2 April 2011, 3 May 2011 and on 18 June 2011) (Figure 7.1):

- Large Dam (D1)
- Homestead Dam (D2)
- Resort Dam (D3)
- Putney Creek (P1, P2 and P3)
- Leeke's Creek (LFC), and
- Resort Creek (RP).

Freshwater surveys included assessment of:

- aquatic habitat
- water quality
- sediment quality
- aquatic flora, and
- aquatic fauna (macroinvertebrates, fish and turtles).

Further details are provided in Appendix G.



Great Keppel Island Revitalisation EIS	
Figure 7.1 Freshwater sites.	
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7.2 Results

Aquatic Habitat

Most sites had a moderate habitat bioassessment score (Figure 7.2); sites D1 (Large Dam), LFC (Leeke's Creek) and P2 (downstream Putney Creek) had a good score. Scores were relatively low at sites D2 (Homestead Dam), D3 (Resort Dam) and RP (Resort Creek) due to limited in-stream habitat and lack of water flow, as the dams were located off-stream. Dense algal cover reduced habitat diversity at sites RP (Resort Creek) and D3 (Resort Dam). Site LFC (Leeke's Creek) had the highest score due to low embeddedness, limited channel alteration and relatively high water flow.

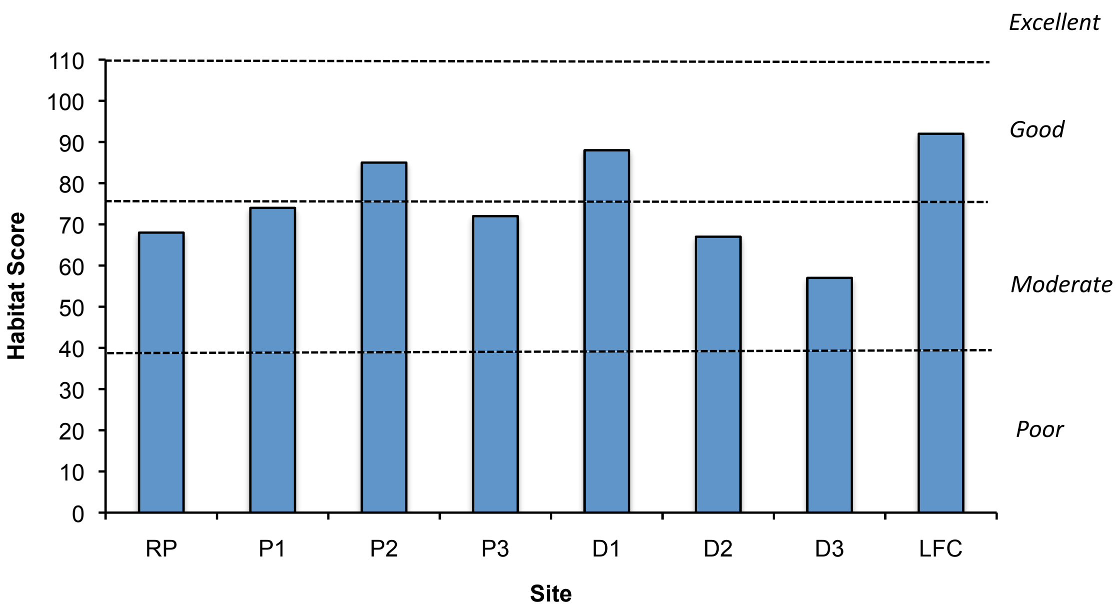


Figure 7.2 Habitat bioassessment scores at each freshwater site, and the DNRM thresholds for poor, moderate and good habitats.

Water Quality

The pH was within the QWQG trigger value range at most sites; it was below the range at sites D2 (Homestead Dam) and LFC (Leeke's Creek) (Figure 7.3). The reason for this is not clear, but may be related to local geology.

Electrical conductivity was above the QWQG upper trigger value at most sites, particularly at site P1 (upstream Putney Creek); the dams (D1 to D3) were below the trigger value

(Figure 7.4). This is likely to be related to evaporation at most sites and the groundwater waters source at site RP (Resort Creek).

The total suspended solid concentration was highest at sites P2 (downstream Putney Creek), P3 (mid Putney Creek) and LFC (Leeke's Creek) and relatively low at sites D3 (Resort Dam) and site RP (Resort Creek) (Figure 7.5).

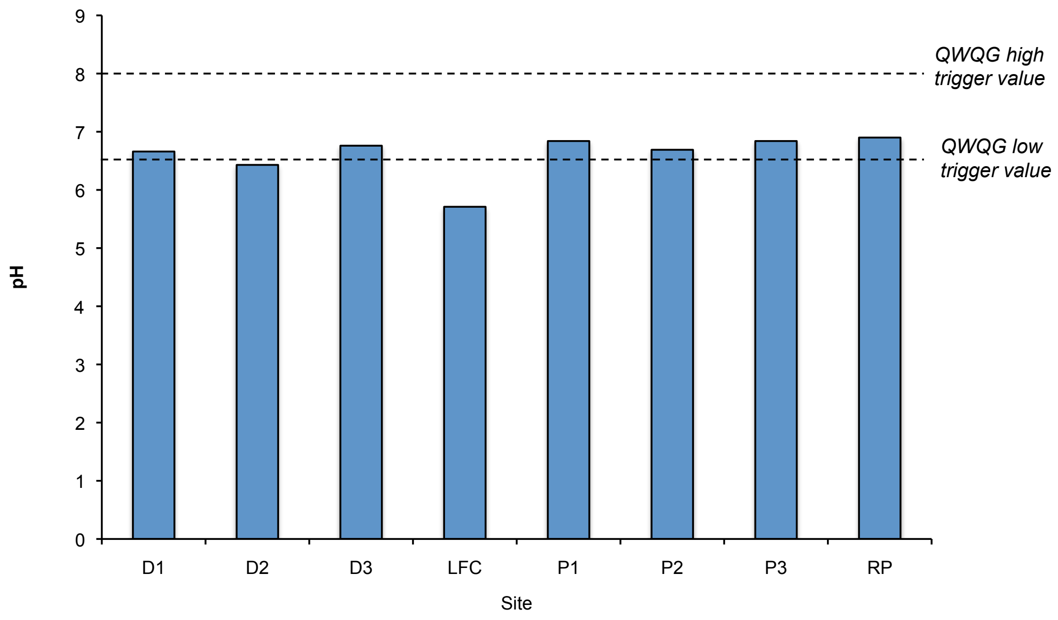


Figure 7.3 The pH at each freshwater site, and the QWQG trigger value range.

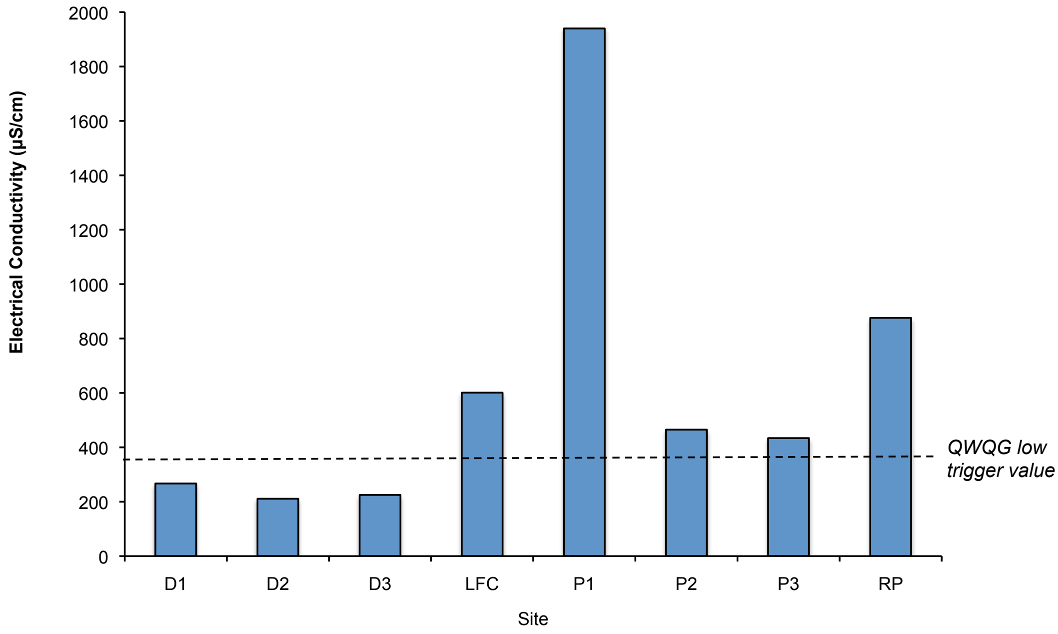


Figure 7.4 Electrical conductivity at each freshwater site, and the QWQG trigger value.

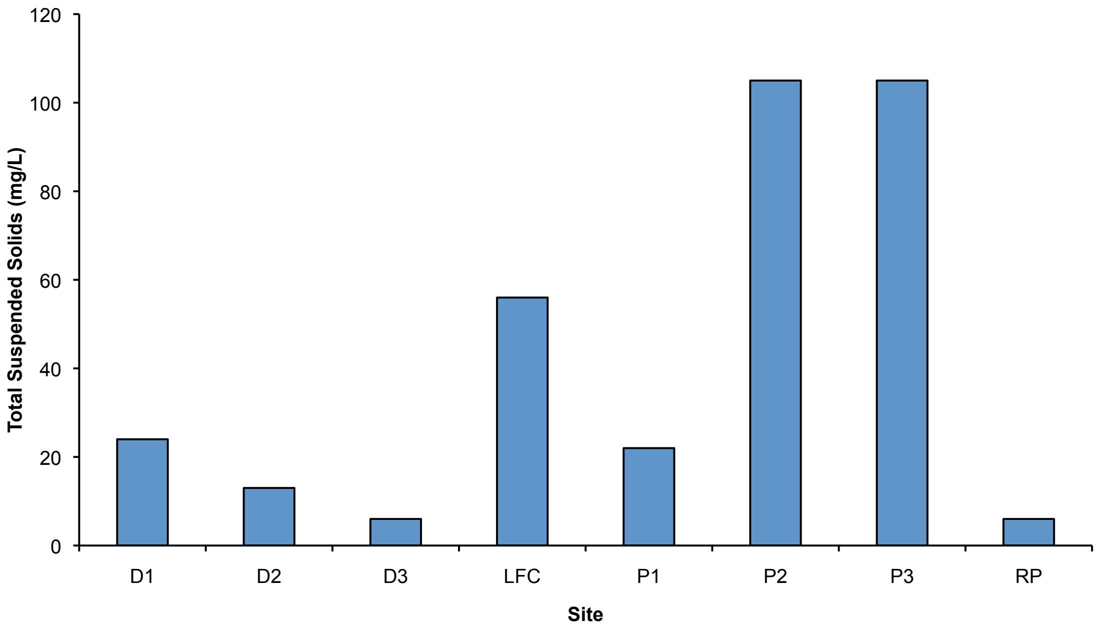


Figure 7.5 Concentration of total suspended solids at each freshwater site.

The concentration of total nitrogen was above the QWQG lower trigger value at all sites (Figure 7.6). The concentration of total phosphorous was above the QWQG lower trigger value at all sites, except site D3 (Resort Dam) (Figure 7.7). This is likely to be related to seepage from septic systems and possibly landfill.

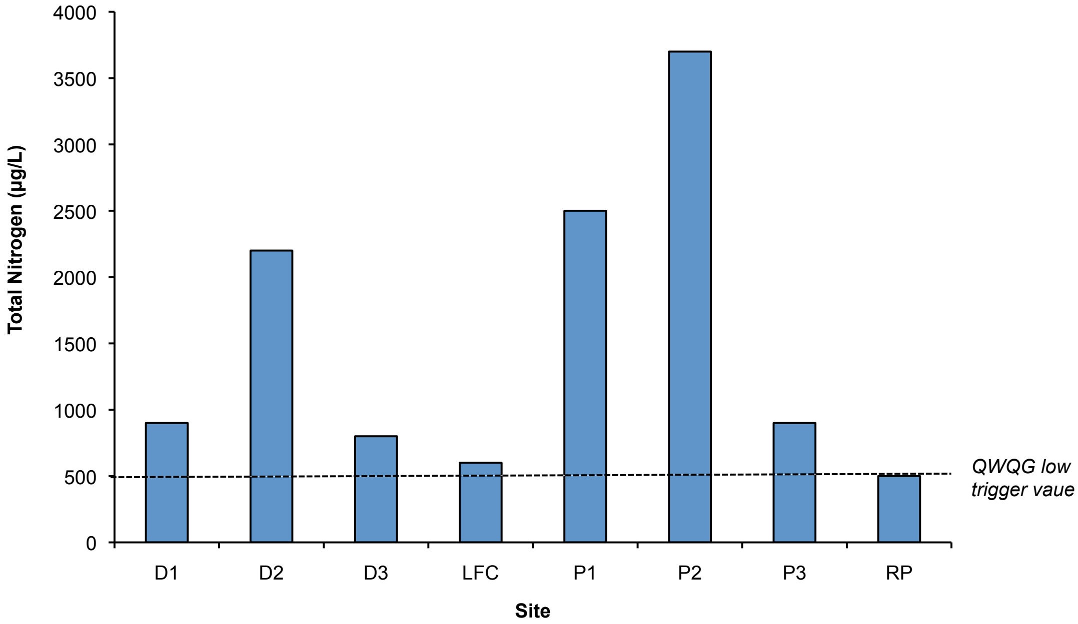


Figure 7.6 Concentration of total nitrogen at each freshwater site, and the QWQG trigger value.

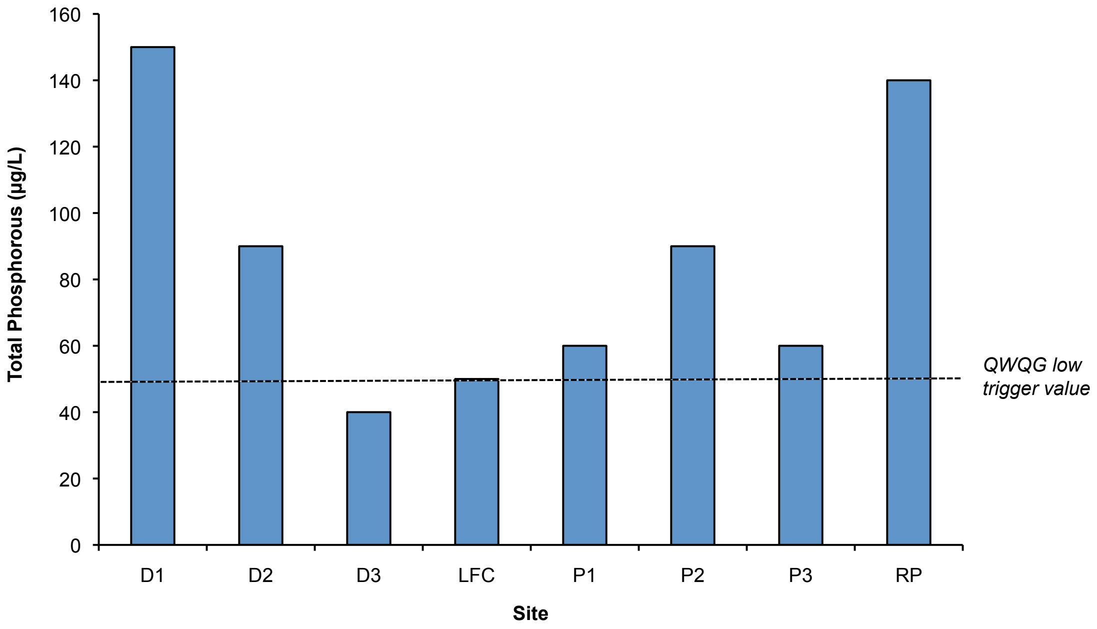


Figure 7.7 Concentration of total phosphorus at each site, and the QWQG trigger value.

Concentrations of total arsenic, cadmium, mercury and nickel were below laboratory detection limits and / or the relevant ANZECC & ARMCANZ trigger values at all sites. Total chromium, copper, lead and zinc concentrations were above laboratory detection limits and / or trigger values at some sites, which is likely to be related to seepage from landfill, historical livestock grazing activities and / or local geology. The concentration of total chromium was above the trigger value at site P1 (upstream Putney Creek). The concentration of total copper was above the trigger value at sites D1 (Large Dam), D2 (Homestead Dam) and in Putney Creek (P1 to P3). The concentration of total lead was above the trigger value at sites D3 (Resort Dam) and LCF (Leeke's Creek). The concentration of total zinc was above the trigger values at most sites; it was below the trigger value at sites D2 (Homestead Dam), D3 (Resort Dam) and LFC (Leeke's Creek).

The concentration of the total petroleum hydrocarbon C15 to C28 fraction was relatively high at site D1 (Large Dam); this site may have been exposed to diesel. The total concentration of the C29 to C36 fraction was relatively high at sites D1 (Large Dam), D2 (Homestead Dam) and P2 (downstream Putney Creek); these sites may have been exposed to mineral-based oils and lubricants.

Sediment Quality

The concentration of total nitrogen in the sediment was highest at sites P2 (downstream Putney Creek), P3 (mid Putney Creek) and RP (Resort Creek) (Figure 7.8). The concentration of total phosphorus in the sediment was highest at sites P3 (mid Putney Creek) and RP (Resort Creek) (Figure 7.9). This is likely to be due to seepage from septic tanks and possibly landfill.

The concentrations of arsenic, cadmium, chromium, copper, lead, mercury, nickel and zinc in the sediment were below the ISQG-low trigger value at all sites. Concentrations were relatively high at some sites, which is likely to be related to seepage from landfill, livestock grazing activities and / or local geology.

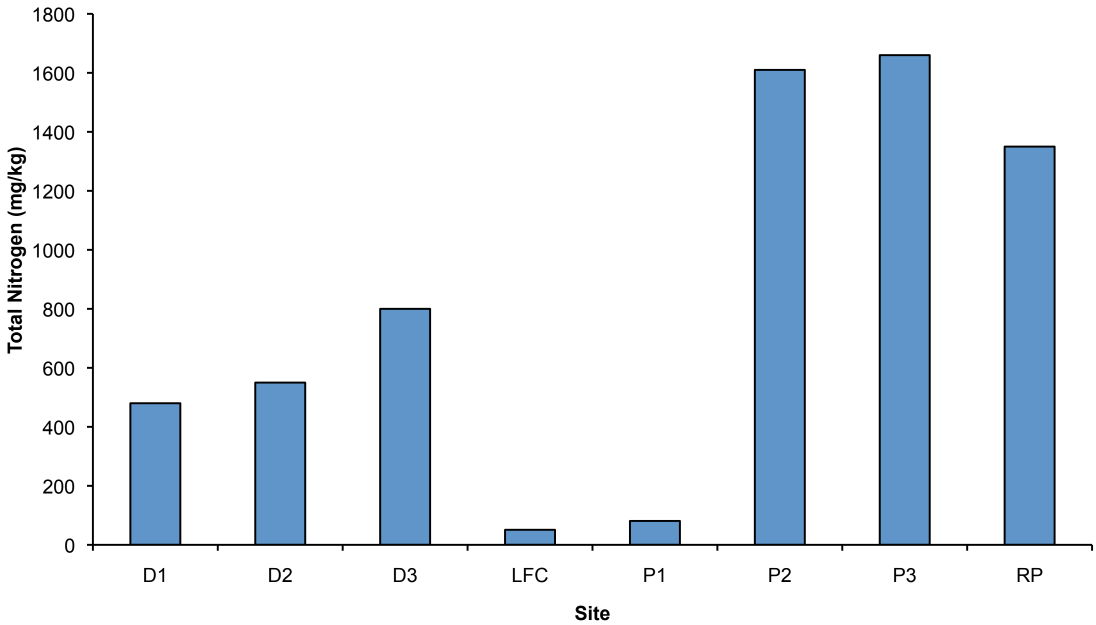


Figure 7.8 Concentration of total nitrogen in the whole fraction of sediment at each freshwater site.

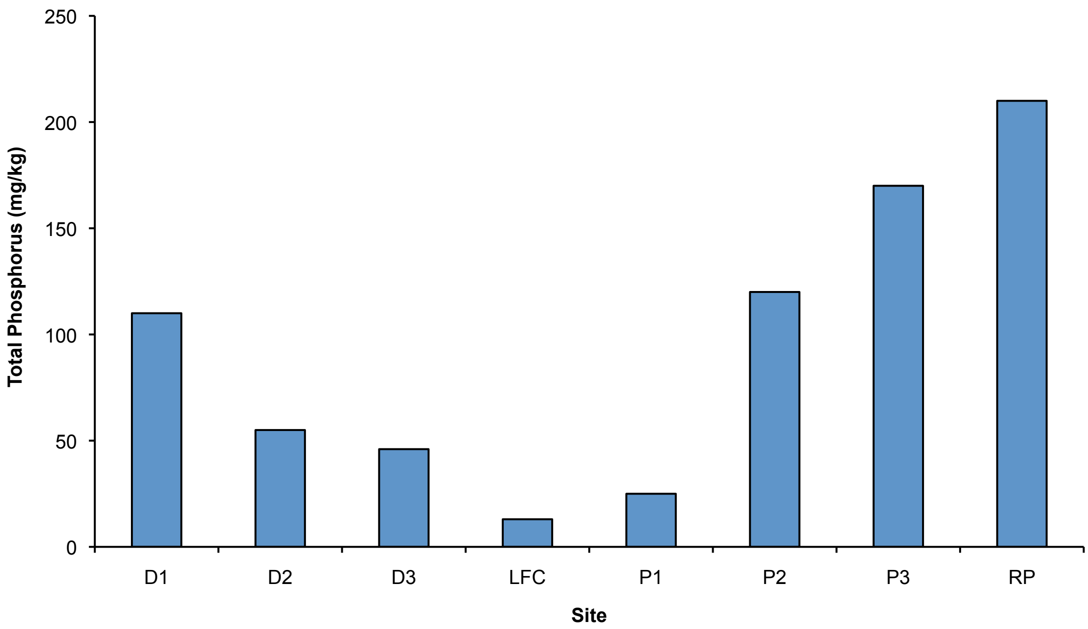


Figure 7.9 Concentration of total phosphorus in the whole fraction of sediment at each freshwater site.

Aquatic Flora

Taxonomic richness of aquatic flora (macrophytes) was highest at site LFC (Leeke's Creek) and lowest at sites D3 (Resort Dam) and P3 (mid Putney Creek). Macrophyte cover was greatest at site RP (Resort Creek), but also relatively high at sites D1 (large Dam), LFC (Leeke's Creek) and P3 (mid Putney Creek), and lowest at site D2 (Homestead Dam). The low cover at site D2 (Homestead Dam) is likely to be related to clearing for livestock grazing.

No single species was widespread; communities were characterised by a range of species with low cover. Three naturalised species were recorded and one potentially exotic species was recorded. These species were uncommon and sparse, with each species covering <5% of one site.

No macrophytes listed under the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999* or Queensland *Nature Conservation Act 1992* were recorded during the survey, or are likely to occur in the project area.

Aquatic Macroinvertebrate Communities

Diving beetles (family Dytiscidae), midge larvae (subfamilies Chironomidae and Tanypodinae), water boatmen (family Corixidae), backswimmers (family Notonectidae), damselflies (family Coenagrionidae), dragonflies (family Libellulidae) and mayflies (family Baetidae) were the most common and abundant taxa sampled. Typically, these families are tolerant of a wide range of environmental conditions and are often found in moderately disturbed ecosystems.

Total taxonomic richness in the AUSRIVAS samples was below the QWQG value at most sites (Figure 7.10); it was above the guideline value at sites P1 (upstream Putney Creek), RP (Resort Creek) in bed habitat and DERM site 120009 in both habitats. Taxonomic richness was relatively low in both habitats at site LFC (Leeke's Creek) and relatively high in bed habitat at sites P1 (upstream Putney Creek) and RP (Resort Creek). Abundance was lowest at sites LFC (Leeke's Creek), P2 (downstream Putney Creek) and P3 (mid Putney Creek) and relatively high at sites P1 (upstream Putney Creek) and RP (Resort Creek).

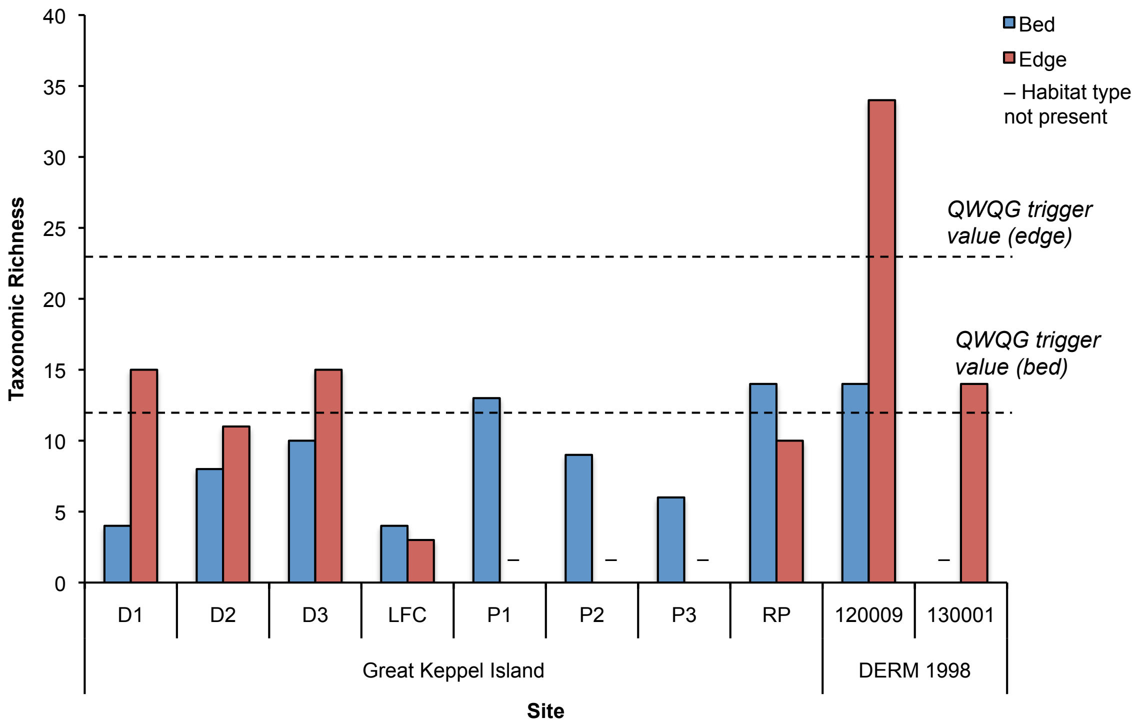


Figure 7.10 Total taxonomic richness in bed and edge habitats at each site, and sites sampled by DERM in 1998.

PET richness in the AUSRIVAS samples was below the QWQG value at most sites (Figure 7.11); it was equal to or above the guideline at site D3 (Resort Dam) in edge habitat, site P2 (downstream Putney Creek) in bed habitat and DERM site 120009 in both habitats. Low abundance of PET taxa may indicate poor water and / or habitat quality, however, several sites were ephemeral and PET taxa are rare in these environments.

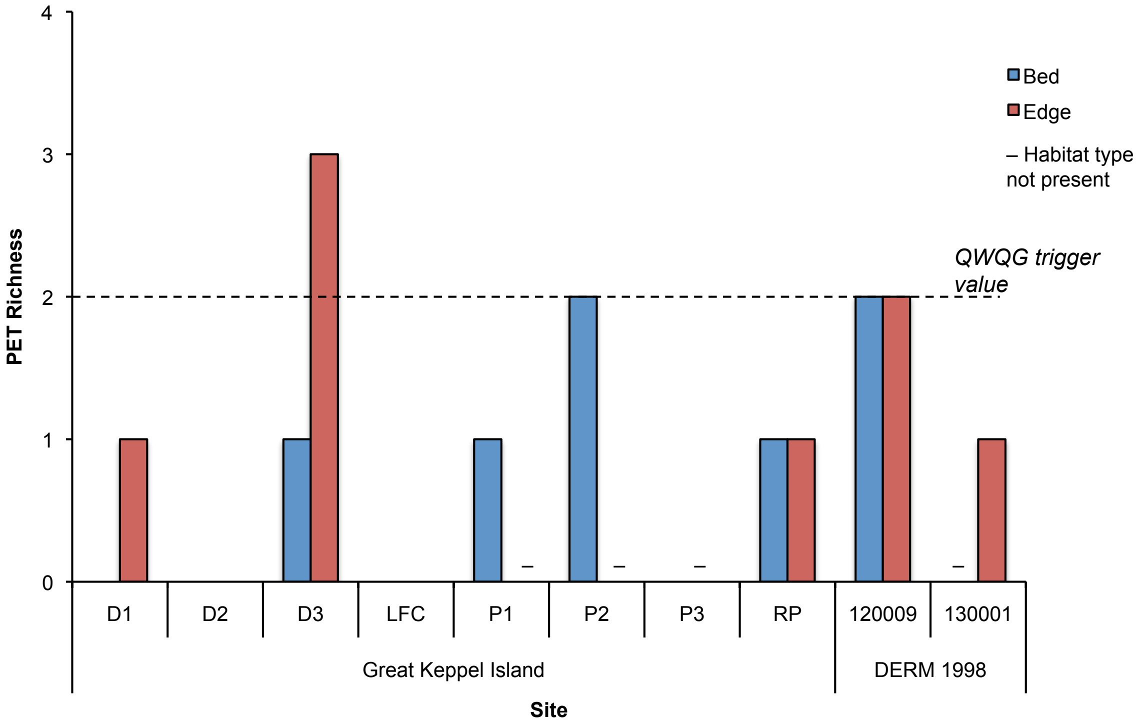


Figure 7.11 PET richness in bed and edge habitat at each site, and at sites sampled by DERM in 1998.

Most macroinvertebrate communities were within Quadrant 4 of the SIGNAL 2 / family bi-plot, which is indicative of urban, industrial or agricultural pollution (Figure 7.12). Bed habitat at sites P1 (upstream Putney Creek) and RP (resort Creek) and both habitats at DERM site 120009 were within Quadrat 2, which is indicative of better water quality than Quadrant 4.

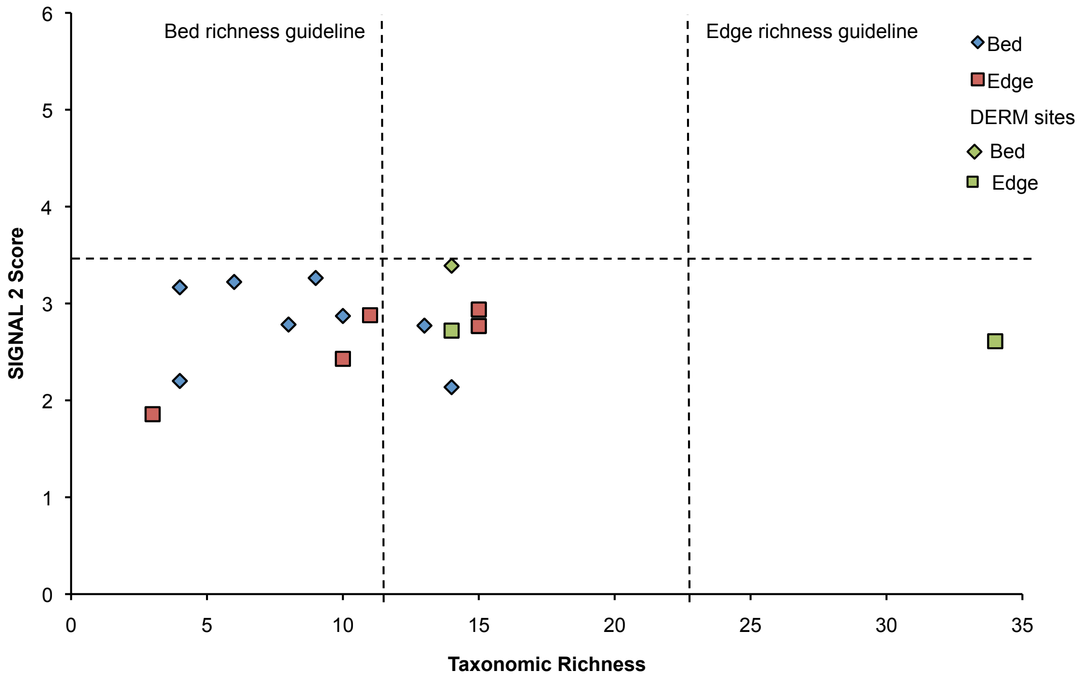


Figure 7.12 SIGNAL 2 / family bi-plot for bed and edge habitat at each site, and at sites sampled by DERM in 1998.

Freshwater Fish Communities

One freshwater fish, Midgley's carp gudgeon (*Hypseleotris* sp.) was caught at site P2 (downstream Putney Creek). This is likely to be because the majority of sites are off-stream dams or ephemeral streams that are dry for most of the year. Although only one fish was captured, the waterways of the project area are likely to support a depauperate community of freshwater fishes common to the region.

Freshwater Turtles Communities

Freshwater turtles were not observed during the surveys, however it is possible that turtles common to the region may occur in the project area.

Further details are provided in Appendix G.

8 Potential Impacts to Marine Ecosystems

8.1 Description of Project

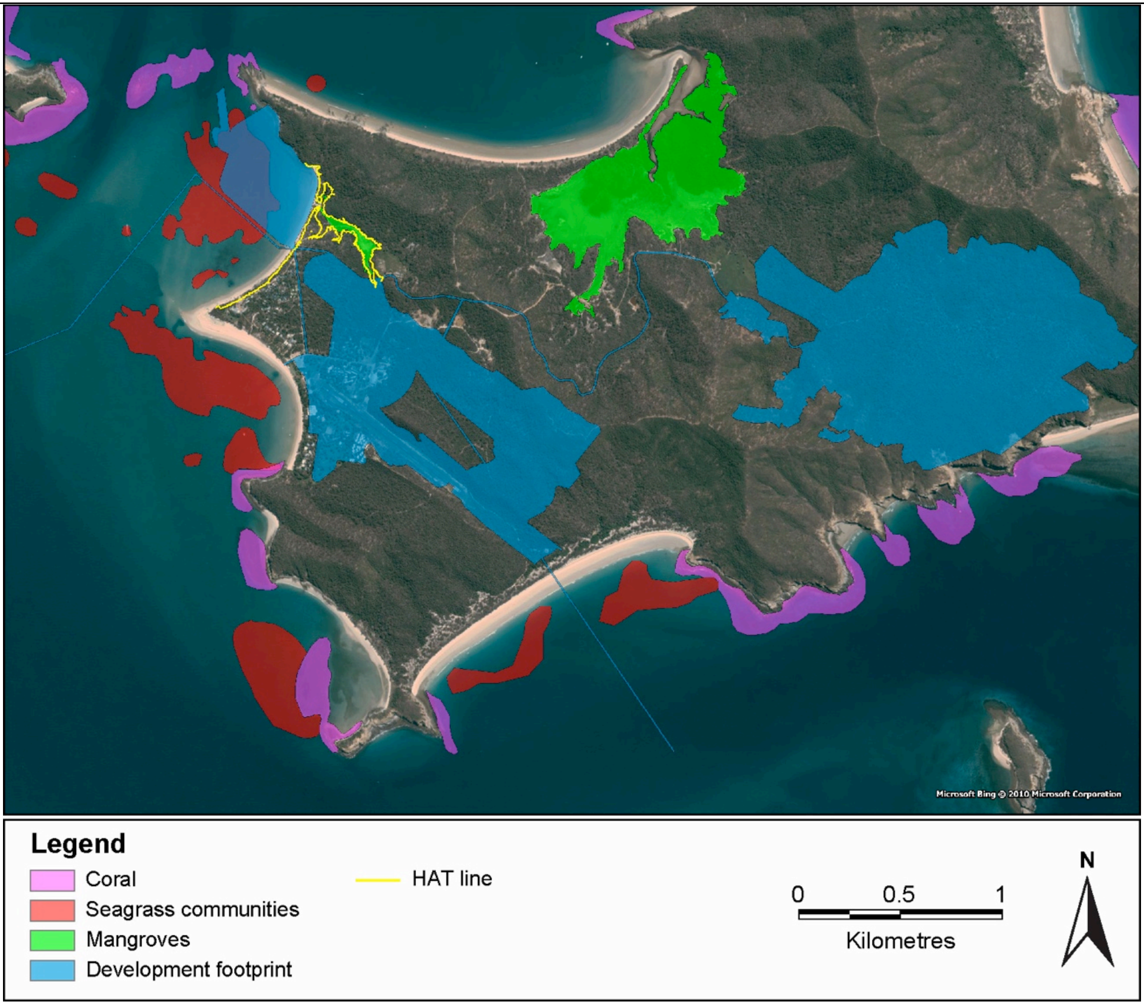
The revised proposal for the Great Keppel Island Resort Revitalisation Plan 2010 includes the following components that have the potential to impact on marine ecosystems:

- dredging for construction of the marina and re-nourishment of Putney Beach using dredge spoil
- development of a marina at Putney Beach comprising 250 berths, emergency services facilities, ferry terminal, yacht club, dry dock storage, and retail area (mix of cafes, restaurants and clothing shops)
- development of an 18-hole golf course, integrated with essential habitats and ecological corridors, and located on previously disturbed grazing lands
- development of associated service facilities and utilities (e.g. fuel storage and wastewater treatment plant)
- establishment of a Water Management Plan to mitigate effects of stormwater run-off and golf course run-off into the Great Barrier Reef Marine Park (GBRMP), and
- installation of a submarine connection of services (e.g. power, telecommunications and potable water) line between Great Keppel Island and Kinka Beach on the mainland.

That is both construction and operation of the proposed development may impact marine ecosystems. Impacts may be both direct (for example, loss of habitat to dredging) and indirect (for example altered community structure in response to altered water quality), and irreversible or temporary.

Figure 8.1 and Figure 8.2 show ecological communities and the proposed development on Great Keppel Island and the mainland, respectively.

Further details are provided in Appendix C.



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Great Keppel Island Revitalisation EIS

Figure 8.1 Ecological communities and the proposed development on Great Keppel Island.

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	Figure 8.2 Ecological communities and the proposed submarine cable alignment on the mainland.
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8.2 Potential Impacts

Associated with Construction

Loss of Marine Habitat (and Floral Communities)

Unvegetated Soft Sediment

Construction and dredging of the marina will results in the direct loss of approximately 20.08 ha of unvegetated[7] soft sediment, and the associated macrobenthos.

Seagrass and Macroalgae

Construction of the marina will result in the direct loss of patches of seagrass within an area of approximately 9.60 ha. These patches cover less than 10% of the of seabed; the cover within the patches ranges from <5% to 15%. A total area of less than 0.96 ha of seagrass will be lost.

Installation of the submarine cables along the marina breakwall will remove an additional 0.004 ha of seagrass (calculation is approximate, based on a 1 m wide installation corridor through an area of 0.04 ha that contains seagrass patches covering less than 10%). A hydrographic survey was undertaken to inform route alignment, and avoid sensitive ecological communities including seagrass meadows.

These calculations are based on the maximum extent of seagrass distribution recorded during this study (the pre-wet season survey in November 2010), and consequently the calculated loss is likely to over-estimate the loss averaged over time. This is equivalent to less than 0.1% of the seagrass recorded in the Central Queensland Region (Mackay to Gladstone), or less than 0.0002% of the seagrass in the Great Barrier Reef Marine Park.

Seagrass as Habitat for Fauna

Seagrasses provide shelter and refuge for resident and transient adult and juvenile finfish, crustaceans and cephalopods. Many of these species are of commercial and recreational importance, and others are the preferred foods of these species. While juvenile abundance of many fish and crustacean species is commonly higher in seagrass habitats than over bare sand or mud, there are significant differences in abundance between seagrass beds. Some sites have consistently higher recruitment, while other sites may

[7] Devoid of macrophytes; benthic micro algae are expected to be associated with the surface sediments.

only periodically or temporarily have higher abundances. This may be due to the structural complexity of the seagrass beds; location of the seagrass beds with respect to currents and the dispersal of larvae; and natural fluctuations (patchiness) in population sizes.

Loss of seagrass has the potential to affect species of conservation significance, as seagrass provides an important food source for several important species, e.g. marine turtles, dugong and syngnathids.

Given that the meadows within and adjacent to the proposed marina are sparse and patchy, and typical of the region, the potential loss is unlikely to have a measurable ecological impact beyond the marina footprint.

Mangroves

Mainland connection of the submarine cables along the current proposed alignment may remove up to 0.04 ha (based on a 2.5 m wide installation corridor) of mangrove forest. This is less than 9.7 $x10^{-7}$% of the mangroves in the Central Queensland Coast Bioregion. There are several gaps in the forest (up to 67 m wide) and removal of mangroves will not be required where the alignment is modified to extend through one of the gaps.

Coral Communities

A small coral colony directly adjacent to the marina footprint may be lost as it is relatively close to the marina breakwall.

Rocky Intertidal Communities

Approximately 0.98 ha of intertidal rocky shore will be lost as a result of the construction of the marina.

Gain of Habitat

Artificial Structures as Habitat within the Marina Basin

Construction of the proposed marina will result in a mosaic of habitats associated with breakwalls, pontoons, piles and other intertidal and subtidal structures, together with moored vessels. The hard surfaces of these structures will provide substrate for many species of algae, hard and soft corals, sponges, ascidians and a variety of other invertebrates. The wastewater outfall will also provide a recruitment surface for a variety of benthic flora and fauna. In turn, this sessile benthic community may provide shelter and food for a variety of fishes and other fauna. The structures associated with the proposed development will also provide a high degree of shade, which is important in attracting many fish species.

The waters of the marina basin are likely to have relatively low ecological value, as the waters are likely to be too deep to support substantial floral communities. The soft sediment community will likely be similarly depauperate to those recorded in the proposed footprint (dominated by polychaete worms). Habitat, and consequently ecological value, could be enhanced with the addition of fish-friendly structures. DERM's *Fisheries Guidelines for Fish-Friendly Structures* describe a number of artificial structures that may enhance fish habitat. These opportunities will be considered at the detailed design stage.

Mangroves of Putney Creek

Opening the Putney Creek mouth would change the flood regime with the potential to positively impact water and sediment quality. Improved water and sediment quality would facilitate improved condition of the mangrove and saltmarsh communities in Putney Creek, which are currently in relatively poor condition and provide relatively poor habitat for fauna compared to forests with better flushing and hence water and sediment quality (e.g. Leeke's Creek and Kinka Beach). The fisheries habitat values of the creek are expected to significantly improve.

Increased Turbidity and Sediment Deposition

Dredge plume modelling by Water Technology (2011) shows the likely dredge plume to be generally confined to the marina footprint. The dredge plume may extend beyond the marina basin on occasion for short periods of time.

Outside the marina footprint, communities are unlikely to be substantially affected by any temporary reduction in light intensity, given that these seagrasses currently inhabit inshore coastal waters with variable turbidity and light penetration, and are capable of recovery following flood-related turbidity and sedimentation (as discussed in Appendix E). Given the very limited cover of seagrass in the vicinity of the marina, and the short duration of any predicted increase in suspended solid concentration, the ecological consequences of predicted seagrass damage / loss is likely to be negligible, even in a local context.

Outside of the marina, silt may settle over a very small area of seagrass to the south of the marina (up to approximately 1 ha). Species with small growth forms (*H. uninervis* and *H. ovalis*) are likely to be more affected than those with a larger growth form (*H. spinulosa* and *S. isoetifolium*). Given the essentially permanent nature of the predicted deposition, *H. uninervis* and *H. ovalis* are unlikely to survive substantial deposition, however these species are likely to rapidly recolonise the area.

The coral communities in the vicinity of the proposed marina are likely to be largely unaffected by increased suspended solid concentration and sediment deposition given the physiological tolerances that are characteristic of corals growing in inshore waters subject to variable turbidity and light penetration. The small coral outcrop directly adjacent to the marina footprint would likely be impacted to a greater extent than the corals of Putney Point, as they are relatively close to the marina breakwall. Any impacts of dredging on these nearby coral communities are likely to be temporary and reversible.

Whilst the proposed dredging may impact the soft sediment invertebrate communities within the dredge plume, any impact will be temporary and reversible. The effect of increased suspended solids concentration and sediment deposition on fish communities of the likely dredge plume dispersal area is likely to be of negligible ecological consequence (unlikely to influence migratory behaviour or health).

Spills of Hydrocarbons and other Contaminants

A moderate spill of hydrocarbons or other contaminants from a marina construction vessel may severely impact the local marine ecosystem. Best-practice vessel management and site management will minimise the risk of contaminant spillage. Where the spill is a ‘once-off’, recovery is likely.

Nutrient Enrichment

Nutrient enrichment of marine environments as a result of the dredging plume during construction of the marina is likely to be low, based on sediment sampling undertaken in accordance with the *National Assessment Guidelines for Dredging.* Modest enhancement of primary production is likely, but it is considered unlikely that any detrimental effects will be manifest. These minor impacts will be of a temporary and reversible nature.

Waste and Litter

Litter and waste associated with construction of the marina has the potential to contribute to the degradation of water quality and may pose a direct hazard to marine fauna. Best-practice site management can be expected to result in a negligible amount of litter escaping to the marine environment.

Acid Sulphate or Potential Acid Sulphate Sediment

Levels of acid sulphate and potential acid sulphate soils are likely to be low based on sediment sampling undertaken in accordance with the *National Assessment Guidelines for Dredging.*

Associated with Operations

Spills of Hydrocarbons and other Contaminants

Whilst 'one off' spills of substantial volume have the potential to severely impact a large area, recovery is likely; chronic small spills, though probably influencing a lesser area, can effectively prevent recovery and lead to cumulative impacts. Frequent spills from a diffuse number of locations within a waterway can act in concert, resulting in an enduring impact over a very wide area. The responsibility for minimising spills will rest with both the marina managers and the boating public.

Nutrient Enrichment

Nutrients may enter the marine environment via the wet weather sewerage outfall at Long Beach, and with storm water run-off from the golf course entering Clam Bay. The addition of nutrients to these environments has the potential to alter the community composition of floral and consequently faunal communities. Increased nutrient loads may also lead to an increase in phytoplankton densities, and consequently a reduction in water clarity and seagrass depth distribution

Moderate amounts of additional nutrients in the water column can also increase seagrass growth. However, as macroalgae are more efficient at absorbing nutrients from the water column than seagrasses or coral, higher levels of nutrient enrichment can lead to an increase in macroalgae growth at the expense of seagrass and coral. Consequently, benthic macroalgae may overgrow and displace seagrass, whilst drift and epiphytic algae may physically shade seagrass and coral, reducing their growth and distribution.

Epiphytic algae may also reduce diffusive exchange of dissolved nutrients and gases at leaf surfaces.

The trophic structure of benthic invertebrate communities often changes with increased nutrient levels, becoming dominated by small opportunistic deposit feeders. In eutrophic estuaries deposit feeding spionid and capetellid polychaete worms often tend to dominate benthic communities.

Wet weather sewage outfall and stormwater runoff are likely to be associated with significant rainfall events that by their nature provide a means of diluting nutrient concentrations. The discharge from mainland rivers dominates water quality of waters surrounding Great Keppel Island: during the wet season, localised discharges are likely to be masked by mainland influences. Localised (of a scale of 10s of meters square) effects of nutrient enrichment (enhanced epiphytic growth, altered benthic macro-invertebrate community structure) may become manifest adjacent to the wet weather sewerage outfall and stormwater outlets.

Detail design of effluent and stormwater discharge structures will seek to maximise dilution and dispersion.

Short-term impacts to marine water quality during operation of the golf course include the potential for nutrient enrichment following stormwater run-off or water storage overflow. However impacts to water quality and ecosystem functioning are likely to be negligible as the wastewater will, as a minimum, be treated to meet section 135(4) of the *Great Barrier Reef Marine Park Regulations 1983* (Opus International Consultants (Australia) Pty Ltd 2011b). None the less, potential impacts associated with nutrient enrichment on mangrove forests are discussed in Appendix C.

Copper Contamination

The concentration of copper in the waters of the marina are likely to be higher than in waters outside the marina, due to leachate from anti-fouling paint on boat hulls. Concentrations up to approximately 3 µg/L may reach the corals of Putney Point or seagrass meadows near the marina (both communities are located within approximately 250 m of the marina access channel). The coral and seagrass communities near the marina are likely to be largely unaffected by the predicted copper concentrations, given reported tolerances and observations of established marinas on the Queensland coast.

Artificial Lighting

The construction and operation of the marina will increase the illumination of the Putney Beach area at night, and operation of the resort may increase the illumination of Fishermans Beach. Increased illumination has the potential to impact nesting turtles and hatchlings (Lutcavage et al. 1997; DERM 2009b).

Nesting turtles do not often utilise Putney and Fisherman's beaches, and Great Keppel Island is not a significant turtle rookery. None the less, 'light leakage' to seaward will be minimised at the detailed design stage. No significant regional impact on turtle nesting or hatching success is expected.

Human Activity

The construction of the proposed marina is likely to result in increased noise and activity. This may temporarily disturb fauna such as dolphins, dugongs and turtles, and they may move away from the area. However, this is likely to be a short-term response, and they are likely to return once construction is completed.

Increases in human activity on turtle nesting beaches such as Leeke's Beach, may interrupt nesting marine turtles. Given that Great Keppel Island is not a significant turtle-nesting rookery, disturbance by people is unlikely to have a significant impact on turtle populations within the region.

The presence of the marina will lead to an increase in the use of recreational vessels around Great Keppel Island, inevitably resulting in more frequent interactions between boating traffic and megafauna. Megafauna may respond to boating disturbance by altering their behaviour (e.g. changing swimming direction or reducing time spent resting (Hodgson & Marsh 2007). Long-term effects of boat traffic include displacement of fauna to deeper waters, where less food resources may be located. Importantly, the waters off Great Keppel Island are not considered to support significant feeding grounds (seagrass meadows) for dugong or green turtles, and substantial coral-dominated habitat (feeding grounds for loggerhead and hawksbill turtles) are relatively distant from the proposed marina. The risk of collision between boats and marine fauna is reduced when vessels operate at slow and consistent speeds (Hazel et al. 2007; Hodgson & Marsh 2007). As such, the enforcement of speed limits around the marina area will be key to reducing the disturbance of marine megafauna.

Introduction of Marine Pests

The introduction of exotic flora and fauna can threaten the integrity of natural communities, the existence of rare and endangered species, the viability of living resource-based industries and pose risks to human health. The proposed marina will not serve as a point of entry to Australia and will not service international commercial shipping; therefore, the risk of introductions via ballast water is negligible.

Boat Strike

During 1999 and 2000, boat strike was the primary cause of human-associated mortality of marine turtles in Queensland, accounting for up to 60% of deaths (GBRMPA 2005). During 2001 and 2002, boat strike was also a major concern for dugongs (QPWS 2004b). More recent data suggests that ‘go slow’ zones are reducing the incident of boat strike in areas with relatively high boat traffic and relatively large marine turtle and dugong populations, i.e. the Great Sandy Straits and Moreton Bay (QPWS 2004b; 2007).

An increased number of high-speed boats in the project area would increase the risk of boat strike in areas frequented by turtles and dugongs. In the project area, dugongs and marine turtles are relatively uncommon and segarass meadows are relatively sparse and patchy, compared to regions such as the Great Sandy Straits and Moreton Bay; hence boat strike is considered manageable where ‘go slow’ zones are introduced over shallow water likely to have increased high-speed boat traffic.

The risk of boat strike associated with wildlife tours is considered manageable where a management plan is developed as part of the Environmental Management Plan (EMP) is developed, with all activities undertaken in accordance with current best practice including GBRMPA’s *Best Environmental Practices* for dugong watching (GBRMPA 2011a).

Resort Activities and Reef Visitation

There is a risk of physical destruction and / or depletion of ecosystems in association with resort activities and reef visitation. The risk is considered manageable where a management plan is developed as part of the EMP, with all activities undertaken in accordance with current best practice, including *GBRMPA’s The Tourism Operator’s Handbook for the Great Barrier Reef* (GBRMPA 2012b) and reefED’s *Best Environmental Practices* (GBRMPA 2012a). The management plan is outlined in Appendix F.

Altered Flow Regimes and Environmental Flows

Capture of stormwater run-off on the golf course, for retention and treatment, is likely to reduce environmental flows in downstream freshwater and estuarine (i.e. mangrove forests) ecosystems. Reduced environmental flows have the potential to negatively affect water quality, sediment quality, flora and fauna.

The potential impact to freshwater ecosystems is considered minor as waterways are ephemeral (i.e. dry for much of the year) and large parts of the catchment area will not be affected by the golf course development (i.e. will continue to provide seasonal environmental flows in downstream environments). The impact will be negligible where environmental flows are maintained, i.e. treated water is released form the water storage facilities in similar quantities and with similar timing to natural flows. None the less, potential impacts associated with altered flow regimes on mangrove forests are discussed in Appendix C.

Cumulative Impacts

Cumulative impacts to marine ecosystems are discussed further in Appendix C.

Nearby Tourism Developments

Nearby tourism developments identified by GBRMPA for assessment include:

- Rosslyn Bay Inn (as known as the Rosslyn Bay Resort), Rosslyn Bay, approximately 15 km to the west
- Seaspray Resort and Spa, Zilzie (near Emu Park), approximately 18 km to the south west
- Zilzie Bay, Zilzie, approximately 20 km to the south west, and
- Mercure Capricorn Resort, Yeppoon, approximately 24 km to the north west.

The extent of potential impact in association with the operation of the Great Keppel Island development is likely to be minimal where appropriate mitigation measures are developed and adhered to. The cumulative impact of the operation of the Great Keppel Island development and nearby resorts is therefore also likely to be negligible for most potential impacts that the resorts have in common. For example:

- potential impacts to recreational fishing are expected to be minor where managed in accordance with fisheries regulations (e.g. bag limits and no catch species) and Great Barrier Reef Marine Park (GBRMP) zoning at all resorts
- potential impacts associated with marina activities are expect to be minor where managed through marine-specific Environmental Management Plans (EMPs) at Great Keppel Island and the Keppel Bay Marina, including the Dredge Management Plans and Spill Management Plans
- potential impacts associated with trampling of coral reef is expected to be minor where managed through guided tours and in accordance with GBRMP zoning and regulations; impacts to reef environments at each of the resorts are unlikely to have a cumulative impact given each respective reef is unlikely to rely on other respective areas for ecosystem functioning (many resident coral reefs species have small home ranges), and there are large areas of coral reef near each of the resorts (e.g. fringing the mainland, Middle Island and other islands of the Keppel Group) that can contribute to local and regional ecosystem functioning for transient coral reef species
- potential impacts associated with degradation of coastal ecosystems (associated with litter and waste, habitat destruction, and collection of shells and other coastal resources as souvenirs) are considered minor where managed through the EMP and GBRMP and national park regulations; impacts to coastal environments at each of the resorts are unlikely to have a cumulative impact given each respective reef is unlikely to rely on other respective areas for ecosystem functioning (many resident coral reefs species have small home ranges), and there are large areas of coral reef near each of the resorts (e.g. fringing the mainland, Middle Island and other islands of the Keppel Group) that can contribute to local and regional ecosystem functioning for transient coral reef species
- potential impacts associated with disturbance to turtle nesting is expected to be minimal where construction activities are undertaken outside of the nesting season and in accordance with the EMP, and resort lighting is not directed to the shoreline (particularly considering beaches around the Great Keppel Island and along the mainland adjacent to each of the resorts are not major rookeries for marine turtles), and
- potential impacts associated with nutrient-laden run-off from the golf courses are considered negligible where all run-off is captured for treatment (there will be no impact to the downstream ecosystems of Leeke’s Creek).

There is a risk of cumulative impact associated with visitation to Great Keppel Island by nearby resort guests, such as litter and waste, hydrocarbon spills, boat strike, disturbance of nesting turtles and trampling of coral. Where nearby resorts apply the same mitigation measures as those proposed by the Great Keppel Island resort, and adhere to GBRMP and other regulations, impacts are expected to be manageable. There remains the potential for a major cumulative impact where island visitation is not managed collaboratively.

Climate Change

Seagrass meadow and coral reef communities in the immediate vicinity of the marina and (possibly) the wastewater wet weather outfall are likely to be negatively impacted by the proposed development. The water quality and mangroves communities of Putney Creek are likely to be positively impacted in the longer term, as may the faunal communities of the marina given the additional physical habitat (hard surfaces) for sessile and mobile epibenthic fauna (e.g. algae, corals, sponges, ascidians and gastropods) and mobile fauna (e.g. fish, sharks and marine turtles seeking refuge and / or food).

The direct impacts of the proposed development are likely to have a substantial impact on the resilience of flora and fauna to other disturbances such as climate change. However the potential cumulative impacts of the proposed development on these species and ecosystem functioning, associated with climate change, are likely to be negligible at the time scale predicted for many climate change impacts (i.e. 30 to 50 years). For example:

- more extreme rainfall and flooding of the Fitzroy River has the potential to completely smother large areas of seagrass and cause large areas of corals to bleach (due to stress associated with high turbidity and inputs of freshwater and potential contaminants) at regular intervals for the foreseeable future (thereby also impacting recovery), whereas a relatively small area of seagrass will be lost to the marina in the short term, and an even smaller area of seagrass may be smothered by modified sedimentation patterns in the medium term
- more extreme cyclones have the potential to physically destroy seagrass meadows and coral reefs (particularly where weakened by ocean acidification) and mangroves forests at regular intervals for the foreseeable future (thereby also impacting recovery), whereas a relatively small area of seagrass and even smaller area of coral will be lost to the marina in the short term, and an even smaller area of seagrass may be smothered by modified sedimentation patterns in the medium term (no major negative impact to mangroves predicted in association with the development), and

- rising sea temperature and increased ocean acidification have the potential to increase coral bleaching and erode calcium carbonate reef structures, whereas a relatively small area of coral will be lost to the marina in the short term with no major impact associated with the development predicted to occur in the medium to long term, and
- increased ocean acidification is likely to effect calcareous algal and plankton communities with flow-on effects to predators such as herbivorous fishes and planktivorous vertebrates (e.g. manta rays), whereas the development is unlikely to have a major negative impact on algal or plankton communities in the medium to long term (the marina has the potential to change the diversity of plankton communities as discussed in Appendix E and will provide more hard substrate for algal growth).

The marina, and to a lesser extent the wastewater wet weather outfall (if at all), may have a minor impact on the resilience and recovery of seagrass meadows and coral reefs in the short term. However there are unlikely to be any cumulative impacts associated with the development and climate change in the medium to long term, given the comparative severity and time scale of climate change impacts, particularly where communities are severely impacted by climate change (e.g. seagrass meadows almost completely smothered by successive flooding of the Fitzroy River).

That is, the magnitude of impact associated with the development will be far less than those impacts predicted to occur as a result of climate change; however any chronic impacts will influence the resilience of ecosystems and will need to be assessed through a rigorous and insightful EMP, with the outcomes used to re-assess management of the development on an on-going basis. Potential chronic issues include marina barriers (e.g. breakwall and marina precinct) that will require protection in the long-term future as sea levels rise, and landward migration of mangrove habitats.

Reefs of the Keppel Group have recently demonstrated resilience to bleaching and strong recovery following severe bleaching (Diaz-Pulido et al. 2009). Coral reefs of the region have been repeatedly affected by bleaching with substantial declines in coral coverage observed in 1998, 2002 and 2006[8]; in January 2006, 100% of corals in Keppel Bay were bleached with approximately 40% mortality by May 2006 (GBRMPA 2007; Weeks et al. 2008). Rapid recovery has been documented (e.g. Diaz-Pulido et al. 2009; Johnson et al. 2010), and some reefs in southern Keppel Bay (Humpy, Middle, Halfway and Pumpkin islands, and the reef surrounding Passage and Outer rocks) have been described as coral

[8] And most likely 2010 -11, although the effect of the recent Fitzroy River flooding on coral reef communities is yet to be confirmed.

'refuges' due to high diversity and connectivity to sites with lower diversity and coral cover (Jones et al. 2011). The development is unlikely to impact on these areas of reef.

Artifically opening Putney Creek has the potential to enhance the landward extent of mangrove and saltmarsh communities (via enhanced tidal flushing) and reduce the corresponding downstream extent of freshwater communities, in association with predicted sea level rise. However, Putney Creek is an ephemeral system that is dry for most of the year and the impact of a relatively slow ecological shift (in terms of ephemeral freshwater faunal communities being able to shift upstream in response to increasing salinities) is likely to be minimal. The ecological benefit of improved tidal flushing, water quality and mangrove ecosystem functioning is considered to be greater than any minor impact to ephemeral freshwater communities.

Nearby Significant Projects

The Coordinator-General's office lists several other significant projects in the Gladstone region that are currently in an environmental impact statement process under Part 4 of the *State Development and Public Works Organisation Act 1971*:

- Balaclava Island, 45 km south of Great Keppel Island
  - Balaclava Island Coal Export Terminal
- Curtis Island, >65 km south of Great Keppel Island
  - Arrow Energy LNG Project
  - Australia Pacific LNG Project
  - Gladstone LNG
  - Queensland Curtis LNG
- Port of Gladstone, ~75 km south of Great Keppel Island
  - Wiggins Island Coal Terminal
  - Fisherman's Landing Port Expansion
  - Port of Gladstone Western Basin Dredging and Disposal Project
  - Port of Gladstone Western Basin Dredging and Disposal Project

Given that these proposed projects are located far from Great Keppel Island (>45 km), it is unlikely that they will contribute to any localised changes to the marine communities around Great Keppel Island.

Coastal water quality of the region and of Great Keppel Island in particular, is highly variable, responding to flood discharge from the Fitzroy River and less frequently cyclonic conditions. It is these event-based 'drivers' of coastal water quality (which affects the health of seagrass and coral reef communities) that have the greatest ecological significance, and within which the potential impacts of the proposed marina should be viewed. However, little is known about how most marine species are able to cope with additional chronic disturbance (e.g. climatic change). Rigorous monitoring of floral and faunal communities of Great Keppel Island will enable management to identify potential issues and respond accordingly (see Section 8.4).

Risk Assessment

A risk assessment of potential impacts has been undertaken (Table 8.1), and a summary of potential and residual risk is presented in Table 8.2.

Table 8.1 Risk assessment matrix.

	Consequence				
Probability	Catastrophic Irreversible Permanent (5)	Major Long Term (4)	Moderate Medium Term (3)	Minor Short Term Manageable (2)	Insignificant Manageable (1)
Almost Certain (5)	(25) Extreme	(20) Extreme	(15) High	(10) Medium	(5) Medium
Likely (4)	(20) Extreme	(16) High	(10) Medium	(8) Medium	(4) Low
Possible (3)	(15) High	(12) High	(9) Medium	(6) Medium	(3) Low
Unlikely (2)	(10) Medium	(8) Medium	(6) Medium	(4) Low	(2) Low
Rare (1)	(5) Medium	(4) Low	(3) Low	(2) Low	(1) Low

8.3 Mitigation Measures

'Best practice' assessment and engineering practices will be employed to minimise the impacts associated with both construction and operation of the proposed development. Table 8.2 provides a summary of mitigation measures and the associated residual risk.

Table 8.2 Summary of potential impacts on marine ecosystems.

Design	Construction	Operation	Potential Impact	Mitigation Measure	Monitoring	Significance of Impact (Unmitigated)	Significance of Residual (Mitigated Impact)
●	●	●	Increased turbidity and sediment deposition	• all dredging activities should be undertaken in accordance with GBRMPA's Dredging and Spoil Disposal Policy • marina design including use of dredge spoil to construct breakwall and no ocean disposal • best practice construction methods including water jetting and burying-in-excavated-trench method for the submarine cable installation • 'isolation' of the dredge / disturbance area, using silt curtains, oil spill booms, bunding, trenching and / or similar technologies	• monitoring of the extent of the turbidity plume, and the use of 'trigger levels', to confirm that plumes do not reach ecologically sensitive areas including coral reefs of Passage Rocks and Middle Island	WQ (15) High Mangroves (1) Low Seagrass (15) High Coral reef (15) High Mobile biota (3) Low Listed species (4) Low	(WQ (5) Medium Mangroves (1) Low Seagrass (5) Medium Coral reef (5) Medium Mobile biota (2) Low Listed species (3) Low
●	●	●	Altered hydrodynamics and flushing – marina	• marina design	• monthly water and sediment quality monitoring during operation	WQ (8) Medium Mangroves (1) Low Seagrass (8) Medium Coral reef (4) Low Mobile biota (3) Low Listed species (4) Low	WQ (4) Medium Mangroves (1) Low Seagrass (5) Medium Coral reef (3) Low Mobile biota (2) Low Listed species (3) Low

Design	Construction	Operation	Potential Impact	Mitigation Measure	Monitoring	Significance of Impact (Unmitigated)	Significance of Residual (Mitigated Impact)
●	●	●	Altered hydrodynamics and flushing – Putney Creek	• marina design including opening of the creek mouth to improve flushing, a sediment basin and low weir to control flow • best practice erosion and sediment control techniques during construction	• monthly water and sediment quality monitoring during operation	WQ (8) Medium Mangroves (8) Medium Seagrass (1) Low Coral reef (1) Low Mobile biota (8) Medium Listed species (4) Low	WQ (4) Low Mangroves (8) Medium Seagrass (1) Low Coral reef (1) Low Mobile biota (8) Medium Listed species (4) Low

Design	Construction	Operation	Potential Impact	Mitigation Measure	Monitoring	Significance of Impact (Unmitigated)	Significance of Residual (Mitigated Impact)
	●	●	Hydrocarbon contamination and other contaminants	• fuel, oil and chemical storage and handling are undertaken in accordance with AS1940 • any fuel, oil or chemical spills are contained and cleaned up immediately • a Spill Management Plan prepared in accordance with State Planning Policy requirements and to the satisfaction of DERM • all refuelling is by licensed fuel suppliers in accordance with their Standard Operating Procedures • refuelling takes place at wharves with suitable access or in designated areas, in accordance with industry standards • the stored volume of fuel, oil or chemical in minimised, with storage in a secure area • any visible (or suspected) fuel, oil or chemical loss will be treated as an 'incident' • vessel crew regularly check equipment for evidence of leaks and condition of hydraulic hoses and seals, and conduct maintenance or repairs as necessary to prevent drips, leaks or likely equipment failures	• monthly water and sediment quality monitoring during construction and operation	WQ (10) Medium Mangroves (6) Medium Seagrass (4) Low Coral reef (4) Low Mobile biota (4) Low Listed species (4) Low	WQ (6) Medium Mangroves (4) Medium Seagrass (2) Low Coral reef (2) Low Mobile biota (2) Low Listed species (2) Low

Design	Construction	Operation	Potential Impact	Mitigation Measure	Monitoring	Significance of Impact (Unmitigated)	Significance of Residual (Mitigated Impact)
				• spill kit are provided and include bilge socks, heavy duty absorbent polypropylene pads, floating booms and blowback refuelling collars • a register of Materials Safety Data Sheets (MSDS) relating to all hazardous substances on board is maintained			
	●	●	Litter and waste	• waste materials contained within the designated maintenance area to prevent contamination of surrounding watercourses and vegetation • used oils, greases, rags, hoses and filters from maintenance activities will be collected and disposed of in designated bins • on vessels, areas are allocated for solid and liquid waste storage, and waste should not be stored outside these areas • any waste fuels, oils or other chemicals are collected in separate drums and transported to an approved facility for disposal • all waste is disposed of lawfully and wastes listed as 'trackable wastes' are handled or transferred, documentation in accordance with Environmental Protection Policy	• observations during monthly water and sediment quality monitoring during operation	WQ (8) Medium Mangroves (6) Medium Seagrass (6) Medium Coral reef (4) Low Mobile biota (4) Low Listed species (12) High	WQ (4) Low Mangroves (4) Low Seagrass (4) Low Coral reef (2) Low Mobile biota (2) Low Listed species (8) Medium

Design	Construction	Operation	Potential Impact	Mitigation Measure	Monitoring	Significance of Impact (Unmitigated)	Significance of Residual (Mitigated Impact)
				(Waste) (refer EPP Waste) • a record / manifest is maintained for general and regulated waste disposal • waste is removed from vessels and disposed of at an approved facility • housekeeping procedures, including spillage control, are implemented to minimise the generation of waste, and • all waste is stored appropriately.			
●	●	●	Nutrient enrichment	• wet weather sewerage outfall design • golf course design and operation (particularly retention of stormwater for treatment and appropriate fertiliser application) • stormwater retention and treatment as required • contain dredge plume (although levels of nutrients are likely to be low based on sampling in accordance with NAGD)	• monthly water and sediment quality monitoring during operation	WQ (9) Medium Mangroves (9) Medium Seagrass (9) Medium Coral reef (9) Low Mobile biota (4) Low Listed species (9) Medium	WQ (4) Low Mangroves (6) Medium Seagrass (6) Medium Coral reef (6) Low Mobile biota (2) Low Listed species (6) Medium

Design	Construction	Operation	Potential Impact	Mitigation Measure	Monitoring	Significance of Impact (Unmitigated)	Significance of Residual (Mitigated Impact)
	●		Acid sulphate or potential acid sulphate sediment	• contain dredge plume (although levels of acid sulphate and potential acid sulphate soils are likely to be low based on sampling in accordance with NAGD)	• monthly water and sediment quality monitoring during operation	WQ (4) Low Mangroves (4) Low Seagrass (2) Low Coral reef (2) Low Mobile biota (2) Low Listed species (2) Low	WQ (2) Low Mangroves (2) Low Seagrass (2) Low Coral reef (2) Low Mobile biota (2) Low Listed species (2) Low
		●	Copper contamination	• marina design	• monthly water and sediment quality monitoring during operation • ecotoxicology experiments (where species from the survey area are exposed to copper) can also be undertaken to assess site- and species-specific tolerances	WQ (9) Medium Mangroves (2) Low Seagrass (2) Low Coral reef (4) Low Mobile biota (2) Low Listed species (2) Low	WQ (9) Medium Mangroves (2) Low Seagrass (2) Low Coral reef (4) Low Mobile biota (2) Low Listed species (2) Low

Design	Construction	Operation	Potential Impact	Mitigation Measure	Monitoring	Significance of Impact (Unmitigated)	Significance of Residual (Mitigated Impact)
●	●	●	Boat strike	• 'go slow' zones • Resort Tours Management Plan as part of the EMP • report of any boat strikes or standings to management and relevant agency	• undertaken by agencies	Marine turtles (15) High Dugongs (15) High Dolphins (5) Medium Whales (5) Medium	Marine turtles (10) Medium Dugongs (10) Medium Dolphins (5) Medium Whales (5) Medium
●		●	Damage or depletion associated with resort activities and reef visitation	• Resort Tours Management Plan as part of the EMP	• an annual (pre-wet) coral monitoring program would provide the opportunity to assess the severity of predicted impacts and inform management of potential issues, including operational EMPs and remediation	Mangroves (4) Low Seagrass (4) Low Coral reef (10) Medium Mobile biota (6) Medium Listed species (8) Medium	Mangroves (2) Low Seagrass (2) Low Coral reef (9) Medium Mobile biota (4) Low Listed species (6) Medium

Design	Construction	Operation	Potential Impact	Mitigation Measure	Monitoring	Significance of Impact (Unmitigated)	Significance of Residual (Mitigated Impact)
●	●	●	Altered flow regimes – mangrove forests	• maintain environmental flows	• an annual (pre-wet) mangrove monitoring program would provide the opportunity to assess the severity of predicted impacts and inform management of potential issues, including operational EMPs and remediation	WQ (8) Medium Mangroves (8) Medium Seagrass (1) Low Coral reef (1) Low Mobile biota (4) Low Listed species (4) Low	WQ (4) Low Mangroves (4) Low Seagrass (1) Low Coral reef (1) Low Mobile biota (2) Low Listed species (2) Low

Potential Offsets

An environmental offset is an action taken to counterbalance unavoidable, negative environmental impacts resulting from an activity or development. An offset differs from mitigation in that it addresses remaining impacts, after attempts to reduce (or mitigate) the impact have been undertaken (EPA 2008). There are three specific-issue offset policies, including a policy for offsets for marine fish habitat (Dixon & Beumer 2002). This policy applies to all proposed work that may result in permanent or temporary loss of fisheries resources and habitats. Offsets for the loss of marine fish habitat can include:

- fish habitat enhancement
- fish habitat restoration, rehabilitation or creation
- fish habitat exchange and secured where the lands proposed for exchange contribute similar fish habitat, and
- contribution of an offset amount constituting financial support for one or more of the following where associated with fish habitats:
  - applied research
  - enhancement, restoration, rehabilitation or creation
  - education, training or extension, or
  - fish habitat acquisition or exchange (QPIF 2010).

Queensland Fisheries provide indicative guidelines for monetary compensation for unavoidable loss of marine plant habitat (Table 8.3). These guidelines are based on the ecosystem service value estimates provided by Costanza et al. (1997), and allow for an economic evaluation of the contribution that these habitats would make to local and regional fisheries over a 20 year production cycle, if left undisturbed. These guidelines are only indicative and are designed to form the basis for initial discussions. These guidelines were used to estimate the monetary compensation required for the areas to be lost (Table 8.4).

Table 8.3 Ecosystem services values of mangroves, saltmarsh and bare areas.9

Fish Habitat Type	Ecosystem Services Rate ($/ha/yr), 2011	Temporal Loss / Gain Over a 20 Year Production Cycle
Seagrass		
Impact (Permanent)	41 310	20
Impact (Temporary)	41 310	2
Created Area	41 310	18
Mangrove and Saltmarsh		
Impact (Permanent)	21 716	20
Impact (Temporary)	21 716	2
Created Area	21 716	18
Bare Substrate		
Impact (Permanent)	8 808	20
Impact (Temporary)	8 808	2
Created Area	8 808	18

Impacts of the proposed development will result in:

- a permanent loss of less than 0.964 ha of seagrass, and
- a loss of up to 0.04 ha of mangroves, which may or may not be permanent.

This will be offset by a gain of approximately 2.02 ha of marina wall (based on the height of the wall under HAT, and a slope of 1.5), and the gain of approximately 0.55 ha associated with walkways and pontoons (total length of 3674 m nominal width of 1.5 m) of 'bare' substrate. This substrate is likely to be colonised by a variety of flora and fauna including many species of algae, hard and soft corals, sponges, ascidians, molluscs and a variety of other invertebrates. This sessile benthic community will provide shelter and food for a variety of fishes and other fauna.

Table 8.4 shows the value of loss and gain of marine plant habitat, based on Queensland Fisheries valuations.

[9] Queensland Fisheries pers. com., 2011.

Table 8.4 Value of loss and gain of marine plant habitat, based on Queensland Fisheries valuations.

Fish Habitat Type	Ecosystem Services Rate ($/ha/yr), 2011	Temporal Loss / Gain Over a 20 Year Production Cycle	Area Lost or Gained (ha)	Offset Value ($)
Seagrass				
Impact (Permanent)	41 310	20	-0.10	796 457
Mangrove				
Impact (Permanent)	21 716	20	-0.04	869
Bare Substrate				
Impact (Temporary)	8 808	2	-20.08	367 223
Created Area	8 808	18	+2.02	453 342

In addition to the offset created by the infrastructure associated with the marina, a number of other offsets are proposed including:

- Construction of the first specialised Research Centre in the Keppel Island Group on Great Keppel Island. The Research Centre will be used to support research programs and conservation activities on Great Keppel Island and within the marine park, monitor fringing coral and marine plant communities, and facilitate student research activities. Students from local schools and universities will have access to the Research Centre to advance their learning through practical application, and it will be available for scientists, government agencies and other interested parties (Tower Holdings 2010), and
- A biodiversity conservation fund to provide significant and ongoing funding for the Research Centre. A proportion of all revenue generated from the resort operations will be directed to this fund. The fund will be managed through a research partnership with key environmental associations and the Reef and Rainforest Research Centre. The funds will be spent on research and conservation works on Great Keppel Island and throughout the Keppel Island Group.

Innovative approaches to the design of the marina are being considered, and will be detailed in the marine plant offset plan including:

- Vegetating the internal side and top of the marina revetment wall, above high tide with marine plants such as *Sporobolus virginicus*.

- Incorporation of fish friendly structures into the design of the marina (Derbyshire 2006) and monitoring of these structures to determine if they do enhance the abundance and species diversity of fish habitats and communities in the area.

8.4 Monitoring

Associated with Construction

During dredging / sediment disturbance, the extent and density of the turbidity plume will be monitored, and the results of monitoring will inform the implementation of a dredging EMP.

Monitoring of seagrass, mangroves, coral communities and soft-sediment macrobenthic communities will also take place during the construction phase.

Associated with Operations

Undertaking annual (pre-wet) monitoring of seagrass, mangrove, coral and soft-sediment macrobenthos health is proposed. Monitoring will both support an assessment of the accuracy of predictions of impacts, and more importantly inform management (and construction and operation Environmental Management Plans, EMPs), of potential issues and the need for responsive action.

Monitoring will focus of the community structure and health of communities in the vicinity of the development footprint (including around the island and adjacent to the mainland), and in areas where altered hydrodynamics may impact on habitat characteristics.

Detailed dredge, construction and operational marine environment monitoring programs will be developed at the detailed design stage.

9 Potential Impacts to Freshwater Ecosystems

9.1 Description of Project

The revised proposal for the Great Keppel Island Resort Revitalisation Plan 2010 includes the following components that have the potential to impact on (freshwater) surface water quality, sediment quality and freshwater ecosystems:

- development of an 18-hole golf course, integrated with essential habitats and ecological corridors, and located on previously disturbed grazing lands
- replacement of the existing airstrip runway
- development of associated service facilities and utilities (e.g. electricity / communications / wastewater / potable water infrastructure corridor, access tracks, waste collection area, fire-fighting and emergency services hub, fuel storage, solar panels and wastewater treatment plant), and
- establishment of a Water Management Plan to mitigate effects of stormwater run-off and golf course run-off into the Great Barrier Reef Marine Park (GBRMP).

Construction and operation activities associated with the following components of the development have the potential to impact on surface water quality, sediment quality and freshwater ecosystems:

- golf course
- airstrip
- service facilities and utilities, particularly the transport and infrastructure corridor, and
- stormwater management.

9.2 Potential Impacts

Associated with Construction

Hydrocarbon Contamination

Various vehicles and equipment will be used in the construction phase of the resort. Spilt hydrocarbons are most likely to enter the creeks via an accidental spill on tracks near creek crossings; or when there are construction activities adjacent to waterways.

A significant fuel spill to a watercourse (in the order of tens or hundreds of litres) is likely to have a locally significant impact on water quality, with the quantity spilt and the volume of water in the creeks being the most significant factors influencing the length of stream impacted. Implementation of best practice fuel management will effectively address this risk.

Vegetation Clearing and Earthworks

Vegetation clearing and earthworks will be required in association with the construction of several components of the development. There is a high potential for soil erosion and sedimentation following vegetation clearing and earthworks due to the intense seasonal rainfall and soil characteristics present on-site. This could lead to impacts on water and sediment quality via increased turbidity and nutrient and contaminant levels in these waterways.

It is expected that un-contained and un-treated run-off from vegetation clearing and earthworks pose a moderate risk to water quality through increases in suspended fine sediment loads and associated nutrients and contaminants during rainfall events. However, where the run-off from disturbed areas is effectively managed by the use of retention basins, and construction takes place during the dry season, the impact on freshwaters is likely to be negligible.

Increased Turbidity and Subsequent Sedimentation

Creek crossings will be constructed within the transport and service corridor, including over Putney and Leeke's creeks. Construction of new permanent and temporary crossings may disturb sediments, leading to increases in localised turbidity and sediment deposition. When construction is carried out during the dry season, these impacts will be minimal or absent, although a highly localised loss of emergent macrophytes and aestivating crustaceans may be expected within the construction footprint.

The impacts of disturbance to habitat will be highly localised and are considered acceptable in both a local and regional context, given the existing disturbed nature of creek crossing locations.

Impacts to Aquatic Fauna Passage

When construction of creek crossings is carried out in the wet season, there is likely to be an impact to fish passage during construction activities, and potentially also to water quality. If the waterway holds water, isolation of the work area may leave fish stranded. These fish will perish unless they are relocated.

Stream crossings can create waterway barriers that prevent or impede movements of aquatic fauna such as fish. Many of the fish native to ephemeral systems in Queensland migrate up- and downstream and between different habitats at particular stages of their lifecycle. Fish passage is already restricted in creeks by constructed fords and culverts, and poorly-designed crossings have the potential to further impact on fish movement within the study area. Given the depauperate freshwater fish community in the project area, the impact of the development on fish passage is considered manageable. Opportunities exist to redress existing restrictions to fish passage, and will be considered at the detailed design stage.

Litter and Waste

Litter and waste associated with the construction and operation of the resort also has the potential to contribute to the degradation of water quality. As appropriate controls will be in place, the risk to water and sediment quality from litter and spilt waste is likely to be manageable during construction and operation.

Associated with Operations

Hydrocarbon Contamination

During operation the major of vehicles will be electric or solar powered and therefore the risk of hydrocarbon spills is very low. Vehicles may use substances such as hydraulic fluid and lubricating fluids, which each pose a potential threat to water and sediment quality if spilt. Spilt hydrocarbons are most likely to enter the creeks via an accidental spill on tracks near creek crossings; or when there are construction activities adjacent to waterways. A significant fuel spill to a watercourse (in the order of tens or hundreds of litres) is likely to have a locally significant impact on water quality, with the quantity spilt and the volume of water in the creeks being the most significant factors influencing the length of stream impacted.

Implementation of best practice fuel management will effectively address this risk. Additionally, the risk to aquatic flora and fauna in the project area and downstream waters is reduced as the creeks are dry or isolated pools for much of the year, and therefore many spills could be effectively cleaned up before they can disperse downstream. There is evidence of current hydrocarbon contamination in the project area.

Increased Turbidity and Subsequent Sedimentation

Following the installation of creek crossings, the newly formed bed and banks may continually erode, given the high flows that occur in the region in the wet season. This may result in an increase in channel width and a loss in channel definition, which could in turn lead to a decrease in downstream flow.

Currently, most creek crossings in the project area are dirt fords or culverts. The existing dirt fords have a high potential for erosion, which can increase sediment run-off into creeks and elevate turbidity. The proposed development provides the opportunity to remediate or replace existing crossings to reduce the opportunity for erosion. These opportunities will be considered at the detailed design stage.

Changes to Flow Regimes

The potential impact associated with altered flow regimes is considered minor as waterways are ephemeral (i.e. dry for much of the year) and large parts of the catchment area will not be affected by the golf course development (i.e. will continue to provide seasonal environmental flows in downstream environments). The impact will be negligible where environmental flows are maintained, i.e. treated water is released form the water storage facilities in similar quantities and with similar timing to natural flows.

Water Quality Issues within Water Features

There is potential for blue-green algae (cyanobacteria) booms to occur in the water features during operation. However, as the water features will be exposed to wind-induced mixing and are likely to receive relatively large inflows during rainstorm events, the risk of blooms is considered to be low.

Nutrient Enrichment

Aquatic biota could be impacted by nutrients or contaminants washed into the waterways, e.g. nutrients from fertilisers used at the golf course. Nutrient inputs can lead to algal or macrophytes blooms, which produce high levels of dissolved oxygen in the water when photosynthesising during the day, and consume the dissolved oxygen at night through respiration. This can cause dissolved oxygen to be reduced to very low levels, which is harmful to fish and biota.

High algal cover was present during the field surveys at several dams near the resort. The implementation of best practice erosion and sediment controls and stormwater runoff management plans will effectively manage the risk of nutrient-laden runoff.

Cumulative Impacts

Nearby Tourism Developments

Nearby tourism developments identified by GBRMPA for assessment include:

- Rosslyn Bay Inn (as known as the Rosslyn Bay Resort), Rosslyn Bay, approximately 15 km to the west
- Seaspray Resort and Spa, Zilzie (near Emu Park), approximately 18 km to the south west
- Zilzie Bay, Zilzie, approximately 20 km to the south west, and
- Mercure Capricorn Resort, Yeppoon, approximately 24 km to the north west.

The extent of potential impact in association with the operation of the Great Keppel Island development is likely to be minimal where appropriate mitigation measures are developed and adhered to. The cumulative impact of the operation of the Great Keppel Island development and nearby resorts is therefore likely to be minor or negligible. For example:

- potential impacts associated with spills of hydrocarbons and other potential contaminants are considered minor where managed through respective EMPs (noting that most golf carts are electric and use of vehicles fuelled with hydrocarbons will be minimal on golf courses)
- potential impacts associated with nutrient-laden run-off from the golf courses are considered negligible where all run-off is captured for treatment (noting there will be no impact to the downstream ecosystems of Leeke's Creek on Great Keppel Island, and there will be no impact in association with Zilzie Bay given the synthetic golf course does not require fertilisers or watering)
- potential impacts associated with litter and waste are considered minor where managed through the respective EMPs (and national park regulations); impacts to freshwater environments at each of the resorts are unlikely to have a cumulative

impact given the minor nature of the potential impacts, the ephemeral nature of all waterways of Great Keppel Island, and the lack of freshwater connectivity between each of the respective resorts

- potential impacts to altered passage of aquatic fauna are considered negligible where barriers are constructed in accordance with best practice on Great Keppel Island (noting the apparent lack of major waterway barriers at each of the other developments)
- potential impacts associated with litter and waste are considered minor where managed through respective EMPs
- potential impacts associated with loss of catchment area and changes to flow regimes (e.g. increased stormwater run-off) are considered negligible at other resorts given their beachfront location and / or small development footprint (i.e. most of the drainage lines and gullies discharge in a disperse manner via localised flow paths and are not defined waterways supporting stable freshwater ecosystems); the impact associated with the Great Keppel Island development is considered manageable given that the upper reaches of Putney Creek appear to have not been connected to the lower reaches for some time (due to the existing resort), most of the drainage lines and gullies discharge in a disperse manner via localised flow paths, and stormwater will be captured in basins, and
- potential impacts associated with water quality issues within water features are considered minor given the coastal location of all golf course developments, and consequential exposure to wind-induced mixing and relatively large inflows during rainstorm events (thereby reducing the risk of blue-green algal blooms).

Climate Change

Given the uncertainty around predicting impacts to freshwater ecosystems it is very difficult to assess the cumulative impacts of climate change and the proposed development.

There is the potential for impacts to flow associated with the development (in association with loss of catchment area and flow regimes due to the golf course) to be exasperated by climate change. However potential impacts associated with the development are considered minor as waterways are ephemeral (i.e. dry for much of the year) and large parts of the catchment area will not be affected by the golf course development (i.e. will continue to provide seasonal environmental flows in downstream environments); potential impact will be negligible where environmental flows are maintained (i.e. treated water is released form the golf course water storage facilities in similar quantities and with similar timing to natural flows).

Given the manageable nature of impacts to freshwater ecosystems in association with the proposed development, there are unlikely to be any major cumulative impacts associated with climate change.

9.3 Mitigation Measures

'Best practice' engineering design and implementation will be employed to minimise the impacts associated with both construction and operation of the proposed development. Table 9.1 provides a summary of mitigation measures and the associated residual risk.

Table 9.1 Summary of potential impacts on freshwater ecosystems.

Design	Construction	Operation	Potential Impact	Mitigation Measure	Monitoring	Significance of Impact (Unmitigated)	Significance of Residual (Mitigated Impact)
	●	●	Hydrocarbon contamination	• fuel, oil and chemical storage and handling are undertaken in accordance with AS1940 • any fuel, oil or chemical spills are contained and cleaned up immediately • a Spill Management Plan prepared in accordance with State Planning Policy requirements and to the satisfaction of DERM • all refuelling is by licensed fuel suppliers in accordance with their Standard Operating Procedures • refuelling takes place in designated areas, in accordance with industry standards • the stored volume of fuel, oil or chemical in minimised, with storage in a secure area • any visible (or suspected) fuel, oil or chemical loss will be treated as an 'incident' • operators regularly check equipment for evidence of leaks and condition of hydraulic hoses and seals, and conduct maintenance or repairs as necessary to prevent drips, leaks or likely equipment failures • spill kit are provided and include bilge socks, heavy duty absorbent polypropylene pads, floating booms and blowback refuelling collars • a register of Materials Safety Data Sheets (MSDS) relating to all hazardous substances on board is maintained	• monthly water and sediment quality monitoring during construction and operation • annual (post-wet) aquatic ecology monitoring	WQ (10) Medium Flora (9) Medium Invertebrates (10) Medium Vertebrates (6) Medium	WQ (6) Medium Flora (6) Medium Invertebrates (6) Medium Vertebrates (3) Low

Design	Construction	Operation	Potential Impact	Mitigation Measure	Monitoring	Significance of Impact (Unmitigated)	Significance of Residual (Mitigated Impact)
●	●	●	Increased turbidity and sediment deposition	• an erosion and sediment control management plan is developed (as a part of the EMP) and implemented • water features are constructed prior to vegetation clearing and earthworks • vegetation clearing and earthworks are staged • clearing and earthworks for construction of creek crossings is undertaken in the dry season where possible	• monitoring and the use of 'trigger levels' during construction • monthly water and sediment quality monitoring during construction and operation • annual (post-wet) aquatic ecology monitoring	WQ (8) Medium Flora (8) Medium Invertebrates (8) Medium Vertebrates (4) Low	WQ (6) Medium Flora (6) Medium Invertebrates (6) Medium Vertebrates (2) Low
●	●		Vegetation clearing and earthworks – decreased habitat for aquatic fauna	• vegetation clearing and earthworks are staged • clearing and earthworks are undertaken in the dry season where possible • habitat (e.g. woody debris, riparian flora and boulders) is salvaged for use in other waterways / water features	• annual (post-wet) aquatic ecology monitoring	WQ (4) Low Flora (4) Low Invertebrates (4) Low Vertebrates (4) Low	WQ (2) Low Flora (2) Low Invertebrates (2) Low Vertebrates (2) Low
●	●	●	Creek crossings - aquatic fauna passage	• construction of creek crossings is undertaken in the dry season where possible • if waterway hold water, fish are salvaged if present	• annual (post-wet) aquatic ecology monitoring	WQ (6) Medium Flora (2) Low Invertebrates (4) Low Vertebrates (6) Medium	WQ (2) Low Flora (1) Low Invertebrates (2) Low Vertebrates (2) Low

Design	Construction	Operation	Potential Impact	Mitigation Measure	Monitoring	Significance of Impact (Unmitigated)	Significance of Residual (Mitigated Impact)
	●	●	Litter and waste	• waste materials contained within the designated maintenance area to prevent contamination of surrounding watercourses and vegetation • used oils, greases, rags, hoses and filters from maintenance activities will be collected and disposed of in the designated bins located at the workshop areas • on vessels, areas are allocated for solid and liquid waste storage, and waste should not be stored outside these areas • any waste fuels, oils or other chemicals are collected in separate drums and transported to an approved facility for disposal • all waste is disposed of lawfully and wastes listed as 'trackable wastes' are handled or transferred, documentation in accordance with Environmental Protection Policy (Waste) (refer EPP Waste) • a record / manifest is maintained for general and regulated waste disposal • waste is removed from vessels and disposed of at an approved facility • housekeeping procedures, including spillage control, are implemented to minimise the generation of waste, and • all waste awaiting disposal is stored appropriately	• observations during monthly water and sediment quality monitoring during operation • annual (post-wet) aquatic ecology monitoring	WQ (8) Medium Flora (6) Medium Invertebrates (6) Medium Vertebrates (6) Medium	WQ (4) Low Flora (4) Low Invertebrates (4) Low Vertebrates (4) Low

Design	Construction	Operation	Potential Impact	Mitigation Measure	Monitoring	Significance of Impact (Unmitigated)	Significance of Residual (Mitigated Impact)
●	●	●	Nutrient enrichment	• golf course design and operation (particularly retention of stormwater for treatment and appropriate fertiliser application) • stormwater retention and treatment as required • erosion control during earthworks (as nutrients can be introduced with sediment)	• monthly water and sediment quality monitoring during operation • annual (post-wet) aquatic ecology monitoring	WQ (9) Medium Flora (9) Medium Invertebrates (9) Medium Vertebrates (6) Medium	WQ (4) Low Flora (4) Low Invertebrates (4) Low Vertebrates (4) Low
●		●	Loss of catchment area	• maintenance of drainage lines and gullies where possible	• NA	WQ (4) Low Flora (2) Low Invertebrates (4) Low Vertebrates (4) Low	WQ (3) Low Flora (2) Low Invertebrates (3) Low Vertebrates (3) Low
●	●	●	Changes to flow regime	• best practice erosion and sediment control techniques during construction • stormwater will be retained, for treatment as required, in detention and bio-detention basins to control the quantity and quality of run-off into surface and ground water; bio-retention swales and infiltration areas will also be used	• monthly water and sediment quality monitoring during operation • annual (post-wet) aquatic ecology monitoring	WQ (8) Medium Flora (4) Low Invertebrates (6) Low Vertebrates (6) Low	WQ (4) Low Flora (2) Low Invertebrates (4) Low Vertebrates (4) Low

Design	Construction	Operation	Potential Impact	Mitigation Measure	Monitoring	Significance of Impact (Unmitigated)	Significance of Residual (Mitigated Impact)
●		●	Water quality Issues within water features (blue green algae and stratification)	• designed to maximum wind action and stormwater inflow • aerated if prone to stratification and / or low DO concentration • algal blooms or abundant flora removed	• monthly water and sediment quality monitoring during operation • annual (post-wet) aquatic ecology monitoring	WQ (6) Medium Flora (4) Low Invertebrates (8) Medium Vertebrates (8) Medium	WQ (4) Low Flora (3) Low Invertebrates (6) Low Vertebrates (6) Low

9.4 Monitoring Requirements

Associated with Construction

Monitoring of turbidity levels in the creeks will be undertaken when constructing permanent or temporary creek crossings during the wet season.

Turbidity will be measured:

- immediately upstream of the crossing site immediately prior to construction, to determine background conditions
- daily during construction, at locations both upstream and downstream of the crossing, and
- daily after construction until water quality returns to background conditions, as established by the initial background monitoring prior to crossing construction.

Associated with Operations

Water quality in the water supply dam will be monitored regularly to:

- confirm the suitability of the water for irrigation (including monitoring of blue green algae), and
- to confirm water quality in the event of release to the receiving environment.

The timing of monitoring may need to vary depending on the results and the season. For example, water quality will likely vary more during the wet season than the dry season. As such, monitoring frequencies may need to be higher in the wet season than in the dry season.

Detailed construction and operational freshwater environment monitoring programs will be developed at the detailed design stage.

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Appendix A Survey Design

Contents

Tables

Figures

1 Project Background

1.1 Project Description

Tower Holdings Pty Ltd have proposed a Revitalisation Plan for Great Keppel Island, which will provide a low-rise, low-impact and environmentally focused resort on Great Keppel Island.

On 28 August 2009 the Coordinator-General declared the 'Great Keppel Island Resort Project' to be a 'significant project'. Tower Holdings Pty Ltd subsequently submitted an *Environmental and Biodiversity Conservation Act 1999* (EPBC Act) referral to the Minister of the Department of Environment, Water, Heritage and the Arts (DEWHA). On 28 October 2009, the Minister decided that the proposed action would have unacceptable impacts in accordance with Part 3 of the EPBC Act.

In response to DEWHA's rejection of the proposal, Tower Holdings Pty Ltd submitted a 2010 EPBC Act referral, which included a revised and substantially reduced Revitalisation Plan for Great Keppel Island. On 4 July 2010, the Minister declared the revised plan was to undergo appropriate assessment and approval under the EPBC Act, prior to proceeding.

The revised proposal for the Great Keppel Island Resort Revitalisation Plan 2010 (Figure 1.1) includes the:

- designation of the majority of Lot 21 (approximately 62% or 545 ha) as an Environmental Protection Area, with the footprint to be chosen through collaboration with conservation groups and the Queensland Parks and Wildlife Service (QPWS)
- demolition of the old resort and construction of a new hotel at Fisherman's Beach comprising 250 suites and a day spa
- dredging of Putney Beach for construction of the marina and re-nourishment of Putney Beach using dredge spoil
- development of a marina at Putney Beach comprising 250 berths, emergency services facilities, ferry terminal, yacht club and dry dock storage
- development of a retail area with a mix of cafes, restaurants and clothing shops around the marina
- development of an 18-hole golf course, integrated with essential habitats and ecological corridors, and located on previously disturbed grazing lands

- replacement of the existing airstrip runway
- development of 750 eco-tourism villas incorporating sustainable building design, rooftop solar panels and water tanks
- development of 300 eco-tourism apartments incorporating sustainable building design, rooftop solar panels and water tanks
- development of associated service facilities and utilities (e.g. waste collection area, fire-fighting and emergency services hub, fuel storage, solar panels and wastewater treatment plant and a water desalination plant)
- establishment of buffer zones to ensure protection of habitats and to provide fauna corridors
- establishment of constructed wetlands and a Water Management Plan to mitigate effects of stormwater run-off and golf course run-off into the Great Barrier Reef Marine Park (GBRMP)
- establishment of the Great Keppel Island Research Centre and Biodiversity Conservation Fund (BCF), which will aim to deliver a better understanding of the surrounding environments, and to actively undertake conservation works to enhance the natural environment
- development of a sporting park which can be used by resort guests and other Great Keppel Island residents and visitors
- preservation of indigenous sites of significance (in consultation with the traditional owners)
- restoration of the original Leeke's Homestead, and
- installation of a submarine connection of services (e.g. power, water, telecommunications, wastewater and gas) between Great Keppel Island and Kinka Beach on the mainland.

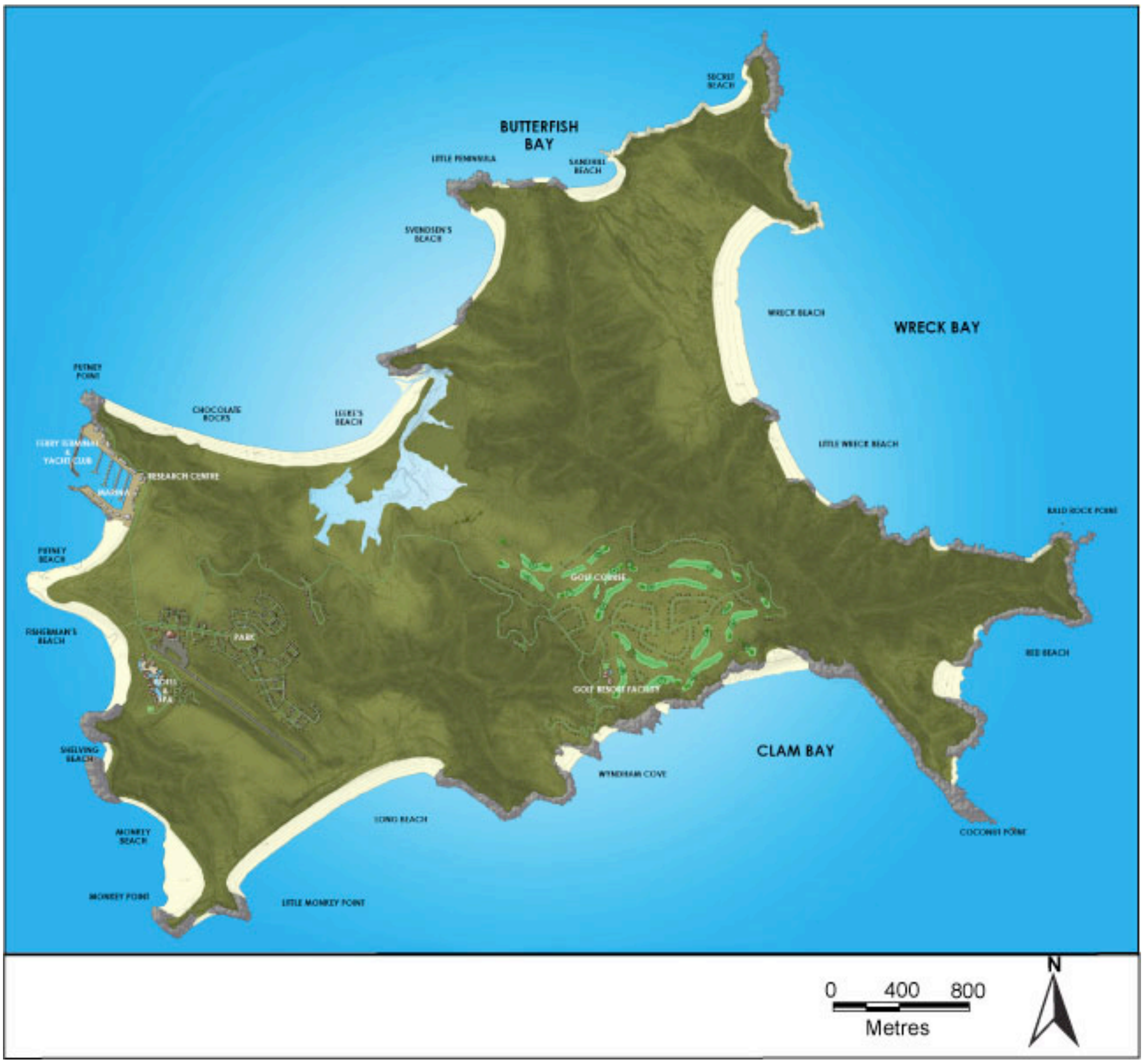

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	Figure 1.1 Project Design.	
	Tower Holdings 2010	June 2011

1.2 Survey Area

The survey area included marine and freshwater communities on and surrounding Great Keppel Island, and marine communities near Kinka Beach and Tanby Beach on the mainland (Figure 1.2).

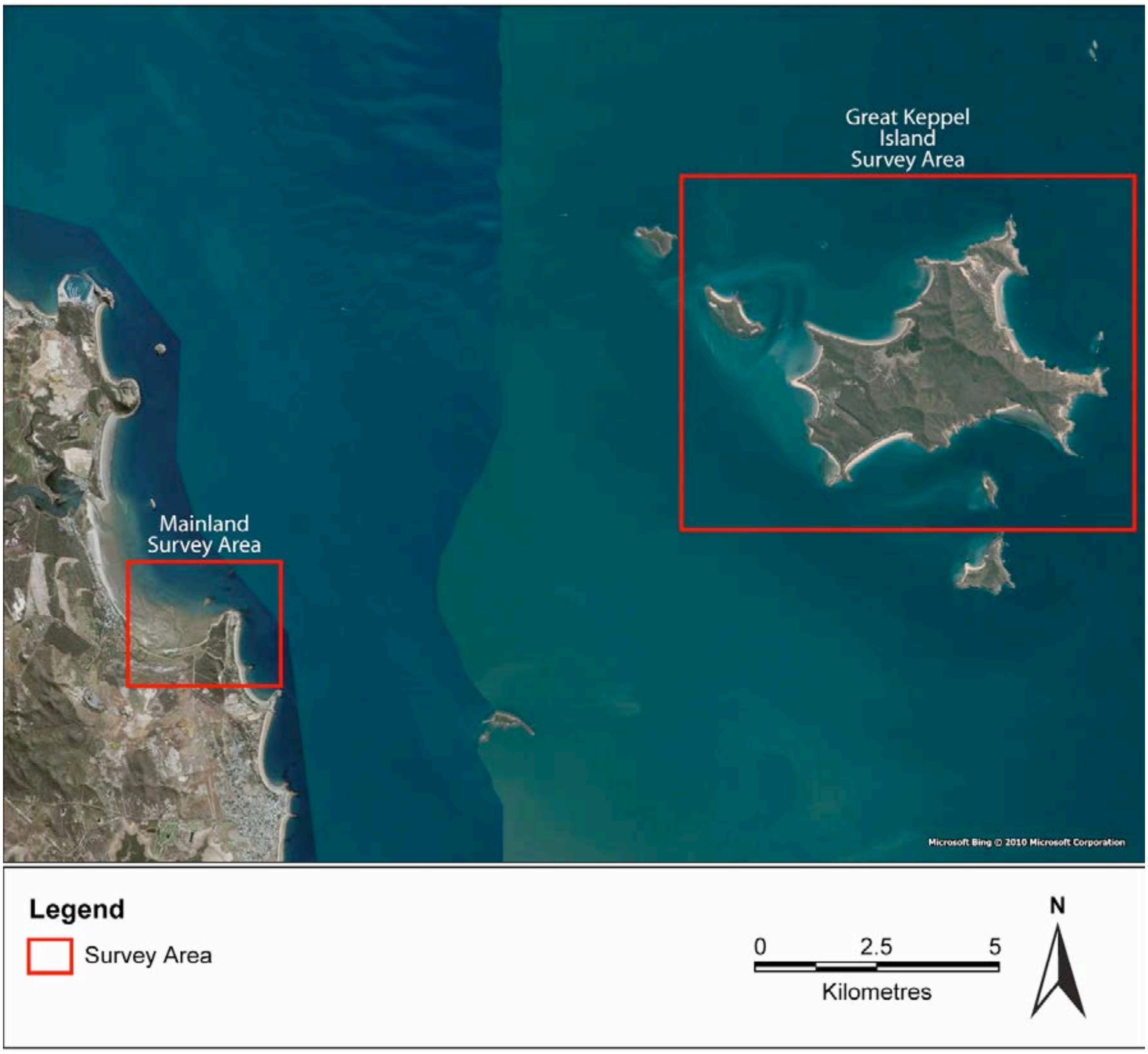

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	Figure 1.2 Great Keppel Island and mainland survey areas.	
	Microsoft Bing © 2010	June 2011

Great Keppel Island

Great Keppel Island is part of a group of 16 continental islands called the Keppel Island Group that covers an area of 14.5 km^2. It is located in the southern reaches of the Great Barrier Reef, approximately 15 km offshore of Yeppoon in northern Queensland and more than 200 km inshore of the Outer Barrier Reef and the Swain Reef complex.

The Keppel Bay Island Group is a designated National Park that includes 15 islands (Great Keppel Island is not part of the National Park). The Great Barrier Reef Marine Park surrounds the Keppel Island Group and together they form the Great Barrier Reef World Heritage Area, the world's largest reef and island archipelago.

The Keppel Island Group is located directly offshore of the Fitzroy Basin, which is the largest basin draining into the Great Barrier Reef. The islands lie in a shallow basin north of Keppel Bay, and are surrounded by a patchwork of fringing reefs (GBRMPA 2007). The Keppel Island Group is managed by the Rockhampton Regional Council (RRC).

Great Keppel Island is the largest island (1 454 ha) of the Keppel Island Group. There are 17 beaches on Great Keppel Island and its natural environment offers a range of popular tourist activities including swimming, diving, snorkelling and bushwalking. Until recently, Great Keppel Island had a number of different commercial accommodation facilities ranging from camping to resort accommodation. The Great Keppel Island Resort was the main tourism resort on the island, until it closed in early 2008. There are two backpacker facilities and approximately 20 residential / commercial premises currently on the island.

Mainland

Kinka Beach and Tanby Beach are a part of a small coastal settlement about 15 km west of Great Keppel Island, 3 km north of Emu Park and 7 km south of Yeppoon. The land was originally part of a pastoral lease, until a small residential development began in the 1930s. The area is residential, except for one shop, a caravan park and three motels. In the 2006 census, the local settlement had a population of 621.

2 Survey Design

2.1 Survey Timing

Surveys were undertaken during the following seasons:

- pre-wet – 15 to 19 November 2010
- wet – 17 to 21 January 2011
- post-wet – 28 March to 2 April 2011 (March/April), and 30 April to 2 May 2011 (April/May), and
- winter (to quantify marine community 'recovery' post-flooding) – 11 to 14 July 2011.

2.2 Marine Surveys

The following marine communities, together with water and sediment quality, were assessed at sites around Great Keppel Island:

- mangroves
- seagrass meadows
- coral outcrops
- soft sediment macroinvertebrate communities
- rocky shore communities, and
- marine vertebrates.

The following marine communities were assessed at sites near the mainland:

- mangroves, and
- soft sediment macroinvertebrate communities.

The locations of the marine survey sites around Great Keppel Island and the mainland are shown in Figure 2.1 to Figure 2.13. The design tree for the marine assessment is shown in Table 2.1. Sites were surveyed at different times of the year, due to restrictions associated with rough weather (the March/April 2011 survey was cut short by strong winds and large swell and could not resume until April/May 2011) and boat availability and permits (delays in sourcing commercial vessel and permits to green zones meant that the November 2010 survey could not be completed until January 2011), together with the addition of new sites as potential locations for project elements were refined (e.g. the location for wastewater release at Long Beach was advised at the post-wet season stage).

Spatial and temporal replication was determined adequate to describe the existing environment and ***predict an impact***, as opposed to ***future assessment of the extent of impact***. Water quality monitoring was not designed to set local water quality guidelines. Additional replicated sampling to inform post-development impact assessment and local water quality guidelines will be addressed at the Environmental Management Plan (EMP) and / or conditions of approval stage.

Table 2.1 Design tree for marine surveys.

Location	Sites	Spatial Replication	Temporal Replication	Description
Water quality – physiochemical				
Leeke's Creek	WQ09 (1) WQ10 (2) WQ11 (3) WQ12 (4) WQ13 (5)	4 readings per site	November 2010 (1), April/May 2011 (2)	0.2 m below the surface and near bottom waters to 10 m depth on both outgoing and incoming tide
Offshore waters	WQ14 (1) WQ15 (2) WQ16 (3) WQ17 (4) WQ18 (5) WQ19 (6) WQ30 (7)	4 readings per site	November 2010 (1), January 2011 (2), March/April 2011 (3), April/May 2011 (4)	
Offshore waters	WQ20 (1) WQ21 (2) WQ22 (3) WQ23 (4) WQ24 (5) WQ25 (6) WQ26 (7) WQ27 (8) WQ28 (9) WQ29 (10) WQ31 (11)	4 readings per site	November 2010 (1), March 2011 (2)	

Location	Sites	Spatial Replication	Temporal Replication	Description
Putney Beach to Fishermans Beach	WQ1 (1) WQ2 (2) WQ3 (3) WQ4 (4) WQ5 (5) WQ6 (6) WQ8 (7)	4 readings per site	November 2010 (1), April/May 2011 (2)	
Water quality – potential contaminants				
Clam Bay	CB (1)	1 sample per site	April/May 2011 (1)	Field replicate sample collected in January (site LOB) and March/April (sites PC and LOB) 2011. Blanks collected in March/April 2011 and May 2011 to test for cross-contamination.
Leeke's Creek Mouth / Beach	LCM (1) LB (2)	1 sample per site	November 2010 (1), April/May 2011 (2) for LCM January 2011 (1) and March/April 2011 (2) for LB	
Long Beach	LOB (1)	1 sample per site	January 2011 (1) and April/May 2011 (2)	
Mainland	KB (1) TB (2)	1 sample per site	April/May 2011 (1)	
Middle Island	MI1 (1) MI2 (2)	1 sample per site	January 2011 (1) and April/May 2011 (2)	
Passage Rocks	PR (1)	1 sample per site	April/May 2011 (1)	
Putney Beach to Fishermans Beach	M4 (1) PC (3) TS (3) FB (4)	1 sample per site	November 2010 (1), April/May 2011 (2)	
Wreck Beach	WB (1)	1 sample per site	January 2011 (1) and April/May 2011 (2)	
Surface sediment quality – potential contaminants				
Clam Bay	CB (1)	1 sample per site	April/May 2011 (1)	Field replicate sample collected in November 2010 (sites LCM and MI), January 2011 (sites CB and LOB), March/April 2011 (sites FB, LOB and M1) and April/May 2011 (site MI2)
Leeke's Creek Mouth / Beach	LCM (1) LB (2)	1 sample per site	November 2010 (1), April/May 2011 (2) for LCM January 2011 (1) and March/April 2011 (2) for LB	
Long Beach	LOB (1)	1 sample per site	January 2011 (1) and April/May 2011 (2)	

Location	Sites	Spatial Replication	Temporal Replication	Description
Mainland	KB (1) TB (2)	1 sample per site	April/May 2011 (1)	
Middle Island	MI1 (1) MI2 (2)	1 sample per site	January 2011 (1) and April/May 2011 (2)	
Passage Rocks	PR (1)	1 sample per site	April/May 2011 (1)	
Putney Point to Fishermans Beach	M4 (1) PC (3) TS (3) FB (4)	1 sample per site	November 2010 (1), April/May 2011 (2)	
Wreck Beach	WB (1)	1 sample per site	January 2011 (1) and April/May 2011 (2)	
Sediment quality – contaminants in accordance with NADG				
Marina footprint	NA	12 cores	NA	Field replicates in accordance with the National Assessment Guidelines for Dredging 2009 (NAGD) and the Sampling and Analysis Procedure for Lowland Acid Sulfate Soils in Queensland. The NAGD recommends 23 sites, however the number of sites analysed was halved as the sediments are considered to be 'probably clean'.
Mangrove forests – distribution, community composition and condition				
Kinka Beach	NA	30 quadrats per site in January 2011 and 29 quadrats per site in March/April 2011	January 2011 (1), March/April 2011 (2)	10 x 10 m quadrat with number of replicates dependent on spatial extent of mangroves

Location	Sites	Spatial Replication	Temporal Replication	Description
Leeke's Creek	NA	105 quadrats per site in November 2010 and 99 quadrats per site in March/April 2011	November 2010 (1), April/May 2011 (2)	
Putney Creek	NA	7 quadrats per site in November 2010 and 8 quadrats per site in March/April 2011	November 2010 (1), April/May 2011 (2)	
Mangrove forests – values to fisheries				
Kinka Beach	2	1 large quadrat and 3 small quadrats per site	January 2011 (1), March/April 2011 (2)	Canopy height, canopy cover, number of live and number of dead trees assessed in each large aquadat (10 x 10 m); number of aerial roots, pneumatophores, burrows, molluscs and crabs, and cover of litter, large debris, seedlings and *Catanella* sp. in each small (1 x 1 m) quadrat
Leeke's Creek	10	1 large quadrat and 3 small quadrats per site	November 2010 (1), March/April 2011 (2)	
Putney Creek	3	1 large quadrat and 3 small quadrats per site	November 2010 (1), March/April 2011 (2)	
Seagrass meadows – distribution, community composition and condition				
Clam Bay	NA	9 quadrats	January 2011 (1)	1 x 1 m quadrat with number of quadrats dependent on spatial extent of mangroves. Seagreass species, percant cover, morphology (small, medium or lareg), aboveground biomass rank and epiphytic cover was recorded in each quadrat.
Fishermans Beach	NA	97 quadrats in November 2010, 23 quadrats in March/April 2011, 45 quadrats in July 2011	November 20110 (1), March/April 2011 (2), July 2011 (3)	

Location	Sites	Spatial Replication	Temporal Replication	Description
Leeke's Beach / Creek Mouth	NA	47 quadrats in January 2011	January 2011 (1)	Macroalgae, benthic epifaunal invertebrates, vertebrates and water depth was also recorded.
Long Beach	NA	15 quadrats in January 2011, 14 quadrats in March/April 2011, 13 quadrats in July 2011	January 2010 (1), March/April 2011 (2), July 2011 (3)	
Middle Island	NA	35 quadrats in January 2011, 78 quadrats in April/May 2011, 37 quadrats in July 2011	January 2010 (1), April/May 2011 (2), July 2011 (3)	
Monkey Beach	NA	16 quadrats in March/April 2011, 20 quadrats in July 2011	March/April 2011 (1), July 2011 (2)	
Putney Beach	NA	92 quadrats in November 2010, 13 quadrats in March/April 2011, 39 quadrats in July 2011	November 20110 (1), March/April 2011 (2), July 2011 (3)	
The Spit	NA	39 quadrats in January 2011, 35 quadrats in July 2011	January 2011 (1), July 2011 (2)	
Submarine Cable	NA	1 belt transect	March 2011 (1)	1 continous belt transect surveyed using sub-bottom profiling and side scan sonar

Location	Sites	Spatial Replication	Temporal Replication	Description
Coral reefs – community composition and condition				
Clam Bay centre	1 transect	16 photos in January 2011, 19 photos in April/May 2011, 20 photos in July 2011	January 2011 (1), April/May 2011 (2), July 2011 (3)	The benthic community was photographed every 5 to 10 m along each transect, with photo locations chosen haphazardly. Each photo included an approximate area of 35 x 35 cm. The percent cover of live coral (by growth form), severely bleached coral, macroalgae, epifaunal invertebrates (e.g. ascidians and sponges) and rubble / sediment was determined using CPCe with approximately 50 points per photo.
Clam Bay west	1 transect	10 photos in January 2011, 20 photos in April/May 2011, 20 photos in July 2011	January 2011 (1), April/May 2011 (2), July 2011 (3)	
Fishermans Beach	1 transect	20 photos in November 2010, 15 photos in March/April 2011, 20 photos in July 2011	November 2010 (1), March/April 2011 (2), July 2011 (3)	
Long Beach	1 transect	11 photos January 2011, 20 photos in March/April 2011, 20 photos in July 2011	January 2011 (1), March/April 2011 (2), July 2011 (3)	
Middle Island	1 transect	20 photos in January 2011, 20 photos in April/May 2011, 20 photos in July 2011	January 2011 (1), April/May 2011 (2), July 2011 (3)	

Location	Sites	Spatial Replication	Temporal Replication	Description
Middle Island observatory	1 transect	18 photos in January 2011, 20 photos in April/May 2011, 20 photos in July 2011	January 2011 (1), April/May 2011 (2), July 2011 (3)	
Monkey Beach	1 transect	17 photos in January 2011, 15 photos in April/May 2011, 20 photos in July 2011	January 2011 (1), April/May 2011 (2), July 2011 (3)	
Passage Rocks	1 transect	20 photos in November 2010, 20 photos in April/May 2011, 20 photos in July 2011	January 2011 (1), April/May 2011 (2), July 2011 (3)	
Putney Beach	1 transect	20 photos in November 2010, 20 photos in April/May 2011, 20 photos in July 2011	January 2011 (1), April/May 2011 (2), July 2011 (3)	
Wreck Beach	1 transect	17 photos in January 2011, 20 photos in March/April 2011, 20 photos in July 2011	January 2011 (1), March/April 2011 (2), July 2011 (3)	

Location	Sites	Spatial Replication	Temporal Replication	Description
Benthic infaunal invertebrates				
Clam Bay	1 site	3 cores per site in January 2011, 5 cores per site all other events	January 2011 (1), April/May 2011 (2), July 2011 (3)	The number of cores assessed was increased from three to five at most sites. Three cores were collected from Putney Beach sites as the areas will be lost to the development.
Fishermans Beach	1 site	3 cores per site in January 2011, 5 cores per site all other events	November 2010 (1), March/April 2011 (2), July 2011 (3)	
Kinka Beach	1 site	3 cores per site	November 2010 (1), March/April 2011 (2), July 2011 (3)	
Leeke's Beach	1 site	3 cores per site in January 2011, 5 cores per sample all other events	January 2011 (1), March/April 2011 (2), July 2011 (3)	
Leeke's Creek Mouth	1 site	3 cores per site in January 2011, 5 cores per sample all other events	January 2011 (1), March/April 2011 (2), July 2011 (3)	
Long Beach	1 site	3 cores per site in January 2011, 5 cores per sample all other events	January 2011 (1), March/April 2011 (2), July 2011 (3)	

Location	Sites	Spatial Replication	Temporal Replication	Description
Passage Rocks	1 site	5 cores per site	April/May 2011 (1)	
Putney Beach	4 sites	3 cores per site	January 2011 (1), March/April 2011 (2), July 2011 (3)	
Tanby Beach	1 site	3 cores per site	November 2010 (1), March/April 2011 (2), July 2011 (3)	
The Spit	1 site	3 cores per site in January 2011, 5 cores per sample all other events	November 2010 (1), March/April 2011 (2), July 2011 (3)	
Wreck Beach	1 site	3 cores per site in January 2011, 5 cores per sample all other events	January 2011 (1), March/April 2011 (2), July 2011 (3)	

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	Figure 2.1 Marine locations around Great Keppel Island.	
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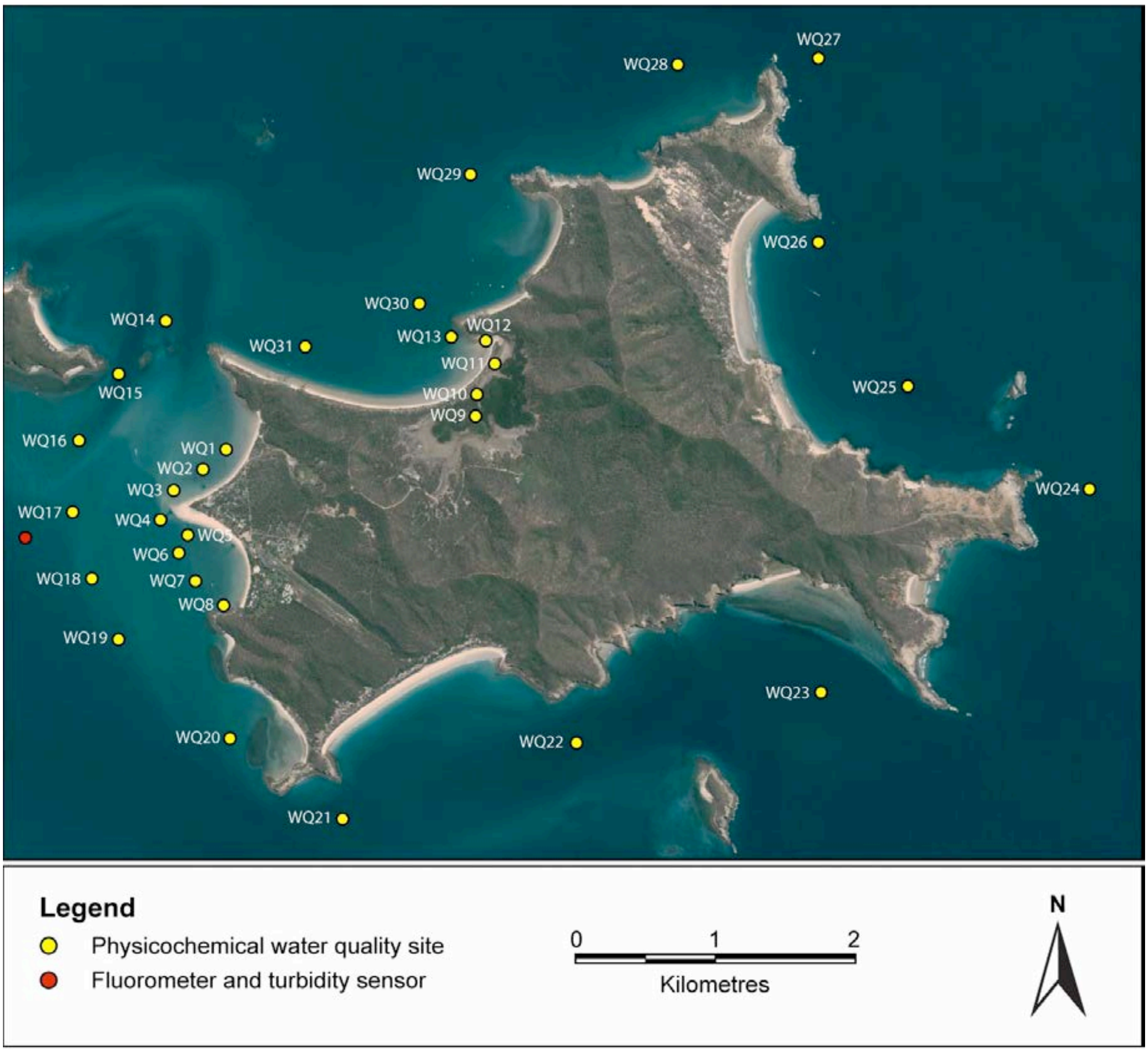
frc environmental AQUATIC ECOLOGISTS deep thinking. science.	Great Keppel Island Revitalisation EIS	
	Figure 2.2 Marine locations near the mainland.	
	Microsoft Bing © 2010	June 2011



frc environmental AQUATIC ECOLOGISTS deep thinking. science.	Great Keppel Island Revitalisation EIS	
	Figure 2.3 Physicochemical water quality sites around Great Keppel Island.	
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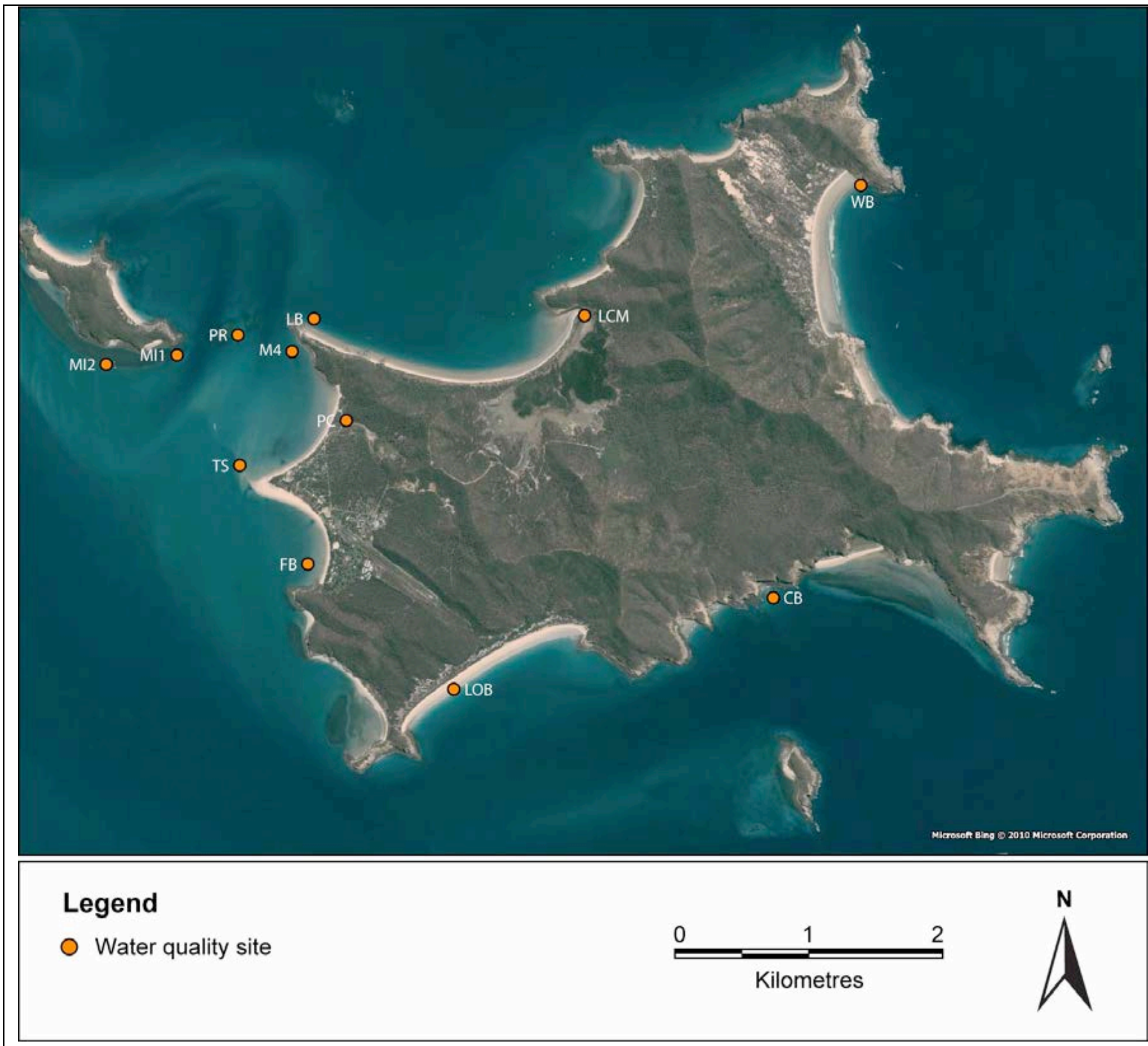

frc environmental AQUATIC ECOLOGISTS deep thinking. science.	Great Keppel Island Revitalisation EIS
	Figure 2.4 Water quality sites for laboratory analysis of contaminants around Great Keppel Island.
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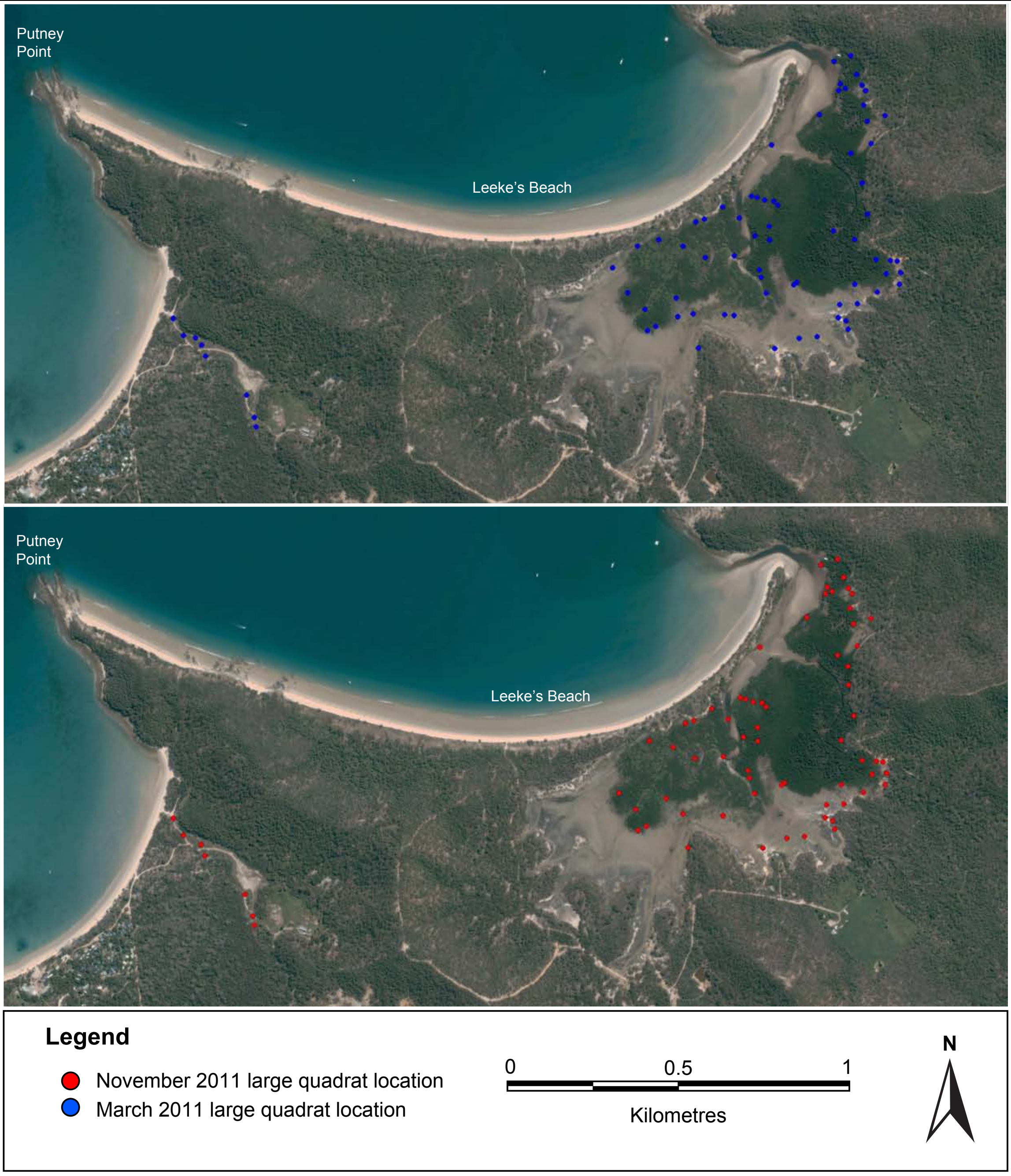
frc environmental AQUATIC ECOLOGISTS deep thinking. science.	Great Keppel Island Revitalisation EIS	
	Figure 2.5 Water quality sites for laboratory analysis of contaminants near the mainland.	
	Microsoft Bing © 2010	June 2011



frc environmental AQUATIC ECOLOGISTS deep thinking. science.	Great Keppel Island Revitalisation EIS
	Figure 2.6 Quadrat locations for assessment of mangrove distribution, community composition and condition in Leeke's and Putney creeks.
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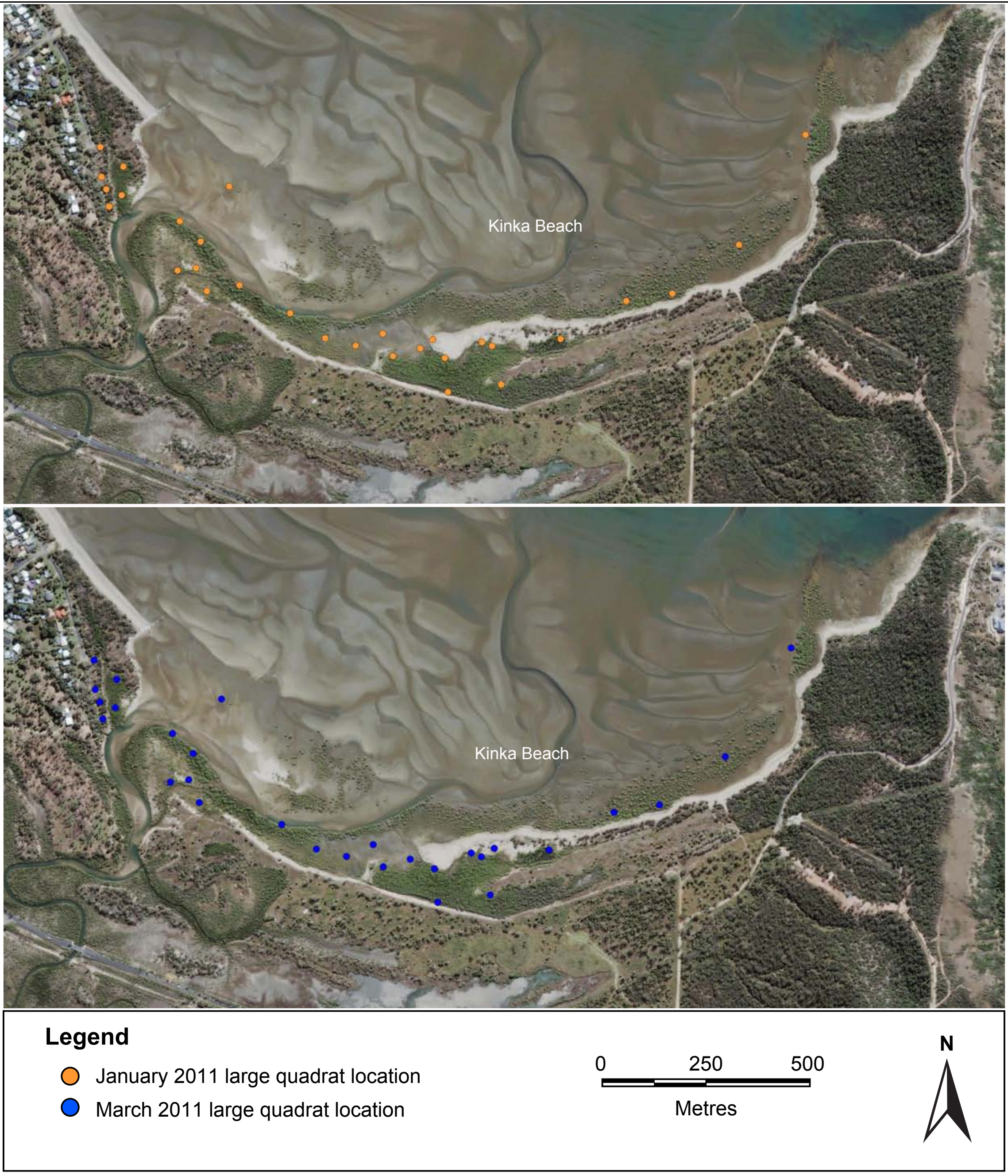

frc environmental AQUATIC ECOLOGISTS deep thinking. science.	Great Keppel Island Revitalisation EIS
	Figure 2.7 Quadrat locations for assessment of mangrove distribution, community composition and condition at Kinka Beach.
	Microsoft Bing © 2010 Microsoft Corporation — May 2012

	Great Keppel Island Revitalisation EIS
	Figure 2.8 Quadrat locations for quantitative assessment of mangrove values to fisheries in Putney Creek.
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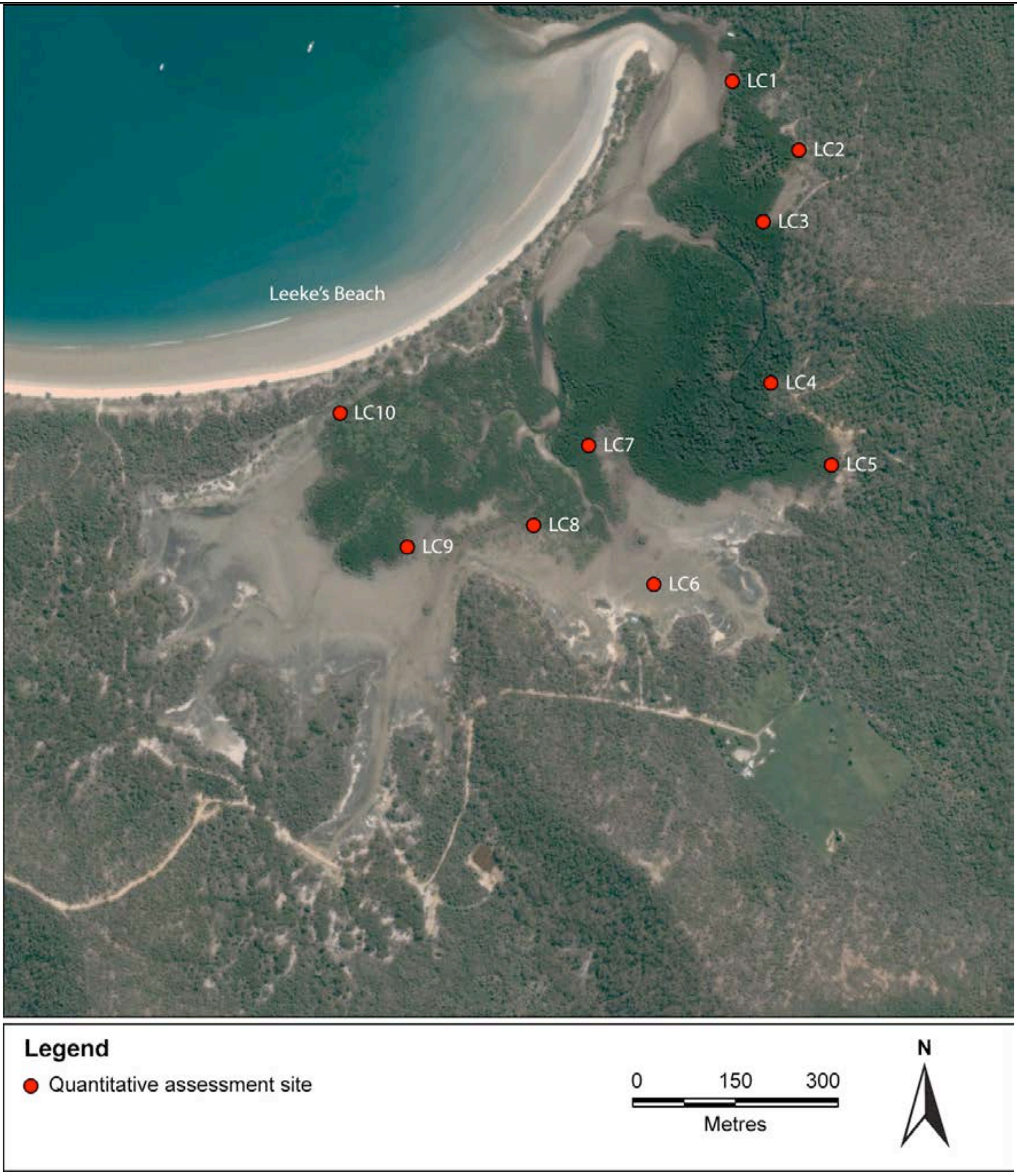
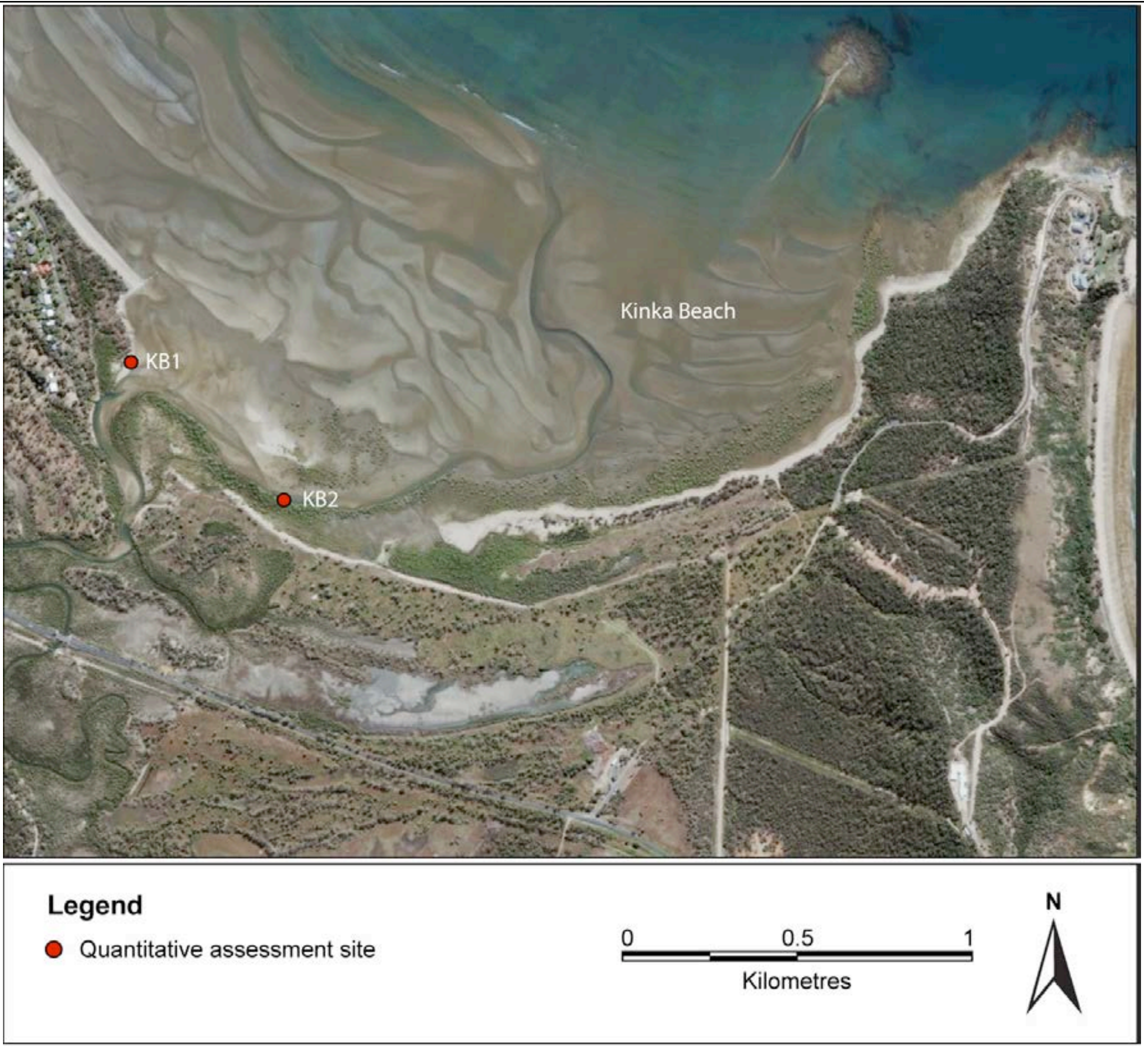


frc environmental AQUATIC ECOLOGISTS deep thinking. science.	Great Keppel Island Revitalisation EIS
	Figure 2.9 Quadrat locations for quantitative assessment of mangrove values to fisheries in Leeke's Creek.
	Microsoft Bing © 2010 Microsoft Corporation — July 2011



frc environmental AQUATIC ECOLOGISTS deep thinking. science.	Great Keppel Island Revitalisation EIS
	Figure 2.10 Quadrat locations for quantitative assessment of mangrove values to fisheries at Kinka Beach.
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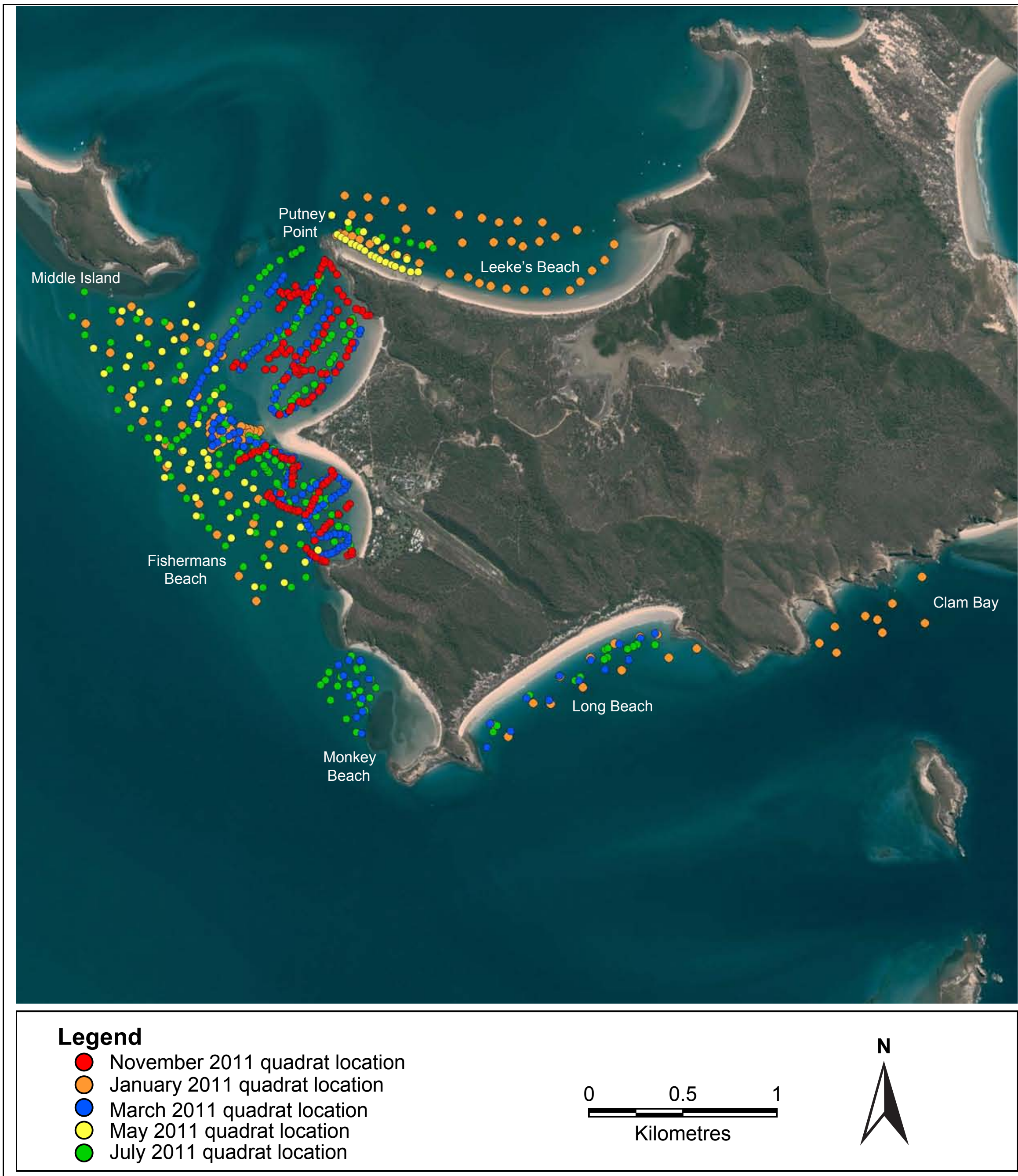
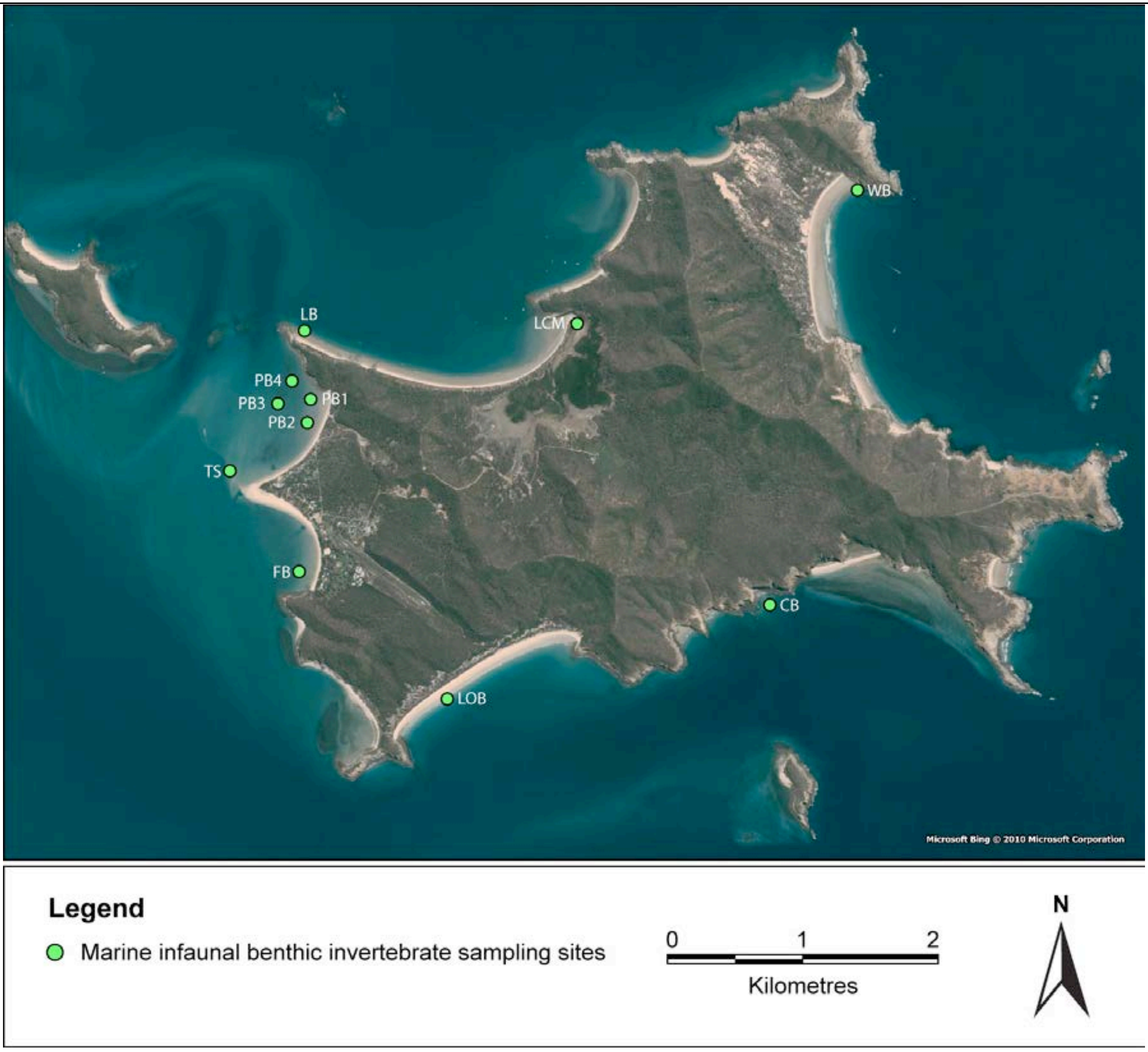


frc environmental AQUATIC ECOLOGISTS deep thinking. science.	Great Keppel Island Revitalisation EIS	
	Figure 2.11 Quadrat locations for assessment of seagrass meadows around Great Keppel Island.	
	Microsoft Bing © 2010 Microsoft Corporation	May 2012



frc environmental AQUATIC ECOLOGISTS deep thinking. science.	Great Keppel Island Revitalisation EIS
	Figure 2.12 Great Keppel Island benthic infaunal invertebrate sites.
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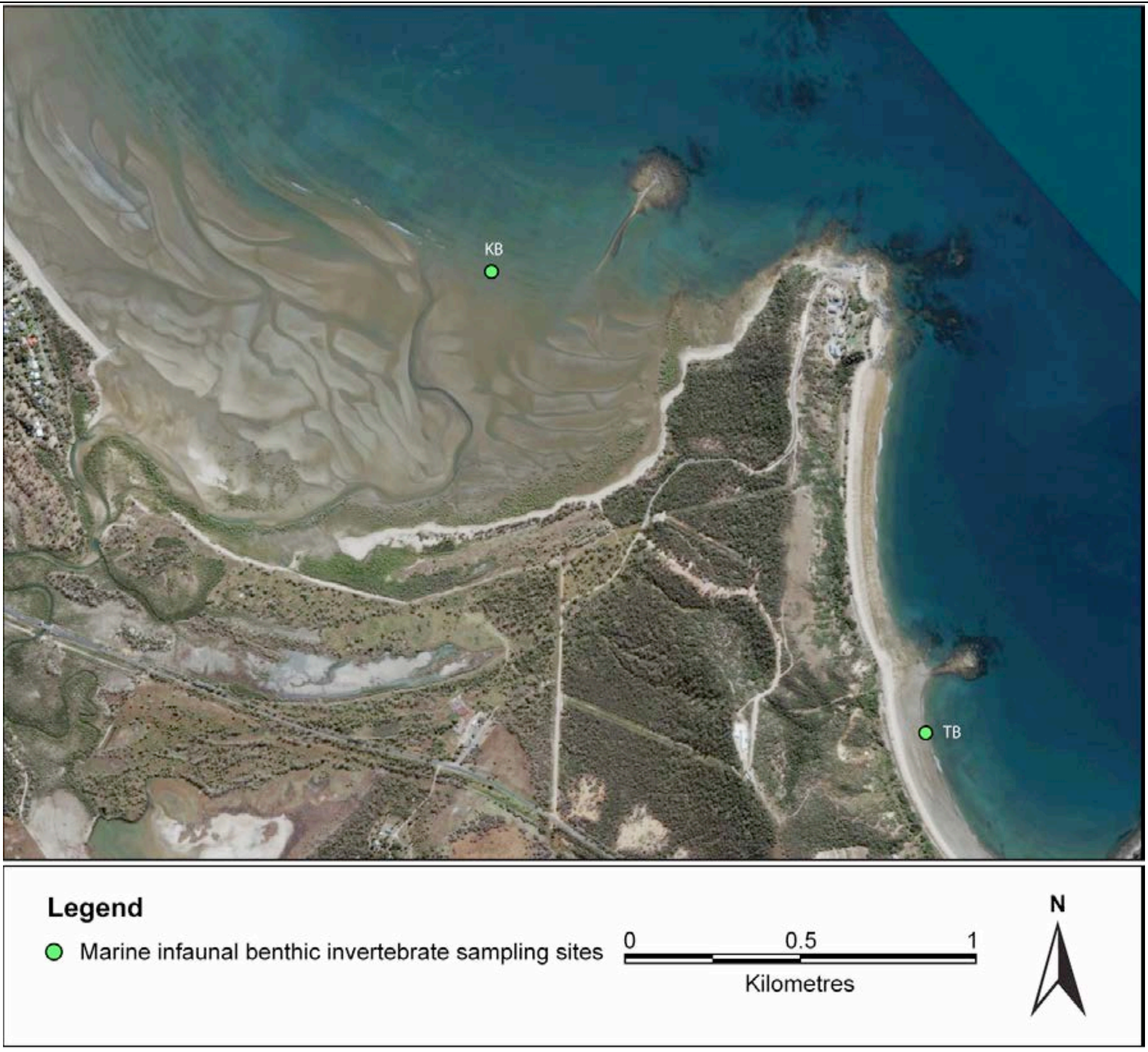

Great Keppel Island Revitalisation EIS	
Figure 2.13 Mainland benthic infaunal invertebrate sites.	
Microsoft Bing © 2010 Microsoft Corporation	June 2011

Physicochemical water quality was recorded at 30 sites around Great Keppel Island. Water quality samples were collected at 12 sites around Great Keppel Island and two sites near the mainland, for assessment of potential contaminants. Water quality results are presented in Appendix C.

Surface sediment quality samples were collected at 12 sites around Great Keppel Island and two sites near the mainland. The quality of the sediment to be dredged for the marina and channel were also assessed in accordance with the *National Assessment Guidelines for Dredging* (NAGD) (DEWHA 2009), the *Guidelines for Sampling and Analysis Procedure for Lowland Acid Sulfate Soils (ASS) in Queensland 1998* (Ahern et al. 1998) and the *State Planning Policy 2/02 Guideline: Acid Sulfate Soils*. Sediment quality results are presented in Appendix D. The sediment sampling and analysis plan (SAP) for dredging is presented in Appendix J.

Mangrove forests at Leeke's Creek and Putney Creek on Great Keppel Island, and at Kinka Beach on the mainland were assessed for their value as fisheries habitat, and for community composition and health. The results of the mangrove forest surveys are presented in Appendix E.

Seagrass meadows were surveyed in eight areas (nine sites) around Great Keppel Island, and along the submarine cable alignment. The results of the seagrass meadow surveys are presented in Appendix E.

Coral reefs were surveyed at ten sites around Great Keppel Island. The results of the coral reef surveys are presented in Appendix F.

Soft sediment communities (benthic infaunal macroinvertebrates) were surveyed at eight sites around Great Keppel Island, and two sites near the mainland. Details of the soft sediment communities are presented in Appendix F. Samples were also collected at Passage Rocks during the post-wet survey.

Rocky shore communities were surveyed at the Putney Beach and Fishermans Beach rocky headlands. Details of the rocky shore communities are presented in Appendix F.

Turtle nesting surveys were undertaken between December 2010 and April 2011 along Putney Beach, Leeke's Beach and Long Beach. Marine megafauna were surveyed opportunistically around Great Keppel Island during all surveys. Details of turtle nesting activity and the presence of marine megafauna around Great Keppel Island are presented in Appendix F.

2.3 Freshwater Surveys

Freshwater surveys were undertaken at eight sites on Great Keppel Island during the post-wet season. Freshwater surveys included assessments of:

- water quality
- sediment quality
- aquatic habitat
- macrophytes
- aquatic macroinvertebrates, and
- fish.

The locations of the freshwater sites on Great Keppel Island are shown in Figure 2.14. The design tree for the freshwater assessment is provided in Table 2.2. Sites were surveyed at different times of the year, but within the post-wet season, in response to water levels and as information about new waterbodies became available. Natural channel sites (non-dam sites) are ephemeral and dry throughout most of the year.

Spatial and temporal replication was determined adequate to describe the existing environment and ***predict an impact***, as opposed to ***future assessment of the extent of impact***. Water quality monitoring was not designed to set local water quality guidelines. Additional replicated sampling to inform post-development impact assessment and local water quality guidelines will be addressed at the Environmental Management Plan (EMP) and / or conditions of approval stage.

Results of the freshwater surveys are presented in Appendix G.

Table 2.2 Design tree for freshwater surveys.

Location	Sites	Spatial Replication	Temporal Replication	Description
Water quality – physiochemical				
Large dam	D1	1 reading per site	March/April 2011	
Homestead dam	D2	1 reading per site	April/May 2011	
Resort dam	D3	1 reading per site	April/May 2011	

Location	Sites	Spatial Replication	Temporal Replication	Description
Leeke's Creek	LFC	1 reading per site	March/April 2011	
Putney Creek	PC1 (1) PC2 (2) PC3 (3)	1 reading per site	June 2011	
Resort creek	RP	1 reading per site	March/April 2011	
Water quality – potential contaminants				
Large dam	D1	1 sample per site	March/April 2011	Field replicate sample collected in March/April 2011 (site D3) and April/May 2011 (site D1). Blanks collected in March/April 2011 and May 2011 to test for cross-contamination.
Homestead dam	D2	1 sample per site	April/May 2011	
Resort dam	D3	1 sample per site	April/May 2011	
Leeke's Creek	LFC	1 sample per site	March/April 2011	
Putney Creek	PC1 (1) PC2 (2) PC3 (3)	1 sample per site	June 2011	
Resort creek	RP	1 sample per site	March/April 2011	
Sediment quality – potential contaminants				
Large dam	D1	1 sample per site	March/April 2011	
Homestead dam	D2	1 sample per site	April/May 2011	
Resort dam	D3	1 sample per site	April/May 2011	
Leeke's Creek	LFC	1 sample per site	March/April 2011	
Putney Creek	PC1 (1) PC2 (2) PC3 (3)	1 sample per site	June 2011	
Resort creek	RP	1 sample per site	March/April 2011	

Location	Sites	Spatial Replication	Temporal Replication	Description
Aquatic habitat				
Large dam	D1	1 assessment per site	March/April 2011	
Homestead dam	D2	1 assessment per site	April/May 2011	
Resort dam	D3	1 assessment per site	April/May 2011	
Leeke's Creek	LFC	1 assessment per site	March/April 2011	
Putney Creek	PC1 (1) PC2 (2) PC3 (3)	1 assessment per site	June 2011	
Resort creek	RP	1 assessment per site	March/April 2011	
Aquatic macroinvertebrates				
Large dam	D1	6 samples per site	March/April 2011	One AUSRIVAS-style sample and five replicated samples from bed habitat at each site. One sample was ollected at site PC1 and PC3 as these sites will be lost to the development.
Homestead dam	D2	6 samples per site	April/May 2011	
Resort dam	D3	6 samples per site	April/May 2011	
Leeke's Creek	LFC	6 samples per site	March/April 2011	
Putney Creek	PC1 (1) PC2 (2) PC3 (3)	6 samples at site PC2; 1 AUSRIVAS-style sample at PC1 and PC3	June 2011	
Resort creek	RP	6 samples per site	March/April 2011	
Fish				
Large dam	D1	5 box traps per site	March/April 2011	
Homestead dam	D2	5 box traps per site	April/May 2011	
Resort dam	D3	5 box traps per site	April/May 2011	

Location	Sites	Spatial Replication	Temporal Replication	Description
Leeke's Creek	LFC	Not trapped due to low water levels	March/April 2011	
Putney Creek	PC1 (1) PC2 (2) PC3 (3)	Not trapped due to low water levels	June 2011	
Resort creek	RP	5 box traps per site	March/April 2011	

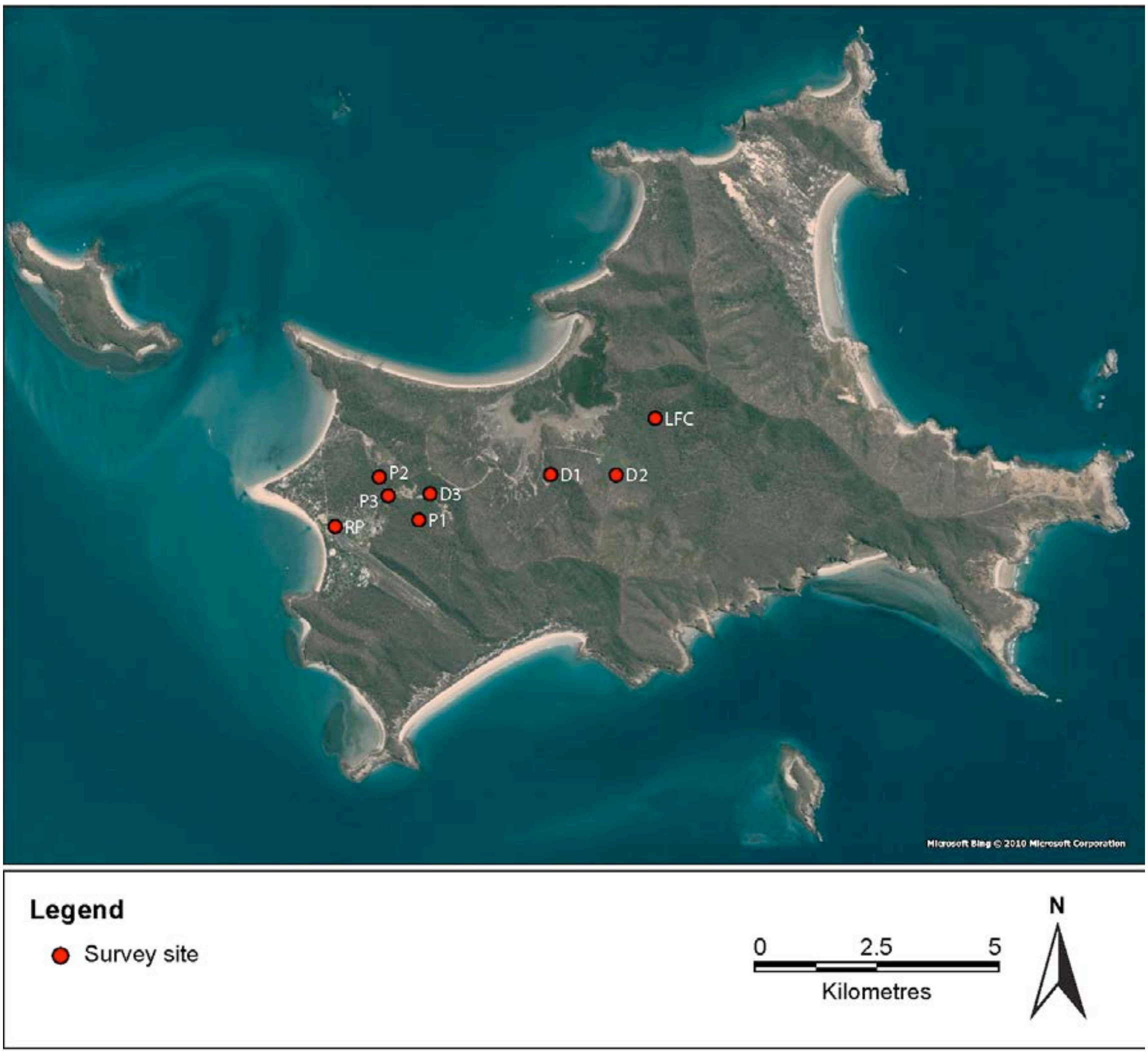

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	Figure 2.14 Freshwater sites on Great Keppel Island.	
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Appendix B Legislation and Guidelines of Relevance to Aquatic Ecology and Wetlands

Contents

Tables

Figures

1 Commonwealth *Environment Protection and Biodiversity Conservation Act 1999*[1]

Any actions that are likely to have a significant impact on a Matter of National Environmental Significance (MNES) are subject to assessment under the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) approval process. Matters of National Environmental Significance include:

- world heritage properties
- national heritage places
- wetlands of international importance (Ramsar wetlands)
- listed threatened species and ecological communities
- migratory species protected under international agreements
- Commonwealth marine environment
- Great Barrier Reef Marine Park, and
- nuclear actions.

There are world heritage properties, national heritage places, Ramsar wetlands, Commonwealth marine areas and the Great Barrier Reef Marine Park in the vicinity of the proposed project (within approximately 10 km of Great Keppel Island or the proposed undersea cable alignment running to Kinka Beach) or within the wider project area (from Shoalwater Bay to Curtis Island). Listed threatened species, ecological communities[2] or migratory species also occur in the project area or in the vicinity of the site.

The project does not affect or involve nuclear actions.

[1] Act no. 91 of 1999 as amended, prepared on 1 January 2011 taking into account amendments up to Act No. 139 of 2010. Prepared by the Office of Legislative Drafting and Publishing, Attorney-General's Department, Canberra.

[2] Ecological communities listed within the project area include the littoral rainforest and coastal vine thickets of eastern Australia and the semi-evergreen vine thickets of the Brigalow Belt (north and south) and Nandewar bioregions. These communities are not considered aquatic and therefore will not be covered in this report.

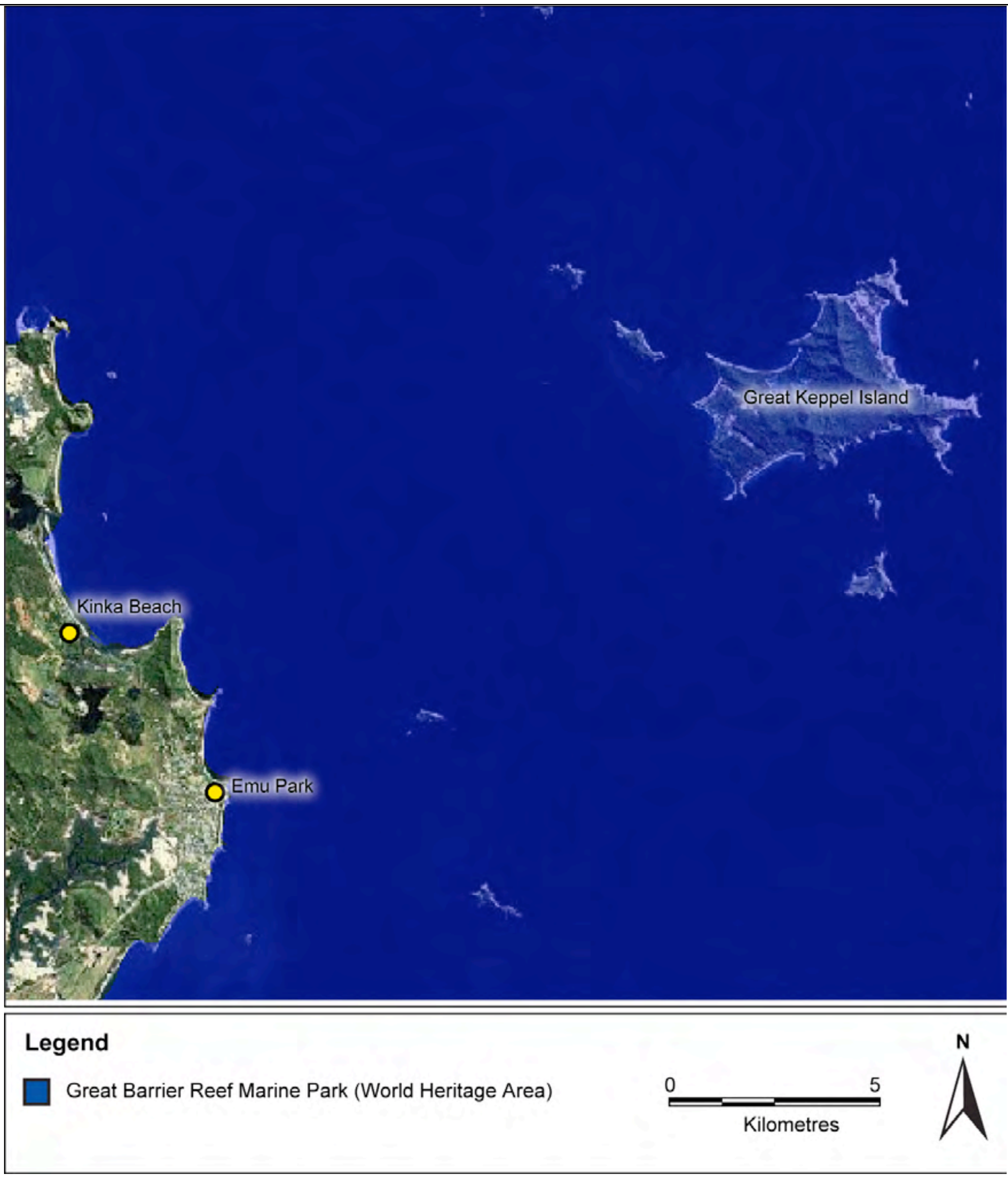
1.1 World Heritage Properties

Properties that have been inscribed on the world heritage list are automatically 'declared world heritage properties'. There are currently 18 world heritage properties in Australia. The EPBC Act regulates actions occurring within or outside a declared world heritage property that is likely to have a significant impact on the world heritage values of that property. An action is likely to have a significant impact on the world heritage values of a world heritage property if there is a real chance or possibility that it will cause one or more world heritage values to be lost; degraded or damaged; or notably altered, modified, obscured or diminished.

The Great Barrier Reef World Heritage Area (GBRWHA) extends into part of the project area (Figure 1.1). The marina and access channel, undersea cable alignment and land-based infrastructure on Great Keppel Island (e.g. golf course) are located within the GBRWHA.

The GBRWHA supports extensive mangrove, saltmarsh, seagrass, algal, and coral communities. It is listed for all four world heritage criteria as it:

- is an outstanding example representing the major stages in the earth's evolutionary history
- is an outstanding example representing significant on-going ecological and biological processes
- is an example of superlative natural phenomena, and
- contains important and significant habitats for in situ conservation of biological diversity.



	Great Keppel Island Revitalisation EIS
frc environmental AQUATIC ECOLOGISTS deep thinking. science.	Figure 1.1 Great Barrier Reef world heritage area in relation to the proposed project.
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1.2 National Heritage Places

Natural heritage places include natural, historic and indigenous places of outstanding heritage and value. There are currently 107 national heritage places, which include world heritage properties. An action is likely to have a significant impact on the national heritage values of a national heritage place if there is a real chance or possibility that it will cause values to be lost; degraded or damaged; or notably altered, modified, obscured or diminished.

There are no national heritage places (related to aquatic ecology) in the vicinity of the proposed project, other than the GBRWHA (discussed in Section 1.1).

1.3 Wetlands of International Importance (Ramsar Wetlands)

In 1971, representatives of 18 nations, including Australia, met in the small Iranian town of Ramsar to sign the Convention on Wetlands of International Importance, commonly referred to as the Ramsar convention. Countries that are party to the Ramsar convention promote wetland conservation by nominating specific sites to the list of Wetlands of International Importance, and by various other activities.

The Ramsar Convention lists the important ecological functions of wetlands as including:

- water storage
- storm protection and flood mitigation
- shoreline stabilisation and erosion control
- groundwater recharge (the movement of water from the wetland down into the underground aquifer)
- groundwater discharge (the movement of water upward to become surface water in a wetland)
- water purification
- retention of nutrients
- retention of sediments
- retention of pollutants, and
- stabilisation of local climate conditions, particularly rainfall and temperature (DEWHA 2009a).

An action is likely to have a significant impact on the ecological character of a declared Ramsar wetland if there is a real chance or possibility that it will result in:

- areas of the wetland being destroyed or substantially modified
- a substantial and measurable change in the hydrological regime of the wetland
- the habitat or lifecycle of native species, including invertebrate fauna and fish species, dependant upon the wetland being seriously affected
- a substantial and measurable change in the water quality of the wetland, or
- an invasive species that is harmful to the ecological character of the wetland being established (or an existing invasive species being spread) in the wetland.

There are no Ramsar wetlands on Great Keppel Island or in the project area. The nearest site is the Shoalwater and Corio Bays Ramsar site, located approximately 25 km north east of Great Keppel Island (Figure 1.2).

The Shoalwater and Corio Bays area is approximately 239 100 ha and contains diverse landscape types, including undulating lowlands and hills, riverine plains, swamps, estuarine inlets, old beach ridges, dunes, sand beaches flanked by coastal cliffs, and intertidal sand and mudflats. Wetland types on the site include freshwater lagoons, swamps and streams; as well as marine, estuarine and intertidal wetlands. The area contains a high diversity of freshwater, estuarine and marine species, mangroves, seagrass and tidal mudflat and salt flats.

The Shoalwater and Corio Bays area is also gazetted as a Defence Practice Area under the *Defensive Act 1903* (DEWHA 2010).

Given the distance between the project area and Shoalwater and Corio Bays, it is highly unlikely that the project will have an impact on this area.

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	Figure 1.2 Ramsar wetlands in relation to the proposed project.	
	Microsoft Bing © 2010 Microsoft Corporation; © The State of Queensland (DERM) 2010	March 2011

1.4 Threatened Species and Ecological Communities

Several species that are identified as potentially inhabiting waters within the vicinity of the project are listed under the EPBC Act (DEWHA 2011). The likelihood of these species occurring in the project area was reviewed in accordance with the criteria outlined in the *Matters of National Environment Significance Significant Impact Guidelines* (DEWHA 2009b) (Table 1.1)[3].

Table 1.1 Criteria used to assess the likelihood of occurrence of species.

Likelihood of Occurrence	Definition	Further assessment required
Low	The species is considered to have a low likelihood of occurring in the study area. Existing database records are considered historic, invalid or based on predictive habitat modelling. Either habitat does not exist for the species or the species is considered locally extinct. Despite a low likelihood based on the above criteria, the species cannot be totally ruled out of occurring within the study area.	No
Moderate	Habitat exists for the species; however it is either marginal or not particularly abundant. The species is known from the wider region and could potentially occur.	Yes
High	The species is known to occur within the study area and core habitat exists.	Yes

An action is likely to have a significant impact if there is a real chance or possibility that it will have the following impacts on a population of 'critically endangered' or 'endangered' species or on an important population[4] of 'vulnerable' species:

- lead to a long-term decrease in the size of a population
- reduce the area of occupancy
- fragment an existing population into two or more populations
- adversely affect habitat critical to the survival of a species
- disrupt the breeding cycle of a population

[3] excludes birds and amphibians which are not considered truly aquatic and therefore will not be covered in this report.

[4] an important population is defined as a population that is necessary for a species' long-term survival and recovery.

- modify, destroy, remove, isolate or decrease the availability or quality of habitat to the extent that the species is likely to decline
- result in invasive species that are harmful to the species becoming established in the habitat
- introduce disease that may cause the species to decline, or
- interfere with the recovery of the species.

Six species listed as ‘vulnerable’ and three listed as ‘endangered’ are considered moderately or highly likely to use habitats in the project area (Table 1.2). The ecology and distribution of these species is discussed in Appendix F.

Species that are likely to be only transient visitors of the region, or are not likely to occur in the region, are considered to have a low likelihood of occurrence (i.e. they are not considered likely to be affected by the proposed project) and have not been discussed in further detail.

There are no threatened aquatic ecological communities listed within the project area.

Protected Species in Commonwealth Areas

There are several species, mainly syngnathids (seahorse and pipefish) and seasnakes, that are protected under the ‘syngnathids’ schedule of the EPBC Act as ‘listed’ marine species and are considered moderately or highly likely to use habitats in the project area (Table 1.2). The ecology and distribution of these species in relation to the project area is discussed in Appendix F.

Under the EPBC Act, activities in Commonwealth waters (refer to Section 1.6) that may result in killing, injuring, taking, trading, keeping or moving a member of a listed threatened species or ecological community, a member of a listed migratory species (refer to Section 1.5) or a member of a listed marine species are illegal without a permit.

Cetaceans

There are several cetaceans (whales, dolphins and porpoises) that are protected under the ‘cetaceans’ schedule of the EPBC Act and are considered moderately or highly likely to use habitats in the project area (Table 1.2). The ecology and distribution of these species in relation to the project area is discussed in Appendix F.

Under the EPBC Act, all cetaceans are protected in Australian waters. The Australian Whale Sanctuary includes all Commonwealth waters (refer to Section 1.6). It is an offence to injure, take, trade, keep, move, harass, chase, herd, tag, mark or brand a cetacean in the Australian Whale Sanctuary without a permit.

1.5 Migratory Species

Migratory species are those animals that migrate to Australia and its external territories, or pass through or over Australian waters during their annual migrations. Many migratory species listed under the international conventions and agreements of Australia are protected under the EPBC Act. An action is likely to have a significant impact on a migratory species if there is a real chance or possibility that it will:

- substantially modify (including by fragmenting, altering fire regimes, altering nutrient cycles or altering hydrological cycles), destroy or isolate an area of important habitat for a migratory species
- result in an invasive species that is harmful to the migratory species becoming established in an area of important habitat for the migratory species, or
- seriously disrupt the lifecycle (breeding, feeding, migration or resting behaviour) of an ecologically significant proportion of the population of a migratory species.

Eleven species listed as ‘migratory’ are considered moderately or highly likely to use habitats in the project area (Table 1.2). The ecology and distribution of these species in relation to the project area is discussed in Appendix F.

Table 1.2 Species listed under Commonwealth and / or state legislation that may occur in the vicinity of the project area (10 km buffer) or the wider study area (from Shoalwater Bay to Curtis Island), and the likelihood that they occur in the project area.

Species	Common Name	EPBC Act[1]	NCWR[2]	Vicinity of Project Area	Wider Study Area	Likelihood of occurrence[3]
Marine Mammals						
Xeromys myoides	water mouse	V	V	–	✓	M
Balaenoptera acutorostrata	minke whale	C	–	✓	✓	M
Balaenoptera edeni	Bryde's whale	M, L, C	–	✓	✓	M
Balaenoptera musculus	blue whale	E, M	–	✓	✓	L
Delphinus delphis	short-beaked common dolphin	C	–	✓	✓	H
Dugong dugon	dugong	M, L	V	✓	✓	H
Feresa attenuata	pygmy killer whale	C	–	–	✓	L
Globicephala macrorhynchus	short-finned pilot whale	C	–	–	✓	L
Grampus griseus	Risso's dolphin, grampus	C	–	✓	✓	M
Kogia breviceps	pygmy sperm whale	C	–	–	✓	L
Kogia simus	dwarf sperm whale	C	–	–	✓	L
Megaptera novaeangliae	humpback whale	V, M, L, C	V	✓	✓	M
Mesoplodon layardii	strap-toothed beaked whale	C	–	–	✓	L
Orcaella brevirostris	Irrawaddy dolphin	M, L, C	–	✓	✓	M
Orcaella heinsohni	Australian snubfin dolphin*	M, L, C	R	✓	✓	M
Orcinus orca	killer whale	M, L, C	–	✓	✓	L
Peponocephala electra	melon-headed whale	C	–	–	✓	L
Physeter macrocephalus	sperm whale	C	–	–	✓	L
Pseudorca crassidens	false killer whale	C	–	–	✓	L

Species	Common Name	EPBC Act[1]	NCWR[2]	Vicinity of Project Area	Wider Study Area	Likelihood of occurrence[3]
Sousa chinensis	Indo-Pacific humpback dolphin	M, L, C	–	✓	✓	M
Stenella attenuata	spotted dolphin	C	–	✓	✓	L
Stenella coeruleoalba	striped dolphin	C	–	–	✓	L
Stenella longirostris	long-snouted spinner dolphin	C	–	–	✓	L
Steno bredanensis	rough-toothed dolphin	C	–	–	✓	L
Tursiops aduncus	Indian Ocean bottlenose dolphin	C	–	✓	✓	L
Tursiops truncatus s. str.	bottlenose dolphin	C	–	✓	✓	M
Ziphius cavirostris	Cuvier's beaked whale	C	–	–	✓	L
Reptiles						
Caretta caretta	loggerhead turtle	E, M, L	E	✓	✓	H
Chelonia mydas	green turtle	V, M, L	V	✓	✓	H
Crocodylus porosus	estuarine crocodile	M, L	V	✓	✓	L
Dermochelys coriacea	leatherback turtle	E, M, L	E	✓	✓	L
Eretmochelys imbricata	hawksbill turtle	V, M, L	V	✓	✓	M
Lepidochelys olivacea	Olive Ridley turtle	E, M, L	E	✓	✓	M
Natator depressus	flatback turtle	V, M, L	V	✓	✓	M
various species	seasnakes and kraits	L	–	✓	✓	M
Sharks						
Isurus oxyrinchus	shortfin mako	M	–	–	✓	L
Isurus paucus	longfin mako	M	–	–	✓	L
Lamna nasus	mackerel shark	M	–	–	✓	L
Pristis zijsron	green sawfish	V	–	✓	✓	L

Species	Common Name	EPBC Act[1]	NCWR[2]	Vicinity of Project Area	Wider Study Area	Likelihood of occurrence[3]
Rhincodon typus	whale shark	V, M, L	–	✓	✓	L
Ray-finned fishes						
Various species	seadragons and pipefishes	L	–	✓	✓	M

[1] The status of species under the *Environmental Protection & Biodiversity Conservation Act 1999*: Endangered (E), Migratory (M), Vulnerable (V), Listed (L) and Cetacean (C).

[2] The status of species under the Queensland Nature Conservation (Wildlife) Regulation 2006[5]: Endangered (E), Rare (R), Vulnerable (V), Near Threatened (NT), not listed (-).

[3] Likelihood of occurrence in the project area, based on *Wildnet* searches (DERM 2011c), EPBC Act Protected Matters search (DEWHA 2011), scientific literature and EPA stranding reports: L – Low, M – Moderate, H – High.

[4] DERM annual cetacean and pinniped marine strandings report for waters between 23-24°S during 1999-2007 (Haines et al. 1999; Haines & Limpus 2002; Limpus et al. 2003; Greenland et al. 2004; Greenland et al. 2005; Greenland & Limpus 2006; 2007; Greenland & Limpus 2008).

[5] DERM marine turtle strandings report for waters between 23-24°S during 1999, 2000 and 2001-2002 (Haines et al. 1999; Haines & Limpus 2000; Greenland & Limpus 2003; Greenland et al. 2004)

* Irrawaddy and snubfin dolphins were considered to be the same species, and the snubfin dolphin was described as a separate species from the Irrawaddy dolphin in 2005.

[5] Reprint No. 1C, Reprinted as in force on 21 May 2010. Reprint prepared by the Office of the Queensland Parliamentary Council.

1.6 Commonwealth Marine Waters

The Commonwealth marine waters generally include the area from the edge of the state coastal waters (3 nautical miles) out to 200 nautical miles from the coast. Commonwealth marine areas are MNES under the EPBC Act. Marine protected areas (MPAs) that are Commonwealth reserves are also protected under the EPBC Act. This includes the Great Barrier Reef Marine Park (GBRMP). An action is likely to have a significant impact on these areas if there is a real chance or possibility that the action will:

- result in a known or potential pest species becoming established
- modify, destroy, fragment, isolate or disturb an important or substantial area of habitat such that an adverse impact on marine ecosystem functioning or integrity results
- have a substantial adverse effect on a population of a marine species or cetacean including its life cycle and spatial distribution
- result in a substantial change in air quality or water quality which may adversely impact on biodiversity, ecological integrity, social amenity or human health
- result in persistent organic chemicals, heavy metals, or other potentially harmful chemicals accumulating in the marine environment such that biodiversity, ecological integrity, social amenity or human health may be adversely affected, or
- have a substantial adverse impact on heritage values of the Commonwealth marine area.

The project is located approximately 18 km from Commonwealth marine waters, however is within the GBRMP (refer to Section 2).

1.7 Great Barrier Reef Marine Park

The GBRMP is recognised as a MNES and is protected under the EPBC Act. Consequently, an activity needs to be referred to the Federal Environment Minister if it is likely to have a significant impact on the environment, is within the marine park, or if it includes other nationally protected matters (if outside of the marine park).

An action is likely to have a significant impact on the environment of the GBRMP if there is a real chance or possibility that the action will:

- modify, destroy, fragment, isolate or disturb an important, substantial, sensitive or vulnerable area of habitat or ecosystem component such that an adverse impact on marine ecosystem health, functioning or integrity in the GBRMP results
- have a substantial adverse effect on a population of a species or cetacean including its life cycle (e.g. breeding, feeding, migration behaviour and life expectancy) and spatial distribution
- result in a substantial change in air quality or water quality (including temperature) which may adversely impact on biodiversity, ecological health or integrity or social amenity or human health
- result in a known or potential pest species being introduced or becoming established in the GBRMP
- result in persistent organic chemicals, heavy metals, or other potentially harmful chemicals accumulating in the marine environment such that biodiversity, ecological integrity, or social amenity or human health may be adversely affected, or
- have a substantial adverse impact on heritage values of the GBRMP, including damage or destruction of an historic shipwreck.

The project is located within the GBRMP (refer to Section 2).

2 Commonwealth Great Barrier Reef Marine Park Act 1975[2]

The *Great Barrier Reef Marine Park Act 1975* is the primary Act with respect to the GBRMP. It includes provisions that establish the GBRMP and the Great Barrier Reef Marine Park Authority (GBRMPA), who are the authority responsible for managing the GBRMP. The Act provides a framework for planning and management, including through zoning plans, plans of management and a system of permissions. The GBRMP Zoning Plan 2003 ensures the protection of habitat types by defining activities that can occur at each location. The project area is located within the Mackay / Capricorn Management Area of the GBRMP (Figure 2.1).

The strongest level of protection is in the 'preservation zone' (pink). This provides high-level protection for special places, habitats, plants and animals within the park. None of the reefs or areas in the vicinity of the proposed project are within preservation zones. The closest preservation zone in the Mackay / Capricorn Management Area is around Peak Island, approximately 18 km to the south (GBRMPA 2010).

The next highest level of protection is the 'marine national park zone' (green). This zone protects biodiversity in the GBRMP by protecting important breeding and nursery areas, such as important seagrass beds, mangrove communities, deep-water shoals and reefs. This includes no-take areas, and while anchoring is allowed in this zone, in high use and sensitive areas the use of an established mooring may be required. Middle Island, Halfway Island and an area to the south east of Great Keppel Island are in 'marine national park zones'.

The area from Putney Point south is in a 'conservation park zone' (yellow). This zone provides protection and conservation, while providing reasonable opportunities for enjoyment and use of the area. To the north of Putney Point there is a 'habitat protection zone' (dark blue). This zone provides for the conservation of areas and management of sensitive habitat by ensuring they are free from potentially damaging activities.

The remainder of the project area is within the 'general use zone' (light blue), which is aimed at providing for conservation, while providing opportunities for reasonable use. Trawling is only permitted in the 'general use zone' (GBRMPA 2010).

'Special management areas' within the GBRMP are designated to conserve the conservation of a particular species or natural resource, public safety, appreciation by the

[2] Act No. 85 of 1975 as amended, prepared on 29 March 2011 taking into account amendments up to Statute Law Revision Act 2011. Prepared by the Office of Legislative Drafting and Publishing, Attorney-General's Department, Canberra.

public and designated as a response to an emergency (e.g. a ship grounding, oil spill or marine pest outbreak). There are several ‘special management areas’ within the vicinity of the project. These include four sites within Keppel Bay and are designated as ‘no anchoring zones’, Barren Island, Great Keppel Island (Big Peninsula and Monkey Beach Reef) and Humpy Island. Two ‘public appreciation areas’ are also located adjacent to the western coastline of Great Keppel Island, and another in Considine Bay adjacent to North Keppel Island. In these areas spearfishing, aquaculture and harvest fisheries are prohibited. Additional spearfishing closures are in effect along the western coastlines of Great Keppel and North Keppel Islands (Figure 2.2). Details on fishing and fisheries are discussed in Appendix G.

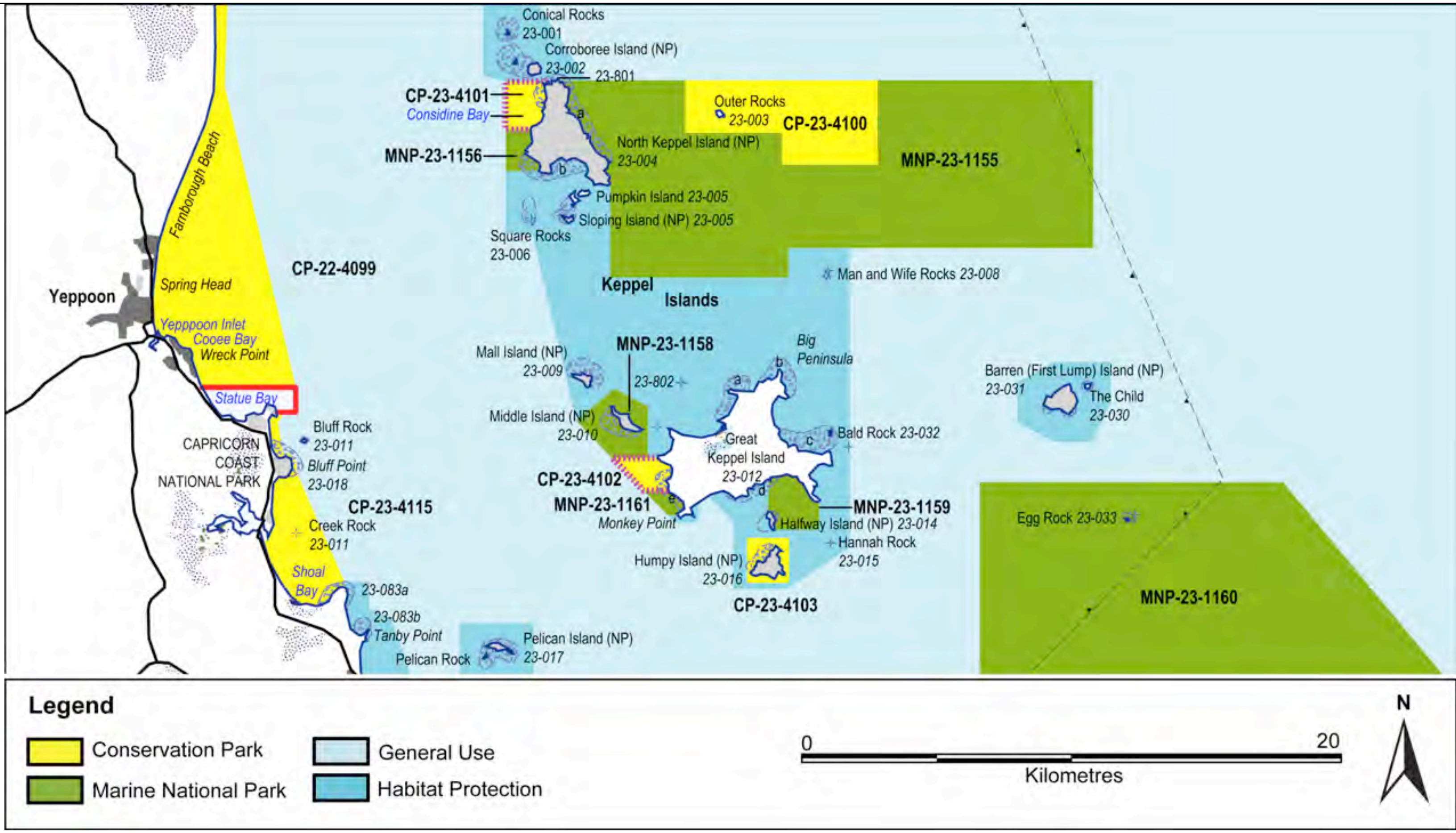

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Figure 2.1 Great Barrier Reef Marine Park zoning in the vicinity of the project.	
GBRMPA Zoning Plan 2003 MPZ17	March 2011

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	Figure 2.2 Spearfishing closure areas around Great Keppel Island.	
	Microsoft Bing © 2010 Microsoft Corporation; © The State of Queensland (DERM) 2010	March 2011

3 Queensland *Marine Parks Act 2004*[2]

The GBRMP is also declared and protected under the State *Marine Parks Act 2004*, the *Marine Parks (Declaration) Regulation 2006* and the *Marine Parks Regulation 2006*. Management is jointly shared between the Commonwealth GBRMPA and the State Queensland Parks and Wildlife Service, which work together to ensure consistent zoning (represented on the GBRMPA plans in Figure 2.1). A permit from GBRMPA will also cover the state marine park.

The Great Barrier Reef Coast Marine Park (GBR Coast MP) is a state marine park protected under the *Marine Parks (Great Barrier Reef Coast) Zoning Plan 2004* (GBR Coast MP Zoning Plan). It provides protection of areas of the GBRMP from the edge of state coastal waters up to the highest astronomical tides (HAT), thus protecting tidal lands and waters. The GBR Coast MP Zoning Plan ensures the protection of habitat types by defining activities that can occur at each location (DERM 2011a).

[2] Reprint No. 1D, Reprinted as in force on 4 April 2011. Reprint prepared by the Office of the Queensland Parliamentary Council.

4 Queensland *Nature Conservation Act 1992*[6]

Rare and threatened species are protected in Queensland under the *Nature Conservation Act 1992* (NCA); protected species are listed in the Nature Conservation (Wildlife) Regulation 2006 (NCWR). Several species that are likely to occur in the vicinity of the project are listed under the NCWR. Three species listed as ‘endangered’, seven species listed as ‘vulnerable’, one species listed as ‘rare’ and one species listed as ‘near threatened’ under the NCWR, may occur in the vicinity of the project (Table 1.2). Each species listed under the NCWR has a *Nature Conservation Plan*. The ecology and distribution of these species in relation to the project area are discussed in Appendix F.

6 Reprint No. 6F, Reprinted as in force on 14 April 2011. Reprint prepared by the Office of the Queensland Parliamentary Council.

5 Queensland *Coastal Protection and Management Act 1995*[4]

The coastal zone is defined in the *Coastal Protection and Management Act 1995*(the Coastal Act) as 'coastal waters and all areas to the landward side of coastal waters in which there are physical features, ecological or natural processes or human activities that affect, or potentially affect the coast or coastal resources.' State coastal waters are defined as waters three nautical miles from low water or as otherwise stated.

The State Coastal Management Plan – Queensland's Coastal Policy (the State plan; EPA 2001) describes how the coastal zone of Queensland is managed. In early 2011, the Queensland Government approved a new coastal plan, which will commence in mid 2011 (DERM 2011b).

5.1 The Current State Coastal Management Plan

Until the new plan commences, the current State Coastal Management Plan remains in force.

Specifically under the current State Coastal Plan, development must not:

- degrade water quality
- increase the risk of flooding
- degrade coastal wetlands
- degrade or diminish declared fish habitat areas, or
- degrade or diminish shorebird roost areas.

Policies under the current State Coastal Plan are divided into ten categories:

- Coastal use and development
- Physical coastal processes
- Public access to the coast
- Water quality
- Indigenous traditional owner cultural resources
- Cultural heritage
- Coastal landscapes

4 Reprint No. 4G, Reprinted as in force on 4 April 2011. Reprint prepared by the Office of the Queensland Parliamentary Council.

- Conserving nature
- Coordinated management, and
- Research and development.

Areas of state significance (social and economic) are defined under policy 2.1.1. Under this policy adjoining and neighbouring areas should be preserved in their natural state or have land uses compatible with the functioning of the area of state significance (social and economic).

Areas of state significance (scenic coastal landscapes) are defined under policy 2.7.1. Under this policy Major Island Groups (including the Keppel Islands) are defined as Level 1 Scenic Quality. The following scenic management issues are relevant:

- maintaining areas with natural character
- visual enhancement of islands with significant development
- protecting shorelines and water edge to islands
- sensitive location of infrastructure, particularly transmission lines
- rehabilitating mining areas, and
- avoiding ridgeline development.

Three policies in category '8. Conserving Nature' directly relate to the protection and preservation of coastal wetlands and aquatic ecology throughout the state (described in detail below). These are policies:

- 2.8.1 Areas of state significance (natural resources)
- 2.8.2 Coastal wetlands, and
- 2.8.3 Biodiversity.

The remaining two policies in this category: 2.8.4 Rehabilitation of coastal resources and 2.8.5 Pest species management, also have implications for the protection and preservation of coastal wetlands and aquatic ecology.

Other policies in the State Coastal Plan relate to the impacts on aquatic ecology of developments such as that proposed. These are policies:

- 2.1.5 Maritime Infrastructure
- 2.1.8 Dredging
- 2.1.10 Tourism and Recreational Activities
- 2.1.12 Managing Water Resources

- 2.1.13 Fishing
- 2.1.14 Aquaculture
- 2.3.2 Design of access
- 2.2.5 Beach protection structures, and
- 2.4.4 Stormwater management.

Policy 2.8.1 Areas of State Significance (Natural Resources)

Land identified for future development of urban, maritime and rural land uses in regional plans, planning schemes and port land use plans is to be located outside areas of state significance (natural resources). Existing developments in these areas will not expand into these areas unless it can be demonstrated there will be no adverse impacts on coastal resources and values. If a use or activity that has adverse effects occurs within areas of state significance (biodiversity) it must have a net benefit to the state as a whole. Land allocation in adjacent areas is to be compatible with the area's values.

Policy 2.8.2 Coastal Wetlands

Further loss or degradation of coastal wetlands is to be avoided and impacts on coastal wetlands are to be prevented, minimised or mitigated (in order of preference).

Policy 2.8.3 Biodiversity

Biodiversity on the coast is to be safeguarded through conserving and appropriately managing the diverse range of habitats in the coastal zone.

5.2 The New Queensland Coastal Plan

The new Coastal Plan will commence mid 2011. It has two parts: the State Policy for Coastal Management, containing policies and guidance for coastal land managers on managing and maintaining coastal land; and the State Planning Policy for Coastal Protection, for planning and assessment decisions made under the *Sustainable Planning Act 2009*. The State Planning Policy for Coastal Protection contains policies, criteria and maps and is directed at planning and development outcomes in the coastal zone.
Under the new Queensland Coastal Plan:

- all of Great Keppel Island is in the Coastal Management District, which means DERM have assessment manager or concurrence agency powers and responsibilities under the *Sustainable Planning Act 2009*
- no areas are designated for medium to large-scale maritime development around the foreshores of Great Keppel Island
- no areas are designated for aquaculture development around the foreshores of Great Keppel Island
- all of Great Keppel Island is mapped as an area subject to erosion due to storm impact and long term trends of sediment loss and channel migration, that may occur with climate change impacts up to 2100
- all of Great Keppel Island is mapped as an area of high ecological significance (HES), and consequently the nature conservation policies under the new Coastal Plan will apply. The new Queensland Coastal Plan requires that all development is outside areas of HES, and does not impact on these areas. However, it is recognised that impacts cannot always be avoided, in these cases, development must minimise and offset any impacts (DERM 2011b). The policies requiring protection of areas of ecological significance do not apply if a field assessment demonstrates the mapping under the plan is incorrect and that development will not have adverse impacts on areas of ecological significance (DERM 2011b).

6 Queensland *Environmental Protection Act 1994*[7]

The *Environmental Protection Act 1994* (EP Act) is the key legislation for environmental management and protection in Queensland. The EP Act establishes a general environmental duty and a duty to notify of environmental harm that applies to all persons and corporations. The EP Act provides for environmental protection policies that establish the environmental values to be preserved and which may set quality standards for segments of the environment (e.g. water, air, waste and noise). The environmental values of waterways in Queensland are protected under the EP Act and the subordinate *Environmental Protection (Water) Policy 2009* (EPP Water)[8].

6.1 Environmental Protection (Water) Policy 2009

Environmental Values (EVs) and Water Quality Objectives (WQOs) have been established for many waterways in Queensland under Schedule 1 of the EPP Water. The EPP Water defines an indicator for an EV as a property that can be measured or decided in a quantitative way. WQOs are numerical concentrations or statements for indicators that protect a stated EV and are generally developed based on the review of the available site-specific information relevant to each EV.

The EVs of waters to be enhanced or protected under the EPP Water are:

- biological integrity of an aquatic ecosystem
- suitability for recreational use
- suitability for minimal treatment before supply as drinking water
- suitability for agricultural use, and
- suitability for industrial use.

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[7] Reprint No. 9J, Reprinted as in force on 14 April 2011. Reprint prepared by the Office of the Queensland Parliamentary Council.

[8] Reprint No. 1B, Reprinted as in force on 16 July 2010. Reprint prepared by the Office of the Queensland Parliamentary Council.

The following documents are used to decide the appropriate EVs and WQOs (when not specifically described for a site):

- site specific documents
- *Queensland Water Quality Guidelines* (QWQG) (DERM 2009)
- *Australian and New Zealand Water Quality Guidelines for Fresh and Marine Waters* (the national guidelines) (ANZECC & ARMCANZ 2000), and
- documents published by a recognised entity such as GBRMPA's *Water Quality Guidelines for the Great Barrier Reef Marine Park* (2009).

EVs and WQOs (e.g. trigger levels for contaminants) for the project are discussed further in Appendix C and D for water quality and sediment quality, respectively.

Queensland Water Quality Guidelines

The Queensland Water Quality Guidelines (QWQG) (DERM 2009) have been created to better tailor guidelines to specific regions, and to address the natural regional and local variability in the water quality across the state. The QWQG are specific to regions within Queensland, and should be used in preference to the ANZECC & ARMCANZ (2000) guidelines where possible (DERM 2009).

Australian Water Quality Guidelines for Fresh and Marine Waters

The ANZECC & ARMCANZ (2000) guidelines should 'be used as a general tool for assessing water quality and are the key to determining water quality objectives that protect and support the designated environmental values of water resources, and against which performance can be measured' (ANZECC & ARMCANZ 2000). The guideline values refer to physical and chemical stressors, toxicants and biological indicators for water and sediment quality.

Water Quality Guidelines for the Great Barrier Reef Marine Park

The GBRMPA has prepared *Water Quality Guidelines for the Great Barrier Reef Marine Park* (2009) based on the available scientific evidence of direct biological effects, from exposure to particular contaminants, to set a guide for good water quality. Trigger levels have been identified for managers to take action if conditions exceed the guides.

Level of Protection

The level of protection for an ecosystem is based on the current ecosystem condition.

Ecosystem condition for waters in the Great Barrier Reef Marine Park has been defined in the *Water Quality Guidelines for the Great Barrier Reef Marine Park* as follows:

- areas influenced by discharges from rivers in the Great Barrier Reef catchments have are considered to be slightly to moderately disturbed, unless they are within a Marine National Park or Preservation Zone of the Great Barrier Reef Marine Park, and
- areas outside of the influence of discharges from rivers in the Great Barrier Reef catchments, or that are within a Marine National Park or Preservation Zone of the Great Barrier Reef Marine Park, are considered to be of high ecological value.

The ANZECC & ARMCANZ (2000) guidelines define ecosystem conditions as:

- 'High conservation/ecological value systems — effectively unmodified or other highly-valued ecosystems, typically (but not always) occurring in national parks, conservation reserves or in remote and/or inaccessible locations. While there are no aquatic ecosystems in Australia and New Zealand that are entirely without some human influence, the ecological integrity of high conservation/ecological value systems is regarded as intact.
- Slightly to moderately disturbed systems — ecosystems in which aquatic biological diversity may have been adversely affected to a relatively small but measurable degree by human activity. The biological communities remain in a healthy condition and ecosystem integrity is largely retained. Typically, freshwater systems would have slightly to moderately cleared catchments and/or reasonably intact riparian vegetation; marine systems would have largely intact habitats and associated biological communities. Slightly to moderately disturbed systems could include rural streams receiving runoff from land disturbed to varying degrees by grazing or pastoralism, or marine ecosystems lying immediately adjacent to metropolitan areas.
- Highly disturbed systems – these are measurably degraded ecosystems of lower ecological value. Examples of highly disturbed systems would be some shipping ports and sections of harbours serving coastal cities, urban streams receiving road and stormwater runoff, or rural streams receiving runoff from intensive horticulture.'

The survey area is therefore considered to be a slightly to moderately disturbed system.

7 Queensland *Fisheries Act 1994*[9]

All waters of the state are protected against degradation by direct or indirect impact under section 125 of the *Fisheries Act 1994* (Fisheries Act). If litter, soil, a noxious substance, refuse or other polluting matter is on land (including the foreshore and non-tidal land), in waters, or in a fish habitat, and it appears to the Chief Executive that the polluting matter is likely to adversely affect fisheries resources or a fish habitat, the Chief Executive of the Department of Employment, Economic Development and Innovation (DEEDI) may issue a notice requiring the person, suspected of causing the pollution, to take action to redress the situation.

7.1 Fish Habitat Areas

Fish Habitat Areas (FHAs) are declared under the Fisheries Act to enhance existing and future fishing activities and to protect the habitat upon which fish and other fauna depend. They predominantly cover inshore and estuarine habitats, as these are recognised as being highly valuable habitats for commercially and recreationally important fish and crustaceans. While normal community use and activities (including legal fishing activities) are not restricted in FHAs, any works or activities requiring the disturbance of habitats within an FHA, require a specific permit under the provisions of the Fisheries Act.

Each declared FHA is classified as Management level ‘A’ or ‘B’. Management level ‘A’ is designed to protect critical fish habitat for the purpose of productive and sustainable fishing, short and long term, maintain the ecological character and integrity of undisturbed fisheries habitat and maintain the biodiversity of fisheries resources. Management level ‘B’ is designed to protect important fish habitat for the purpose of productive and sustainable fishing, short and long term, minimise the impacts of non-fisheries related disturbance to important fisheries habitat, maintain biodiversity of fisheries resources, and provide a management buffer to FHAs ‘A’.

There are three FHAs in the wider study are: the Fitzroy River FHA (Management level ‘A’), the Corio Bay FHA (Management level ‘A’) and the Cawarral Creek FHA (Management level ‘A’). The Cawarral Creek FHA is located approximately 10 km, from the project area, while the Fitzroy River (located at the mouth of the river) and Corio Bay FHAs are located approximately 25 and 30 km from the project area, respectively (Figure 7.1). It is very unlikely that the project will impact these FHAs.

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9 Reprint No. 6G, Reprinted as in force on 1 December 2010. Reprint prepared by the Office of the Queensland Parliamentary Council.

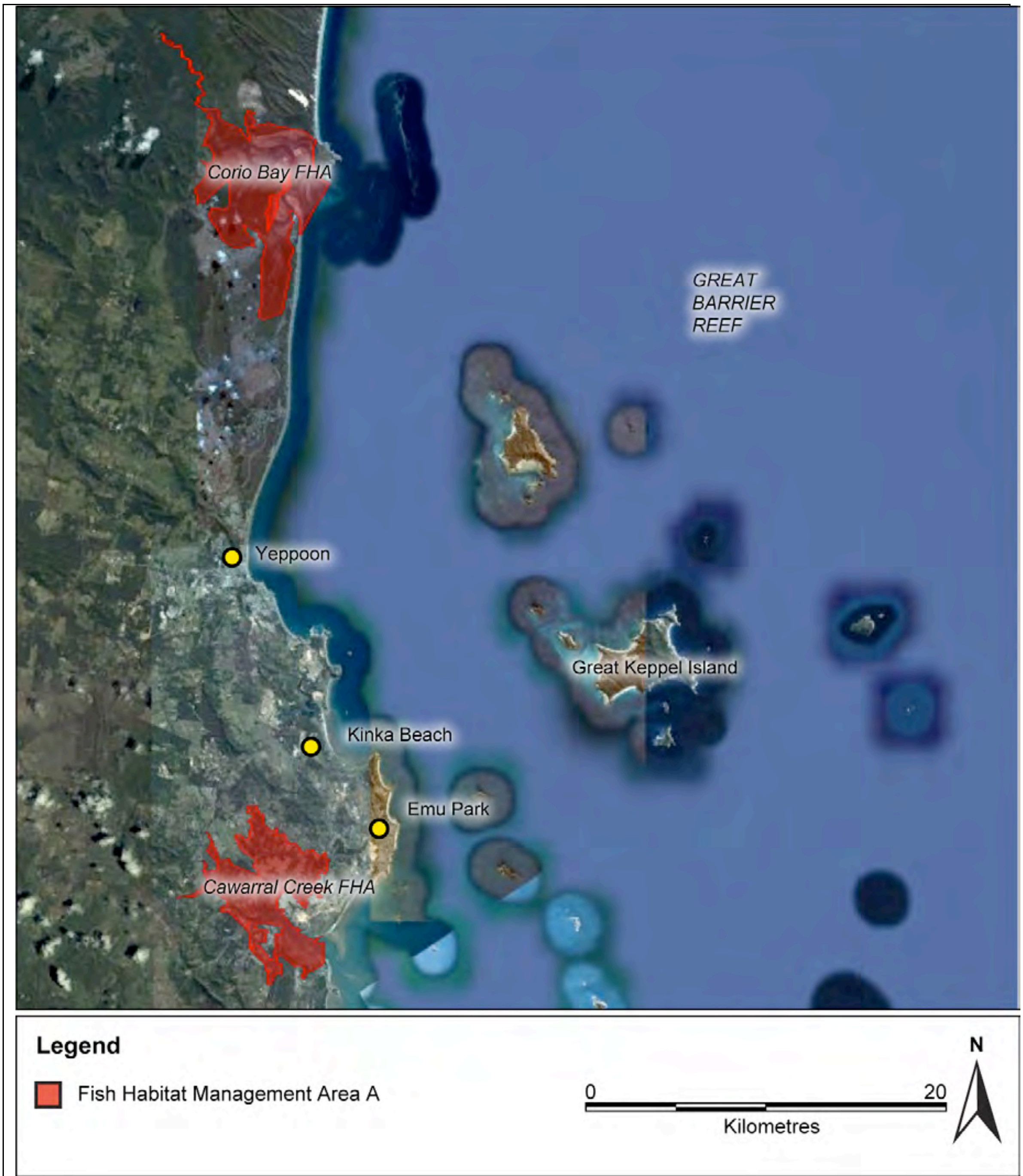

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	Figure 7.1 Fish Habitat Areas in relation to the project.	
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A new FHA was proposed for Leeke's Creek on Great Keppel Island, but this application was rejected by DPI&F (Derbyshire 2011, *pers. comm.*)[10].

7.2 Marine Plants

All plants that grow on intertidal and subtidal land are protected under the Fisheries Act. Under this Act 'marine plants' include:

- a plant that usually grows on or adjacent to tidal land, whether living, dead, standing or fallen
- material of a tidal plant, or other plant material on tidal land, and
- a plant, or material of a plant, prescribed under a regulation or management plan to be a marine plant (Couchman & Beumer 2002).

Tidal land is defined under the Act as any land that is at or below the highest astronomical tide (HAT) level (Couchman & Beumer 2002).

Marine plants include macro and microscopic plants including mangroves, seagrass, samphires, saltcouch and saltmarsh plants, algae and other tidal plants growing adjacent to the tidal zone, landward and seaward (Couchman & Beumer 2002). The primary values of marine plants to estuarine ecology and fisheries are their contribution, through the process of photosynthesis, to a detritus-based food web; and the provision of a range of habitats (for shelter, feeding and nursery areas) for fish and invertebrates (Connolly 1999) (Luxford 2004). Plants of highest significance to fisheries include all mangroves, seagrasses, marine algae, marine couch and samphires (Couchman & Beumer 2002).

There are extensive areas of marine plants, particularly mangrove forests and saltmarsh, in the vicinity of the project and these communities are discussed in Appendix E. HAT level is also mapped in Appendix E.

7.3 Listed Species

Endangered species may be prescribed as 'protected species' under the Fisheries Act. Endangered species are discussed in Appendix F.

[10] The Leeke's Creek FHA proposal was rejected due to objections from the traditional owners of Great Keppel Island. Primary Industries and Fisheries requested that the proponent work with the traditional owners to develop a new proposal, however this has not eventuated.

Declared noxious species are listed under the Fisheries Regulation 2008[8]. Declared noxious fish cannot be kept, hatched, reared or sold, and must be destroyed if caught. They must not be returned to the water in any form, and cannot be used as bait (alive or dead).

Under the Fisheries Regulation, non-indigenous fish are fish living in an area where they are not naturally found. A non-indigenous fish can be a native Australian species or a non-native species (i.e. exotic).

7.4 Commercial and Recreational Fisheries

Commercial fishing can be prohibited in certain areas or at certain times under the Fisheries Act. Recreational fishers are also subject to closed areas, closed seasons, protected species and minimum sizes. Bag limits have also been set for some species (Quinn et al. 1992).

There are many commercial and recreational fisheries in the vicinity of the project and these are discussed in Appendix G.

[8] Reprint No. 3, Reprinted as in force on 10 December 2010. Reprint prepared by the Office of the Queensland Parliamentary Council.

8 Queensland *Vegetation Management Act 1999*[9]

The purpose of this *Vegetation Management Act 1999* (VMA) is to regulate the clearing of vegetation and conserve remnant vegetation. Regional ecosystems (REs) are classified as 'endangered', 'of concern' or 'of least concern'. Clearing within 'endangered' REs (listed in schedule 1 of the VMA) and vegetation in areas of high nature conservation value (declared under section 19 of the VMA) on lease and freehold land, require the submission of a development application permit (which includes a property vegetation management plan that outlines matters listed in schedule 3 of the VMA). Removal of vegetation in REs 'of concern' (listed in schedule 2) on leasehold land requires a permit.

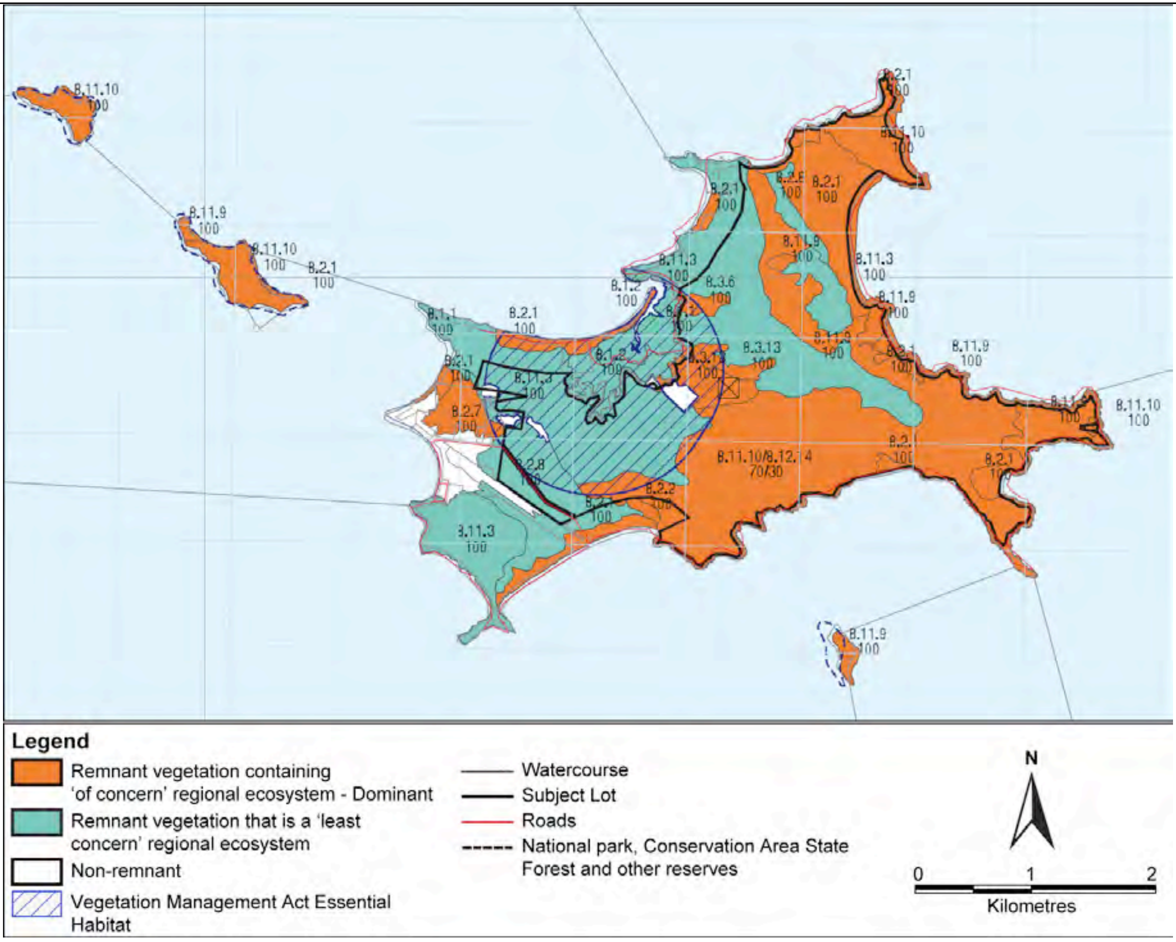
REs in the project area are listed in Table 8.1 and are presented in Figure 8.1 and Figure 8.2. There are two REs that relate to aquatic flora (RE 8.1.1 and 8.1.2; Table 8.1). These communities are discussed further in Appendix E.

Table 8.1 Aquatic Regional Ecosystems in the project area.

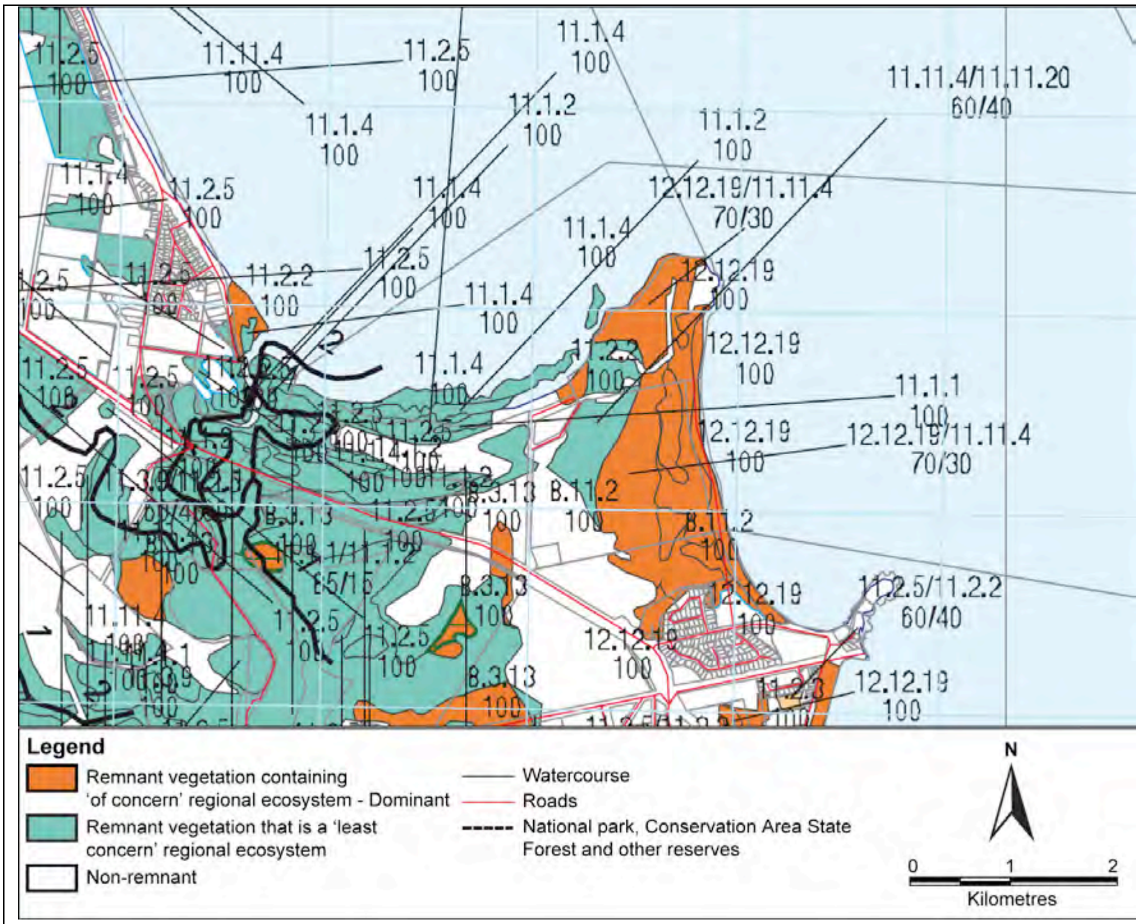
Regional Ecosystem	Short Description	VMA status[1]
8.1.1	Mangrove vegetation of marine clay plains and estuaries. Estuarine wetland.	Not of concern
8.1.2	Samphire open forbland to isolated clumps of forbs on saltpans and plains adjacent to mangroves.	Not of concern

1 Status under the *Vegetation Management Act 1999* (VMA)

[9] Reprint No. 4, Reprinted as in force on 1 December 2010. Reprint prepared by the Office of the Queensland Parliamentary Council.



	Great Keppel Island Revitalisation EIS	
	Figure 8.1 Regional Ecosystem vegetation types of Great Keppel Island.	
	Microsoft Bing © 2010 Microsoft Corporation; DERM 2011	March 2011



Great Keppel Island Revitalisation EIS	
Figure 8.2 Regional Ecosystem vegetation types in the vicinity of Kinka Beach.	
Microsoft Bing © 2010 Microsoft Corporation; DERM 2011	March 2011

9 Queensland *Sustainable Planning Act 2009*[11]

9.1 Integrated Development Assessment System: Referable Wetlands

DERM has an advice agency role for wetlands under the Integrated Development Assessment System (IDAS) and Schedule of the Sustainable Planning Regulation 2009. These wetlands are identified as 'wetland management areas' on maps of referable wetlands produced by DERM. Wetland management areas consist of wetlands of ecological significance plus a 100-metre wide trigger area.

Development triggers for wetlands as listed in Schedule 7 of the Sustainable Planning Regulation include:

- reconfiguring a lot if:
  - any part of the land is situated wholly or partly within a wetland management area; and
  - the reconfiguration results in more than six lots being created, or any lot resulting from the reconfiguring is less than 5 ha.
- material change of use, other than for a domestic activity, if any part of the land is situated wholly or partly within a wetland management area.

There are a number of wetland management areas on Great Keppel Island (Figure 9.1).

DERM also has concurrence powers for wetlands of high ecological significance within the Great Barrier Reef catchments. These areas have been identified as 'wetland protection areas' on the map of referable wetlands.

No wetland protection areas are mapped on the referable wetlands map for Great Keppel Island.

[11] Reprint No. IG, Reprinted as in force on 14 April 2011. Reprint prepared by the Office of the Queensland Parliamentary Council.

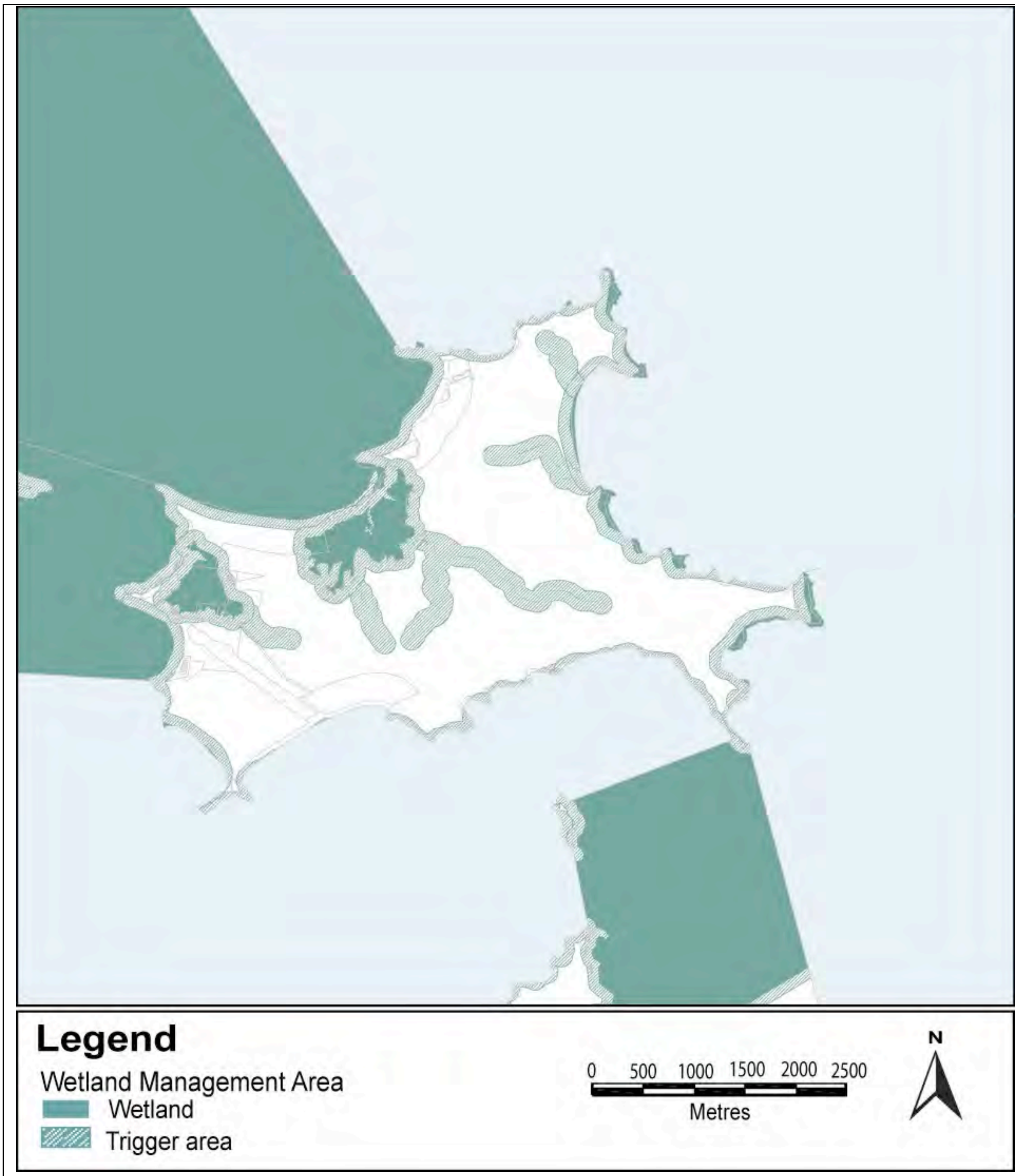


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	Figure 9.1 Referable wetlands of Great Keppel Island.	
	Microsoft Bing © 2010 Microsoft Corporation; DERM 2011	May 2011

9.2 Temporary State Planning Policy Protecting Wetlands of High Ecological Significance in Great Barrier Reef Catchments May 2011

This policy, which came into effect on 3 May 2011, provides direction on the following wetland protection issues relevant to the *Sustainable Planning Act 2009*:

- how planning instruments can protect environmental values in wetlands of high ecological significance in Great Barrier Reef catchments, and
- how particular development can achieve the relevant policy outcomes for protecting wetland environmental values.

The policy requires that development within GBR wetland protection areas, other than in an urban area is outside of the wetland and avoids adverse effects on the wetland, and that development within an urban area is outside of the HES wetland and avoids adverse effects on the wetland and, where adverse effects cannot be avoided, those effects are minimised and offset.

The policy applies to the GBR wetland protection areas on the map of referable wetlands in Annex 2 of the policy. On this map Great Keppel Island does not appear to be mapped as a wetland of high ecological significance. However this map is relatively large scale and lacks detail: no wetland protection areas are mapped on the more detailed referable wetlands map for Great Keppel Island produced by DERM. Further, under code AO1.1 of the policy, an alternative mapped boundary of an HES wetland can be submitted as part of the development application, supported by a detailed assessment and site analysis in accordance with the Queensland Wetland Definition and Delineation Guidelines, and may be accepted by the assessment manager or concurrence agency as a more accurate representation of this boundary.

Developments that trigger development assessment for a Great Barrier Reef wetland protection area are listed in the Sustainable Planning Regulation 2009 (Schedule 3, Part 1 Table 4) and include operational works that are high impact earthworks and material change of use, and reconfiguring a lot that involves operational works that are high impact earthworks. Schedule 26 of the Sustainable Planning Regulation 2009 also provides the definition of high impact earthworks and works that are excluded from the definition. Examples of high impact earthworks are:

- filling of land, including raising the level of land, by the placing of fill material
- excavation of land, including excavation to create a canal, channel or water storage
- construction of a levee, bund wall or diversion bank
- construction or raising of a dam, weir or other barrier across a waterway, and
- construction of a road, culvert or causeway.

10 Wetlands of Significance

10.1 Wetlands of National Significance

Wetlands of National Significance are not specifically protected under state or Commonwealth legislation, however nationally important wetlands are described in the *Directory of Important Wetlands in Australia* (DEWHA 2009a). A wetland is listed as a Wetland of National Significance if it (from DEWHA 2009a):

- is a good example of a wetland type occurring within a biogeographic region in Australia
- is a wetland which plays an important ecological or hydrological role in the natural functioning of a major wetland system / complex
- is a wetland which is important as the habitat for animal taxa at a vulnerable stage in their life cycles, or provides a refuge when adverse conditions such as drought prevail
- supports 1% or more of the national populations of any native plant or animal taxa
- supports native plant or animal taxa or communities which are considered endangered or vulnerable at the national level, or
- is of outstanding historical or cultural significance.

Wetlands of National Significance (and their approximate distance to the project) in the vicinity of the project include the (Figure 9.1):

- Great Barrier Reef Marine Park (the project area below HAT level)
- Yeppoon – Keppel Islands Tidal Wetlands (12.5 km)
- Fitzroy River Delta (33.5 km)
- Fitzroy River Floodplain (48 km)
- Northeast Curtis Island (28 km)
- The Narrows (36 km)
- Hedlow Wetlands (31.5 km), and
- Iwasaki Wetlands (28 km).

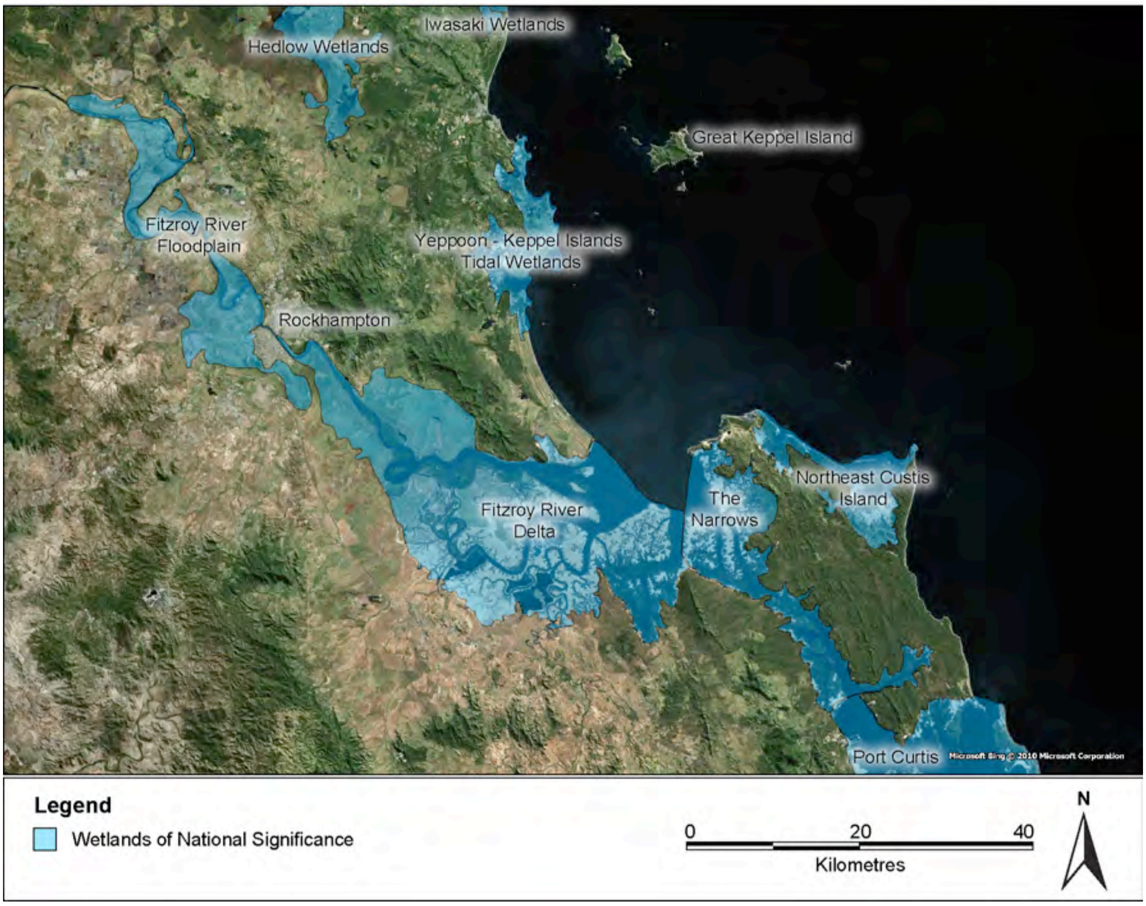

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	Figure 9.1 Wetlands of National Significance in relation to Great Keppel Island.	
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10.2 Other Mapped Wetlands

Riverine, lacustrine, palustrine and estuarine and marine wetlands of the region have been mapped under the Department of Environment and Resource Management's (DERM's) wetland mapping program (Figure 10.2). These wetlands are not necessarily protected under state or Commonwealth legislation (although note that in this case, the estuarine wetlands mapped are protected under the Commonwealth EPBC Act and / or the Queensland Coastal Act); however, wetlands offer important habitat to variety of aquatic flora and fauna species.

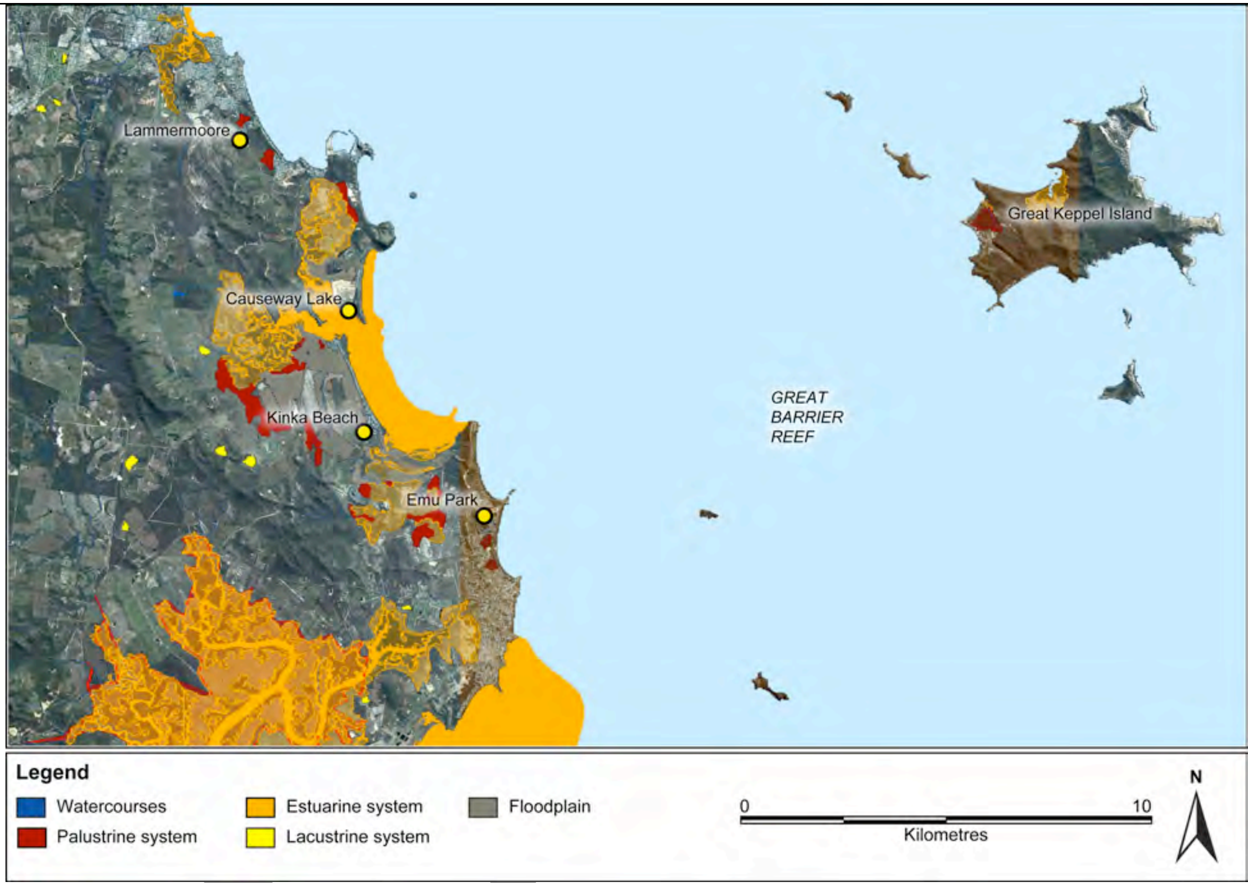

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Figure 10.2 Wetlands mapped by DERM on Great Keppel Island and mainland.

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March 2011

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Appendix C Marine Water Quality

Contents

Tables

Figures

1 Environmental Values and Water Quality Objectives

1.1 Environmental Values

Environmental values include the specific values of each waterway determined by physical, biological, social, economic and historical features. Environmental values are recognised under the Environmental Protection (Water) Policy 2009. Details of legislation relevant to the proposed development are presented in Appendix B.

The following environmental values apply to waterways in Queensland, as outlined in the Environmental Protection (Water) Policy 2009 (adapted from EPA 2005):

- Ecosystem – the intrinsic biological value of aquatic ecosystems that are:
  - unmodified or highly valued (high ecological value waters)
  - unmodified in terms of biological indicators, but slightly modified with respect to other indicators such as water quality (slightly disturbed waters)
  - adversely affected by human activity to a relatively small but measurable degree (moderately disturbed waters), or
  - measurably degraded and of lower ecological value than those waters described in points above (highly disturbed waters).
- Primary industries – the suitability of the water for:
  - irrigation – of crops (e.g. sugar cane and lucerne)
  - farm water supply – uses other than drinking water
  - aquaculture – (e.g. barramundi or red-claw farming), and
  - human consumers – health of humans consuming wild or stocked fish, or crustaceans from natural waterways.
- Recreation and aesthetic values – the suitability of the water for:
  - primary recreation – health of humans undertaking activities where there is a high probability of water being swallowed (e.g. swimming)
  - secondary recreation – health of humans undertaking activities where there is a low probability of water being swallowed (e.g. boating and fishing)
  - visual recreation – amenity of waterways for recreation that does not involve direct contact with the water (e.g. picnicking next to the waterway)
  - drinking water – the suitability of the water for supply as drinking water

- industrial uses – the suitability of the water for industrial use, and
- cultural and spiritual values – indigenous and non-indigenous cultural values.

Environmental values most relevant to the current study were defined for the project area using a conservative approach. For instance, if waterways were possibly or likely to be used for a particular purpose, this was included as an environmental value.

Based on the environmental values described in the Environmental Protection (Water) Policy 2009 (see Appendix B) and available information, the (water-based) environmental values that apply to the proposed development area include:

- ecosystem (high ecological value) – the intrinsic biological value of unmodified or highly valued ecosystems; for waters offshore of Great Keppel Island
- ecosystem (slightly to moderately disturbed) – the intrinsic biological value of aquatic ecosystems that are affected adversely, to a relatively small but measurable degree, by human activity; for the estuarine waters of Leeke's and Putney creeks and for the waters at Kinka and Tanby beaches on the mainland
- aquaculture and human consumption of aquatic foods
- primary recreation – health of humans undertaking activities where there is a high probability of water being swallowed (e.g. swimming)
- secondary recreation – health of humans undertaking activities where there is a low probability of water being swallowed (e.g. boating and fishing)
- visual recreation – amenity of waterways for recreation that does not involve direct contact with the water (e.g. picnicking next to the waterway), and
- cultural heritage – indigenous and non-indigenous cultural heritage.

1.2 Water Quality Objectives

Water quality objectives (WQOs) have been defined based on published guidelines (Appendix B) including the *Water Quality Guidelines for the Great Barrier Reef Marine Park* (GBRMPA 2009b) and the *Queensland Water Quality Guidelines* (QWQG) for coastal / inshore waters in the central Queensland region (QWQG; DERM 2009). For parameters not specified in these guidelines, the WQOs have been based on the *Australian and New Zealand Water Quality Guidelines for Fresh and Marine Waters* (the national guidelines) (ANZECC & ARMCANZ 2000) for tropical Australia (Table 1.1, Table 1.2 and Table 1.3).

These published guidelines are considered sufficient to protect the described environmental values of the proposed development area, with the exception of visual recreation and cultural heritage, to which the following guidelines apply:

- visual recreation – water should be free of: floating debris; oil and grease; substances that produce undesirable colour, odour, taste or foaming; and undesirable aquatic life such as algae or dense growth of attached plants or insects, and
- cultural heritage – protect or restore indigenous and non-indigenous cultural heritage, consistent with relevant policies and plans.

Table 1.1 Water quality objectives for physicochemical water quality parameters measured in the current study.

Physicochemical Parameter	Units	WQOs for Marine Waters	WQOs for Estuarine Waters
Temperature	°C	–	–
pH	pH units	8.1–8.4[1]	7.0–8.4[2]
Salinity	ppt	–	–
Dissolved oxygen	% saturation	95–105[1]	85–100[2]
Turbidity	NTU	1.0[1]	8.0[2]
TSS	mg/L	2.0[1,3]	20[2]

– no trigger value available

1 *Source*: *Queensland Water Quality Guidelines* (DERM 2009) for open coastal waters (up to 20 km from the seaward edge of the enclosed coastal areas of the Fitzroy region) of the Central Coast Queensland region (waters within the Great Barrier Reef Marine Park)

2 *Source*: *Queensland Water Quality Guidelines* (DERM 2009) for mid-estuarine waters of the Central Coast Queensland region (in slightly to moderately disturbed waters)

3 *Source*: *Water Quality Guidelines for the Great Barrier Reef Marine Park* (GBRMPA 2009b)

Table 1.2 Water quality objectives for nutrients and chlorophyll-a in the current study.

Nutrient (µg/L)	WQOs for Marine Waters[1]	WQOs for Estuarine Waters[2]
Total nitrogen	140	300
Total phosphorus	20	25
Chlorophyll-a	0.45	–

– no trigger value available

1 *Source*: *Queensland Water Quality Guidelines* (DERM 2009) for open coastal waters (up to 20 km from the seaward edge of the enclosed coastal areas of the Fitzroy region) of the Central Coast region (waters within the Great Barrier Reef Marine Park)

2 *Source*: *Queensland Water Quality Guidelines* (DERM 2009) for mid-estuarine waters of the Central Coast Queensland region (slightly to moderately disturbed waters)

Table 1.3 Water quality objectives for potential contaminants in the current study.

Parameter (µg/L)	99% Protection Level WQOs[1]	95% Protection Level WQOs[2]
Metals and Metalloids		
Arsenic	–	–
Cadmium	0.7	5.5
Chromium (Cr III)	7.7	27.4
Chromium (Cr VI)	0.14	4.4
Copper	0.3	1.3
Lead	2.2	4.4
Mercury	0.1	0.4
Nickel	7	70
Zinc	7	15
Petroleum Hydrocarbons		
C6–C9	–	–
C10–C14	–	–
C15–C28	–	–
C29–C36	–	–
Aromatic Hydrocarbons		
Benzene	500	700
Toluene	–	–
Ethylbenzene	–	–
m+p-xylene	–	–

Parameter (µg/L)	99% Protection Level WQOs[1]	95% Protection Level WQOs[2]
o-xylene	–	–
Organochlorine Pesticides		
Aldrin	–	–
alpha-BHC	–	–
beta-BHC	–	–
gamma-BHC	–	–
delta-BHC	–	–
cis-Chlordane	–	–
trans-Chlordane	–	–
p,p'-DDD	–	–
p,p'-DDE	–	–
p,p'-DDT	–	–
Dieldrin	–	–
alpha-endosulfan	–	–
beta-endosulfan	–	–
Endosulfan	0.005 [3]	0.01
Endrin	0.004	0.008
Endrin aldehyde	–	–
Endrin ketone	–	–
Heptachlor	–	–
Heptachlor epoxide	–	–
Hexachlorobenzene	–	–
Methoxychlor	–	–
Mirex	–	–

– no trigger value available

1 *Source*: *Australian and New Zealand Water Quality Guidelines* (ANZECC & ARMCANZ 2000) for slightly to moderately disturbed waters

2 *Source*: *Australian and New Zealand Water Quality Guidelines* (ANZECC & ARMCANZ 2000) for waters of high ecological value

3 Also included in the *Water Quality Guidelines for the Great Barrier Reef Marine Park* (GBRMPA 2009b)

2 Methods

2.1 Sites Surveyed

Surveys were undertaken during the following seasons:

- pre-wet – 15 to 19 November 2010
- wet – 17 to 21 January 2011, and
- post-wet – 30 March to 2 April 2011, and 30 April to 2 May 2011

Water quality assessments included *in situ* physicochemical measurements at 30 sites around Great Keppel Island (Figure 2.1):

- Putney Point to Putney Beach (WQ1–8) (near the proposed marina)
- the Leeke's Creek area (WQ 9–13) (downstream of the proposed golf course), and
- offshore[1] (WQ14–30) (around the entire island, approximately 500 m from the shore).

Water samples were collected at 12 sites surrounding Great Keppel Island (Figure 2.2) and two sites near the mainland (Figure 2.3) for laboratory analysis of potential contaminants.

A combination fluorometer and turbidity logger was placed offshore of The Spit (site TS; located between Putney and Fishermans beaches) by Water Technology from 11 February to 13 March 2011 to measure chlorophyll-a concentration and turbidity (Figure 2.1).

[1] Only offshore sites were surveyed during the wet season due to time-constraints.

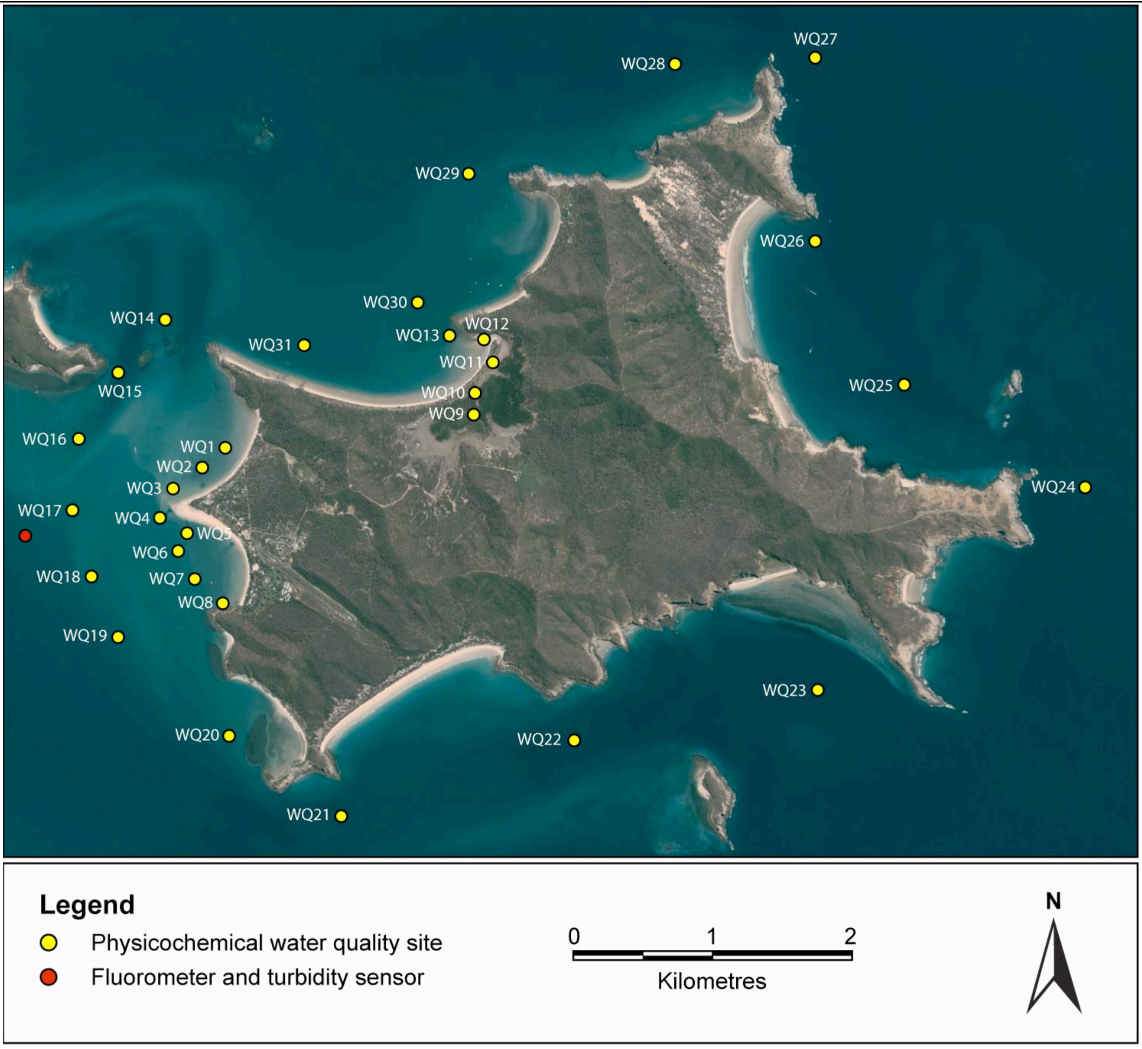

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	Figure 2.1 Great Keppel Island physicochemical water quality sites.	
	(Microsoft Bing © 2010)	June 2011

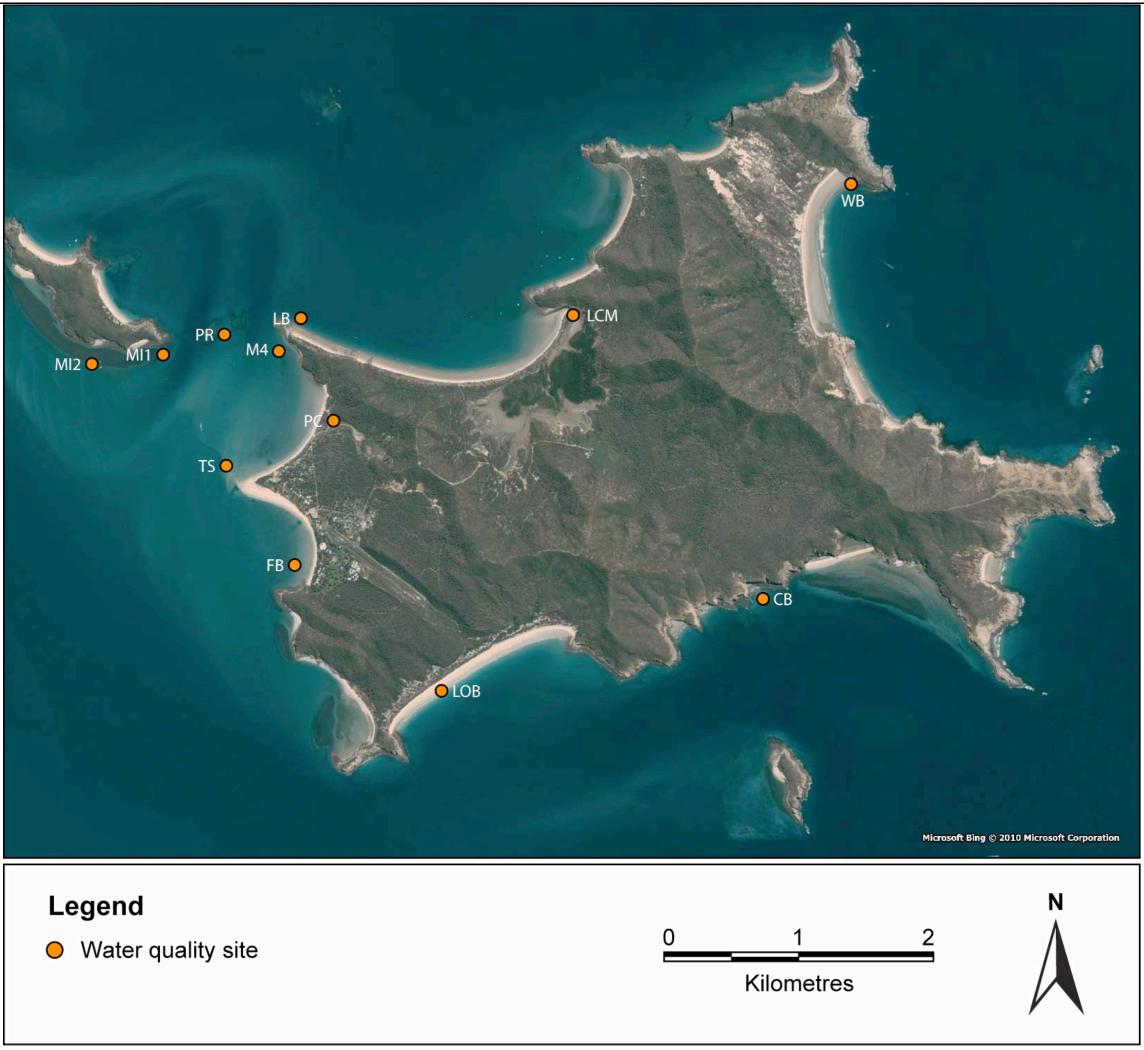

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	Figure 2.2 Great Keppel Island water quality sites for laboratory analysis of contaminants.
	(Microsoft Bing © 2010) — June 2011

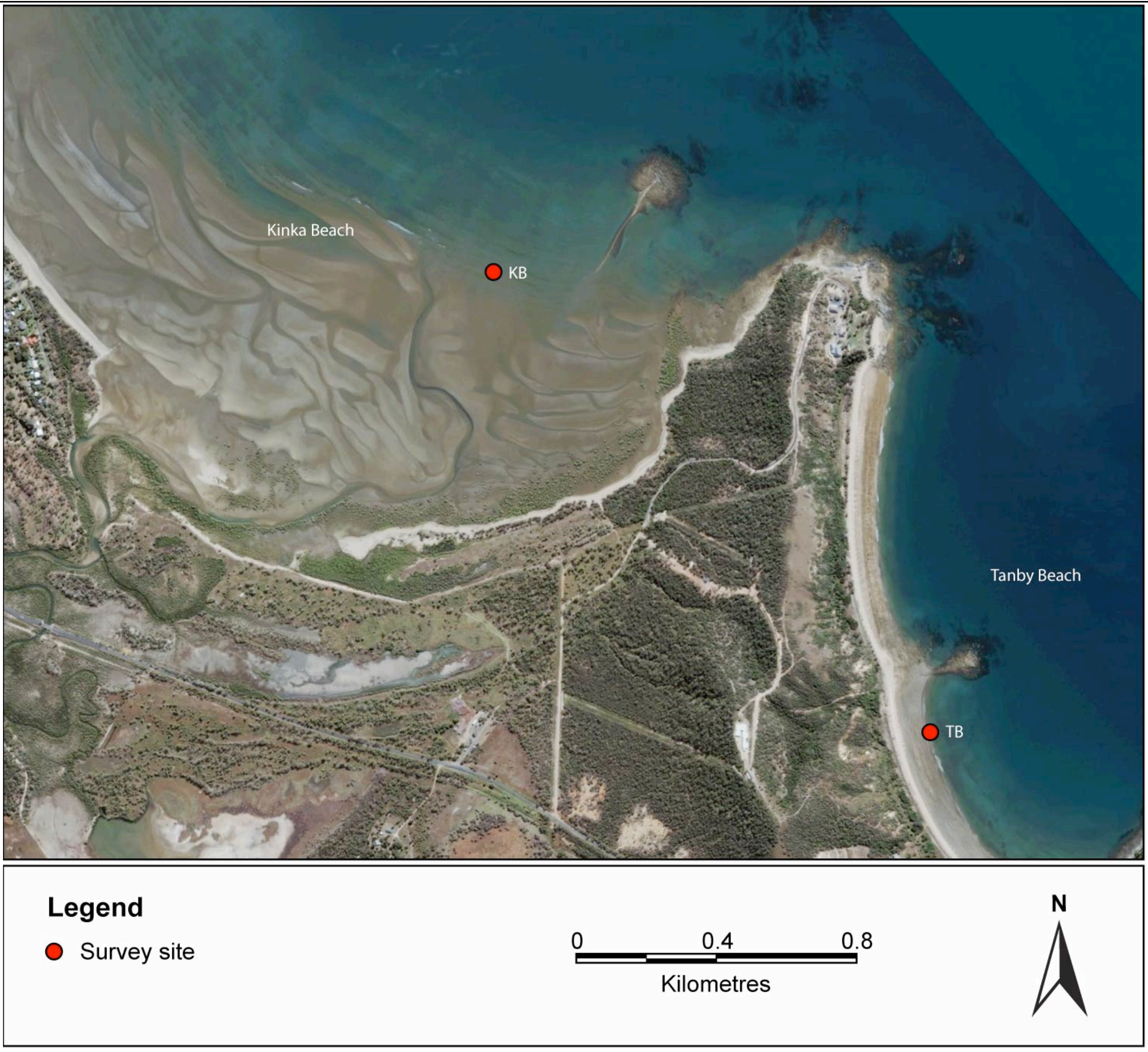

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Figure 2.3 Mainland water quality sites for laboratory analysis of contaminants.

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2.2 *In situ* Snapshot and Logging

Physicochemical water quality measurements were recorded *in situ* at two depths (near the surface and at depth to a maximum of 10 m) on both a mid-incoming and mid-outgoing tide. A Hydrolab QUANTA multi-parameter water quality probe was used to measure:

- water temperature
- salinity
- pH, and
- dissolved oxygen.

In situ turbidity was measured using a Hydrolab QUANTA multi-parameter water quality probe during the pre-wet season survey. A Hach 2100Q turbidity meter was used to measure turbidity during all other surveys.

Turbidity and chlorophyll-a concentration were measured continuously for 30 days using a Wetlabs ECO FLNTU combination fluorometer and turbidity sensor set by Water Technology. The logger was placed 1 m off the seabed (approximately 7.5 m from the water surface) and was set to burst sample at 1 Hz for 10 seconds, repeating every 10 minutes.

2.3 Laboratory Analyses

Water samples were collected in accordance with Australian/New Zealand Standard (AS/NZS) 5667.9:1998 *Water quality – Sampling, Part 9: Guidance on sampling from marine waters* (Standards Australia 1998) and the *Monitoring and Sampling Manual 2009* (DERM 2010).

Water samples were analysed by Advanced Analytical (a NATA-accredited laboratory) for the concentration of:

- total suspended solids (TSS)
- nutrients (total nitrogen, total Kjeldahl nitrogen, nitrate as N, nitrite as N, phosphate as P and total phosphorus)
- metals and metalloids (arsenic, cadmium, chromium, copper, lead, mercury, nickel, and zinc)
- petroleum hydrocarbons (C6–9, C10–14, C15–C28 and C29–C36)

- aromatic hydrocarbons (benzene, ethylbenzene, toluene and *m+p*-xylene, *o*-xylene), and
- organochlorine pesticides (aldrin, *alpha*-BHC, *beta*-BHC, *gamma*-BHC, *delta*-BHC, *cis*-Chloradane, *trans*-Chloradane, p,p^{1}-DDE, p,p^{1}-DDT, dieldrin, *alpha*-endosulfan, *beta*-endosulfan, endosulfan sulphate, endrin, endrin aldehyde, endrin ketone, heptachlor, heptachlor epoxide, hexachlorobenzene, methoxychlor, and mirex).

2.4 Data Analysis

Water quality data for estuarine sites in Leeke's and Putney creeks were compared with the relevant WQOs; i.e. the QWQG trigger values for mid-estuarine waters of the Central Coast Queensland region (slightly to moderately disturbed waters), and ANZECC & ARMCANZ 99%[2] protection trigger values (where possible[3]).

Water quality data for sites adjacent to Great Keppel Island and near Kinka and Tanby beaches on the mainland were compared with the relevant WQOs; i.e. the QWQG trigger values for open coastal waters of the Central Coast Queensland region (slightly to moderately disturbed waters), and ANZECC & ARMCANZ 99%[1] protection trigger values (where possible[2]).

Where values were greater than the laboratory detection limits, the results were graphed and discussed. Any results less than the laboratory detection limits were entered as half the laboratory detection limit, for graphical purposes (DEWHA 2009).

Turbidity and chlorophyll-a data (measured continuously for 30 days) were averaged over one-hourly time intervals and graphed.

2.5 Regional Context

A regional water quality perspective was provided through literature review. Available literature and water quality data was sourced from research publications, government agencies and consultancies.

[2] The 99% protection level trigger values were considered most appropriate, due to the high ecological significance of the waters sampled, and as they were most similar to the GBRMPA trigger values.

[3] Data were compared to the 95% protection level where comparison to the 99% protection level was not possible (e.g. due to analytical laboratory detection limits).

3 Existing Environment

3.1 Physicochemical

Temperature

There are no trigger values for water temperature in marine or estuarine waters. Water temperature was highest during the wet season survey. Temperature at the surface and at depth was generally similar, except in the wet season survey when the surface waters were warmer. Temperature was often lower on the outgoing than incoming tide. Changes to water temperature typically reflect prevailing environmental conditions (Table 3.1).

Pre-wet Season Survey

On the incoming tide, surface water temperature ranged from 25.16 to 27.09 °C; and temperature at depth ranged from 25.16 to 27.11 °C. On the outgoing tide, the surface temperature ranged from 25.00 to 25.33 °C; and temperature at depth ranged from 24.97 to 25.23 °C.

Wet Season Survey

On the incoming tide, surface temperature ranged from 28.36 to 30.00 °C; and temperature at depth ranged from 27.09 to 28.98 °C. On the outgoing tide, surface temperature ranged from 28.83 to 29.85 °C; and temperature at depth ranged from 27.02 to 28.44 °C.

Post-wet Season Survey

On the incoming tide, surface temperature ranged from 23.77 to 29.57 °C; and temperature at depth ranged from 23.79 to 29.58 °C. On the outgoing tide, surface temperature ranged from 22.76 to 26.13 °C; and temperature at depth ranged from 22.18 to 26.11 °C.

Table 3.1 Physicochemical water quality at each site in each survey, near the surface and at depth, and on an incoming and outgoing tide.

		Near Surface (0.2m)					At Depth (Near Bottom)					
Location	Site	Temp (ºC)	Salinity (ppt)	pH	Turbidity (NTU)	DO (% sat)	Depth (m)	Temp (ºC)	Salinity (ppt)	pH	Turbidity (NTU)	DO (% sat)
Pre-wet Season Survey												
Incoming tide												
Putney Point to Fishermans Beach [a]	WQ01	26.06	34.40	8.2	<10	101	2.7	25.71	34.38	8.2	<10	100
	WQ02	26.63	34.40	8.2	<10	100	2.6	25.79	34.39	8.2	<10	99
	WQ03	26.42	34.41	8.2	<10	101	2.5	25.78	34.38	8.2	<10	102
	WQ04	25.60	34.19	8.2	<10	105	4.0	25.30	34.36	8.2	<10	101
	WQ06	25.82	34.39	8.2	<10	109	2.8	25.39	34.36	8.2	<10	102
	WQ08	26.79	34.37	8.1	<10	106	2.5	25.94	34.48	8.0	<10	105
Leeke's Creek [b]	WQ09	27.09	33.86	8.0	<10	103	0.6	27.11	33.86	8.1	<10	99
	WQ10	26.69	33.77	8.1	<10	103	1.2	26.71	33.84	8.1	<10	101
	WQ11	26.56	33.76	8.1	<10	103	0.8	26.59	33.76	8.1	<10	103
	WQ12	26.42	33.75	8.1	<10	103	1.8	26.28	33.75	8.1	<10	102
	WQ13	26.20	33.74	8.1	<10	103	4.0	25.88	33.72	8.1	<10	102
Offshore [a]	WQ14	25.77	34.38	8.2	<10	99	7.0	25.49	34.37	8.2	<10	97
	WQ15	25.53	34.37	8.2	<10	101	10.0	25.49	34.37	8.2	<10	99
	WQ16	25.48	34.37	8.2	<10	103	5.3	25.43	34.37	8.2	<10	102
	WQ17	25.16	34.35	8.2	<10	101	5.0	25.16	34.35	8.2	<10	99
	WQ19	25.17	34.35	8.2	<10	98	5.0	25.17	34.35	8.2	<10	96
	WQ30	25.70	33.72	8.1	<10	102	5.6	25.71	33.72	8.1	<10	102
Outgoing tide												
Putney Point to Fishermans Beach [a]	WQ01	25.06	33.68	8.1	<10	98	1.9	25.06	33.68	8.1	<10	97
	WQ02	25.07	33.68	8.1	<10	98	2.2	51.03	33.68	8.1	<10	96
	WQ03	25.09	33.68	8.1	<10	–	1.8	25.04	33.68	8.1	<10	95

Location	Site	Near Surface (0.2m) Temp (ºC)	Salinity (ppt)	pH	Turbidity (NTU)	DO (% sat)	At Depth (Near Bottom) Depth (m)	Temp (ºC)	Salinity (ppt)	pH	Turbidity (NTU)	DO (% sat)
	WQ04	25.06	33.68	8.1	<10	94	3.9	24.97	33.68	8.1	<10	95
	WQ06	25.08	33.68	8.1	<10	98	3.5	24.98	33.68	8.1	<10	97
	WQ08	25.00	34.71	8.0	<10	95	2.5	24.99	33.68	8.1	<10	94
Leeke's Creek [b]	WQ09	25.09	33.32	8.0	<10	88	1.0	25.08	33.32	8.0	<10	89
	WQ10	25.08	33.32	8.0	<10	92	1.5	25.08	33.32	8.0	<10	89
	WQ11	25.10	33.32	8.1	<10	89	1.4	25.10	33.32	8.1	<10	87
	WQ12	25.16	33.32	8.1	<10	92	0.9	25.16	33.32	8.1	1.0	88
	WQ13	25.23	33.25	8.1	<10	97	3.5	25.23	33.25	8.1	<10	94
Offshore [a]	WQ14	25.25	33.69	8.1	<10	98	5.5	25.05	33.68	8.1	<10	96
	WQ15	25.30	33.70	8.1	<10	99	7.0	25.04	33.68	8.1	<10	97
	WQ16	25.11	33.69	8.1	<10	99	4.5	24.99	33.68	8.1	<10	97
	WQ17	25.07	33.68	8.1	<10	98	4.0	24.98	33.68	8.2	<10	92
	WQ19	25.08	33.68	8.1	<10	94	5.0	24.97	33.68	8.0	<10	94
	WQ30	25.33	33.25	8.1	<10	96	6.0	25.22	33.32	8.1	<10	91
Wet Season Survey												
Incoming tide												
Offshore [a]	WQ14	28.96	23.97	8.0	1.2	110	5.5	27.27	31.80	7.9	23.9	97
	WQ15	29.93	23.69	8.1	2.0	110	9.0	27.23	31.73	7.9	13.0	85
	WQ16	28.36	27.77	7.9	1.6	101	3.0	27.30	31.66	7.9	11.3	84
	WQ17	29.59	22.27	7.9	0.8	121	2.5	28.98	25.65	7.9	1.2	112
	WQ19	28.66	25.21	8.0	0.3	106	4.0	27.37	30.93	7.9	3.8	91
	WQ20	28.80	22.88	8.0	0.5	112	3.0	27.28	31.66	7.9	0.8	92
	WQ21	28.99	22.16	8.1	0.6	113	10.0	27.21	31.95	7.9	1.1	94
	WQ22	28.97	22.25	8.1	0.8	118	10.0	27.14	32.31	7.9	0.4	93

Location	Site	Near Surface (0.2m) Temp (ºC)	Salinity (ppt)	pH	Turbidity (NTU)	DO (% sat)	At Depth (Near Bottom) Depth (m)	Temp (ºC)	Salinity (ppt)	pH	Turbidity (NTU)	DO (% sat)
	WQ23	28.89	21.90	8.1	0.8	114	8.0	27.34	30.93	7.9	0.0	89
	WQ24	28.76	27.72	8.0	0.0	117	10.0	27.23	32.10	7.9	0.0	88
	WQ25	28.63	31.21	8.0	0.0	103	12.0	27.09	32.60	7.9	0.5	87
	WQ26	28.47	31.93	8.0	0.0	105	9.0	27.21	32.46	7.9	0.0	90
	WQ27	29.29	28.99	8.0	0.0	107	10.0	27.14	32.46	7.9	0.0	88
	WQ28	30.00	22.71	8.1	6.3	117	9.5	27.11	32.38	7.9	4.5	85
	WQ29	29.77	22.91	8.0	0.3	114	5.5	27.18	32.09	7.9	14.8	88
	WQ30	29.39	23.25	8.0	1.7	113	4.5	27.37	31.88	7.9	10.6	87
	WQ31	29.97	23.13	8.0	0.7	114	4.0	28.17	31.39	7.9	4.2	97
Outgoing tide												
Offshore [a]	WQ14	29.62	23.86	8.0	1.1	106	6.0	27.23	31.66	7.9	17.5	83
	WQ15	29.79	23.74	8.0	0.5	110	7.0	27.25	31.66	7.9	12.1	82
	WQ16	29.14	22.61	8.0	0.9	110	2.0	27.28	31.58	7.9	12.4	84
	WQ17	29.35	22.34	8.0	0.9	112	2.5	27.47	30.50	7.9	11.4	93
	WQ18	29.42	22.33	8.0	0.1	117	3.0	27.62	29.84	7.9	3.4	97
	WQ19	28.87	22.18	8.0	0.0	107	3.0	28.14	26.18	7.9	1.0	100
	WQ20	29.63	20.24	8.0	1.2	107	3.0	28.44	24.91	7.9	4.6	101
	WQ21	28.83	22.74	8.0	0.0	106	10.0	27.28	31.66	7.9	6.8	85
	WQ22	28.89	26.29	7.9	1.1	109	12.0	27.19	32.76	7.8	0.0	91
	WQ23	28.95	25.79	8.0	0.0	104	14.0	27.12	33.57	7.9	1.8	86
	WQ24	29.36	25.23	8.0	0.0	113	10.0	27.11	33.34	7.9	0.0	83
	WQ25	29.62	25.09	8.0	0.0	109	13.0	27.02	34.23	8.0	0.2	87
	WQ26	29.85	24.25	8.0	0.9	110	10.0	27.06	33.71	7.9	0.0	81
	WQ27	29.09	25.80	8.0	0.9	112	15.0	27.35	32.40	7.9	3.4	88
	WQ28	28.88	28.74	8.0	0.0	104	8.0	27.85	31.09	7.9	1.0	93

Location	Site	Near Surface (0.2m) Temp (ºC)	Salinity (ppt)	pH	Turbidity (NTU)	DO (% sat)	At Depth (Near Bottom) Depth (m)	Temp (ºC)	Salinity (ppt)	pH	Turbidity (NTU)	DO (% sat)
	WQ29	29.01	28.31	8.0	0.8	107	5.0	28.06	29.87	8.0	0.0	96
	WQ30	29.13	29.55	8.0	0.0	106	4.0	27.51	31.52	7.9	1.1	91
	WQ31	29.17	28.53	8.0	0.0	105	4.0	27.55	31.81	7.9	0.7	99
Post-wet Season Survey												
Incoming tide												
Putney Point to Fishermans Beach [a]	WQ1	23.77	33.17	7.8	3.8	103	2.0	23.79	33.18	8.1	4.3	98
	WQ2	24.32	33.20	8.3	2.6	99	2.0	23.82	33.18	8.3	4.4	97
	WQ3	24.55	33.21	8.3	3.2	105	1.3	24.41	33.21	8.3	9.9	102
	WQ4	24.13	33.12	8.3	1.9	101	3.0	23.85	33.18	8.3	0.0	98
	WQ5	23.87	33.11	8.3	1.7	97	3.5	23.89	33.45	8.3	0.0	99
	WQ6	23.83	33.18	8.3	1.6	99	4.0	23.85	33.18	8.3	2.9	96
	WQ8	24.55	33.01	8.3	5.6	101	2.1	24.01	33.19	8.3	8.7	102
Leeke's Creek [b]	WQ9	26.57	31.85	6.6	204.0	58	0.5	26.51	31.84	6.9	81.5	46
	WQ10	26.72	31.26	7.8	19.6	66	0.4	26.50	31.33	7.9	24.4	66
	WQ11	24.41	31.09	8.2	8.9	95	0.5	24.30	31.09	8.2	10.0	94
	WQ12	24.10	31.07	8.2	5.2	95	1.0	24.10	31.07	8.2	7.2	94
	WQ13	24.08	31.07	8.3	3.2	97	3.0	23.96	31.06	8.3	6.3	96
Offshore [a]	WQ14	26.04	33.66	8.0	87.9	96	5.0	26.05	33.66	8.1	7.0	95
	WQ15	26.03	33.66	7.8	5.3	102	6.0	26.03	33.75	8.0	5.4	101
	WQ16	29.57	33.66	8.1	6.8	95	3.0	29.58	33.66	8.1	4.9	94
	WQ17	25.99	33.07	8.1	4.1	96	3.0	26.00	32.99	8.1	3.0	96
	WQ18	26.03	33.07	8.1	4.0	95	4.0	26.05	33.00	8.1	3.0	95
	WQ19	26.13	33.74	8.1	3.1	95	4.0	26.13	33.81	8.1	2.0	95
	WQ20	25.96	33.66	8.1	3.2	98	3.0	26.02	33.66	8.1	1.4	96

Location	Site	Near Surface (0.2m) Temp (ºC)	Salinity (ppt)	pH	Turbidity (NTU)	DO (% sat)	At Depth (Near Bottom) Depth (m)	Temp (ºC)	Salinity (ppt)	pH	Turbidity (NTU)	DO (% sat)
	WQ21	26.16	33.96	8.1	2.1	96	5.0	26.14	33.89	8.1	2.5	95
	WQ22	26.24	34.11	8.1	3.1	94	0.6	26.28	34.04	8.1	1.2	93
	WQ23	26.24	34.04	8.1	2.7	95	6.0	26.24	34.04	8.1	1.2	94
	WQ24	26.32	34.12	8.1	2.1	94	8.0	26.31	34.12	8.1	0.8	93
	WQ25	26.34	34.12	8.1	2.0	93	8.0	26.36	34.12	8.1	0.4	92
	WQ26	26.29	34.04	8.9	3.5	96	5.0	26.27	34.04	8.1	2.1	95
	WQ27	26.28	33.90	8.1	4.6	94	8.0	26.30	34.04	8.1	0.9	92
	WQ28	26.27	34.04	8.1	5.8	94	8.0	26.28	34.04	81	5.9	93
	WQ29	26.19	33.74	8.1	6.6	93	6.0	26.20	33.74	8.1	10.6	91
	WQ30	26.17	32.19	8.1	10.2	93	5.0	26.17	33.74	8.1	11.7	93
	WQ31	26.09	33.66	8.1	11.6	96	5.0	26.06	33.66	8.1	7.7	94
Outgoing tide			33.12						33.18			
Putney Point Fishermans Beach [a]	WQ1	24.39	33.18	8.3	4.0	99	1.0	24.03	33.18	8.3	14.1	99
	WQ2	23.83	33.19	8.3	2.8	99	1.0	23.87	33.11	8.3	4.0	99
	WQ3	24.17	33.18	8.3	1.8	106	0.8	24.07	33.18	8.3	0.2	96
	WQ4	23.91	33.18	8.3	1.6	98	2.0	23.90	33.18	8.3	0.0	98
	WQ5	23.88	33.18	8.3	2.0	99	2.0	23.86	33.17	8.3	0.0	97
	WQ6	23.81	33.17	8.2	1.8	98	2.0	23.74	33.17	8.3	0.0	95
	WQ8	23.70	31.23	7.5	1.6	97	1.0	23.67	31.23	8.2	0.1	96
Leeke's Creek [b]	WQ9	22.80	31.08	8.2	4.8	92	0.5	22.18	31.08	8.2	5.1	91
	WQ10	22.76	31.09	8.2	4.7	87	1.0	22.74	31.01	8.2	5.2	86
	WQ11	22.88	31.02	8.2	4.4	86	0.5	22.89	31.02	8.2	3.1	86
	WQ12	23.03	31.03	8.2	3.7	86	1.0	23.05	31.03	8.2	3.3	86
	WQ13	23.20	35.52	8.2	3.5	88	3.0	23.20	35.52	8.2	4.3	88

		Near Surface (0.2m)					At Depth (Near Bottom)					
Location	**Site**	**Temp (ºC)**	**Salinity (ppt)**	**pH**	**Turbidity (NTU)**	**DO (% sat)**	**Depth (m)**	**Temp (ºC)**	**Salinity (ppt)**	**pH**	**Turbidity (NTU)**	**DO (% sat)**
Offshore [a]	WQ14	26.11	35.52	8.1	4.6	96	5.0	26.10	35.52	8.1	2.1	94
	WQ15	26.13	35.52	8.1	1.2	95	8.0	26.10	35.52	8.1	1.2	92
	WQ16	26.11	35.52	8.1	2.8	96	2.5	26.10	35.52	8.1	1.2	93
	WQ17	26.11	35.52	8.1	2.4	96	3.0	26.09	35.52	8.1	0.9	94
	WQ18	26.09	35.52	8.1	2.4	95	3.0	26.08	35.52	8.1	1.0	94
	WQ19	26.10	35.43	8.1	1.8	96	4.0	26.11	35.43	8.1	0.9	94
	WQ20	25.87	35.15	8.1	2.4	97	3.5	25.92	35.04	8.1	2.6	93
	WQ21	26.06	35.51	8.1	2.6	95	8.0	25.99	35.51	8.1	0.9	93
	WQ22	26.05	35.52	8.1	2.9	97	3.0	26.06	35.44	8.1	0.7	95
	WQ23	26.08	35.52	8.1 thei	2.7	95	6.0	26.07	35.52	8.1	0.7	94
	WQ25	25.86	35.51	8.0	2.6	94	10.0	26.08	35.50	8.1	1.0	93
	WQ26	25.91	35.43	8.1	3.4	95	8.0	25.86	35.51	8.0	1.6	93
	WQ27	25.96	35.52	8.0	3.7	95	11.0	25.94	35.52	8.0	2.1	93
	WQ28	26.09	35.36	8.0	3.1	94	8.0	26.08	35.36	8.1	1.9	92
	WQ29	25.97	30.98	8.0	2.3	94	7.0	26.00	30.97	8.0	1.9	92
	WQ30	23.63	35.21	8.1	1.3	93	4.0	23.53	35.20	8.3	12.7	93
	WQ31	25.85		8.1	5.5	93	5.0	25.76		8.1	11.4	91

grey shading indicates measurements that exceeded relevant guidelines

[a] compared to QWQG trigger value for open coastal waters

[b] compared to QWQG trigger value for mid-estuarine waters

Temp temperature

PPT parts per thousand

NTU nephelometric turbidity unit

DO dissolved oxygen

sat saturation

Salinity

There is no trigger value for salinity in marine or estuarine waters. During the post-wet survey, salinity was typically lower near the surface than at depth. Salinity was lowest on an outgoing tide during the wet survey. This is likely to reflect tidal movement of freshwater run-off (floodwaters), and stratification of fresh and marine waters during the wet survey. Salinity of the survey area was typical of inshore waters. They could also be related to water temperature (Table 3.1).

Pre-wet Season Survey

On the incoming tide, surface salinity ranged from 33.72 to 34.41 ppt; and salinity at depth ranged from 33.72 to 34.48 ppt. On the outgoing tide, surface salinity ranged from 33.25 to 34.71 ppt; and salinity at depth ranged from 33.25 to 33.68 ppt.

Wet Season Survey

On the incoming tide, surface salinity ranged from 21.90 to 31.93 ppt and; salinity at depth ranged from 25.56 to 32.60 ppt. On the outgoing tide, surface salinity ranged from 20.24 to 29.55 ppt; and salinity at depth ranged from 24.91 to 34.23 ppt.

Post-wet Season Survey

On the incoming tide, surface salinity ranged from 31.07 to 34.12 ppt; and salinity at depth ranged from 31.06 to 34.12 ppt. On the outgoing tide, surface salinity ranged from 30.98 to 35.52 ppt; and salinity at depth ranged from 30.97 to 35.52 ppt.

pH

pH was slightly (typically within 0.2 pH units) below the relevant QWQG trigger value range at several sites during the wet and post-wet surveys, and near Fisherman's Beach (site WQ08 and WQ19) during the pre-wet survey. pH was similar near the surface and at depth, and generally similar on an outgoing and incoming tide (Table 3.1).

Pre-wet Season Survey

On the incoming tide, surface pH ranged from 8.0 to 8.3; and pH at depth ranged from 8.0 to 8.2. On the outgoing tide, surface pH ranged from 8.0 to 8.1; and pH at depth ranged from 8.0 to 8.2. On the incoming and outgoing tides, the pH near the point at Fishermans Beach (site WQ08) exceeded the QWQG trigger value range. All other sites were within the QWQG trigger value range.

Wet Season Survey

On the incoming tide, surface pH ranged from 7.9 to 8.1; and pH at depth was 7.9 at all sites. On the outgoing tide, surface pH ranged from 7.9 to 8.0; and pH at depth ranged from 7.8 to 8.0. On the incoming tide the pH slightly exceeded the QWQG trigger value range at most sites near the surface and all sites at depth. On the outgoing tide, the pH slightly exceeded the QWQG trigger value range at all sites, near the surface and at depth.

Post-wet Season Survey

On the incoming tide, surface pH ranged from 6.6 to 8.3; and pH at depth ranged from 6.9 to 8.3. On the outgoing tide, surface pH ranged from 7.5 to 8.3; and pH at depth ranged from 8.0 to 8.3. On the incoming tide, pH was slightly below the QWQG trigger value range at several sites near Passage Rocks (WQ14 and WQ15), Putney Point (WQ01) and Leeke's Creek (WQ09). On the outgoing tide, pH near the surface and at depth was slightly above the QWQG trigger value range at the point near Fishermans Beach (WQ08) and several offshore sites.

Dissolved Oxygen

Dissolved oxygen concentrations were typically (and expectedly) higher near the surface than at depth, and highest during the wet season survey. Concentrations near the surface were often above the relevant QWQG trigger value range whereas concentrations at depth were often below the relevant range. Leeke's Creek tended to have lower dissolved oxygen concentrations than other sites. These patterns are likely to reflect wind- and wave-drive water movement that mixes the water column with oxygen in the atmosphere (strong winds and large waves characterised the wet season survey); together with primary production (photosynthesis during the day, which produces oxygen, and over-night respiration which consumes oxygen) and microbial activity (Table 3.1).

Pre-wet Season Survey

On the incoming tide, the percent saturation of dissolved oxygen ranged from 98 to 110% near the surface; and from 96 to 105% at depth. On the outgoing tide, the percent saturation ranged from 88 to 99% at the surface; and from 87 to 97% at depth. On the incoming tide, the percent saturation slightly exceeded the QWQG trigger value range at several sites near the surface or at depth; most Leeke's Creek sites (WQ10, WQ11 and WQ12) exceeded the range near the surface and at depth. On the outgoing tide, the percent saturation at depth was below the QWQG trigger value range at several offshore sites (WQ13, WQ17, WQ19 and WQ30).

Wet Season Survey

On the incoming tide, the percent saturation of dissolved oxygen ranged from 101 to 121% near the surface; and from 84 to 112% at depth. On the outgoing tide, the percent saturation ranged from 104 to 117% near the surface; and from 81 to 101% at depth. On both tides, the percent saturation of dissolved oxygen near the surface slightly exceeded the QWQG trigger value range at several sites, while the percent saturation at depth was below the QWQG trigger value range at several sites.

Post-wet Season Survey

On the incoming tide, the percent saturation of dissolved oxygen ranged from 58 to 105% at the surface; and from 46 to 102% at depth. On the outgoing tide, the percent saturation of dissolved oxygen ranged from 86 to 106% at the surface and from 86 to 99% at depth.

On the incoming tide, the percent saturation of dissolved oxygen was below the QWQG trigger value range at several sites, and particularly low at the point near Fishermans Beach (site WQ8: 58% near the surface and 46% at depth) and at upper Leeke's Creek (site WQ9: 66% near the surface and 67% at depth).

On the outgoing tide, the percent saturation of dissolved oxygen was below the QWQG trigger values near Passage Rocks (WQ15) and offshore of Leeke's Creek (WQ13) in surface waters, and at all offshore sites at depth.

Turbidity

Turbidity was typically higher during the post-wet survey, than other surveys, and higher at depth than near the surface. The turbidity at several sites exceeded the relevant QWQG trigger value during the wet and post-wet surveys; turbidity tended to be highest in Leeke's Creek but was also relatively high near Passage Rocks and Putney Point. High turbidity reflects sediment-laden run-off associated with rainfall and / or disturbance of the substrate due to wind, wave and tidal action; all of which introduce suspended particles into the water column (Table 3.1).

Pre-wet Season Survey

On the incoming and outgoing tide, turbidity at the surface and at depth was <10 NTU[4] at all sites.

Wet Season Survey

On the incoming tide, surface turbidity ranged from 0.0 to 6.3 NTU; and turbidity at depth ranged from 0.0 to 23.9 NTU. The turbidity at several sites exceeded the QWQG trigger value, at the surface and at depth. Most sites only slightly exceeded the relevant QWQG trigger value, however turbidity at the following sites was substantially higher at depth:

- near Passage Rocks at sites WQ14 (23.9 NTU), WQ15 (13.0 NTU) and WQ16 (11.3 NTU), and
- offshore sites WQ29 (14.8 NTU) and WQ30 (10.6 NTU).

On the outgoing tide, surface turbidity ranged from 0.0 to 1.2 NTU; and turbidity at depth ranged from 0.0 to 17.5 NTU. The turbidity at several sites exceeded the QWQG trigger value, at the surface and at depth. The turbidity at most sites only slightly exceeded the relevant QWQG trigger value, however the following sites were substantially higher at depth:

- near Passage Rocks at sites WQ14 (17.4 NTU), WQ15 (12.1 NTU) and WQ16 (12.4 NTU), and
- offshore of The Spit at site WQ17 (11.4 NTU).

[4] The water quality multi-probe used during the pre-wet season survey provided unreliable turbidity readings for water with a turbidity reading below 10 NTU, hence results have been presented as <10 NTU. It is not possible to comment on this value with regards to trigger values as trigger values are below 10 NTU (1 NTU in marine waters and 8 NTU in estuarine waters).

Post-wet Season Survey

On the incoming tide, surface turbidity ranged from 1.6 to 204[5] NTU; and turbidity at depth ranged from 0.0 to 81.5[6] NTU. The turbidity at most sites exceeded the QWQG trigger value; most sites only slightly exceeded the QWQG trigger value, however turbidity at the following sites was substantially higher:

- Leeke's Creek sites WQ9 (204 NTU near the surface and 81.5 NTU at depth), WQ10 (19.8 NTU near the surface and 24.4 NTU at depth) and WQ11 (10.0 NTU at depth)
- near Passage Rocks at site WQ14 (87.9 NTU near the surface)
- offshore of Leeke's Creek sites WQ29 (10.6 NTU at depth) and WQ30 (10.2 NTU near the surface and 11.7 NTU at depth), and
- near Putney Point at site WQ31 (11.6 NTU).

On the outgoing tide, surface turbidity ranged from 1.2 to 5.5 NTU; and turbidity at depth ranged from 0.0 to 14.1 NTU. At the surface, turbidity at all sites exceeded the QWQG trigger value however turbidity was less than 3.8 NTU at most sites; maximum turbidity was recorded near Putney Point at site WQ31 (5.5 NTU). At depth, turbidity at several sites exceeded the QWQG trigger value; turbidity at most sites was only slightly above the QWQG trigger value, however the following sites were substantially higher:

- adjacent to Putney Beach at site WQ1 (14.1 NTU)
- offshore of Leeke's Creek at site WQ30 (12.7 NTU), and
- near Putney Point at site WQ31 (11.4 NTU).

5 This was recorded in upper Leeke's Creek and was substantially higher than all other sites. The next highest reading was near Passage Rocks (87.9 NTU). All other sites had a turbidity reading <11.6 NTU near the surface.

6 This was recorded in upper Leeke's Creek and was substantially higher than all other sites. The next highest reading was also in Leeke's Creek (24.4 NTU). All other sites had a turbidity reading <11.7 NTU at depth.

In situ Logger

Turbidity, offshore of The Spit, ranged from 0.4 NTU at 2 am on 4 March to 2.6 NTU at 7 pm on 12 March (Figure 3.1). Turbidity exceeded the QWQG trigger value on several occasions and often for an extended period (more than five days). This is likely to be related to water movement associated with the wind, wave and / or tidal action (T Womersley [Water Technology] pers. comm., June 2011), which disturb the substrate and introduce suspended particles into the water column.

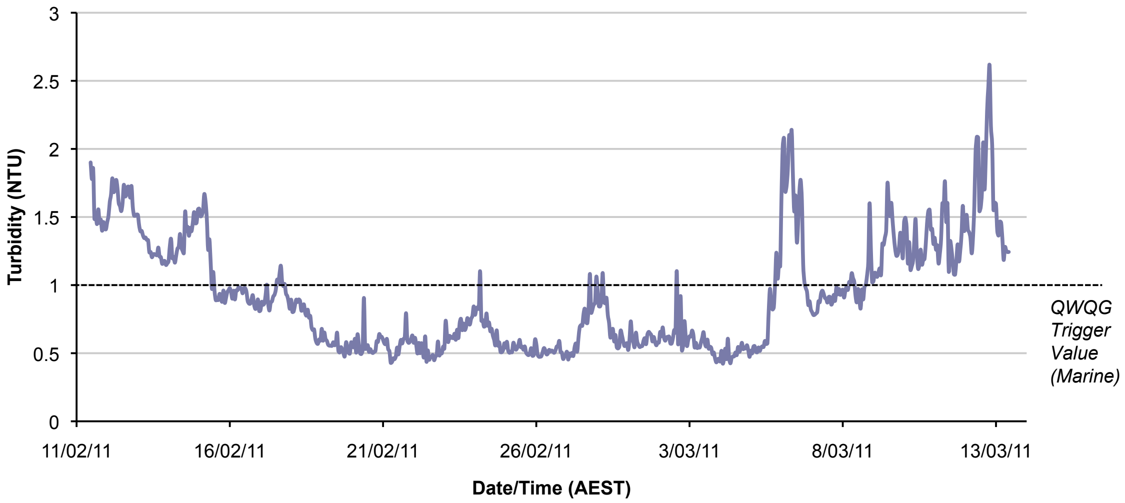


Figure 3.1 Turbidity offshore of The Spit from 11 February 2011 to 13 March 2011.

Total Suspended Solids

The concentration of total suspended solids (TSS) exceeded the relevant QWQG trigger value at site LCM (Leeke's Creek mouth) in the post-wet survey and at site PC (Putney Creek) in the pre-wet season survey. TSS exceeded the relevant QWQG and GBRMPA trigger value at both mainland sites (KB and TB) in the post-wet survey. Concentrations were generally highest in the post-wet survey. High concentrations are likely to be related to sediment-laden run-off associated with heavy rain (Figure 3.2).

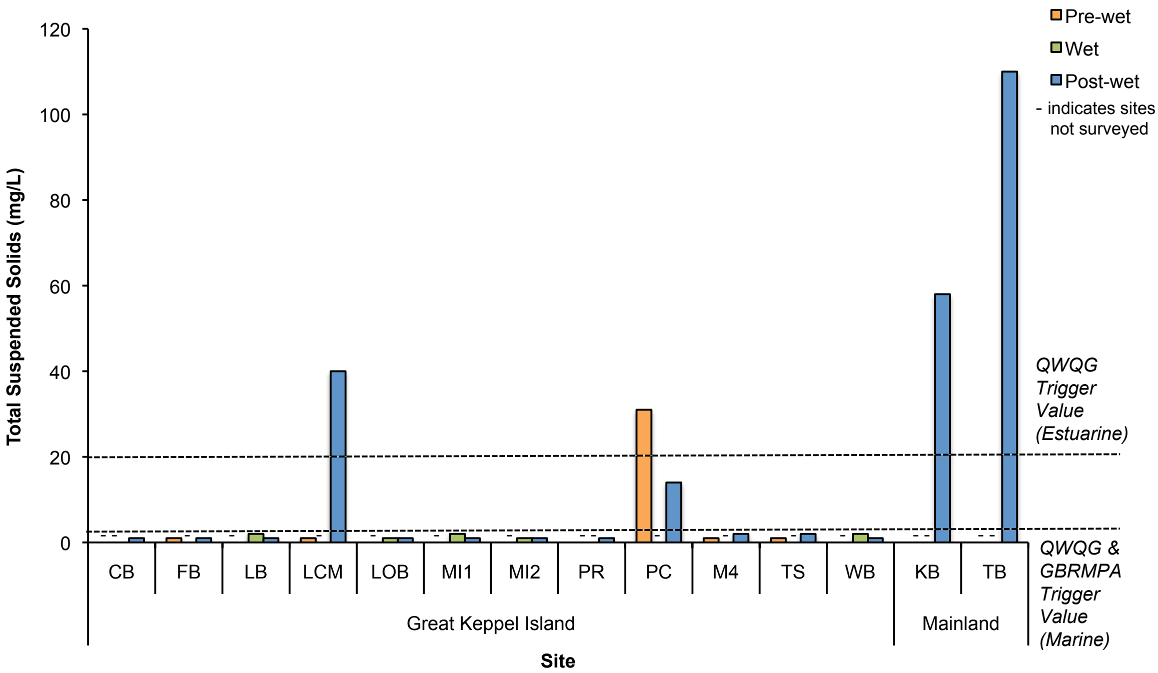


Figure 3.2 Total suspended solids at each site in each survey.

3.2 Laboratory Analyses

Nutrients

Total Nitrogen

The concentration of total nitrogen at site PC (Putney Creek) exceeded the relevant QWQG trigger value in the pre- and post-wet surveys, and was particularly high in the pre-wet survey. The concentrations at the Great Keppel Island sites were often above the relevant trigger value, however the concentrations at the mainland sites were below the relevant trigger value. In the pre-wet survey, sites FB (Fisherman's Beach), LCM (Leeke's Creek mouth), M4 (Marina 4) and TS (The Spit) also exceeded the relevant QWQG trigger value. In the post-wet survey, sites CB (Clam Bay), M1 (Marina 1), M2 (Marina 2), PR (Passage Rocks) and WB (Wreck Beach) also exceeded the relevant trigger value. In the wet survey, site LOB (Long Beach) exceeded the relevant trigger value (Figure 3.3).

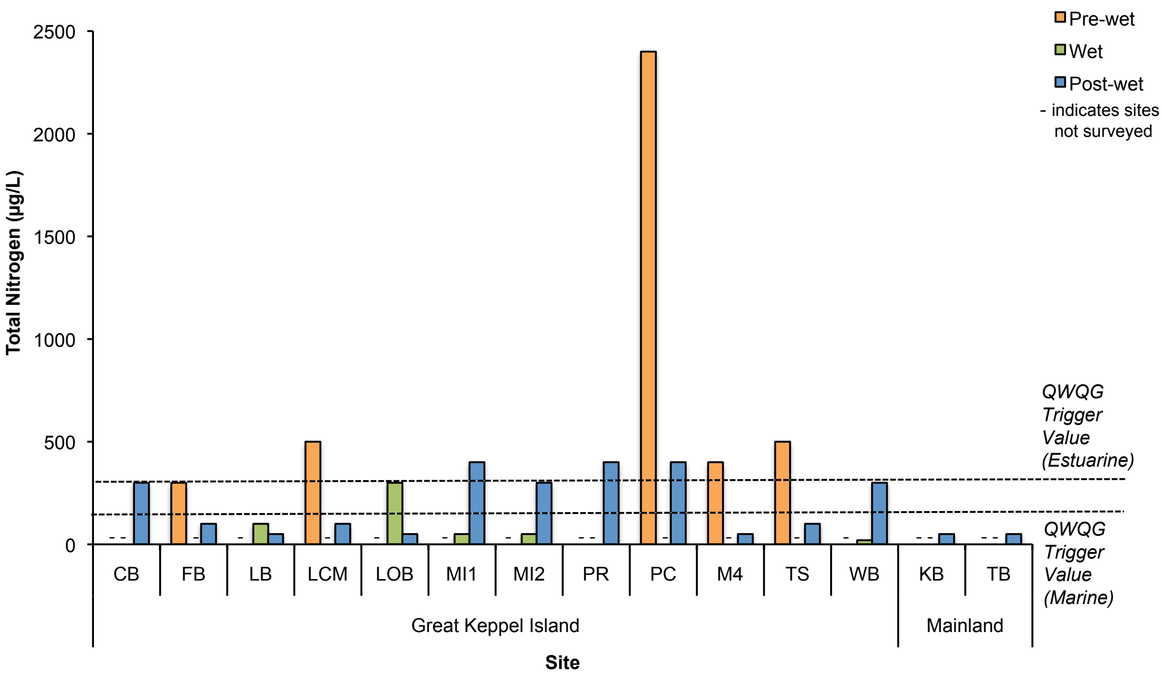


Figure 3.3 Total nitrogen concentration at each site in each survey.

Total Phosphorus

The concentration of total phosphorus at site PC (Putney Creek) exceeded the relevant QWQG relevant trigger value in the pre- and post-wet surveys, and was particularly high in the pre-wet survey. The concentration at each site in each survey exceeded the relevant QWQG trigger value, and concentrations were generally higher in the wet and post-wet survey than the pre-wet survey. The concentrations at the mainland sites were typically higher than the concentrations at the Great Keppel Island sites (Figure 3.4).

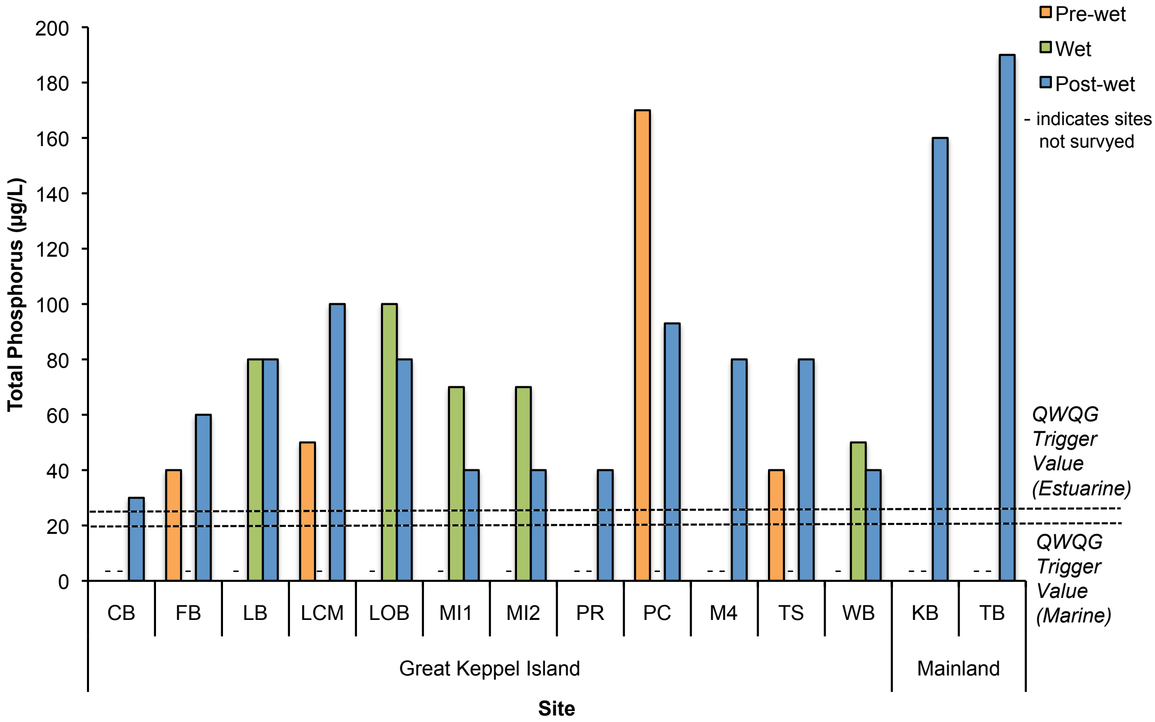


Figure 3.4 Total phosphorus concentration at each site in each survey.

Chlorophyll-a

The concentration of chlorophyll-a (an index of phytoplankton abundance) offshore of The Spit was above the QWQG upper trigger value (0.45 µg/L) for much of the logging duration. This is likely to be related to the concentration of nitrogen in nearby waters exceeding the QWQG upper trigger value prior to the survey, and the concentration of phosphorus exceeding the QWQG upper trigger value before and after the survey (Figure 3.5).

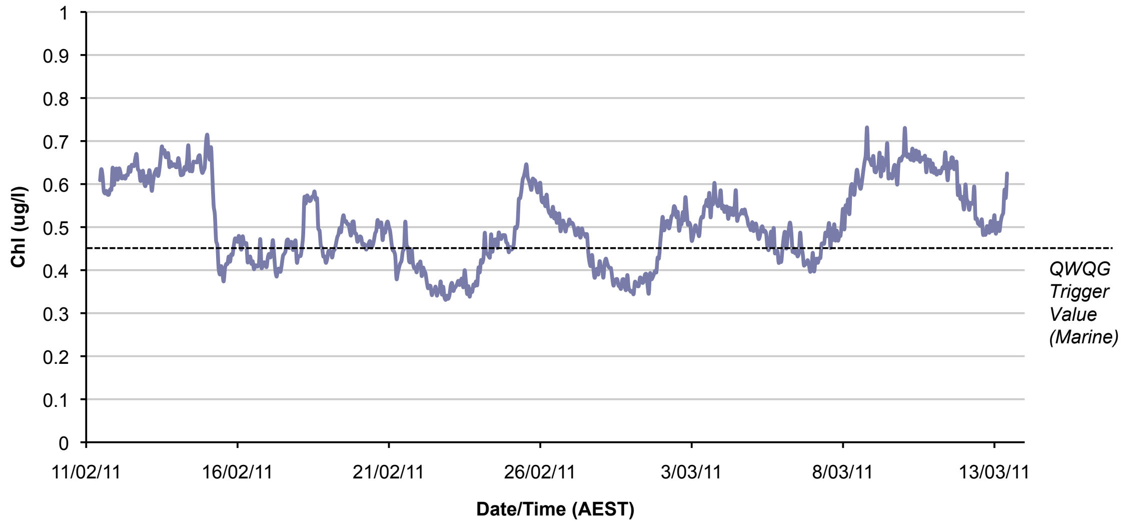


Figure 3.5 Concentration of chlorophyll-a offshore of The Spit from 11 February 2011 to 13 March 2011.

The concentration of chlorophyll-a ranged from 0.3 µg/L at 9 pm on 22 February to 0.7 µg/L at 7 pm on 8 March and followed a cyclic pattern. The cyclic pattern reflects small phytoplankton blooms, which are related to environmental factors such as water temperature and nutrient availability (e.g. nutrient-laden runoff following rainfall[7] enhances phytoplankton growth, particularly in warmer months).

[7] Rainfall data is not readily available for the survey area so a comparison of rainfall and concentration is not possible.

Metals and Metalloids

Arsenic

There are no trigger values for arsenic in estuarine or marine waters. The concentration of total arsenic was below the laboratory detection limit (5 µg/L) at all sites in all of the surveys, except at site PC (Putney Creek) in the pre-wet survey where it was 13 µg/L.

Copper

The concentration of total copper exceeded the ANZECC & ARMCANZ 99% protection trigger value at site FB (Fishermans Beach) in the pre-wet survey, and sites PC (Putney Creek), KB (Kinka Beach) and TB (Tanby Beach) in the post-wet survey[8]. It also exceeded the ANZECC & ARMCANZ 95% protection trigger value at sites PC, KB and TB in the post-wet survey (Figure 3.6).

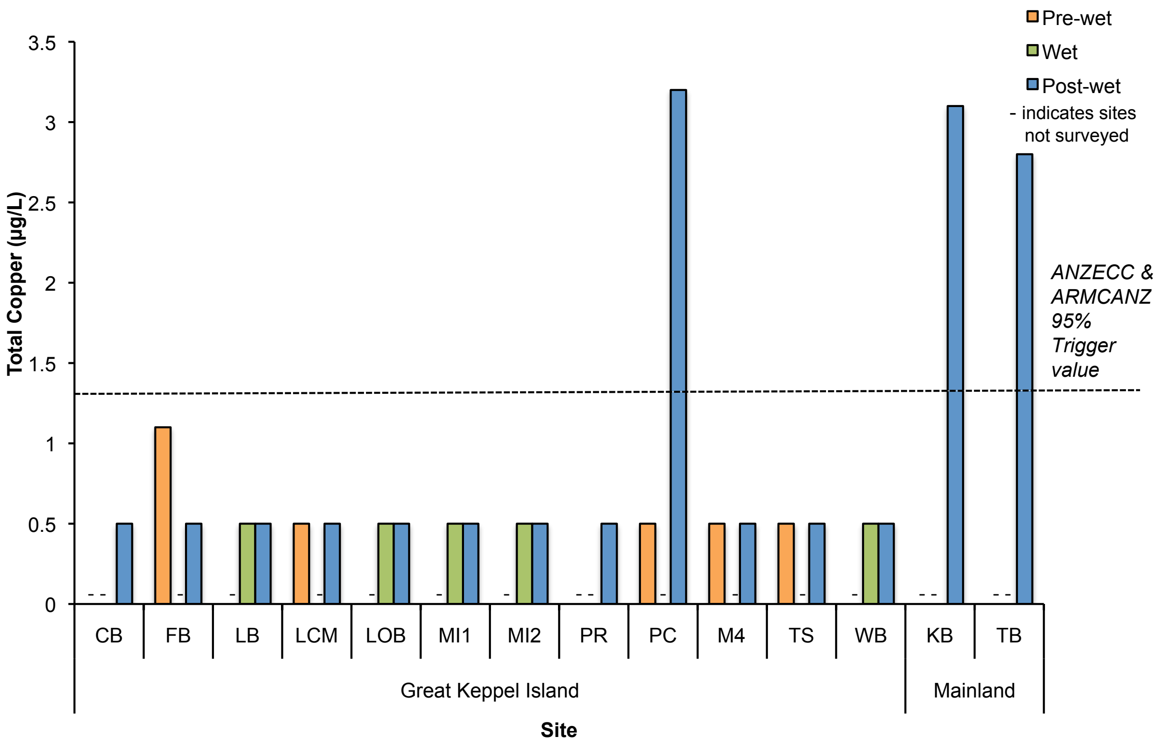


Figure 3.6 Total copper concentration at each site in each survey.

[8] It is not possible to determine if the concentration exceeded the 99% trigger value at other sites because the laboratory detection limit (1 µg/L) was higher than the 99% trigger value (0.3 µg/L), consequently the 99% protection trigger value not graphed.

Zinc

The concentration of total zinc exceeded the ANZECC & ARMCANZ 99% protection trigger value at most sites in the post-wet survey, and was particularly high at site TS (The Spit). The concentration of zinc at site PC (Putney Creek) exceeded the 99% protection trigger value in the pre- and post-wet survey. The concentration of total zinc at sites PC, TS (The Spit) and KB (Kinka Beach) also exceeded the 95% protection trigger value in the post-wet survey (Figure 3.7).

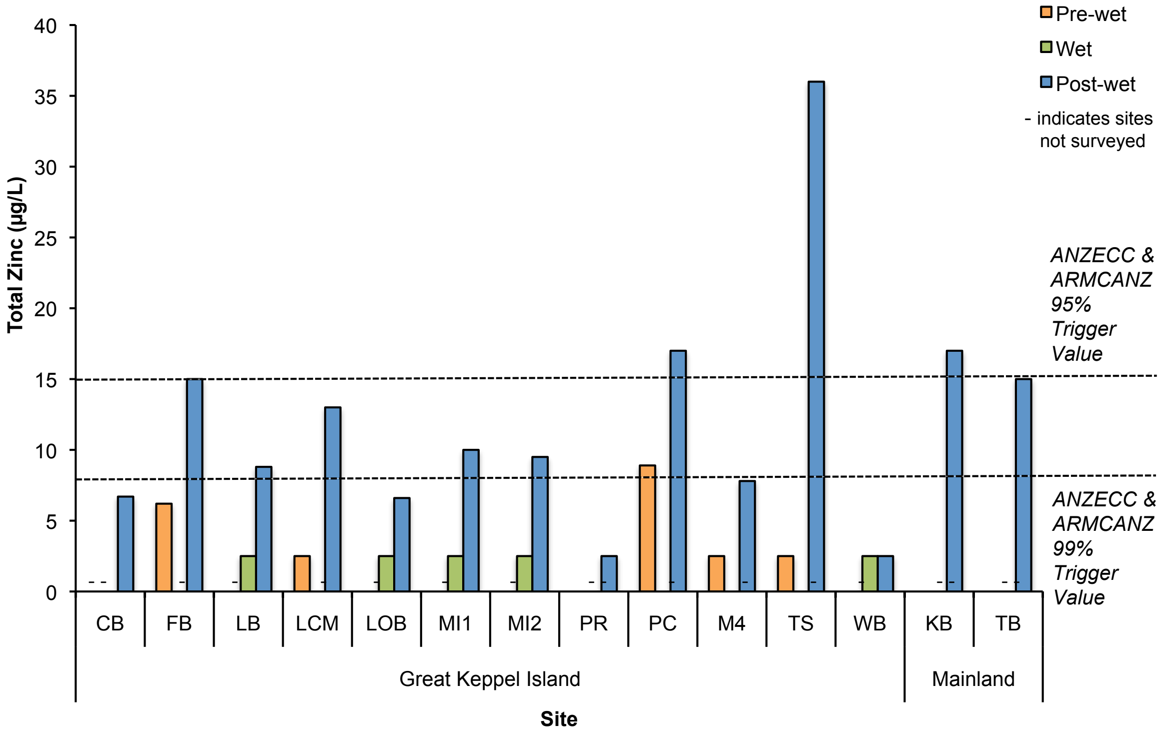


Figure 3.7 Total zinc concentration at each site in each survey.

Other Metals and Metalloids

The concentration of cadmium, chromium, nickel, lead and mercury were below laboratory detection limits and / or the relevant trigger value at all sites in all surveys.

Hydrocarbons and Pesticides

The following variables were below laboratory detection limits and / or relevant trigger values at all sites:

- petroleum hydrocarbons (C6–9, C10–14, C15–C28 and C29–C36)
- aromatic hydrocarbons (benzene, ethylbenzene, toluene and xylene), and
- organochlorine pesticides (aldrin, *alpha*-BHC, *beta*-BHC, *gamma*-BHC, *delta*-BHC, *cis*-Chloradane, *trans*-Chloradane, *p,p1*-DDE, *p,p*1-DDT, dieldrin, *alpha*-endosulfan, *beta*-endosulfan, endosulfan sulphate, endrin, endrin aldehyde, heptachlor, heptachlor epoxide, hexachlorobenzene, methoxychlor, and mirex).

4 Regional Context

Concern regarding the trend of decline in the quality of water draining to the Great Barrier Reef, as well as its lagoon, is well documented (GBRMPA 2001).

4.1 Physicochemical

Located approximately 40 km off the mouth of the Fitzroy River, the waters surrounding Great Keppel Island have a seasonal input of fresh and turbid waters that can result in episodes of poor water quality. The Fitzroy Basin is the largest river basin draining to the Great Barrier Reef, draining an area of approximately 142 645 km^2 (GBRMPA 2007). Rainfall in the catchment is highly episodic and is concentrated in the summer months (December to March) (Webster & Ford 2010).

Land use in the Fitzroy Basin is dominated by grazing and agriculture, together with mining and forestry (Rolfe et al. 2004). During large floods, run-off from agricultural and mining across a large catchment area result in substantial influences on estuarine and inshore coastal areas, as well as areas further offshore (Jones et al. 2000).

The average annual discharge of suspended sediment from the Fitzroy Basin into the Great Barrier Reef is estimated to be between 2.6 to 4.0 million tonnes (Taylor & Jones 2000; CRC 2003). Over most of Keppel Bay, tidal currents are not large enough to resuspend fine sediments, but waves (induced by wind) in combination with tidal currents, are able to resuspend and redistribute sediments (Webster & Ford 2010).

4.2 Potential Contaminants

Nutrients

The main sources of nutrients in the project area are derived from river and land run-off, particularly during floods. Nutrients (nitrogen and phosphorous) are mostly derived from diffuse sources, however point sources are locally significant in the upper estuary during extended periods of very low flow (as nutrients remain for a long time). There is little evidence to indicate that nutrient loads from the Fitzroy Basin are having a major impact on the ecology of the Fitzroy River estuary and offshore waters (Rolfe et al. 2004, references cited herein).

Pesticides

Pesticides, commonly used in cattle grazing and crop growing include:

- organophosphates (e.g. chlorpyrifos)
- triazines (e.g. atrazine, simazine, ametryn, prometryn), and
- urea-based herbicides (e.g. diuron, tebuthiuron, flumeturon).

The mobility of these pesticides varies with their physicochemical properties, but those that are persistent have the potential to be transported from the sites of application in a catchment via rivers into coastal waters. Pesticides (including endosulfan sulphate, diuron and profenofos) are found in irrigation areas of the catchment, particularly in the Dawson River near Emerald (Jones et al. 2000). The herbicide atrazine (primarily applied in dryland cropping) is likely to be an issue for the condition of streams and their flora and funa in most subcatchment of the Fitzroy Basin, whilst diuron (usually associated with cotton growing areas) has the potential for widespread contamination due to its mobility and persistence in the environment (Jones et al. 2000). There are significant concentrations of several herbicides (atrazine, tebuthiuron and diuron) and lower concentrations of additional herbicides entering the Fitzroy River estuary in summer flows (Packett et al. 2005; Vicente-Beckett et al. 2006), with the potential to flow into coastal waters.

Sampling done at North Keppel Island has detected the pesticides diuron (0.46 to 1.1 ng/L) and tebuthiuron (0.0 to 0.18 ng/L), at low concentrations. The flame retardant, tris (1-chloro-2-propyl) phosphate (TCPP), has also been detected in passive sampling devices. While overall concentrations of land-sourced pollutants within these waters are low, due to the sensitive nature and high conservation value of the Great Barrier Reef, concern remains for the potential consequences of continuous low exposure to pollutants (Kennedy et al. 2010).

4.3 Interaction of Freshwater Flows with Coastal Waters

Coastal water quality of the region and of Great Keppel Island in particular, is highly variable, responding to flood discharge from the Fitzroy River and less frequently cyclonic conditions. An understanding of the influence of event-based ‘drivers’ of coastal water quality is critical, as it is these ‘drivers’ that have the greatest ecological significance (and within which the potential impacts of the proposed marina should be viewed).

A major flood event occurred In January 1991, with floodwaters from the Fitzroy River extending out to the Keppel Islands. This caused a decrease in salinity for a period of 19 days (8 to 10 ppt near the surface and 15 to 28 ppt at depth of 3 m) and increasing nutrient inputs (BOM 2010a). Major flood events were also recorded in:

- 1918 (BOM 2010b)
- 1954 (BOM 2010c)
- 1960 (BOM 2010d)
- 1973, 1974, 1976, 1978 (BOM 2010e)
- 2003, 2008 (BOM 2010f), and
- 2011 (BOM 2010g).

5 Potential Impacts

This section describes the potential impact on marine surface water quality, and sediment quality (as they are closely associated). Some impacts may be permanent while others will be temporary and reversible.

5.1 Description of Project

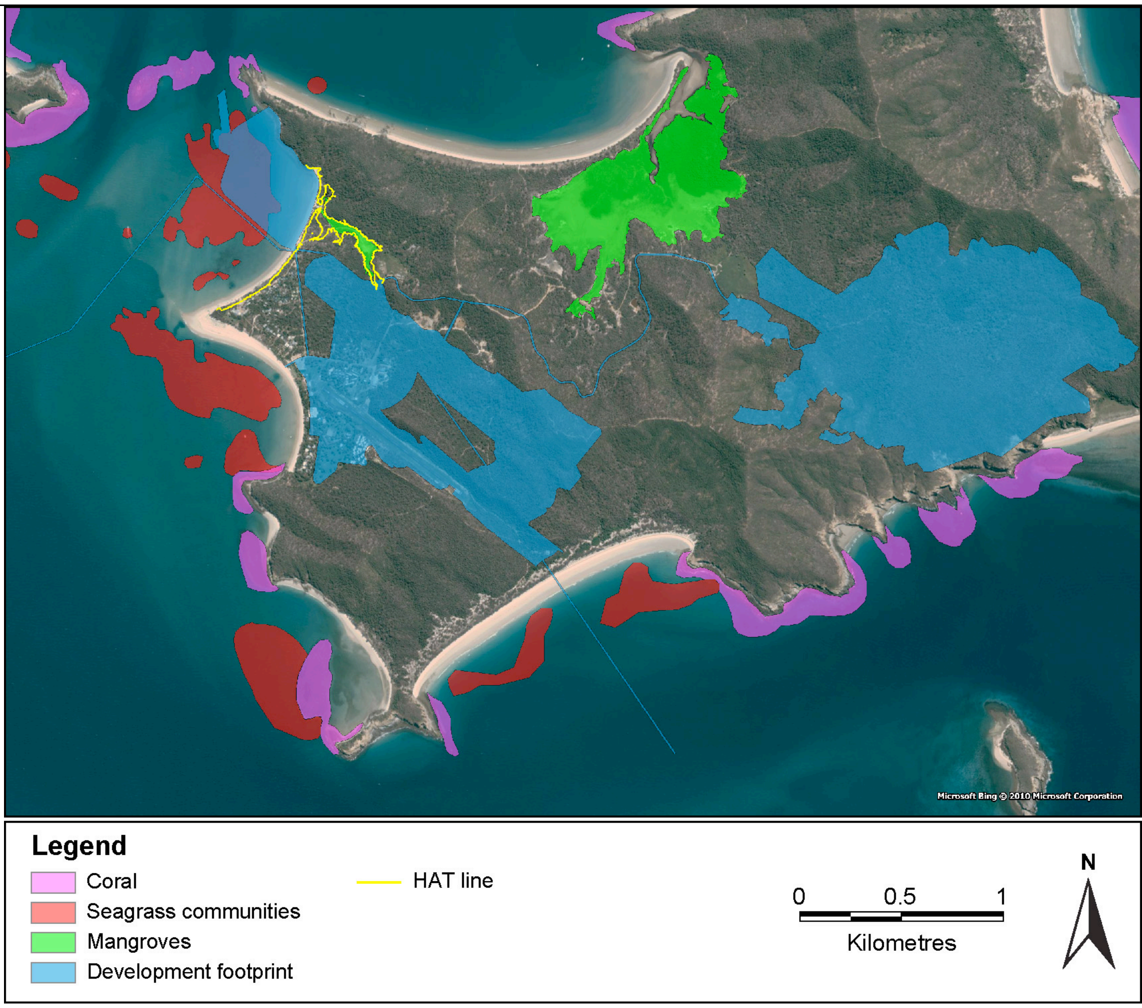
The revised proposal for the Great Keppel Island Resort Revitalisation Plan 2010 includes the following components that have the potential to impact on marine surface water (and sediment) quality:

- dredging for construction of the marina and re-nourishment of Putney Beach using dredge spoil
- development of a marina at Putney Beach comprising 250 berths, emergency services facilities, ferry terminal, yacht club, dry dock storage, and retail area (mix of cafes, restaurants and clothing shops)
- development of an 18-hole golf course, integrated with essential habitats and ecological corridors, and located on previously disturbed grazing lands
- development of associated service facilities and utilities (e.g. fuel storage and wastewater treatment plant)
- establishment of a Water Management Plan to mitigate effects of stormwater run-off and golf course run-off into the Great Barrier Reef Marine Park (GBRMP), and
- installation of a submarine connection of services (e.g. power, telecommunications and potable water) line between Great Keppel Island and Kinka Beach on the mainland.

Construction and operation activities associated with the following components of the development have the potential to impact on marine surface water (and sediment) quality:

- marina precinct
- wastewater treatment plant wet weather outfall
- golf course precinct, and
- submarine connection of services to the mainland.

Figure 5.1 and Figure 5.2 show ecological communities and the proposed development on Great Keppel Island and the mainland, respectively.



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Great Keppel Island Revitalisation EIS

Figure 5.1 Ecological communities and the proposed development on Great Keppel Island.

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	Figure 5.2 Ecological communities and the proposed submarine cable alignment on the mainland.
	Microsoft Bing © 2010 Microsoft Corporation — August 2011

Marina

The main components of the marina are (Figure 5.3):

- a 90 000 m^2 marina basin to a depth of -4.9 to -5.9 Australian Height Datum (AHD) (-2.5 to -3.5 m chart datum, i.e. lowest astronomical tide, LAT)
- a breakwall along the seaward margin (to the west and south of the marina)
- a 46 000 m^2 bunded reclamation area along the landward margin (to the east and north of the marina), and
- an access channel approximately 45 m wide and 190 m long, with a minimum depth of -5.9 m AHD (-3.5 m LAT).

The development will also open the mouth of Putney Creek, which is currently closed by a sand bar for most of the year (it is occasionally washed-out by large storm run-off). To control discharge into the marina, a permanent, lined, discharge channel will be constructed, with a sediment basin located upstream of the mouth to trap sediment during low flow events, and a low weir at the mouth to control flow.

The proposed dredging of the marina requires the following work:

- dredging of the marina entrance channel to a depth of -5.9 m AHD (-3.5 m chart datum), and
- dredging of the marina basin to a depth of -4.9 m AHD (-2.5 m chart datum).

It is estimated that this dredging will generate a maximum total dredge volume of 300 000 m^3. All dredge spoil is proposed for use in the breakwater (i.e. to fill geotextile bags) and as reclamation fill. Spoil is not proposed for ocean disposal.

The marina will be constructed in four stages:

- seaward (southern / western) breakwall construction and basin dredging
- marina basin revetment and basin dredging
- landward (eastern / northern) reclamation, and
- placement of breakwater armour and marine basin rip-rap.

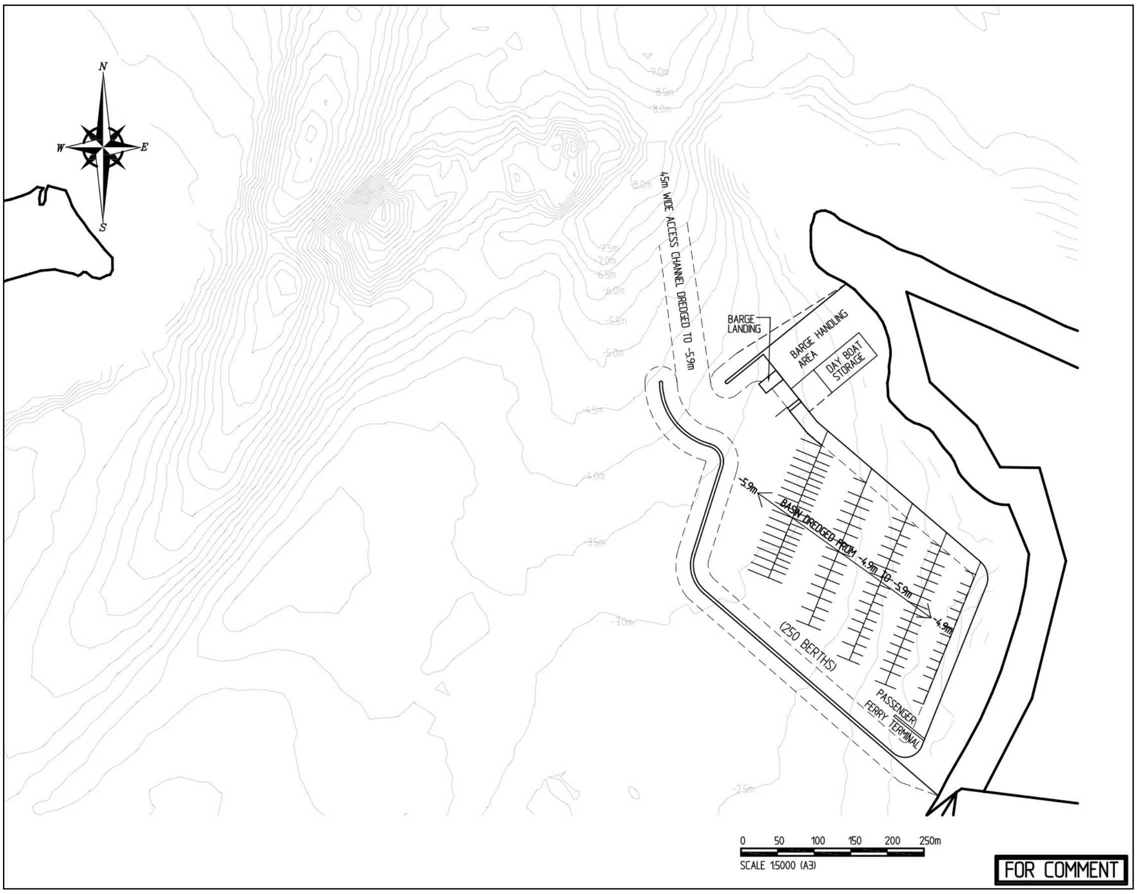

Figure 5.3 The proposed marina development at Putney Beach.

Submarine Cables

Submarine cables will be installed to connect power (22kV high voltage supply), communications (fibre optic supply of IP telephony, video phone / conferencing, television and video on demand) and potable water with the mainland. The design is currently preliminary and will be confirmed during the detailed design stage. The proposed development includes trenched cables and pipes along the sea bed together with a proposed exchange building for telecommunications, and connections to Ergon's power supply and Council's water supply on the mainland and island. The connection point on Great Keppel Island will be near the marina precinct and the preferred connection point on the mainland is at the end of Ritamada Road, Emu Park (Kinka Beach). The final locations are to be determined (Opus International Consultants (Australia) Pty Ltd 2011a).

The cable alignment extends for approximately 16 km along the seabed, to a depth of -10 m AHD. The cables will be buried (trenched) to reduce to likelihood of subsequent physical damaged associated with activities such as anchoring and trawling. The proposed method for trenching is water jetting by a continuous jet trenching machine, which involves laying the cables on the seabed and then burial as the trencher travels along the alignment. The disturbance to the seabed is localised to the width of the trench and the trench is immediately backfilled. On the beach and in very shallow waters, the trench is likely to be buried using the burying-in-excavated-trench method, which involves excavation by a grab dredger or backhoe and burial using the excavated sediment.

The depth of trenching depends on water currents and will be confirmed during a detailed investigation by the contractor prior to installation. The depth is likely to be approximately 1.2 m below the seabed surface and the width of the trench is likely to be approximately 1 m (0.3 m for the power and communication cable and 0.6 m for the water pipe). Trenching in the mangroves on the mainland will be approximately 2.5 m wide (i.e. a one vehicle wide access track).

A hydrographic survey was undertaken to inform route alignment. The proposed alignment avoids sensitive ecologically communities including coral reefs, and where practical seagrass meadows and mangroves. A small area of seagrass will be removed adjacent to the marina, and a small area of mangroves may be removed on the mainland (subject to final alignment). Prior to the installation, the contractor will undertake an additional hydrographic and seismic survey to confirm the alignment.

Adjacent to Great Keppel Island, the alignment will extend through Conservation Park Zone 23-822 ('yellow zone') but avoid the adjacent Marine National Park Zone 23-802 ('green zone'). Adjacent to the mainland it will extend through Conservation Park Zone 23-103 off Kinka Beach.

Wastewater Treatment Plant

The proposed wastewater treatment plants will treat wastewater to an A^{+} tertiary standard (for unrestricted non-potable use), with the larger facility capable of performing nitrogen and phosphorus removal. Approximately 99% of the treated effluent would be stored in water feature/s on the golf course and re-used to irrigate golf course turf, landscape and open areas. During the first two years, the treated effluent will be used to irrigate the area adjacent to the airstrip and other open areas (Opus International Consultants (Australia) Pty Ltd 2011c).

Approximately 1% of the treated effluent will be discharged to the ocean during extreme wet weather events (which are predicted to occur approximately once every ten years) together with periodic release to keep the infrastructure operational. The ocean outfall will be located approximately 1 000 m offshore of Long Beach in water approximately 11 m deep (Figure 5.3) (Opus International Consultants (Australia) Pty Ltd 2011b; c). The outfall pipeline would be constructed in a similar manner to the submarine cables, that is water jetting by a continuous jet-trenching machine with sediment disturbed to approximately 1 m below the surface (G Chen [Opus International Consultants] pers. comm., 22 August 2011).

A specialised wastewater pump-out facility will be provided at the marina to receive sewage from berthed vessels. Marina wastewater management facilities will be developed in accordance with the *Best Practice Guidelines for the Provision of Waste Reception Facilities at Ports, Marina and Boat Harbours in Australia and New Zealand* and other relevant guidelines and legislation. This wastewater will be piped to the wastewater treatment plant on the island (Opus International Consultants (Australia) Pty Ltd 2011b).

Golf Course

Fertilisers applied to the golf course have the potential to reach the marine environment through run-off into creeks and leaching through groundwater. Golf course design and operation ensures that no nutrients enter the marine environment. Stormwater will be captured in water features for treatment prior to being used as turf irrigation, with the water features lined to prevent infiltration of the groundwater. Furthermore, fertiliser application levels will managed so that no nutrients leach through the sand to the groundwater ((T Burt [Opus International Consultants] pers. comm., 27 July 2011; Opus International Consultants (Australia) Pty Ltd 2011d; c).

Stormwater

Stormwater has the potential to introduce contaminants and sediment (which increases turbidity and sedimentation) in surface waters. The proposed development is predicted to increase stormwater runoff due to an increased area of hard (impermeable) surfaces and decreased area of permeable surface, compared to the current condition. Stormwater will be retained, for treatment as required, in detention and bio-detention (wetland vegetation) basins to control the quantity and quality of runoff into marine (and freshwater) surface waters. Bio-retention swales and infiltration areas will also be used. Modelling by Opus International Consultants predicts no impact to marine and / or fresh surface water quality (Opus International Consultants (Australia) Pty Ltd 2011c).

Altered environmental flows have the potential to impact on downstream freshwater and estuarine ecosystems.

5.2 Marina Construction

Marina construction activities including excavation, dredging, spoil handling, and pile driving have the potential to result in:

- increased suspended sediment levels (turbidity) and consequent sediment deposition
- altered hydrodynamics and consequently altered flushing and patterns of sediment deposition and erosion
- spills of hydrocarbons and other potential contaminants
- litter and waste
- release of contaminants from the disturbed sediments
- disturbance of acid sulphate or potential acid sulphate sediments (ASS / PASS), and
- overall ecosystem functioning.

Increased Suspended Solids and Sediment Deposition

The effects of increased suspended solids and sedimentation resulting from excavation and spoil handling are highly variable and will depend on both the techniques used and the season. The likelihood of increases in suspended sediments and of smothering are closely related to the characteristics of the sediment. Coarse sediments, characteristic of the marina footprint, settle from the water column quickly and are less likely to move away from the excavation site. Fine sediments, which are rare in the marina footprint, remain suspended longer and may be carried further before settling, and consequently are more likely to smother marine organisms.

Increased Suspended Solids

Dredge plume modelling by Water Technology (2011) shows the likely dredge plume to be generally confined to the marina footprint. The maximum concentration of total suspended solids (TSS) in the water of the marina basin would be approximately:

- 25 mg/L during Stage 1 (Figure 5.4)
- 40mg/L during Stage 2 (Figure 5.5), and
- 5 mg/L during Stage 3 (Figure 5.6) (based on mean TSS concentration).

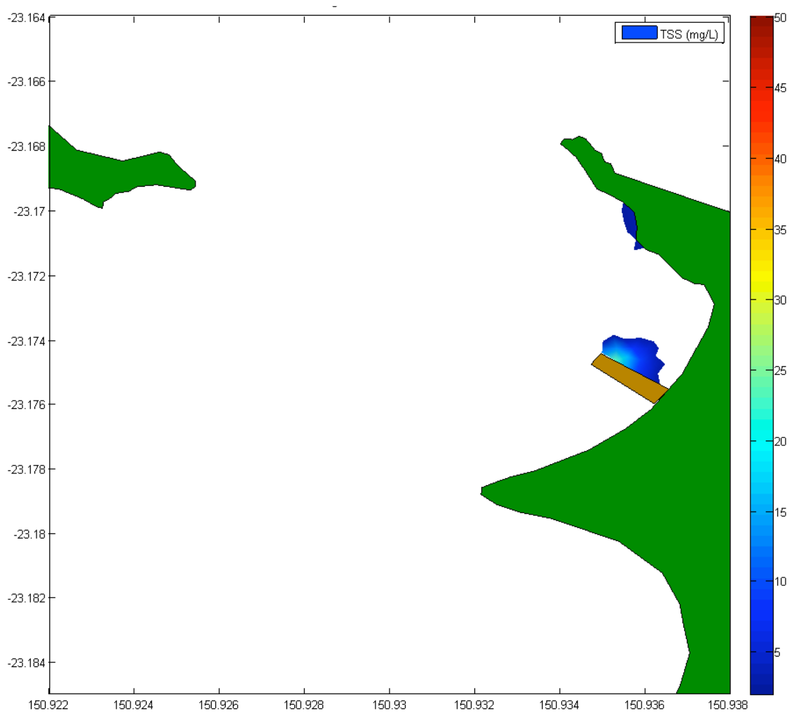

Figure 5.4 Predicted median TSS concentrations in the water column during Stage 1 of marina construction.

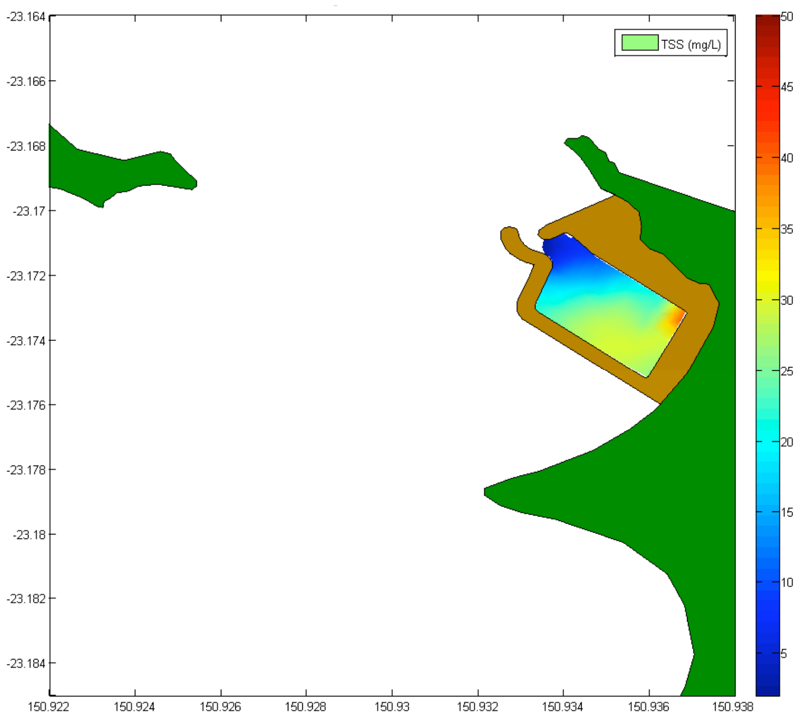

Figure 5.5 Predicted median TSS concentrations in the water column during stage 2 of marina construction.

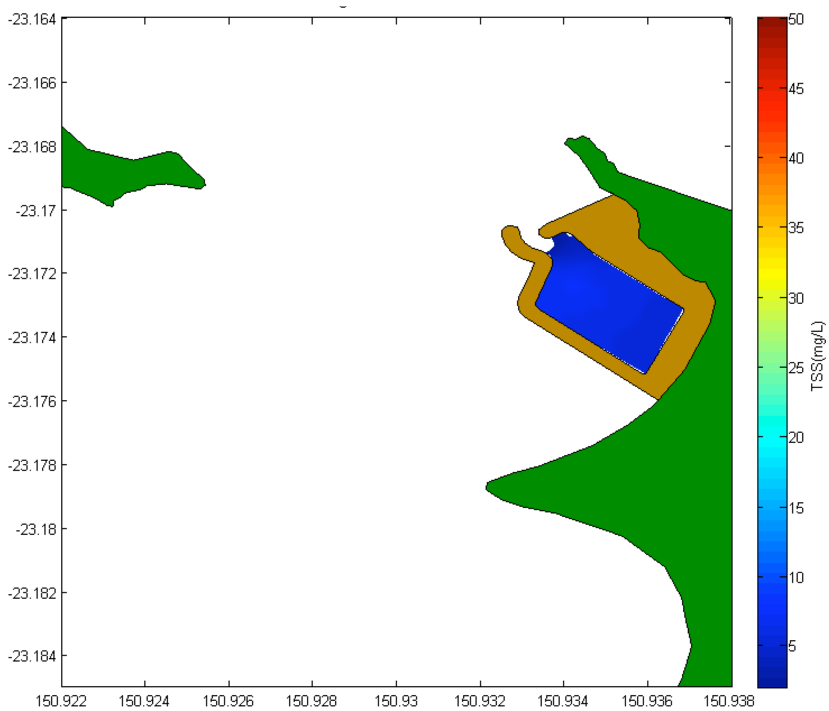

Figure 5.6 Predicted median TSS concentrations in the water column during Stage 3 of marina construction.

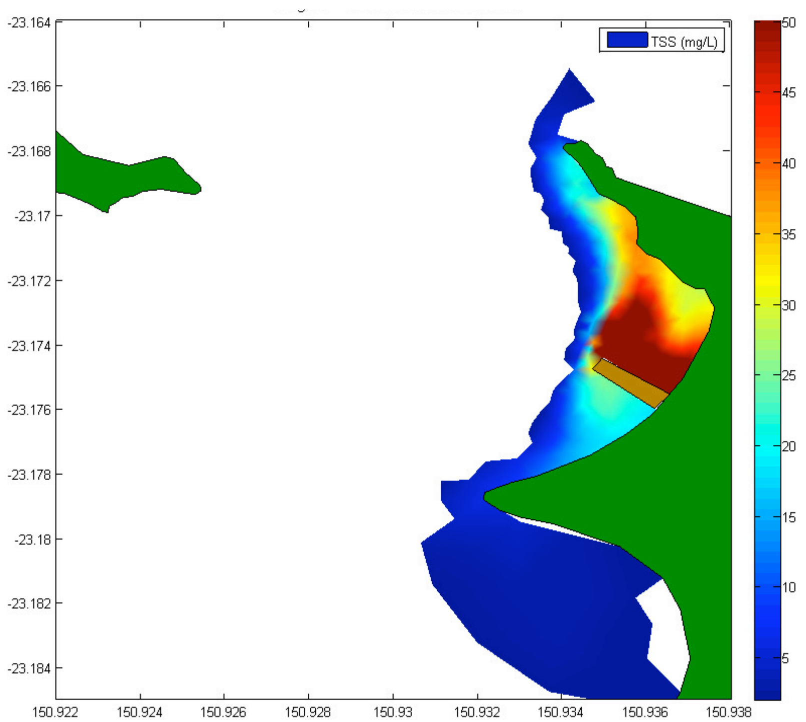

Figure 5.7 Predicted TSS concentrations in the water column for 90th percentile exceedances during Stage 1 of marina construction.

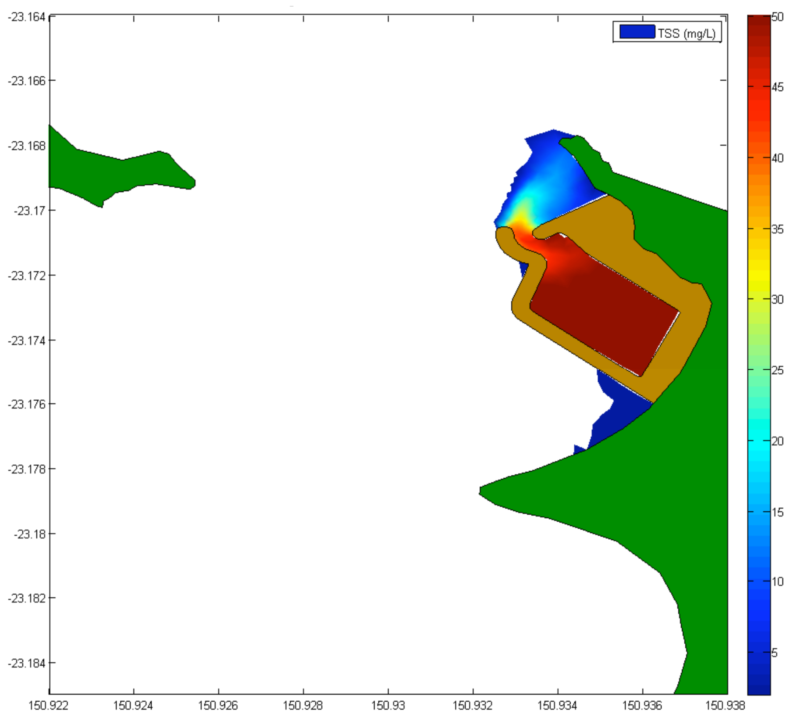

Figure 5.8 Predicted TSS concentrations in the water column for 90th percentile exceedances during stage 2 of marina construction.

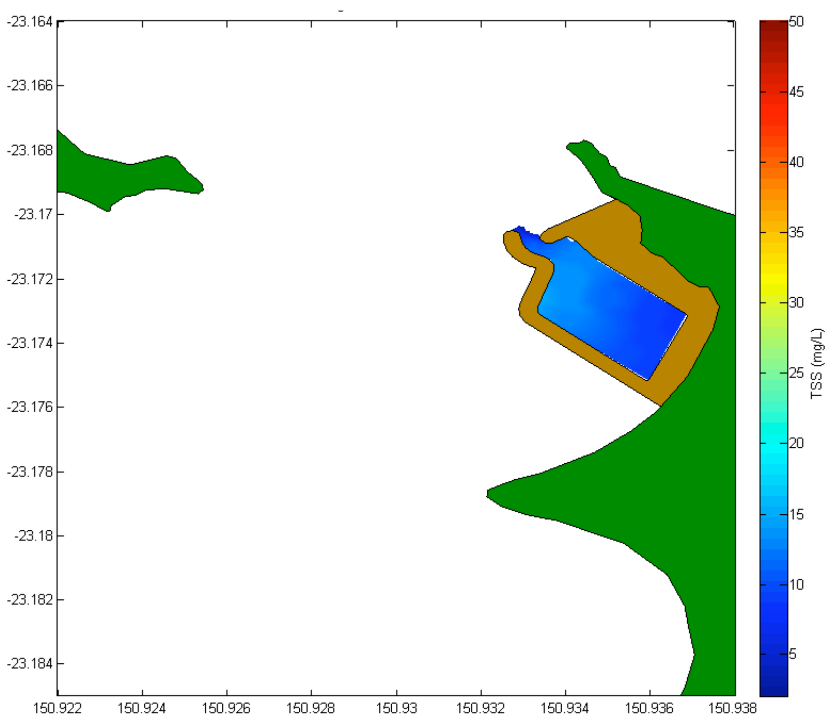

Figure 5.9 Predicted TSS concentrations in the water column for 90th percentile exceedances during Stage 3 of marina construction.

The dredge plume may extend beyond the marina basin on occasion for short periods of time, including:

- beyond Putney Point and to Fishermans Beach during Stage 1, with a concentration of up to approximately 25 mg/L but mostly below 15 mg/L, and
- beyond Putney Point during Stage 2, with a concentration of up to approximately 25 mg/L but mostly below 15 mg/L (based on 90th percentile exceedence).

The dredge plume is predicted to not extend beyond the marina footprint during Stage 3.

The concentration of TSS at Passage Rocks is predicted to be:

- up to approximately 6 mg/L (but mostly below 3 mg/L) during Stage 1
- up to approximately 4 mg/L (with a concentration of approximately 6 mg/L predicted on one occasion) during Stage 2, and
- up to approximately 3 mg/L (with a concentration of approximately 8 mg/L predicted on three occasions) during Stage 3.

The predicted maximums are substantially higher than the ANZECC & ARMCANZ 99% protection trigger value of 2.0 mg/L. These predicted concentrations compare with typical TSS concentrations of up to 2 mg/L in the waters of the proposed marina site and at nearby Passage Rocks, and up to 31 mg/L in lower Putney Creek.

This modelling is based on a conservative approach, which assumes that approximately 5% of excavated material is suspended in the water column; the extent of the dredge plume could be substantially less than predicted.

Sediment Transportation

Sediment transport modelling by Water Technology (2011) predicts the following areas of altered sand movement (Figure 5.10) associated with the marina development:

- reduced sand transport from the seabed between Putney Point and Passage Rocks, extending to offshore of Leeke's Beach
- reduced sand movement from the area to the south of the marina entrance
- reduced sand movement from the spit between Putney and Fishermans beaches, and
- variable (patches of both reduced and increased) sand movement is predicted in deeper water off Putney Beach.

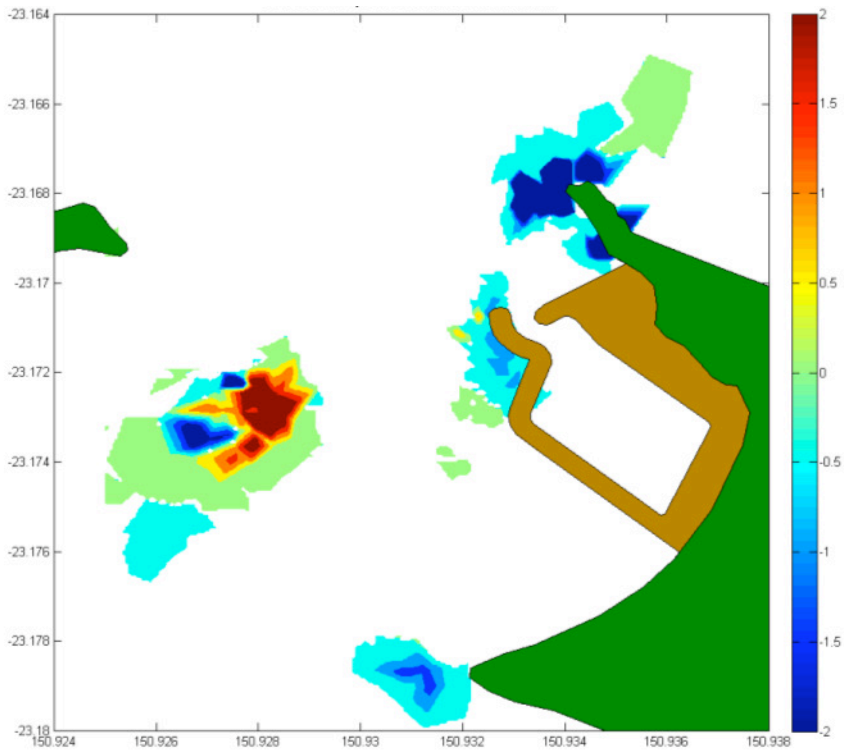

Figure 5.10 Predicted difference in sand transport associated with the marina.

This sand movement is unlikely to have a substantial effect on ecological communities, as it is similar (same order of magnitude) to the existing condition.

Sediment transport modelling by Water Technology (2011) predicts the following areas of siltation (Figure 5.11) associated with the marina development:

- within the marina footprint
- within the entrance channel, and
- to the south of the marina along Putney Beach.

That is, in the long-term silt is predicted to settle on the sea bed in those locations.

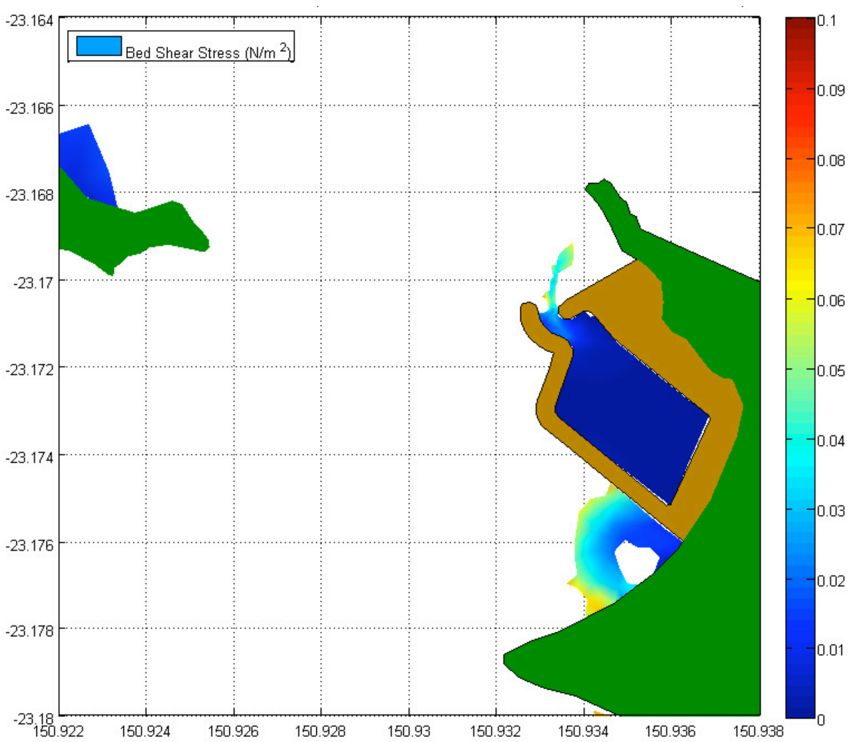

Figure 5.11 Predicted siltation associated with the marina.

Potential Effects on Seagrasses and Macroalgae

The temporary increase in turbidity associated with the dredging and marina construction will reduce the penetration of light through the water column. Light availability, or specifically the duration of light intensity exceeding the photosynthetic light saturation point, effects seagrass condition and distribution (Dennison & Alberte 1985; Dennison 1987; Hillman et al. 1995; Abal & Dennison 1996). Seagrasses in shallow waters are typically less susceptible to light reduction due to pulse turbidity events than seagrasses in deeper water (Longstaff & Dennison 1999).

Halophila ovalis, which grows near the proposed marina, has a particularly low tolerance to light deprivation caused by pulsed turbidity such as floods and dredging, with plant death occurring after 38 days in low light conditions. However, *H. ovalis* can quickly recolonise areas due to its high growth rate and high seed production. *Halodule pinifolia*, which has a similar morphology and is closely related to the dominant species growing near the proposed marina (*Halodule uninervis*) is tolerant of low light levels; condition (shoot density, biomass and canopy height) was effected after 38 days of low light conditions and complete die-off was predicted after 100 days (Longstaff & Dennison 1999).

There is limited scientific literature relating seagrass condition to TSS concentrations. Studies of *Zostera muelleri*[9] report that, on average, 30% of surface light (a light attenuation co-efficient of less than 1.4 m^{-1}) is required for survival, which equates to TSS concentration of up to 10 mg/L (Abal & Dennison 1996; Longstaff et al. 1998). A suspended solids level of below 15 mg/L is a predicted prerequisite for healthy growth of seagrass (Dennison et al. 1993).

Availability of light also affects the productivity of seagrasses. Seagrass exposed to higher light intensity is more productive than seagrass in less intense light (e.g. Mazzella & Alberte 1986; Grice et al. 1996; Stapel et al. 1997); (Manikandan et al. 2011). Consequently, impacts associated with dredging may result in at least a temporary decrease in seagrasses productivity. Light also controls the population dynamics of macroalgae (Lukatelich & McComb 1986a; cited in Lavery & McComb 1991).

Seagrass within the marina footprint will be lost to the development (approximately 21 ha; see Appendix E for a discussions of the area to be lost). If the dredge plume extends beyond the marina basin on occasion for short periods of time, as indicated by the 90th percentile exceedances, it will extend over seagrasses in parts of Putney the Fishermans beaches. During Stage 1, approximately half of the remaining Putney Beach meadow (up to approximately 10 ha) and most of the Fishermans Beach meadow (up to approximately 17 ha) could be impacted. During Stage 2, a small area of sparse seagrass (up to approximately 1 ha) may be impacted. The dredge plume is predicted to not extend beyond the marina footprint during Stage 3.

Outside the marina footprint, communities are unlikely to be substantially affected by any brief reduction in light intensity, given that these seagrasses currently inhabit inshore coastal waters with variable turbidity and light penetration, and are capable of rapid recovery following flood-related turbidity and sedimentation (as discussed in Appendix E). Furthermore, *H. pinifolia* (which has a similar morphology to *H. uninervis*) can tolerate low light levels for up to 38 days. Given the very limited cover of seagrass in the vicinity of the marina, and the short duration of any predicted increased suspended solid concentration, any seagrass loss will likely be minor and temporary. Seagrass communities of the region are primarily influenced by the discharges of the Fitzroy River.

Outside of the marina, silt may settle over a very small area of seagrass to the south of the marina (up to approximately 1 ha). Species with a small growth form (*H. uninervis* and *H. ovalis*) are likely to be more affected than those with a larger growth form (*H. spinulosa* and *S. isoetifolium*). Given the permanent nature of the predicted deposition, *H. uninervis*

[9] Formerly classified as *Zostera capricorni.*

and *H. ovalis* are unlikely to survive substantial deposition, however these species are likely to rapidly recolonise the area.

The seagrass meadows of the project area are sparse (<5% overall cover) and dominated by the more tolerant *H. uninervis,* together with *H. ovalis,* and small, scattered patches of *Halophila spinulosa* and *Syringodium isoetifolium* (mostly in deeper water). Loss of seagrass has the potential to affect species of conservation significance, as seagrass provides an important food source for several important species, e.g. turtles, dugong and syngnathids. Given that the meadows adjacent to the marina are sparse and patchy and typical of the region, the potential loss of a small area due to smothering or sediment erosion is unlikely to have a measurable ecological impact beyond the marina footprint.

Potential Effects on Corals

The impacts of increases in turbidity and sediment deposition on coral communities can include reduced algal and coral diversity and reductions in epifaunal densities (Hatcher et al. 1989). The varied biota found associated with coral communities, living or feeding in the crevices within and around corals are likely to suffer as these spaces are filled with deposited sediment (Johannes 1975). Coral communities are generally better developed, more diverse, and with greater coral coverage and rates of coral growth, under lower turbidity and / or sediment loads (Rogers 1990). Clear water promotes the photosynthetic activity of zooxanthellae hosted by most shallow water corals. .
Increased turbidity and sediment deposition can affect corals by (Johannes 1975; Rogers 1979; Hubbard 1988):

- decreasing light availability to zooxanthellae
- affecting the planktonic food supply of corals (this is unlikely to be significant for hermatypic corals)
- abrasion
- stimulation of energy-consuming sediment rejection behaviour, and
- the reduction of available sites for larval settlement.

Whilst models for predicting critical levels of turbidity have been proposed (Bell 1992; Lapointe 1997; Te 1997), various studies have shown that different species of corals have very different tolerances.

Effects range from mild coral stress to subtle changes in reef community structure, to outright coral mortality and ecological collapse of the reef (Dodge & Brass 1984)Raaymakers and Oliver 1993). However, decreased growth rates of corals due to increased turbidity and sediment deposition are generally only associated with dredging operations that run for extended periods of time (e.g. a two-year dredging campaign in Castle Harbour, Bermuda; Dodge and Vaisnys 1977 in Pastorok & Bilyard 1985) or for operations conducted in very close proximity to corals (Bak 1978). Complete burial of corals generally leads to death after a number of hours (Marshall & Orr 1931), however some species are far more resilient than others. There is no quantitative information on the sub-lethal effects of elevated turbidity and sedimentation on corals.

At a community scale, the impacts of increased sediment deposition can include reduced algal and coral diversity and reduced epifaunal densities (Hatcher et al. 1989). The varied biota that live and feed in the cryptic spaces within and around corals may also suffer as these spaces are filled by sediment (Johannes 1975). The effects of light attenuation and increased sedimentation on coral reefs, associated with sediment plumes, can range from mild coral stress to subtle changes in reef community structure to outright coral mortality and ecological collapse (Raaymakers & Oliver 1993).

Dredging activities at Magnetic Island (for the Magnetic Quays development), in close proximity to coral reefs, and for the Port of Townsville, approximately 2 km distant from reefs, resulted in no detectable impact to corals (Oliver pers. comm. 1993; Raaymakers & Oliver 1993). While under particular circumstances the continual resuspension and transport of dredged materials can cause reef degradation years after dredging ceases, this is typically associated with regions experiencing very low background levels of turbidity and suspended solids, such as coral atolls (e.g. Brock et al. 1966 in Rogers 1990).

Isolated corals may be lost to the marina footprint. If the dredge plume extends beyond the marina basin on occasion for short periods of time, as indicated by the 90^{th} percentile exceedances, it will extend over a small coral outcrop (up to approximately 0.1 ha) directly adjacent to the marina and approximately half of the corals of Putney Point (up to approximately 1 ha). During Stage 1 and 2, these two areas could be impacted. The dredge plume is predicted to not extend beyond the marina footprint during Stage 3. The dredge plume is predicted to not extend to the corals of Passage Rocks.

The communities of Putney Beach are sparse, patchy reefs dominated by *Turbinaria* sp. and the soft coral *Sarcophyton* sp., together with *Porites* spp. and massive corals from the families Faviidae and Mussidae. They are typical of inshore, river-influenced communities, and as such, are likely to be tolerant of elevated suspended solid and nutrient concentrations. Corals inhabiting these inshore waters are also generally more efficient at sediment clearance than those species typically found on offshore reefs (Salvat 1987), and can consequently withstand deposition of sediment better than offshore species.

Coral communities of the nearby Whitsunday coast are similar to those of the Keppel group, and are influenced at a broad-scale by the discharges of the Proserpine and O'Connell Rivers (much as the coral communities of the Keppel group are influenced by the discharge of the Fitzroy River). Whilst larval recruitment is near random, environmental factors determine which species survive and grow (Fisk & Harriott 1990; van Woesik et al. 1999). These communities chronically experience sediment deposition rates considerably in excess of rates reported to be catastrophic for coral communities in other parts of the world. Despite this, these communities continue to flourish and are healthy (e.g. (Marshall & Orr 1931; Rogers 1990). Coral communities of the Keppel group are likely to be similarly highly resilient to periodic increases in turbidity and sediment deposition.

The coral communities in the vicinity of the proposed marina are likely to be largely unaffected by increased suspended solid concentration and sediment deposition given that they currently inhabit inshore coastal waters with variable turbidity and light penetration. Small isolated corals may be lost to the marina footprint and the small reef directly adjacent to the marina footprint would be impacted more so than the corals of Putney Point, as they are relatively close to the marina breakwall. Coral communities of the region are influenced at a broad-scale by the discharges of the Fitzroy River.

Loss of coral reef has the potential to affect marine fauna as it provides important habitat for many species. Given that the communities adjacent to the marina are sparse and patchy and typical of the region, the potential loss of a small area (while unlikely) will not impact biodiversity (at even a local scale), and is highly unlikely to have a measurable impact on ecosystem functioning or the productivity of inshore waters.

Potential Effects on Soft Sediment Benthos

Soft sediment benthic communities typically have marked fluctuations in both numbers of animals and number of species. Non-biological factors such as temperature and salinity cannot account for these distributions alone: changes between years appear to be more significant than changes between seasons (DEC 1989).

The fauna associated with soft sediment habitat is typically determined by the character of the sediment: its grain size and stability (McLachlan 1996) and with the presence or absence of seagrass (Bell & Westoby 1986). Grain size influences the ability of organisms to burrow, and the stability of 'permanent' burrows. Unstable sediments support less diverse benthic communities than those that are relatively stable. Re-suspension of fine sediments can interfere with the feeding and respiration of benthic fauna.

Increases in the concentration of suspended solids may impact the respiration and feeding of a variety of taxa reducing abundance, species diversity and productivity. The deposition of fine sediment over existing substrate is likely to influence the community structure in favour of those species most able to cope with fine sediment substrate to the disadvantage of those less able. Filter feeding and other gilled fauna are most likely to be affected. Whilst the proposed dredging may impact the soft sediment invertebrate communities within the dredge plume, any impact will be temporary and reversible.

Potential Effects on Fishes and Other Vertebrates

The effect of increased suspended solid concentrations and sediment deposition on vertebrate communities is likely to be minimal, primarily because mobile organisms tend to avoid unfavourable environments. The sparse nature of the seagrass in the area makes it unlikely habitat for species of legislative significant, such as dugongs (*Dugong dugon)* and syngnathids (seahorses and sea dragons)

While some marine vertebrates will avoid areas of high turbidity, these waters may attract a range of fishes, particularly juveniles, as it confers a greater degree of protection from predators (Blaber & Blaber 1980).

Altered Hydrodynamics and Flushing

Marina

Modelling by Water Technology (2011) show that the marina is likely to be well flushed, with water quality within the marina typically similar to nearby waters outside of the marina. More then 50% of the average marina volume is predicted to be exchanged over a single spring tidal cycle, and the residence time of any contaminants is likely to be less than two days for any location in the marina.

Some sediment movement and accretion of fine sediments is predicted in the vicinity of the marina (as discussed earlier), however mobile sediments will not be re-suspended and the effect on water quality will therefore be negligible (T Womersley [Water Technology] pers. comm., 27 July 2011).

Putney Creek

The marina is located at the mouth of Putney Creek and the development would open the creek mouth. Changes to the flood regime (the timing and magnitude of flows) of Putney Creek, associated with opening of the mouth during marina construction, have the potential to impact water (and sediment) quality. Generally, extended periods of low flow lead to increased contaminant concentrations, elevated salinity, and reduced dissolved oxygen concentrations, while more frequent high flow events often result in lower concentrations of contaminants, more stable salinity and higher dissolved oxygen concentrations, but higher turbidity due to sediment-laden run-off (ANZECC & ARMCANZ 2000).

There will be negligible negative impact to the water and sediment quality of Putney Creek during construction where best practice erosion and sediment control techniques are used (e.g. silt curtains), and during operation. Opening of Putney Creek is expected to improve water quality (and productivity) in Putney Creek and have a negligible impact on water quality in the marina as suspended sediment will be captured in a sediment basin and flow will be controlled by a low weir.

Spills of Hydrocarbons and other Contaminants

Different organisms and different life-stages of particular organisms react to petroleum hydrocarbon pollution in different ways. The damage to marine biota by petroleum hydrocarbons is determined more by the degree of persistence of the oil than its absolute toxicity when fresh (van Gelder-Ottway 1976). As such contamination arguably poses a greater risk during operation of the proposed development than during the construction phase, the potential impacts of hydrocarbon contamination are discussed in Section 5.3 (marina operation).

Litter and Waste

Litter and waste associated with construction of the marina has the potential to contribute to the degradation of water quality. As appropriate controls will be in place, such as a waste management system and direction of potentially contaminated water and / or sediment during dredging, the risk to water (and sediment) quality from litter and spilt waste from the project area is likely to be very low during construction and operation.

Nutrient Enrichment

Nutrients released from disturbed sediments may increase nutrient loads in the water column, and consequently lead to an increase in phytoplankton densities and reductions in water clarity and seagrass depth distribution (Dennison et al. 1993). Moderate amounts of additional nutrients in the water column can also increase seagrass growth (McRoy & Helfferich 1980). However, as macroalgae are more efficient at absorbing nutrients from the water column than seagrasses or coral, higher levels of nutrient enrichment can lead to an increase in macroalgae growth at the expense of seagrass and coral (Wheeler & Weidner 1983; Zimmerman & Kremer 1986; Lapointe 1997; McCook 1999; Koop et al. 2001). Consequently, benthic macroalgae may overgrow and displace seagrass, whilst drift and epiphytic algae may physically shade seagrass and coral, reducing their growth and distribution (Twilley et al. 1985; Silberstein et al. 1986; Maier & Pregnall 1990; Tomasko & Lapointe 1991). Epiphytic algae may also reduce diffusive exchange of dissolved nutrients and gases at leaf surfaces (Twilley et al. 1985; Neckles et al. 1993). Acute nutrient enrichment may also stimulate the growth of mangrove and saltmarsh (Adam 1990; 1995).

The trophic structure of benthic invertebrate communities often changes with increased nutrient levels, becoming dominated by small opportunistic deposit feeders. In eutrophic estuaries deposit feeding spionid and capitellid polychaete worms often tend to dominate benthic communities.

However nutrient levels in the sediment to be dredged are relatively low, with a mean concentration of up to 49 mg/kg of total nitrogen (in surface sediments of the dredge area) and 0.14 mg/kg of total phosphorus (in bottom sediments). This is substantially lower than total nitrogen concentrations in the sediment at nearby (frequently dredged) boat harbours such as Rosslyn Bay (frc environmental 2008) and Bowen Boat Harbour (frc environmental 2004), and in sediments from Moreton Bay in south-east Queensland (frc environmental 2006; 2007b; a; 2009a).

Based on the relatively low nutrient concentrations in the sediment to be dredged, the impact of any dredging-related acute elevation of nutrient concentrations is likely to be ecologically insignificant and temporary.

Potential Effects on Corals

Elevated nutrient levels can negatively impact coral communities. However different species of corals have very different tolerances. For example, concentrations of dissolved inorganic nutrients are poor indicators of reef status, and the concept of a simple threshold concentration that indicates eutrophication has little validity (McCook 1999).

There is concern that, on the Great Barrier Reef in particular, abundant macroalgae on inshore fringing reefs is a result of degradation due to anthropogenic increases in terrestrial inputs of sediments and nutrients (McCook 1999). Reefs dominated by algae often have lower fish stocks, less tourism appeal and lower coral biodiversity than coral dominated reefs (McCook 1999). Whilst increased nutrient loads and associated macroalgal blooms pervasively and fundamentally alter estuarine ecosystems (Valiela & Foreman 1977), the effects of increased nutrient loads on coral reefs seem equivocal and discordant, and may be confounded by many indirect effects (van Woesik et al. 1999). A high abundance of macroalgae is often a sign of low herbivory in coral systems (Hughes et al. 2007).

The response of the corals themselves to increased nutrients is dependent on light and temperature (D'Elia 1977 cited in van Woesik et al. 1999). Increases in nutrient concentrations can have sub-lethal impacts on hard corals, for example elevated nitrogen levels can stunt coral growth and decrease larval settlement (Koop et al. 2001), (Hughes et al. 2007). In areas of high nutrient enrichment, corals may be out-competed by macroalgae (Lapointe 1997), particularly if nutrient enrichment is accompanied by a significant reduction in herbivores (Mccook et al. 2001). By reducing growth and larval settlement, elevated nutrients may effectively prevent the recovery of corals that have suffered some form of acute stress (e.g. a bleaching event, flood or cyclone damage).

Brief periods of moderate nutrient elevation are not expected to effect corals in the vicinity of the marina.

Acid Sulphate or Potential Acid Sulphate Sediments

Disturbance of intertidal and marine sediments may expose acid sulphate potential sediments to oxidising conditions. A direct effect of the oxidation of pyrite is the lowering of pH. Acidification of both the sediment and adjacent waters may severely impact aquatic flora and fauna within the effected area. Net acidity of the sediments to be dredged was above the action criteria outlined in the *State Planning Policy 2/02* in one (of approximately six) samples at three of five sites. In the remaining samples, the acid neutralising capacity of the sediments would be sufficient to neutralise any acidity from potential acid sulfate soils, and that no treatment would be required, at most sites. Given that sediments will be thoroughly mixed during dredging, impacts to pH in the surrounding waters as a result of dredging are not expected.

Other Impacts, including the Disturbance of Contaminated Sediments

Excavation activities may alter other aspects of water quality. For example, disturbance of sediments in a reducing environment can lead to a significant elevation of biological and chemical oxygen demand, depleting enclosed waters of dissolved oxygen. Increases in bacterial concentration are typically associated with turbid waters surrounding dredging operations (Salvat 1987). Bacteria are known to adhere to suspended solids. Toxicants may also be released from the sediment, though it should be noted that concentrations of toxicants in the sediment to be dredged were below the *National Assessment Guidelines for Dredging* (NAGD) Screening Levels (DEWHA 2009). Depending upon the nature and extent of this release, impacts could range from morbidity and the reduction of reproductive capacity of some species, through to outright mortality of plants and animals.

5.3 Marina Operation

Potential impacts associated with marina operation and associated infrastructure are likely to be primarily linked to human activity, e.g. increased boat traffic, refuelling operations, antifoul leaching and increased litter, together with stormwater run-off (which will be mitigated using retention basins as discussed earlier). The risk of fouling-based TBT introduction is also very low as international vessels will be required to clear quarantine, and potentially be subject to inspection, at their port of entry. Maintenance dredging is unlikely to be required due to the design of the marina.

Copper Contamination

The concentration of copper in the waters of the marina are likely to be higher than in waters outside the marina, due to leachate from boat antifouls. Modelling by Water Technology (2011) predicts a maximum (instantaneous) copper concentration of approximately 5 µg/L in the waters of the marina (Figure 5.12). This predicted maximum is substantially higher than the ANZECC & ARMCANZ 99% protection trigger value of 0.3 µg/L; however the actual concentration is dependent on several factors including leaching rate, number of vessels, tidal / freshwater flushing of the marina, and background concentrations.

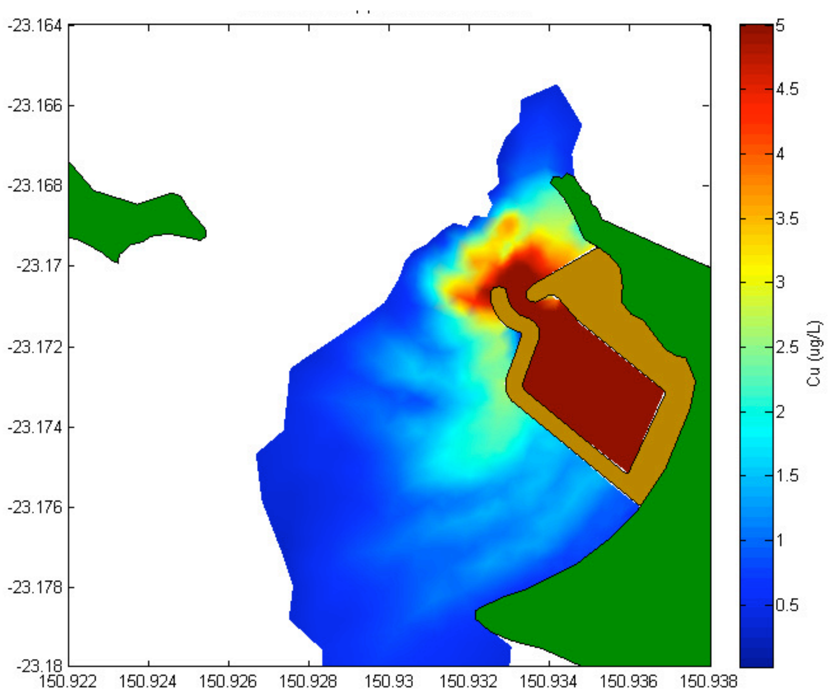

Figure 5.12 Predicted copper concentrations in the water column associated with antifouling leachate.

This maximum concentration is likely to be largely confined to the waters of the marina, and entrance, however concentrations above the ANZECC & ARMCANZ trigger value may extend beyond the marina basin on occasion for short periods of time. Concentrations up to approximately 3 µg/L may reach the corals of Putney Point or seagrass meadows near the marina (both communities are located within approximately 250 m of the marina access channel). This concentration is diluted to below the ANZECC & ARMCANZ trigger value by the time the waters reach Passage Rocks, southern Putney Beach and beyond Putney Point. These values compare with copper concentrations <1 µg/L n the waters of the proposed marina and up to 3.2 µg/L in Putney Creek.

Copper is a naturally occurring substance that can persist indefinitely and is accumulated in flora and bio-accumulated in fauna (ANZECC & ARMCANZ 2000). While copper is an essential trace element required by most aquatic organisms, it can be toxic to marine flora, invertebrates and fishes at concentrations not much higher than those facilitating optimal growth in algae. Copper toxicity typically occurs when the uptake rate exceeds the rates of excretion or detoxification by physiological or biochemical processes, although some organisms have physiology that prevents toxicity, including the seagrass *H. uninervis,* macroalgae and some corals (as discussed below). Copper is commonly bio-regulated by organisms, e.g. algae and fish release dissolved organic ligands that bind copper and control its uptake and bioavailability (ANZECC & ARMCANZ 2000) (Gledhill et al. 1997and references contained within).

Copper toxicity is affected by water chemistry. The bioavailability and toxicity of copper in marine waters is high variable and dependent on several factors such as pH, dissolved organic matter / carbon (DOM / DOC), salinity and redox potential, together with the copper species (ion) and ligands (copper atoms bond with ligands to form a metal complex) present in the water column(e.g. Erickson et al. 1970; Ahsanullah & Florence 1984; Meador 1991; Gledhill et al. 1997) and references cited within, (and references cited within, Markich et al. 2001; Gorski & Nugegoda 2006). Toxicity in marine plants, invertebrates and fishes generally decreases with pH, and increases with salinity (ANZECC & ARMCANZ 2000). Marine invertebrates appear to be able to accumulate metal concentrations in their tissues several-times higher than the surrounding water and survive (Barka 2007). Copper is absorbed strongly by suspended material. Sorption onto minerals, clays and biotic surfaces and precipitate play a major role in determining the fate of Cu(II), and increases with pH to about 8. The free hydrated Copper ion (Cu^{2+}) and copper hydroxy species are thought to be the most toxic to aquatic organisms (ANZECC & ARMCANZ 2000) (Gledhill et al. 1997and references cited within).

Potential Impacts on Seagrasses and Macroalgae

Copper is an important trace element in plant nutrition and is required for activation of certain enzymes, but in excess becomes toxic (Raven et al. 1986). Copper compounds are toxic to plants at only slightly higher than normal levels, and can affect plants by inhibiting a large number of enzymes, interfering with several aspects of plant biochemistry (e.g. photosynthesis, pigment synthesis, and membrane integrity) and reducing growth (Cornell University 1994). Copper can be incorporated into seagrasses through the water column and sediment. Copper can also induce senescence (Fernandes & Henriques 1991).

The sensitivity of seagrasses to copper varies between and within species, and appears to be primarily related to physiology rather than other factors such as morphology (e.g. Pulich 1983; Prange & Dennison 2000; Thangaradjou et al. 2010). A study of five seagrass species from Port Curtis and Moreton Bay revealed three different responses to copper exposure: accumulation, exclusion and toxicity. *Halodule uninervis* (the dominant species near the proposed marina site) accumulated copper, however elevated concentrations did not appear to effect condition (photosynthesis and amino acid content); this species appears to have physiological mechanisms to cope with copper toxicity, as do some terrestrial and algal species (Bassi & Sharma 1993; Peterson 1993). Copper was toxic to *H. ovalis* and *H. spinulosa,* both of which grow near the proposed marina site, together with *Z. muelleri* (Prange & Dennison 2000). Pulich (1983) reported that *Halophila engelmanni* do not typically accumulate copper (as copper sulphate), due to a complex interaction between copper, roots and root microorganisms.

The following tolerances have been reported:

- *Halophila ovalis* reduced growth when exposed to 500 µg/L of copper but continued to grow for up to 18 days, and exposure to 200 µg/L of copper for extended periods of time prevented growth (Ambo-Rappe et al. 2011).
- Photosynthesis was reduced in *H. ovalis* exposed to 1 000 µg/L of copper and concentrations of 5 000 to 10 000 µg/L had a lethal effect (Ralph & Burchett 1998).

Tolerance information is not readily available for the most widespread species near the marina, *H.uninervis.*

The sensitivity of macroalge to copper varies between species, and life stages. Early life stages (zoospore and gamete) appear to be sensitive to copper however later life stages (settlement and germination) appear to be relatively tolerant (e.g. Chung & Brinkhuis 1986; Anderson et al. 1990; Garman et al. 1994). Some species have physiological mechanisms of tolerance including exclusion and intracellular de-toxification, and some species may undergo genetic adaptation to copper (Klerks & Weis 1987). Copper concentrations up to 5000 µg/L have not affected two temperate macroalgae (*Ascophyllum nodosum* and *Fucus vesiculosusi)* (Connan & Stengel 2011); *F. vesiculosusi* is known to grow in chronically contaminated waters (Bryan & Gibbs 1983).

The seagrass meadows near the marina are likely to be largely unaffected by the predicted maximum copper concentration that may occur in the water column (up to 3 µg/L), given seagrass are relatively tolerant to copper (no change to condition when exposed to concentrations up to at least 500 µg/L but as high as 10 000 µg/L). Observations of several marinas in the Whitsundays and Moreton Bay show prolific algal growth on pontoons and piles: actual impacts are consequently considered likely to be significantly less than indicated through modelling.

Potential Impacts on Corals

The sensitivity of scleractinian corals to copper varies with the species of coral and algal symbiont. Bastidas and Garcia (1999) reported no copper accumulate in coral (animal) tissue, while other metals (aluminium, iron, chromium and calcium) accumulated. Howard and Brown (1984) reported that metals may accumulate in coral tissue after long-term exposure but are not likely to affect living tissue. Bielmyer et al (2010) reported no effect on symbiont (*Symbiodinium*) communities. Other researchers report that copper exposure affects symbiont density and / or efficiency, photosynthesis, carbonic anhydrase (an indicator of stress) and / or skeletal growth (e.g. Peters et al. 1997; Gilbert & Guzman 2001; Reichelt-Brushett & McOrist 2003; Bielmyer et al. 2010).

The following tolerances have been reported:

- Laboratory-reared *Acropora cervicornis*, *Pocillopora damicornis*, and *Montastraea faveolata* exhibited significantly different sensitivities to copper, with effects occurring in *A. cervicornis* and *P. damicornis* at concentrations of 4 µg/L. Copper accumulated in the symbiont and animal tissue of *A. cervicornis* and the animal tissue of *M. faveolata*, with no effect on the symbiont. Copper accumulation was not detected in the symbiont or animal tissue of *P. damicornis* (Bielmyer et al. 2010).
- Symbiont loss in *Montipora verrucosa* exposed to concentrations above 10 µg/L (Howard & Brown 1984)
- Cross-fertilisation trials involving *Goniastrea aspera, Favites chinensis* and *Platygyra ryukyuensis* reported a 50% reduction in fertilisation when gametes were exposed to concentrations ≥10 µg/L (copper sulphate) and inhibition of fertilisation at concentrations ≥50 µg/L (Heyward 1988).
- *Acropora formosa* lost symbionts at copper concentrations of 20 to 40 µg/L, and most corals dies after 48 hours of exposure to 40 µg/L (Jones 1997).
- The settlement success of *Acropora tenuis* (from nearby Magnetic Island) was reduced by concentrations > 42 µg/L, while concentrations of 200 µg/L killed all larvae (Reichelt-Brushett & Harrison 2000).
- *Pocillopora damicornis* was severely stressed by concentrations of 50 µg/L (Mitchelmore et al. 2007).
- Fragments of *Galaxea fascicularis* tolerated concentrations up to 10 000 µg/L (Sabdono 2009).

The communities of Putney Beach are sparse, patchy reefs dominated by *Turbinaria* sp. and the soft coral *Sarcophyton* sp., together with *Porites* spp. and massive corals from the families Faviidae and Mussidae. As discussed above, species from these genera and families are relatively tolerant to copper, e.g. *Montastraea faveolata* (from the family Favidae) was not affected by copper concentrations up to 4 µg/L, while *Favites chinensis and Platygyra ryukyuensis* (from the family Favidae) were not affected by copper concentrations up to 10 µg/L.

The coral communities near the marina are likely to be largely unaffected by the predicted maximum copper concentration that may occur in the water column (up to 3 µg/L), given corals are relatively tolerant to copper (no change to condition when exposed to concentrations up to at least 4 µg/L but as high as 10 000 µg/L).

Effects on other Invertebrates and Vertebrates

The effect of increased suspended solid concentrations and sediment deposition on invertebrates other than corals and coral-associated sessile invertebrates and vertebrates such as fish and reptiles is likely to be minimal, primarily because mobile organisms tend to avoid unfavourable environments.

Hydrocarbon Contamination

Chronic hydrocarbon pollution can result from the synergistic effects of small, frequent spills. Such a pattern of spillage may be commonly associated with the refuelling of smaller crafts at marinas, other purpose built and ad hoc refuelling facilities and boat ramps (GBRMPA 1998; Cullen Grummitt & Roe Pty Ltd 2000). Marinas that support considerable activity, including pleasure boat marinas, boat repair facilities and commercial fishing operations have significantly higher levels of both aromatic and aliphatic hydrocarbons than estuaries seldom used by boats (Voudrias & Smith 1986). The small-scale spills commonly associated with small-scale refuelling operations are rarely reported or treated: the petrol, diesel or oils are left to disperse under essentially natural conditions.

In contrast to the comprehensive consideration given to the effects of large scale or ‘industrial’ fuel and oil spills, the effects of small-scale fuel spills have been very poorly documented. However, it is clear that the chronic presence of hydrocarbons has the potential to cause locally significant impacts. Low levels of petroleum hydrocarbons in the aquatic environment are adsorbed onto, or incorporated into, the sediments, where they may persist for years (Voudrias & Smith 1986; Pelletier et al. 1991). A large number of small-scale oil spills may lead to a significant increase in hydrocarbons over time, in effect resulting in a ‘permanent’ impact. Mangrove sediments in particular may serve as long-term reservoirs for chronic contamination holding hydrocarbons for periods in excess of 5 years (Burns et al. 1994). Clearly, in determining the potential for chronic contamination at a particular site, characteristics of flushing and sediment stability need to be considered.

Whilst acute (or at least a 'one off') contamination may result in severe ecological consequences, communities generally recover over time. In contrast, chronic contamination can result in the 'permanent' (or at least for the duration of contamination) morbidity or localised extinction of flora and fauna. Floral communities and sessile faunal communities (such as the many groups of invertebrates that develop attached to the substrate) are clearly most at risk from chronic hydrocarbon pollution. As these communities often form a critical component of 'habitat' (providing structural complexity, shelter and often food), a 'permanent' impact to these communities may have a consequentially widespread impact on the mobile components of the original faunal community, including the fishes and crustacea.

Whilst 'one off' spills of great volume have the potential to severely impact a large area, recovery is likely; chronic small spills, though probably influencing a lesser area, effectively prevent recovery and lead to cumulative impacts. Frequent spills from a diffuse number of locations within a waterway can in concert, resulting in an enduring impact over a very wide area.

Several studies have characterised the potential impacts of hydrocarbons in marine systems, however there is very little quantitative data readily available for specific communities. The potential impacts of hydrocarbons on seagrass range from mortality to sublethal stress and chronic impairment of metabolism (e.g. Consentino-Manning et al. 2010 and references cited therein). Mangroves have been shown to reduce growth rates and seedling survivorship due to acute and chronic hydrocarbon contamination (e.g. Proffitt et al. 1995). The potential impacts of hydrocarbons on corals range from mass mortality to loss of zooxanthellae, reduced growth and tissue degradation, with reduced growth and tissue degradation impairing settling ability (recruitment) and competition for space (e.g. Reimer 1975; White & Strychar 2010). The effect of hydrocarbons on invertebrates other than corals and coral-associated sessile invertebrates and vertebrates such as fish and reptiles is likely to be minimal, primarily because mobile organisms tend to avoid unfavourable environments. The hydrocarbon type and concentration, together with environmental factors (e.g. wave and wind action) and previous exposure influence the severity of impact.

Litter and Waste

Litter and waste associated with operation of the marina has the potential to contribute to the degradation of water quality. As appropriate controls will be in place, such as a waste management system, the risk to water (and sediment) quality from litter and spilt waste from the project area is likely to be very low during construction and operation.

Maintenance Dredging

Maintenance dredging is unlikely to be required due to the design of the marina, but has the potential for the same suite of impacts to water quality as capital dredging.

5.4 Wastewater Wet Weather Outfall

There may be short-term impacts to marine water quality during construction of the wastewater treatment plant ocean outfall, including increased turbidity (and subsequent sedimentation) associated with disturbing the substrate or shallow dredging, hydrocarbon spills, and increased litter. Potential impacts will be similar to the suite described above for the marina development.

Potential impacts to marine water quality during operation of the wastewater treatment plant include the potential for nutrient enrichment following release via the ocean outfall. However impacts to water quality and ecosystem functioning are likely to be negligible as the wastewater will, as a minimum, be treated to meet section 135(4) of the *Great Barrier Reef Marine Park Regulations 1983* (Opus International Consultants (Australia) Pty Ltd 2011b).

Modelling by Water Technology (2011) predicts an absolute maximum total nitrogen and phosphorus concentration of up to approximately 280 and 100 µg/L respectively (based on very conservative modelling and calm conditions with no mixing). This is above the ANZECC & ARMCANZ trigger value of 140 and 20 µg/L respectively, however concentrations will be diluted to a concentration below the respective trigger value before they reach sensitive ecological communities.

Potential impacts associated with nutrient enrichment, while unlikely, would be similar to the suite described above for the marina development. The closest sensitive ecological communities are coral and seagrass, which are approximately 600 and 700 m from the outfall respectively. Nutrient concentrations are at ambient levels in the water column over these communities.

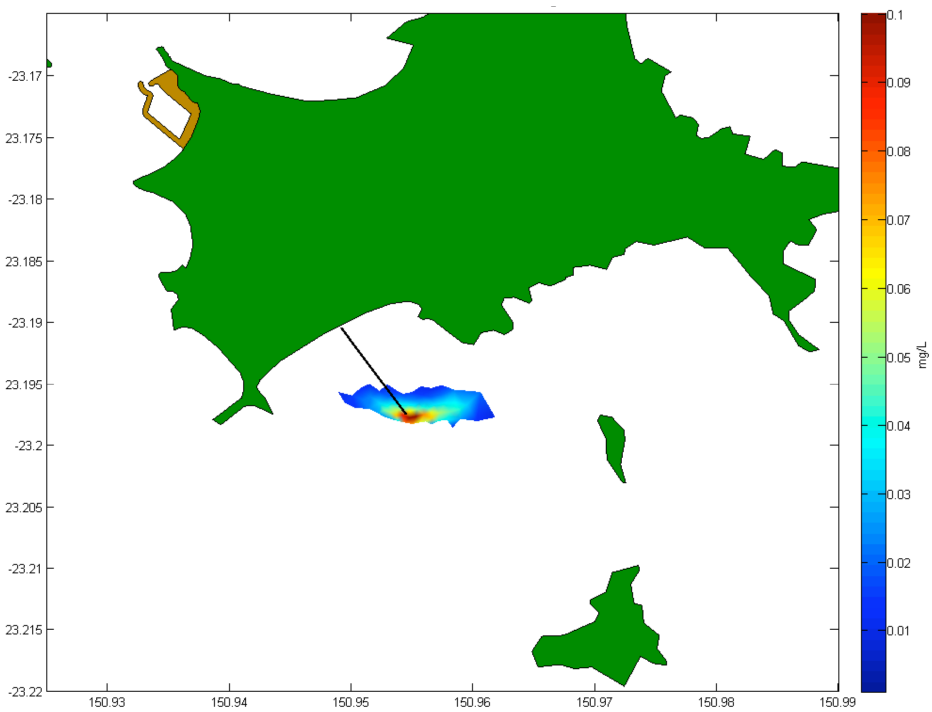

Figure 5.13 Predicted maximum total nitrogen concentrations in the water column associated with the wastewater wet weather outfall.

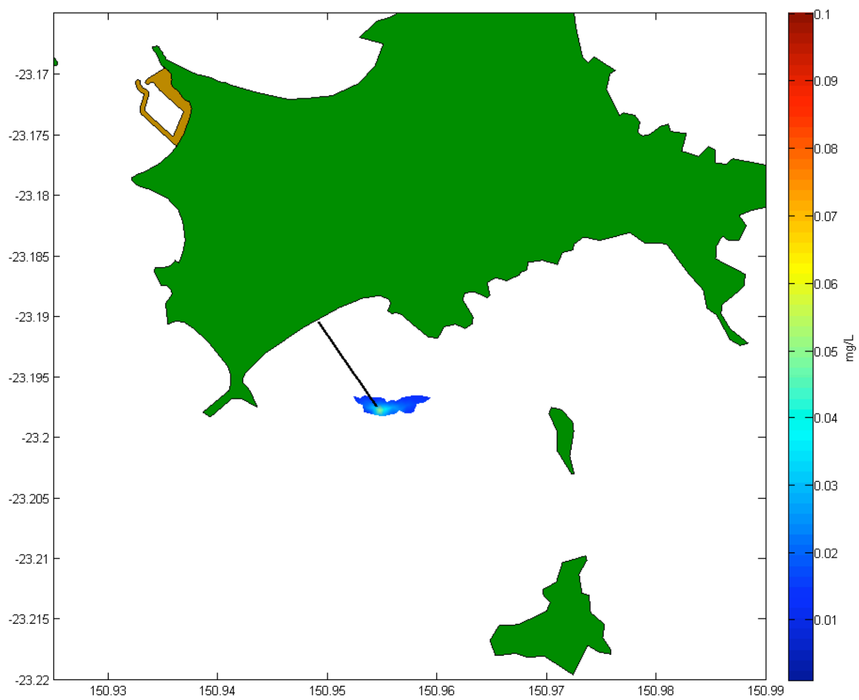

Figure 5.14 Predicted maximum total phosphorus concentrations in the water column associated with the wastewater wet weather outfall.

5.5 Submarine Cables

There may be short-term impacts to marine water quality associated with the installation of the submarine cables, including increased turbidity (and subsequent sedimentation) associated with shallow dredging (to 1.2 m), hydrocarbon spills, and increased litter. Potential impacts will be similar to the suite described above for the marina development. Sediment quality has not been assessed along the cable alignment however sediment quality is likely to be ‘good’ based on assessment of surface sediments at Kinka Beach.

Potential impacts to marine water quality during operation are likely to be negligible.

5.6 Golf Course Precinct

Potential impacts to marine water quality during construction of the golf course are likely to be negligible.

Nutrient Enrichment and Other Potential Contaminants

Short-term impacts to marine water quality during operation of the golf course include the potential for nutrient enrichment following stormwater run-off or water storage overflow. However impacts to water quality and ecosystem functioning are likely to be negligible as the wastewater will, as a minimum, be treated to meet section 135(4) of the *Great Barrier Reef Marine Park Regulations 1983* (Opus International Consultants (Australia) Pty Ltd 2011b). None the less, potential impacts associated with nutrient enrichment on mangrove forests in discussed below, and potential impacts associated with nutrient enrichment in freshwater ecosystems is discussed in Appendix G (Freshwater Ecosystems).

Studies have shown that growth of mangrove forests can be increased by nutrient enrichment. However, nutrient enrichment stimulates growth of shoots, rather than roots, and enhances growth rates can increases vulnerability to environmental stresses at the root-level (i.e. plant water relationships), such as high salinity and low humidity (both of which require root development to meet the water demands of shoots). That is, the benefits of increased growth in response to nutrient enrichment can be offset decreased resilience due to mortality during drought (Lovelock et al. 2009).

The concentrations of nutrients which indicate or cause nutrient enrichment are dependent on the mangrove species and ecosystems, with some able to cope with nutrient stress better than others (Zann 1995). Table 5.1 lists the nutrient concentrations at which observable increases in mangrove plant growth have occurred.

Table 5.1 Nutrient concentrations at which observable increases in mangrove plant growth have occurred in estuarine water bodies (from AEC 1987 cited in Zann 1995).

Water Body / Area	Total nitrogen (µg/L)	Total phosphorous (µg/L)
Hawkesbury Nepean estuary (NSW)	650	55
Peel/Harvey estuary (WA)	150	25
Lake Macquarie (NSW)	600	60

Studies have shown that mangroves growing in sediment with high nitrogen concentrations are typically stressed or dead / dying. It's important to note that concentrations of total extractable nitrogen in mangrove sediments vary with sediment type, with higher levels in finer deposits (Alongi & Christoffersen 1992), and that there are a variety of factors that may have also synergistically contributed to the stress of mangroves in these areas.

Total nitrogen concentrations in mangrove sediment usually range from 600 to 2000 mg/kg (Clough et al. 1983) and total phosphorous from 100 to 1600 mg/kg (Alongi & Christoffersen 1992). At Whyte Island in Moreton Bay, in areas of dead or stressed mangroves, total nitrogen in the sediment ranged from 2520 to 3230 mg/kg and total phosphorous from 134 to 1080 mg/kg (WBM Oceanics 2002b). In areas of stressed or dead mangroves at Fisherman Islands, also in Moreton Bay, total nitrogen ranged from 260 to 2540 mg/kg and total phosphorous ranged from 170 to 494 mg/kg (WBM Oceanics 2002a). At Fisherman Islands apparently healthy mangroves grew in sediments with total nitrogen ranging from 740 to 1570 mg/kg and total phosphorous ranging from 360 to 526 mg/kg (WBM Oceanics 2002a).

As the impact of an increase in nutrients in mangroves appears to be mediated through an increase in algae such as *Ulva* spp. and *Enteropmorpha* spp., the response of these to increased nutrient concentrations will be considered in future reports. *Ulva* invasion needs constant eutrophication of the water column (Cappo et al. 1998).

These concentrations, together with values recorded during the baseline survey of the project area, could be used to set sediment quality guildelines for the development.

Environmental Flows

Capture of stormwater run-off on the golf course, for retention and treatment, is likely to reduce environmental flows in downstream freshwater and estuarine (i.e. mangrove forests) ecosystems. Reduced environmental flows have the potential to negatively affect water quality, sediment quality, flora and fauna.

The potential impact to freshwater ecosystems is considered minor as waterways are ephemeral (i.e. dry for much of the year) and large parts of the catchment area will not be affected by the golf course development (i.e. will continue to provide seasonal environmental flows in downstream environments). The impact will be negligible where environmental flows are maintained, i.e. treated water is released form the water storage facilities in similar quantities and with similar timing to natural flows.

The potential impacts to the mangrove forests of Leeke's Creek are considered manageable where environmental flows are maintained. Reduced environmental flows are likely to negatively impact on mangrove forests as the distribution and condition of forests are influenced by factors such as (Duke et al. 2003):

- salinity of the interstitial water (i.e. in the sediment / soil)
- drainage of the sediment / soil, and
- exposure to freshwater.

Salinity of interstitial water is an important factor regulating growth, height, survival and zonation of mangroves and saltmarsh plants (Hutchings & Saenger 1987). Salinity of interstitial water is dependent on freshwater inputs (i.e. environmental flows) together with factors such as:

- salinity of the ocean or estuarine water
- period and frequency of inundation
- evaporation due to high temperature or wind
- soil type, and
- plant cover.

Mangrove species differ in their ability to withstand poorly drained soils. Hutchings & Saenger (1987) produced a tentative grouping of mangroves based on the soil water content in which they grow. In general, saltmarsh species are more tolerant of high salinities than mangroves. Of the mangroves:

- *A. marina* grows over the largest salinity range
- *Aegiceras corniculatum* grows over a broad range, although not as great as *A. marina*, and
- *Rhizophora stylosa, Bruguiera gymnorrhiza* and *Ceriops tagal* grow at salinities three to four times the concentration of seawater (Hutchings & Saenger 1987).

There will be negligible impact to mangrove forests where environmental flows are maintained. Where environmental flows are not maintained, a decline in mangrove condition is likely in the sort-term with shifts in community composition in the longer term (e.g. increasing distribution of saltmarsh and more salt-tolerant mangroves species, with a decreasing distribution of less salt-tolerant species). This shift could be exasperated by climate change and sea level rise.

6 Cumulative Impacts

6.1 Nearby Tourism Developments

Nearby tourism developments identified by GBRMPA for assessment include:

- Rosslyn Bay Inn (as known as the Rosslyn Bay Resort), Rosslyn Bay, approximately 15 km to the west
- Seaspray Resort and Spa, Zilzie (near Emu Park), approximately 18 km to the south west
- Zilzie Bay, Zilzie, approximately 20 km to the south west, and
- Mercure Capricorn Resort, Yeppoon, approximately 24 km to the north west.

Rosslyn Bay Inn

The Rosslyn Bay Inn is a relatively large (29 studio and suite rooms, 6 ocean view balcony apartments and 12 private spa bungalows) inn located between Keppel Bay Marina (Rosslyn Bay Harbour) and Kemp Beach. Activities offered by the inn (relevant to aquatic ecology) include beach and harbour fishing, snorkeling and diving, charters and day cruises to Great Keppel Island, sailing, surfing, general activities along the shoreline, and national park walks. There are similarities in the potential impacts associated with the Rosslyn Bay Inn and the proposed Great Keppel Island development, including:

- depletion of recreational fisheries
- marina activities such as dredging, mooring of vessels, disposal of effluent from vessels, litter and waste, hydrocarbons spills and copper contamination (associated with antifoul)
- trampling (physical destruction) of coral reef adjacent to the resort and around Great Keppel Island
- increased boat traffic associated with day cruises to Great Keppel Island, and associated boat strike of dugongs and marine mammals
- interactions with marine mammals and turtles in association with sailing and other water sports (although boat strike is not expected to be a major issue where motor boats are not offered for guest usage)

- degradation of coastal ecosystems (e.g. sandy and rocky shores) associated with litter and waste, habitat destruction, and collection of shells and other coastal resources as souvenirs, and
- disturbance to turtle nesting activities, assuming there is some turtle nesting on Kemp Beach.

Seaspray Resort and Spa

The Seaspray Resort and Spa is a relatively small resort (17 two and three bedroom fully self contained apartments) located adjacent Cocoanut Point National Park; this resort is not beachside. Activities offered by the resort (relevant to aquatic ecology) include nature hikes within the Cocoanut Point National Park and Wetlands Reserve. There are similarities in the potential impacts associated with the Seaspray Resort and Spa and the proposed Great Keppel Island development, including:

- degradation of coastal ecosystems associated with litter and waste, habitat destruction, and collection of shells and other coastal resources as souvenirs, and
- degradation of freshwater ecosystems as discussed in Appendix G (Freshwater Ecosystems).

Zilzie Bay

Zilzie Bay is an urban development (accommodation) with the first synthetic gold course alongside the Great Barrier Reef. Potential cumulative impacts include:

- degradation of coastal ecosystems associated with litter and waste, habitat destruction, and collection of shells and other coastal resources as souvenirs
- disturbance to turtle nesting activities, assuming there is some turtle nesting along the resort's shoreline,
- degradation of freshwater ecosystems as discussed in Appendix G (Freshwater Ecosystems).

Mercure Capricorn Resort

The Mercure Capricorn Resort is a large (281 rooms) beachside resort at Yeppoon. The resort's facilities (relevant to aquatic ecology) include two international golf courses, guided beach horse riding, sea kayaks, stand up paddle boards, beach fishing, wetland canoe eco-tours, Great Keppel Islands tours and general activities along the shoreline. There are similarities in the potential impacts associated with the Mercure Capricorn Resort and the proposed Great Keppel Island resort rejuvenation, including:

- run-off from the golf course, particularly nutrients from fertilisers
- trampling (physical destruction) of coral reef adjacent to the resort and around Great Keppel Island
- increased boat traffic associated with day cruises to Great Keppel Island, and associated boat strike of dugongs and marine mammals
- degradation of coastal ecosystems associated with litter and waste, habitat destruction, and collection of shells and other coastal resources as souvenirs
- disturbance to turtle nesting activities, assuming there is some turtle nesting along the resort's shoreline, and
- degradation of freshwater ecosystems as discussed in Appendix G (Freshwater Ecosystems).

Potential Impacts Associated with the Resort Developments

The extent of potential impact in association with the operation of the Great Keppel Island development is likely to be minimal where appropriate mitigation measures are developed and adhered to. The cumulative impact of the operation of the Great Keppel Island development and nearby resorts is therefore also likely to be negligible for most potential impacts that the resorts have in common. For example:

- potential impacts to recreational fishing are expected to be minor where managed in accordance with fisheries regulations (e.g. bag limits and no catch species) and Great Barrier Reef Marine Park (GBRMP) zoning at all resorts
- potential impacts associated with marina activities are expect to be minor where managed through marine-specific Environmental Management Plans (EMPs) at Great Keppel Island and the Keppel Bay Marina, including the Dredge Management Plans and Spill Management Plans
- potential impacts associated with trampling of coral reef is expected to be minor where managed through guided tours and in accordance with GBRMP zoning and regulations; impacts to reef environments at each of the resorts are unlikely to have a cumulative impact given each respective reef is unlikely to rely on other

respective areas for ecosystem functioning (many resident coral reefs species have small home ranges), and there are large areas of coral reef near each of the resorts (e.g. fringing the mainland, Middle Island and other islands of the Keppel Group) that can contribute to local and regional ecosystem functioning for transient coral reef species

- potential impacts associated with degradation of coastal ecosystems (associated with litter and waste, habitat destruction, and collection of shells and other coastal resources as souvenirs) are considered minor where managed through the EMP and GBRMP and national park regulations; impacts to coastal environments at each of the resorts are unlikely to have a cumulative impact given each respective reef is unlikely to rely on other respective areas for ecosystem functioning (many resident coral reefs species have small home ranges), and there are large areas of coral reef near each of the resorts (e.g. fringing the mainland, Middle Island and other islands of the Keppel Group) that can contribute to local and regional ecosystem functioning for transient coral reef species
- potential impacts associated with disturbance to turtle nesting is expected to be minimal where construction activities are undertaken outside of the nesting season and in accordance with the EMP, and resort lighting is not directed to the shoreline (particularly considering beaches around the Great Keppel Island and along the mainland adjacent to each of the resorts are not major rookeries for marine turtles), and
- potential impacts associated with nutrient-laden run-off from the golf courses are considered negligible where all run-off is captured for treatment (there will be no impact to the downstream ecosystems of Leeke's Creek).

There is a risk of cumulative impact associated with visitation to Great Keppel Island by nearby resort guests, such as litter and waste, hydrocarbon spills, boat strike, disturbance of nesting turtles and trampling of coral. Where nearby resorts apply the same mitigation measures as those proposed by the Great Keppel Island resort, and adhere to GBRMP and other regulations, impacts are expected to be manageable. There remains the potential for a major cumulative impact where island visitation is not managed collaboratively.

6.2 Climate Change

Climate change is associated with an enhanced 'greenhouse effect', i.e. increased levels of greenhouse gases (mostly carbon dioxide) trap more heat and warm the Earth. There is now consensus that emissions from human activities are largely responsible for increased greenhouse gas concentrations and the associated global warming. Climate change is a global issue that is likely to have a catastrophic effect on the Great Barrier Reef and coastal ecosystems, specific threats include:

- rising sea level
- increasing sea temperature
- increasing ocean acidification, and
- more extreme weather events such as flooding and storms (GBRMPA 2009a; Hoegh-Guldberg & Bruno 2010 and references cited within).

Sea Level

Sea level across the Great Barrier Reef has risen by approximately 3 mm per year since 1991. Rising sea level poses a threat to low-lying islands, coral cays and coastal ecosystems such as mangroves, saltmarsh, seagrass beds and coral reefs (Hoegh-Guldberg & Bruno 2010). Most coral reefs will probably survive sea level rise of 3 mm per year, as the maximum rate of reef growth is approximately twice this rate. However the rate of sea level rise is predicated to increase and coral reefs may not be able to survive at predicted depths, and the shape and existence of some coral reef islands may change. Sea level rise may also extend the landward extent of marine communities such as mangroves and saltmarsh at the expense of freshwater communities (Lovelock & Ellison 2007; GBRMPA 2009a)and references cited within). Rising sea level poses a significant risk to conservationally significant species such as turtles and sea birds through the erosion of critical nesting and roosting habitat on may low-lying coral cays and islands, especially when combined with more extreme storms which will cause increased erosion of these habitats (GBRMPA 2005).

Sea Temperature

In the last century, the average sea surface temperature of the Great Barrier Reef has increased by 0.4^{o}C. Sea temperature is critical to coral reef growth and survival. When sea temperature thresholds are exceeded, physiological processes breakdown, for example the symbiotic association between coral and clam (animal) and the symbiotic zooxanthellae (which live within the animal tissue) breakdown when water temperatures reach thresholds. This temperature stress, in combination with sunlight, causes mass bleaching in corals and other reef organisms that have symbiotic algae in their tissues (e.g. clams) (GBRMPA 2009a and references cited within). Increased sea temperature can also cause seagrass burning (i.e. loss of biomass and meadow extent), with flow-on effects to marine turtles, dugongs and juvenile fishes and invertebrates that rely upon seagrass meadows for food and refuge (GBRMPA 2005).

Ocean Acidification

In the last century, the pH of the ocean has decreased by 0.1 units (i.e. become more acidic) and recent studies on the Great Barrier Reef suggest that coral growth is already being affected. Unprecedented declines in calcification of 14.2% in *Porites* spp. have been reported since 1900, and appear to be related to both increasing temperature stress and acidification (GBRMPA 2009a and references cited within). Other calcifying species such as molluscs, crustaceans and other plankton taxa may also be impacted.

The interaction with ocean acidification and increased storms may also pose a problem for corals. Increased acidification has the potential to weaken coral skeletons and will consequently be more susceptible to even low intensity storms (Madin & Connolly 2006).

Extreme Weather Events

Cyclones can cause substantial damage to coral reefs, seagrass meadows, mangrove forests and other coastal ecosystems (Gardner et al. 2005). Current global patterns of tropical cyclones indicate an increase in severity, and associated destruction of ecological communities (Walker et al. 2008). In Australia, there were fewer cyclones during the period 1970 to 1997, however there was an increase in the severity of those cyclones. Projections indicate an increase in the intensity and associated destructive potential of cyclones, rather than the frequency (Walsh & Ryan 2000 ; Webster et al. 2005; GBRMPA 2009a and references cited within).

There will also likely be increased intensity in both high rainfall events (and associated flooding) and droughts (GBRMPA 2009a and references cited within), all of which have the potential to impact coral reefs, seagrass meadows, mangrove forests and other coastal ecosystem.

The 1-in-100-year storm tide event is projected to increase by 51 cm in Gladstone and 32 cm at Cape Clinton, under certain conditions (i.e. a 30 cm sea-level rise, 10% increase in cyclone intensity and frequency, and a 130 km shift southwards in cyclone tracks) (DERM 2012).

Projections for the Great Barrier Reef

The pre-industrial concentration of atmospheric carbon dioxide was approximately 277 ppm and the current concentration is approximately 387 ppm. Carbon dioxide projections have not been developed for the Great Barrier Reef; however the following vulnerabilities have been predicted for different concentrations of atmospheric carbon dioxide (GBRMPA 2009a and references cited within):

- At 400 ppm, the frequency of mass bleaching is likely to increase, leading to the dominance of relatively thermally tolerant species. Acidification is expected to be affecting the growth of coral species and coralline algae.
- At 450 ppm, severe mass bleaching is predicted to occur annually with 34% of reefs on the Great Barrier Reef above the critical threshold for bleaching. Ocean acidification is likely to further affect the growth of most calcifying organisms, with reefs increasingly dominated by non-calcareous macroalgae and other non-calcifying organisms. Islands and coastal habitats are likely to be experiencing rising sea levels.
- At 500 ppm, there is likely to be reduced density and diversity of corals, with flow-on effects to other species reliant on coral reef habitats (especially fish). Marine mammals and seagrasses are likely to be affected by the flow-on effects of increasing sea temperatures.
- At 550 ppm, critical limits for coral bleaching would be reached for 65% of reefs on the Great Barrier Reef. Coral reef habitats are expected to erode rapidly. Increasing ocean acidification is likely to impact calcareous forms of macroalgae such as *Halimeda* sp. and cause shifts in community composition of plankton.

The following management responses have been employed to help mitigate the threats of climate change on the Great barrier Reef:

- 'The GBRMPA Zoning Plan ensures all of the habitat types in the Great Barrier Reef are adequately protected. By preserving a portion of each habitat type in a network of protected areas, plants, corals and animals are protected, and connectivity between habitats is maintained.
- The GBRMPA is also working to reduce pressure on the reef from declining water quality through the Reef Water Quality Protection Plan. The aim is to develop on-ground initiatives that help decrease water pollutants from entering the reef. The

latest results for marine water quality can be found in the Annual Marine Monitoring Report 2006.

- The Coral Bleaching Response Plan has improved our ability to predict bleaching risk, detects early warning signs of major coral bleaching events, involves the community in monitoring the health of the reef, and raises awareness about bleaching.

Keppel Bay reefs are being used to trial management responses to climate change. No Anchoring Areas are being trialled as a measure to increase the resilience of reefs against the impacts of climate change (and other disturbances such as flooding). Four sites have been selected for the No Anchoring Areas trial: Barren Island, Humpy Island and both Big Peninsula and Monkey Beach reef on Great Keppel Island. In addition, the peak Queensland marine aquarium fishing industry body (Pro-Vision) also instigated a voluntary moratorium on the commercial take of certain anemonefish and anemone species, following the 2006 bleaching event; as a pro-active measure to increase the resilience of reef ecosystems and aid recovery. A monitoring program, linked to BleachWatch, is also being undertaken to provide information on ecosystem condition health at sites regularly visited by commercial aquarium fishermen (GBRMPA 2011).

Potential Impacts Associated with the Development and Climate Change

Seagrass meadow and coral reef communities in the immediate vicinity of the marina and (possibly) the wastewater wet weather outfall are likely to be negatively impacted by the proposed development. The water quality and mangroves communities of Putney Creek are likely to be positively impacted in the longer term, as may the faunal communities of the marina given the additional physical habitat (hard surfaces) for sessile and mobile epibenthic fauna (e.g. algae, corals, sponges, ascidians and gastropods) and mobile fauna (e.g. fish, sharks and marine turtles seeking refuge and / or food).

The direct impacts of the proposed development are likely to have a substantial impact on the resilience of flora and fauna to other disturbances such as climate change. However the potential cumulative impacts of the proposed development on these species and ecosystem functioning, associated with climate change, are likely to be negligible at the time scale predicted for many climate change impacts (i.e. 30 to 50 years). For example:

- more extreme rainfall and flooding of the Fitzroy River has the potential to completely smother large areas of seagrass and cause large areas of corals to bleach (due to stress associated with high turbidity and inputs of freshwater and potential contaminants) at regular intervals for the foreseeable future (thereby also impacting recovery), whereas a relatively small area of seagrass will be lost to the marina in the short term, and an even smaller area of seagrass may be smothered by modified sedimentation patterns in the medium term

- more extreme cyclones have the potential to physically destroy seagrass meadows and coral reefs (particularly where weakened by ocean acidification) and mangroves forests at regular intervals for the foreseeable future (thereby also impacting recovery), whereas a relatively small area of seagrass and even smaller area of coral will be lost to the marina in the short term, and an even smaller area of seagrass may be smothered by modified sedimentation patterns in the medium term (no major negative impact to mangroves predicted in association with the development), and
- rising sea temperature and increased ocean acidification have the potential to increase coral bleaching and erode calcium carbonate reef structures, whereas a relatively small area of coral will be lost to the marina in the short term with no major impact associated with the development predicted to occur in the medium to long term, and
- increased ocean acidification is likely to effect calcareous algal and plankton communities with flow-on effects to predators such as herbivorous fishes and planktivorous vertebrates (e.g. manta rays), whereas the development is unlikely to have a major negative impact on algal or plankton communities in the medium to long term (the marina has the potential to change the diversity of plankton communities as discussed in Appendix E and will provide more hard substrate for algal growth).

The marina, and to a lesser extent the wastewater wet weather outfall (if at all), may have a minor impact on the resilience and recovery of seagrass meadows and coral reefs in the short term. However there are unlikely to be any cumulative impacts associated with the development and climate change in the medium to long term, given the comparative severity and time scale of climate change impacts, particularly where communities are severely impacted by climate change (e.g. seagrass meadows almost completely smothered by successive flooding of the Fitzroy River).

That is, the magnitude of impact associated with the development will be far less than those impacts predicted to occur as a result of climate change; however any chronic impacts will influence the resilience of ecosystems and will need to be assessed through a rigorous and insightful EMP, with the outcomes used to re-assess management of the development on an on-going basis. Potential chronic issues include marina barriers (e.g. breakwall and marina precinct) that will require protection in the long-term future as sea levels rise, and landward migration of mangrove habitats.

Reefs of the Keppel Group have recently demonstrated resilience to bleaching and strong recovery following severe bleaching (Diaz-Pulido et al. 2009). Coral reefs of the region have been repeatedly affected by bleaching with substantial declines in coral coverage observed in 1998, 2002 and 2006[10]; in January 2006, 100% of corals in Keppel Bay were bleached with approximately 40% mortality by May 2006 (GBRMPA 2007; Weeks et al. 2008). Rapid recovery has been documented (e.g. Diaz-Pulido et al. 2009; Johnson et al. 2010), and some reefs in southern Keppel Bay (Humpy, Middle, Halfway and Pumpkin islands, and the reef surrounding Passage and Outer rocks) have been described as coral 'refuges' due to high diversity and connectivity to sites with lower diversity and coral cover (Jones et al. 2011). The development is unlikely to impact on these areas of reef.

Artifically opening Putney Creek has the potential to enhance the landward extent of mangrove and saltmarsh communities (via enhanced tidal flushing) and reduce the corresponding downstream extent of freshwater communities, in association with predicted sea level rise. However, Putney Creek is an ephemeral system that is dry for most of the year and the impact of a relatively slow ecological shift (in terms of ephemeral freshwater faunal communities being able to shift upstream in response to increasing salinities) is likely to be minimal. The ecological benefit of improved tidal flushing, water quality and mangrove ecosystem functioning is considered to be greater than any minor impact to ephemeral freshwater communities.

6.3 Ecosystem Functioning

Seagrass Meadows

Dredge plume modelling by Water Technology (2011) shows the likely dredge plume to be generally confined to the marina footprint. Sand movement associated with the marine development is unlikely to have a substantial effect on ecological communities, as it is similar (same order of magnitude) to the existing turbidity conditions.

Given that the seagrass meadows within and adjacent to the proposed marina are sparse and patchy, and typical of the region, the potential loss associated with turbidity or sedimentation is unlikely to have a measurable impact to ecosystem functioning beyond the marina footprint. The loss of seagrass and macroalgae within the marina footprint may impact on ecosystem functioning by:

[10] And most likely 2010 -11, although the effect of the recent Fitzroy River flooding on coral reef communities is yet to be confirmed.

- reducing the availability of shelter and food for juvenile fish, crustaceans, cephalopods and other mobile invertebrates, with flow-on effects to functions such as recruitment and food sources (e.g. herbivores feeding on the marine plants and / or carnivores feeding on the juveniles or herbivores)
- reducing the availability of food for listed species such as turtles and dugongs, and
- providing less stabilising for sediments, which could increase turbidity and suspended sediments.

Given the sparse and patchy nature of the seagrass and macroalgal beds in the marine footprint, any impact to ecosystem functioning is likely to be negligible.

Mangroves

Artificial opening of the Putney Creek mouth would change the flood regime with the potential to positively impact water and sediment quality. Improved water and sediment quality would facilitate improved ecosystem functioning, for example juvenile fish, crustaceans, cephalopods and other mobile invertebrates would be able to utilise the physical structure provided by mangroves and saltmarsh for refuge and shelter (currently prevented by limited tidal flushing and extremely poor water and sediment quality), and improved mangrove growth would contribute increased leaf litter and organic matter to the ecosystem (which provides refuge, shelter and food).

Negative impacts to mangrove forests and associated ecosystem functions are likely to be negligible, given that construction of the marina will not involve mangrove removal, the mainland connection of the submarine cables can extend through one of the several gaps in the forest, and Leeke's Creek estuary is unlikely to be impacted by the project.

Corals

Loss of coral reef has the potential to affect marine fauna as it provides important habitat for many species. The loss of reef within the marina footprint will have an impact on ecosystem functioning the short term, however hard surfaces of the marina (e.g. breakwalls) are expected to provide similar coral reef in the medium to long term. Given that the communities adjacent to the marina are sparse and patchy and typical of the region, the potential loss of a small area (while unlikely) will not impact biodiversity (at even a local scale), and is highly unlikely to have a measurable impact on ecosystem functioning.

The submarine cable and wastewater outfall footprints are currently dominated by bare sediment. These bare sediment ecosystems are typically dominated by polychaete worms and sparse epifauna, and would shift to include a variety of flora and fauna including macroalgae, hard and soft corals, sponges, ascidians and a variety of other invertebrates, and fish. It is expected that these hard surfaces will support similar communities to those currently found on rocky substrate at Putney Beach, Long Beach and other parts of the survey area. There is unlikely to be any negative impacts to ecosystem functioning given the large area of bare sediment habitat in the wider area.

Soft Sediment Benthos

Whilst increased suspended solid concentrations and sediment deposition may impact the soft sediment invertebrate communities within the dredge plume, any impact will be temporary and reversible. The impact to ecosystem functioning is likely to be negligible.

Fishes and Other Vertebrates

The effect of increased suspended solid concentrations and sediment deposition on vertebrate communities is likely to be minimal, primarily because mobile organisms tend to avoid unfavourable environments. While some marine vertebrates will avoid areas of high turbidity, these waters may attract a range of fishes, particularly juveniles, as it confers a greater degree of protection from predators (Blaber & Blaber 1980). There may be some shift in community composition, for example avoidance by herbivorous fishes may effectively increase the distribution and abundance of primary producers such as macroalgae (and to a lesser extent seagrasses). However, based on the relatively low nutrient concentrations in the sediment to be dredged, the impact of any dredging-related acute elevation of nutrient concentrations is likely to be ecologically insignificant and temporary and macroalgal blooms are not expected.

7 Measures to Avoid, Minimise and Mitigate Impacts

7.1 Risk Assessment

A risk assessment of potential impacts has been undertaken (Table 7.1), and a summary of potential and residual risk is presented in Table 7.2.

Table 7.1 Risk assessment matrix.

	Consequence				
Probability	Catastrophic Irreversible Permanent (5)	Major Long Term (4)	Moderate Medium Term (3)	Minor Short Term Manageable (2)	Insignificant Manageable (1)
Almost Certain (5)	(25) Extreme	(20) Extreme	(15) High	(10) Medium	(5) Medium
Likely (4)	(20) Extreme	(16) High	(10) Medium	(8) Medium	(4) Low
Possible (3)	(15) High	(12) High	(9) Medium	(6) Medium	(3) Low
Unlikely (2)	(10) Medium	(8) Medium	(6) Medium	(4) Low	(2) Low
Rare (1)	(5) Medium	(4) Low	(3) Low	(2) Low	(1) Low

Table 7.2 Summary of potential impacts on marine water and sediment quality.

Design	Construction	Operation	Potential Impact	Mitigation Measure	Monitoring	Significance of Impact (Unmitigated)	Significance of Residual (Mitigated Impact)
●	●	●	Increased turbidity and sediment deposition	• all dredging activities should be undertaken in accordance with GBRMPA's Dredging and Spoil Disposal Policy • marina design including use of dredge spoil to construct breakwall and no ocean disposal • best practice construction methods including water jetting and burying-in-excavated-trench method for the submarine cable installation • 'isolation' of the dredge / disturbance area, using silt curtains, oil spill booms, bunding, trenching and / or similar technologies	• monitoring of the extent of the turbidity plume, and the use of 'trigger levels', to confirm that plumes do not reach ecologically sensitive areas including coral reefs of Passage Rocks and Middle Island	WQ (15) High Mangroves (1) Low Seagrass (15) High Coral reef (15) High Mobile biota (3) Low Listed species (4) Low	(WQ (5) Medium Mangroves (1) Low Seagrass (5) Medium Coral reef (5) Medium Mobile biota (2) Low Listed species (3) Low
●	●	●	Altered hydrodynamics and flushing – marina	• marina design	• monthly water and sediment quality monitoring during operation	WQ (8) Medium Mangroves (1) Low Seagrass (8) Medium Coral reef (4) Low Mobile biota (3) Low Listed species (4) Low	WQ (4) Medium Mangroves (1) Low Seagrass (5) Medium Coral reef (3) Low Mobile biota (2) Low Listed species (3) Low

Design	Construction	Operation	Potential Impact	Mitigation Measure	Monitoring	Significance of Impact (Unmitigated)	Significance of Residual (Mitigated Impact)
●	●	●	Altered hydrodynamics and flushing – Putney Creek	• marina design including opening of the creek mouth to improve flushing, a sediment basin and low weir to control flow • best practice erosion and sediment control techniques during construction	• monthly water and sediment quality monitoring during operation	WQ (8) Medium Mangroves (8) Medium Seagrass (1) Low Coral reef (1) Low Mobile biota (8) Medium Listed species (4) Low	WQ (4) Low Mangroves (8) Medium Seagrass (1) Low Coral reef (1) Low Mobile biota (8) Medium Listed species (4) Low

Design	Construction	Operation	Potential Impact	Mitigation Measure	Monitoring	Significance of Impact (Unmitigated)	Significance of Residual (Mitigated Impact)
	●	●	Hydrocarbon contamination and other contaminants	• fuel, oil and chemical storage and handling are undertaken in accordance with AS1940 • any fuel, oil or chemical spills are contained and cleaned up immediately • a Spill Management Plan prepared in accordance with State Planning Policy requirements and to the satisfaction of DERM • all refuelling is by licensed fuel suppliers in accordance with their Standard Operating Procedures • refuelling takes place at wharves with suitable access or in designated areas, in accordance with industry standards • the stored volume of fuel, oil or chemical in minimised, with storage in a secure area • any visible (or suspected) fuel, oil or chemical loss will be treated as an 'incident' • vessel crew regularly check equipment for evidence of leaks and condition of hydraulic hoses and seals, and conduct maintenance or repairs as necessary to prevent drips, leaks or likely equipment failures	• monthly water and sediment quality monitoring during construction and operation	WQ (10) Medium Mangroves (6) Medium Seagrass (4) Low Coral reef (4) Low Mobile biota (4) Low Listed species (4) Low	WQ (6) Medium Mangroves (4) Medium Seagrass (2) Low Coral reef (2) Low Mobile biota (2) Low Listed species (2) Low

Design	Construction	Operation	Potential Impact	Mitigation Measure	Monitoring	Significance of Impact (Unmitigated)	Significance of Residual (Mitigated Impact)
				• spill kit are provided and include bilge socks, heavy duty absorbent polypropylene pads, floating booms and blowback refuelling collars • a register of Materials Safety Data Sheets (MSDS) relating to all hazardous substances on board is maintained			
	●	●	Litter and waste	• waste materials contained within the designated maintenance area to prevent contamination of surrounding watercourses and vegetation • used oils, greases, rags, hoses and filters from maintenance activities will be collected and disposed of in designated bins • on vessels, areas are allocated for solid and liquid waste storage, and waste should not be stored outside these areas • any waste fuels, oils or other chemicals are collected in separate drums and transported to an approved facility for disposal • all waste is disposed of lawfully and wastes listed as 'trackable wastes' are handled or transferred, documentation in accordance with Environmental Protection Policy	• observations during monthly water and sediment quality monitoring during operation	WQ (8) Medium Mangroves (6) Medium Seagrass (6) Medium Coral reef (4) Low Mobile biota (4) Low Listed species (12) High	WQ (4) Low Mangroves (4) Low Seagrass (4) Low Coral reef (2) Low Mobile biota (2) Low Listed species (8) Medium

Design	Construction	Operation	Potential Impact	Mitigation Measure	Monitoring	Significance of Impact (Unmitigated)	Significance of Residual (Mitigated Impact)
				(Waste) (refer EPP Waste) • a record / manifest is maintained for general and regulated waste disposal • waste is removed from vessels and disposed of at an approved facility • housekeeping procedures, including spillage control, are implemented to minimise the generation of waste, and • all waste is stored appropriately.			
●	●	●	Nutrient enrichment	• wet weather sewerage outfall design • golf course design and operation (particularly retention of stormwater for treatment and appropriate fertiliser application) • stormwater retention and treatment as required • contain dredge plume (although levels of nutrients are likely to be low based on sampling in accordance with NAGD)	• monthly water and sediment quality monitoring during operation	WQ (9) Medium Mangroves (9) Medium Seagrass (9) Medium Coral reef (9) Low Mobile biota (4) Low Listed species (9) Medium	WQ (4) Low Mangroves (6) Medium Seagrass (6) Medium Coral reef (6) Low Mobile biota (2) Low Listed species (6) Medium

Design	Construction	Operation	Potential Impact	Mitigation Measure	Monitoring	Significance of Impact (Unmitigated)	Significance of Residual (Mitigated Impact)
	●		Acid sulphate or potential acid sulphate sediment	• contain dredge plume (although levels of acid sulphate and potential acid sulphate soils are likely to be low based on sampling in accordance with NAGD)	• monthly water and sediment quality monitoring during operation	WQ (4) Low Mangroves (4) Low Seagrass (2) Low Coral reef (2) Low Mobile biota (2) Low Listed species (2) Low	WQ (2) Low Mangroves (2) Low Seagrass (2) Low Coral reef (2) Low Mobile biota (2) Low Listed species (2) Low
		●	Copper contamination	• marina design	• monthly water and sediment quality monitoring during operation • ecotoxicology experiments (where species from the survey area are exposed to copper) can also be undertaken to assess site- and species-specific tolerances	WQ (9) Medium Mangroves (2) Low Seagrass (2) Low Coral reef (4) Low Mobile biota (2) Low Listed species (2) Low	WQ (9) Medium Mangroves (2) Low Seagrass (2) Low Coral reef (4) Low Mobile biota (2) Low Listed species (2) Low

7.2 Mitigation Measures

Current 'best practice' assessment and engineering practices offer significant opportunities to minimise the impacts associated with both construction and operation of the proposed development.

Increased Turbidity and Sediment Deposition

All dredging activities should be undertaken in accordance with the Great Barrier Reef Marine Park's (GBRMPA) Dredging and Spoil Disposal Policy (GBRMPA 2010).

The effective 'isolation' of the dredge / disturbance area, using silt curtains, oil spill booms, bunding, trenching and / or similar technologies can significantly reduce the spread of waters carrying elevated suspended solids concentrations, potential contaminants and litter. Use of appropriate dredging and spoil handling methods can minimise the release of sediments and associated contaminants to the surrounding waters, for example particular care should be taken to effectively seal the geotextile bags. Use of best practice construction methods including water jetting and burying-in-excavated-trench method for the submarine cable installation further contribute to the minimisation of turbidity and sediment deposition.

Monitoring and the use of 'trigger levels' can also contribute to effectively controlling suspended solids concentrations in adjoining waters. This approach was successful used by the Department of Transport and Main Roads (DTMR) to protect sensitive ecological communities during recent dredging of nearby Rosslyn Bay boat harbour (frc environmental 2009b).

Hydrocarbon Contamination and other Contaminants

The risk of impact associated with spills of hydrocarbons and other contaminants is considered manageable, where:

- fuel, oil and chemical storage and handling are undertaken in accordance with AS1940 (Storage and Handling of Flammable and Combustible Liquids – encompassing spill containment and response protocols),
- any fuel, oil or chemical spills are contained and cleaned up immediately
- a Spill Management Plan is prepared in accordance with State Planning Policy requirements and to the satisfaction of DERM

- all refuelling is by licensed fuel suppliers in accordance with their Standard Operating Procedures
- refuelling takes place at wharves with suitable access and if it is necessary for refuelling of vessels or plant to be undertaken in the works area operations it is in accordance with industry standards
- the stored volume of fuel, oil or chemical in minimised, with storage in a secure area
- any visible (or suspected) fuel, oil or chemical loss will be treated as an 'incident'
- vessel crew regularly check equipment for evidence of leaks and condition of hydraulic hoses and seals, and conduct maintenance or repairs as necessary to prevent drips, leaks or likely equipment failures
- spill kit are provided and include bilge socks, heavy duty absorbent polypropylene pads, floating booms and blowback refuelling collars, and
- a register of Materials Safety Data Sheets (MSDS) relating to all hazardous substances on board is maintained.

Waste and Litter

Where waste materials are contained within the designated maintenance area to prevent contamination of surrounding watercourses and vegetation, and used oils, greases, rags, hoses and filters from maintenance activities will be collected and disposed of in the designated bins located at the workshop areas, the impacts are considered manageable.

The risk associated with waste management is considered manageable where:

- on vessels, areas are allocated for solid and liquid waste storage, and waste should not be stored outside these areas
- any waste fuels, oils or other chemicals are collected in separate drums and transported to an approved facility for disposal
- all waste is disposed of lawfully and wastes listed as 'trackable wastes' are handled or transferred, documentation in accordance with Environmental Protection Policy (Waste) (refer EPP Waste)
- a record / manifest is maintained for general and regulated waste disposal
- waste is removed from vessels and disposed of at an approved facility
- housekeeping procedures, including spillage control, are implemented to minimise the generation of waste, and

- all waste awaiting disposal is stored appropriately.

Copper Contamination

Monitoring of water (and sediment) quality and the use of 'trigger levels' can contribute to effectively controlling copper concentrations in the waters of the marina. Ecotoxicology experiments (where species from the survey area are exposed to copper) can also be undertaken to assess site- and species-specific tolerances.

7.3 Monitoring Requirements

Undertaking a water and sediment quality monitoring program will provide the opportunity to assess the accuracy of predicted impacts and inform management (and construction and operation Environmental Management Plans (EMPs), of potential issues and the need for responsive action. Regular monitoring will provide increased opportunity to identify the source of impacts and as required, distinguish them from the *perceived* source of impact.

During dredging / sediment disturbance, the extent of the turbidity plume will be monitored to confirm that plumes do not reach ecologically sensitive areas including the coral reefs of Passage Rocks and Middle Island, or have a negative sustained impact on seagrass condition. Should monitoring results show that plumes reach and are sustained at pre-determined sensitive sites and levels (trigger values) then dredging should cease until turbidity returns to background levels.

During operation of the marina, routine water and sediment quality monitoring will inform management of potential issues. Monitoring should include a suite of variables including (but not limited to) water temperature, turbidity, salinity, pH, dissolved oxygen, TSS, nutrients, total and dissolved metals (particularly copper), hydrocarbons and pesticides.

8 Summary and Conclusions

8.1 Existing Environment

Physicochemical

During the post-wet survey, salinity was typically lower near the surface than at depth. Salinity was lowest on an outgoing tide during the wet survey. This is likely to reflect tidal movement of freshwater run-off (floodwaters) and stratification of fresh and marine waters. Salinity of the survey area was typical of inshore waters

Dissolved oxygen concentrations were typically higher near the surface than at depth, and highest during the wet survey. Concentrations near the surface were often above the relevant QWQG trigger value range whereas concentrations at depth were often below the relevant range. Leeke's Creek tended to have lower dissolved oxygen concentrations than other sites. These patterns are likely to reflect wind- and wave-drive water movement that mixes the water column with oxygen in the atmosphere (strong winds and large waves characterised the wet survey), together with primary production and microbial activity.

Turbidity was typically higher during the post-wet survey, than other surveys, and higher at depth than near the surface. Turbidity at several sites exceeded the relevant QWQG trigger value during the wet and post-wet survey; turbidity tended to be highest in Leeke's Creek but was also relatively high near Passage Rocks and Putney Point. Turbidity offshore of The Spit (collected by the *in situ* logger) also exceeded the QWQG trigger value on several occasions and often for an extended duration (more than five days). High turbidity reflects sediment-laden run-off associated with rainfall and / or disturbance of the substrate due to wind, wave and tidal action; all of which introduce suspended particles into the water column.

The concentration of TSS exceeded the relevant QWQG trigger value in Leeke's and Putney creeks and at both mainland sites. Concentrations were generally highest in the post-wet survey. High concentrations are likely to be related to sediment-laden run-off associated with heavy rain.

Laboratory Analyses

The concentrations of total nitrogen and total phosphorus exceeded the relevant QWQG trigger values at most sites, and were particularly high in Putney Creek during the pre-wet survey. The concentration of total phosphorus was relatively high at the mainland sites. The concentration of chlorophyll-a offshore of The Spit was above the QWQG upper trigger value for much of the logging duration. This is likely to be related to the concentration of nitrogen in nearby waters exceeding the QWQG upper trigger value prior to the survey, and the concentration of phosphorus exceeding the QWQG upper trigger value both before and after the survey.

The concentration of total arsenic was below the laboratory detection limit at all sites during all surveys, except in Putney Creek during the pre-wet survey. The concentration of total copper exceeded the relevant ANZECC & ARMCANZ trigger value in Putney Creek and at the mainland sites in the post-wet survey. The concentration of total zinc exceeded the relevant ANZECC & ARMCANZ trigger value at most sites in the post-wet survey, and was particularly high near The Spit and to a lesser extent in Putney Creek and at Kinka Beach.

The concentration of other metals and metalloids (cadmium, chromium, nickel, lead and mercury), total petroleum hydrocarbons, aromatic hydrocarbons and organochloride pesticides were below laboratory detection limits and / or relevant trigger values at all sites in all surveys.

Regional Context

Concern regarding the trend of decline in water quality in the water draining to the Great Barrier Reef as well as its lagoon is well documented. Located approximately 40 km off the mouth of the Fitzroy River, the waters surrounding Great Keppel Island have a seasonal input of fresh and turbid waters that can result in episodes of poor water quality. Land use in the Fitzroy Basin is dominated by grazing and agriculture, together with mining and forestry.

The main sources of nutrients in the project area are derived from river and land run-off, particularly during floods. Nutrients (nitrogen and phosphorous) are mostly derived from diffuse sources, however point sources are locally significant in the upper estuary during extended periods of very low flow (as nutrients remain for a long time). There is little evidence to indicate that nutrient loads from the Fitzroy Basin are having a major impact on the Fitzroy River estuary and offshore areas.

There are significant concentrations of several herbicides (atrazine, tebuthiuron and diuron) and lower concentrations of additional herbicides entering the Fitzroy River estuary in summer flows, with the potential to flow into coastal waters.

Coastal water quality of the region and of Great Keppel Island in particular, is highly variable, responding to flood discharge from the Fitzroy River and less frequently cyclonic conditions. It is these event-based ‘drivers’ of coastal water quality that have the greatest ecological significance (and within which the impacts of the proposed marina should be viewed).

8.2 Potential Impacts

Increased Turbidity and Sediment Deposition

Dredge plume modelling by Water Technology (2011) shows the likely dredge plume to be generally confined to the marina footprint. The dredge plume may extend beyond the marina basin on occasion for short periods of time.

Outside the marina footprint, communities are unlikely to be substantially affected by any temporary reduction in light intensity, given that these seagrasses currently inhabit inshore coastal waters with variable turbidity and light penetration, and are capable of recovery following flood-related turbidity and sedimentation (as discussed in Appendix E). Given the very limited cover of seagrass in the vicinity of the marina, and the short duration of any predicted increase in suspended solid concentration, the ecological consequences of predicted seagrass damage / loss is likely to be negligible, even in a local context.

Outside of the marina, silt may settle over a very small area of seagrass to the south of the marina (up to approximately 1 ha). Species with a small growth form (*H. uninervis* and *H. ovalis*) are likely to be more affected than those with a larger growth form (*H. spinulosa* and *S. isoetifolium*). Given the permanent nature of the predicted deposition, *H. uninervis* and *H. ovalis* are unlikely to survive substantial deposition, however these species are likely to rapidly recolonise the area.

The coral communities in the vicinity of the proposed marina are likely to be largely unaffected by increased suspended solid concentration and sediment deposition given that they currently inhabit inshore coastal waters with variable turbidity and light penetration. The small outcrop directly adjacent to the marina footprint would likely be impacted more so than the corals of Putney Point, as they are relatively close to the marina breakwall.

Whilst the proposed dredging may impact the soft sediment invertebrate communities within the dredge plume, any impact will be temporary and reversible. The effect of increased suspended solids concentration and sediment deposition on fish communities of the likely dredge plume dispersal area is likely to be minimal.

Spills of Hydrocarbons and other Contaminants

Whilst 'one off' spills of great volume have the potential to severely impact a large area, recovery is likely; chronic small spills, though probably influencing a lesser area, effectively prevent recovery and lead to cumulative impacts. Frequent spills from a diffuse number of locations within a waterway can act in concert, resulting in an enduring impact over a very wide area.

Waste and Litter

Litter and waste associated with construction and operation of the marina has the potential to contribute to the degradation of water quality. As appropriate controls will be in place, such as a waste management system and direction of potentially contaminated water and / or sediment during dredging, the risk to water (and sediment) quality from litter and spilt waste from the project area is likely to be very low.

Copper Contamination

The concentration of copper in the waters of the marina are likely to be higher than in waters outside the marina, due to leachate from boat antifouls. Concentrations up to approximately 3 µg/L may reach the corals of Putney Point or seagrass meadows near the marina (both communities are located within approximately 250 m of the marina access channel). The seagrass and coral communities near the marina are likely to be largely unaffected by the predicted copper concentrations, given reported tolerances.

8.3 Mitigation Measures

Current 'best practice' assessment and engineering practices offer significant opportunities to minimise the impacts associated with both construction and operation of the proposed development. Table 7.2 provides a summary of mitigation measures and the associated residual risk.

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Appendix D Marine Sediment Quality

Contents

Tables

Figures

1 Methods

1.1 Surface Sediments

Sites Surveyed

Surface sediment sampling was undertaken during the following seasons:

- pre-wet – 15 to 19 November 2010
- wet – 17 to 21 January 2011, and
- post-wet – 30 March to 2 April 2011, and 30 April to 2 May 2011

Sediment samples were collected at 12 sites around Great Keppel Island (Figure 1.1) and two sites near the mainland (Figure 1.2) for laboratory analysis of potential contaminants. Sediment was collected from the top 0.3 m of seabed using a stainless steel trowel, and transferred directly into the sampling containers provided by the analytical laboratory.

Replicate sediment samples were collected at one site during the pre-wet and wet season survey, and at two sites during the post-wet season survey, to provide an indication of within-site variation. In addition, replicate subsamples of two sediment samples were analysed to provide an estimate of variation due to laboratory analysis.

Laboratory Analysis

Sediment samples were analysed by Advanced Analytical (a NATA-accredited laboratory) for the concentration of:

- moisture content
- particle size distribution
- nutrients (total nitrogen and total phosphorus)
- metals and metalloids (arsenic, chromium, copper, lead, mercury and zinc), and
- organochlorine pesticides (aldrin, *alpha*-BHC, *beta*-BHC, *gamma*-BHC, *delta*-BHC, *cis*-Chlordane, *trans*-Chlordane, *p,p'*-DDD, *p,p'-DDE*, *p,p'*-DDT, deildrin, *alpha*-endosulfan, *beta*-endosulfan, endosulfan sulphate, endrin, endrin aldehyde, endrin ketone, heptachlor, heptachlor epoxide, hexachlorobenzene, methoxychlor and oxychlordane).

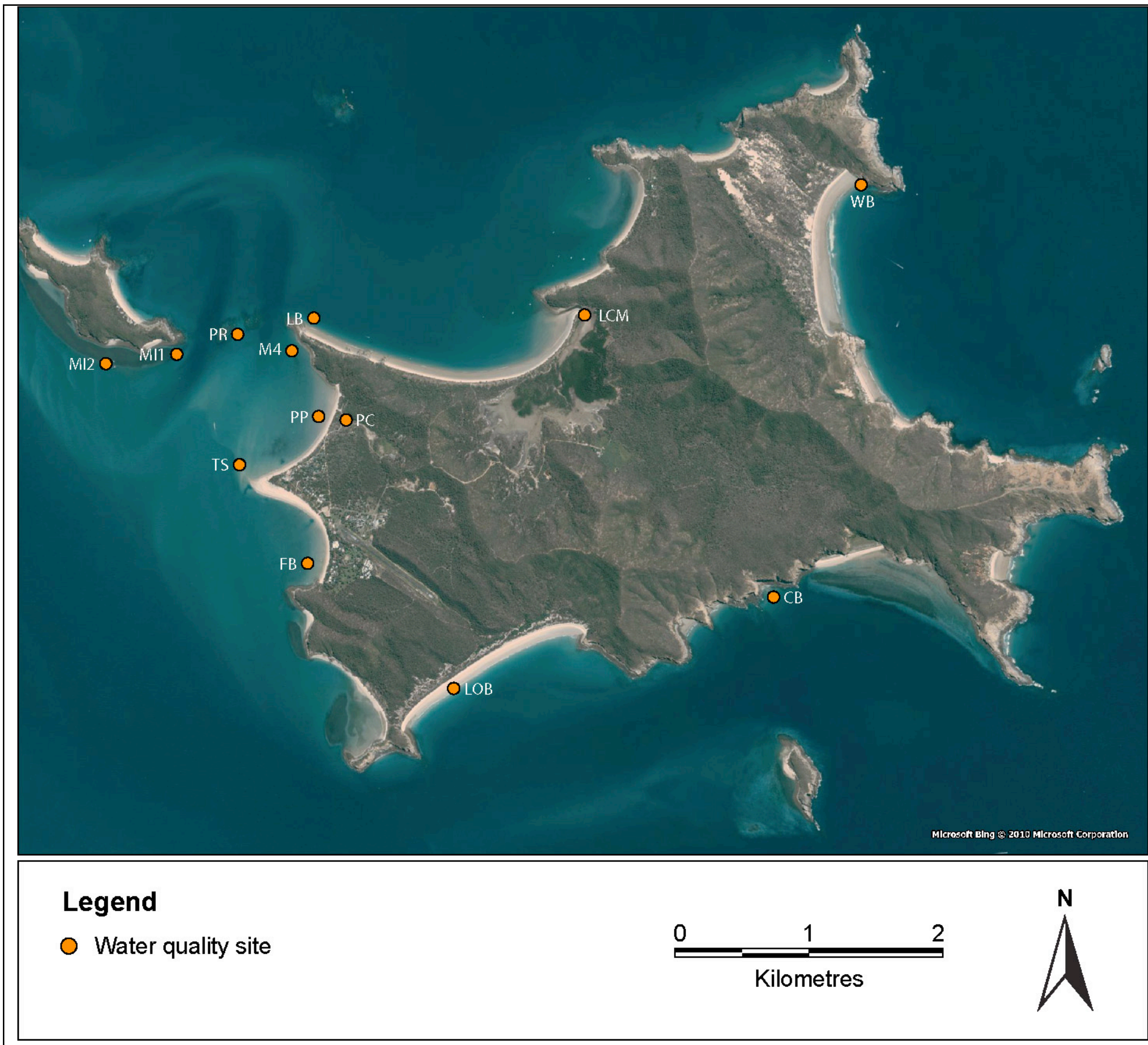

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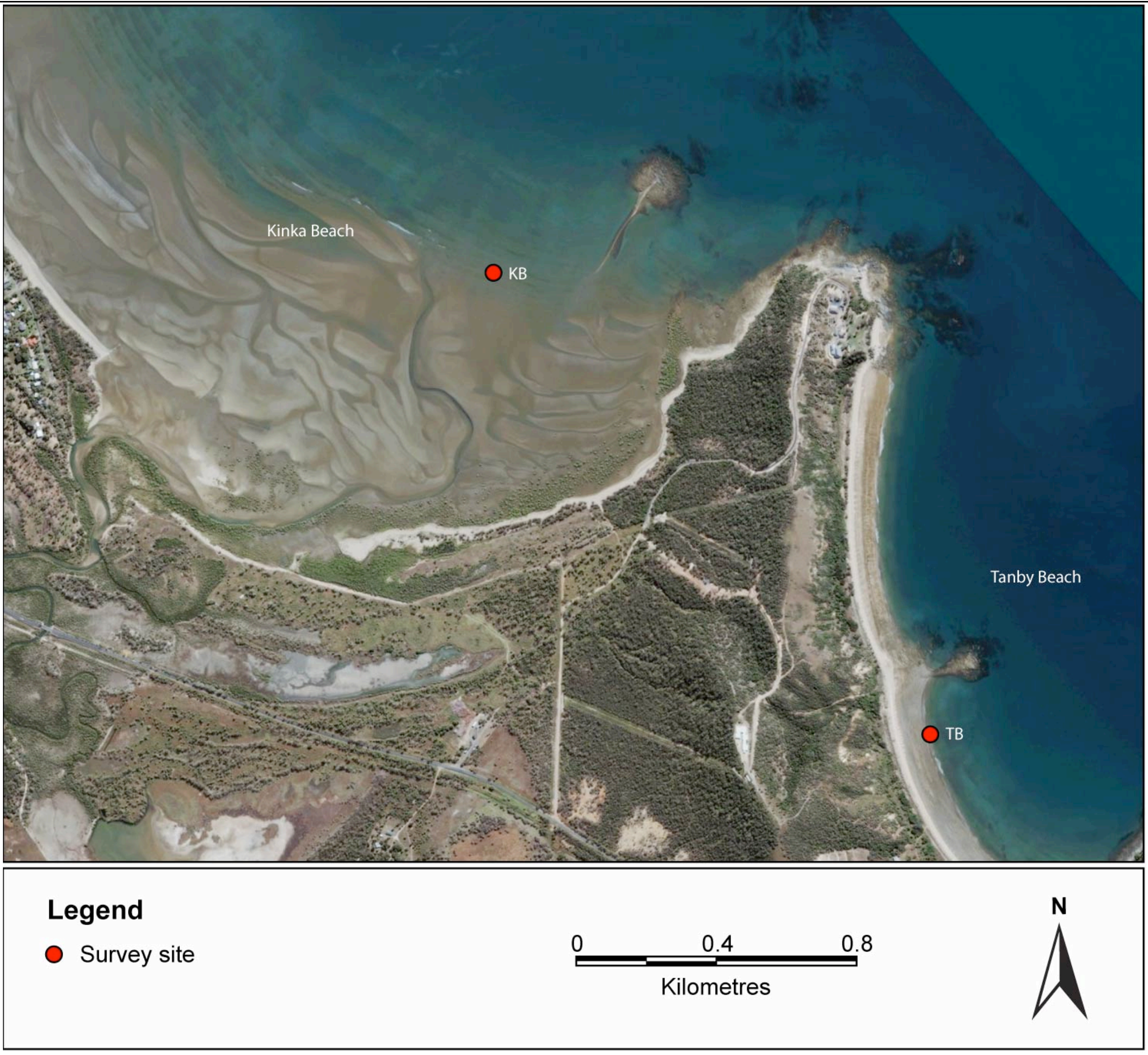
	Figure 1.1 Great Keppel Island surface sediment quality sites.
	Microsoft Bing © 2010 Microsoft Corporation — June 2011



frc environmental AQUATIC ECOLOGISTS deep thinking. science.	Great Keppel Island Revitalisation EIS	
	Figure 1.2 Mainland surface sediment quality sites.	
	Microsoft Bing © 2010 Microsoft Corporation	June 2011

Data Analysis

The *Australian and New Zealand Water Quality Guidelines for Fresh and Marine Waters* (the national guidelines) (ANZECC & ARMCANZ 2000) interim sediment quality guideline (ISQG) values were used as the guidelines, as regional guidelines have not been set for the project area (Table 1.1). Surface sediment quality data was compared to the ISQG-low trigger value (where available). The ISQG-low trigger value is referenced in the ANZECC & ARMCANZ (2000) guidelines as the most conservative trigger value for comparison.

Table 1.1 Trigger values for surface sediment quality parameters measured in the current study.

Parameter	Units	Low-ISQG	High-ISQG
Moisture Content	%	NA	NA
Particle size distribution	%	NA	NA
Nutrients			
ammonia as N	mg/kg	NA	NA
nitrite + nitrate (NO_x)	mg/kg	NA	NA
total kjeldahl nitrogen	mg/kg	NA	NA
total nitrogen	mg/kg	NA	NA
total phosphorus	mg/kg	NA	NA
Total Metals and Metalloids			
arsenic	mg/kg	20 [A]	70 [A]
cadmium	mg/kg	1.5 [A]	10 [A]
chromium	mg/kg	80 [A]	370 [A]
copper	mg/kg	65 [A]	270 [A]
lead	mg/kg	50 [A]	220 [A]
mercury	mg/kg	0.15 [A]	1 [A]
nickel	mg/kg	21 [A]	52 [A]
zinc	mg/kg	200 [A]	410 [A]
Pesticides			
aldrin	mg/kg	NA	NA
alpha-BHC	mg/kg	NA	NA
beta-BHC	mg/kg	NA	NA

Parameter	Units	Low-ISQG	High-ISQG
gamma-BHC	mg/kg	NA	NA
delta-BHC	mg/kg	NA	NA
cis-Chlordane	mg/kg	NA	NA
trans-Chlordane	mg/kg	NA	NA
p,p'-DDD	mg/kg	2 [A]	20 [A]
p,p'-DDE	mg/kg	2.2 [A]	27 [A]
p,p'-DDT	mg/kg	1.6 [A]	46 [A]
deildrin	mg/kg	0.02 [A]	8 [A]
alpha-endosulfan	mg/kg	NA	NA
beta-endosulfan	mg/kg	NA	NA
endosulfan sulphate	mg/kg	NA	NA
endrin	mg/kg	0.02 [A]	8 [A]
endrin aldehyde	mg/kg	NA	NA
heptachlor	mg/kg	NA	NA
heptachlor epoxide	mg/kg	NA	NA
hexachlorobenzene	mg/kg	NA	NA
methoxychlor	mg/kg	NA	NA
oxychlordane	mg/kg	NA	NA

NA No trigger value available.
[A] Source: Australian and New Zealand Water Quality Guidelines for Fresh and Marine Waters (ANZECC & ARMCANZ 2000) ISQG-Low (trigger value) and ISQG-high.

Any results less than the laboratory detection limits were entered as half the laboratory detection limit, for graphical purposes (DEWHA 2009).

1.2 Sediments of the Marina Footprint

Sediment sampling was undertaken in the proposed marina and channel footprint at Putney Beach from 15 to 18 June 2011 (Figure 1.3). This sediment sampling and analysis plan (SAP) for dredging was designed in accordance with the *National Assessment Guidelines for Dredging* (NAGD) (DEWHA 2009), the *Guidelines for Sampling and Analysis Procedure for Lowland Acid Sulphate Soils (ASS) in Queensland 1998* (the ASS guidelines) (Ahern et al. 1998) and the *State Planning Policy 2/02 Guideline: Acid Sulphate Soils*. Further details are provided in Appendix J.

Sites Surveyed

Samples were collected from 23 sites in accordance with Appendix A of the NAGD: sites 1 to 6 were located in the proposed entrance channel (Area 1), and the remaining sites were in the proposed marina basin (Area 2).

Approximately half of these sites (12) were assessed, as preliminary surface sediment sampling indicated that sediments were ‘probably clean’. The 12 sites initially analysed represent the spatial extent of the dredge area and the range of sediment depths to be dredged (Table 1.2, Table 1.3).

Subsamples from the remaining 11 cores have been held under appropriate holding conditions for possible future analysis pending the outcome of the results presented in this report. As this sampling indicates that sediments are clean, no further analyses are proposed.

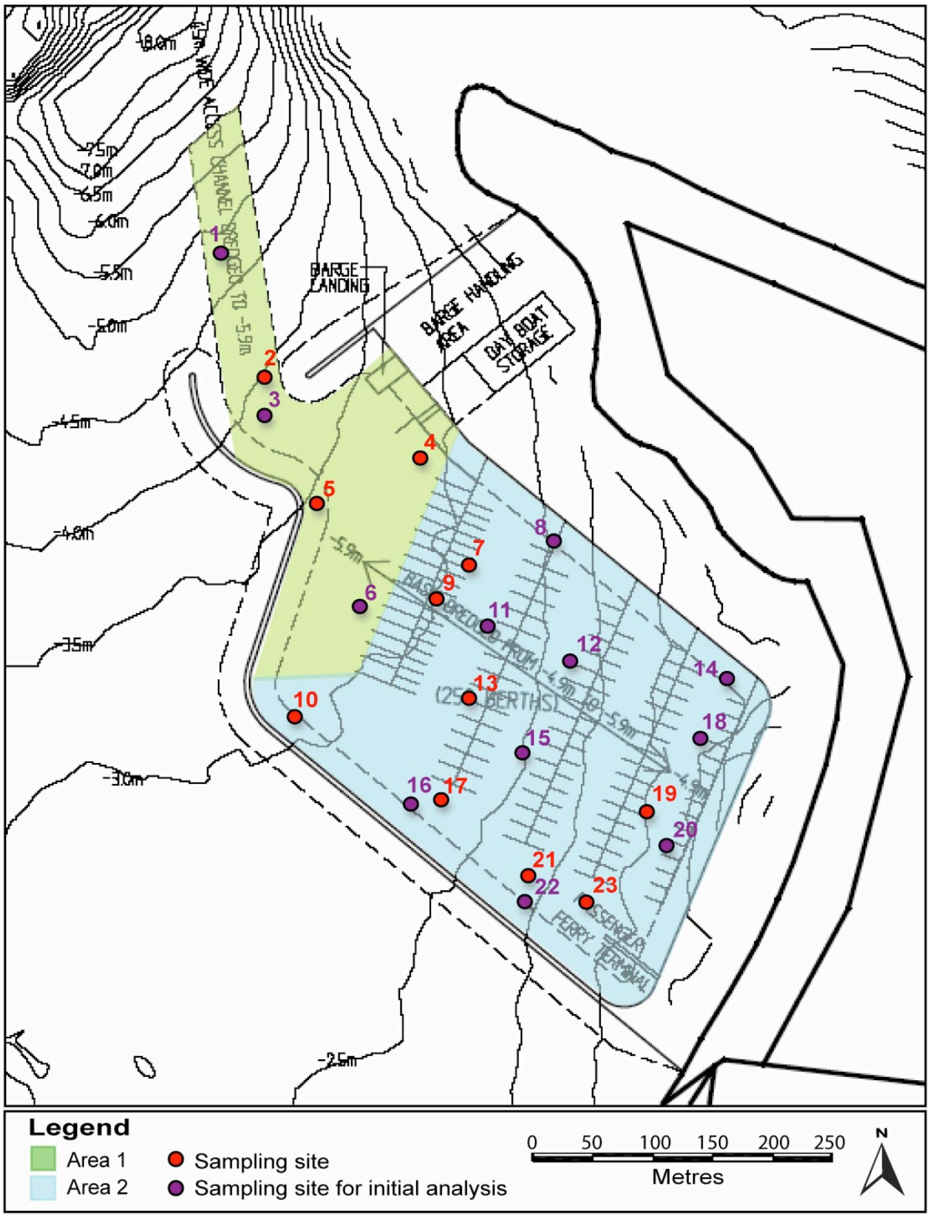


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	Figure 1.3 Sampling sites within the marina footprint.
	Source: International Marina Consultants — May 2011

Table 1.2 GPS position of each site within the marina footprint (UTM WGS 84 Zone 56 K; accuracy within 4 m).

Site	Easting	Northing
1	288438	7436075
2	288405	7436174
3	288438	7436043
4	288563	7436016
5	288479	7435976
6	288506	7435896
7	288598	7435933
8	288655	7435954
9	288572	7435905
10	288462	7435804
11	288605	7435881
12	288673	7435851
13	288599	7435832
14	288784	7435813
15	288633	7435772
16	288551	7435732
17	288574	7435732
18	288780	7435788
19	288733	7435735
20	288748	7435700
21	288643	7435677
22	288635	7435653
23	288687	7435647

Table 1.3 Required core length at each site.

Location	Approximate Depth of Seabed at Site (m below AHD)	Dredge Depth (m below AHD)	Required Core Length (m)	Actual Core Length (m)
1 [A]	–4.8	–5.9	1.6	2.6
2	–4.0	–5.9	2.4	2.5
3 [A]	–3.9	–5.9	2.5	2.2
4	–3.3	–5.9	3.1	2.7 [B]
5	–3.4	–5.9	3.0	2.6 [C]
6 [A]	–3.2	–5.9	3.2	3.6
7	–2.9	–4.9	2.5	2.5
8 [A]	–2.5	–4.9	2.9	2.3 [B]
9	–3.0	–4.9	2.4	2.4
10	–3.2	–4.9	2.2	2
11 [A]	–2.7	–4.9	2.7	1.75 [B]
12 [A]	–2.3	–4.9	3.1	2.9
13	–2.7	–4.9	2.7	2.7
14 [A]	–1.2	–4.9	4.2	2.5 [B]
15 [A]	–2.5	–4.9	2.9	2.9
16 [A]	–2.7	–4.9	2.7	2.75
17	–2.7	–4.9	2.7	2.75
18 [A]	–1.1	–4.9	4.3	3.3 [B]
19	–1.5	–4.9	3.9	2 [B]
20 [A]	–1.2	–4.9	4.2	3.7 [B]
21	–2.2	–4.9	3.2	3 [C]
22 [A]	–2.1	–4.9	3.3	3 [C]
23	–1.7	–4.9	3.7	3 [B]

[A] Samples from these sites were analysed in the first instance
[B] Samples that did not make the dredge depth
[C] Samples that did not make the required core length

Sampling Methods

Cores were collected using a 40 mm vessel-mounted vibracore. The corer was cleaned of all traces of sediment and rinsed with ambient seawater between cores. Collected cores were drawn off into poly-sleeves. At least two cores were taken at each site to ensure an adequate quantity of sediment was collected; in this case cores were taken immediately adjacent to each other.

To fully comply with the NAGD, we included field quality assurance / quality control (QA/QC) samples in our sampling protocol. Field triplicates were collected at site 6 (Cores: 6 amongst three replicates, Rep1, Rep2 and Rep3) and site 12 (Cores: 6 amongst three replicates, Rep1, Rep2 and Rep3) to determine between-core variability within a site (that is, sediments from each triplicate core pair were not mixed with each other when collecting subsamples). Further, the subsample C section of three cores from site 18 were mixed and divided into three homogenous subsamples (subsamples CRep1, CRep2 and CRep3) to assess within core variation and field and laboratory handling. These QA/QC samples were analysed by Advanced Analytical, whilst ALS was used to determine laboratory handling variation.

Each core (including the field triplicate cores) was divided into three sections: the upper 0.5 m of the sediment core, i.e. from the surface to 0.5 m (subsample A), between 0.5 m and the maximum dredge depth (subsample B), and the remainder of the sediment core i.e. deeper than the maximum dredge depth (subsample C[1]). Each section of the core was mixed and a single composite subsample taken from each section.

Cores at all sites were taken to a depth as close as practical to 0.5 m below the proposed maximum dredge depth at most sites. Due to a hard layer and / or clay, the corer did not reach to 0.5 m below the dredge depth at three sites (one of the ‘first instance’ sites), and below the dredge depth at eight sites (five of the ‘first instance’ sites) (Table 1.3).

Field QA/QC, sub-sampling and core log data collection were undertaken in accordance with the NAGD, as outlined in Appendix J.

[1] Different protocol to that outlined in the NAGD, which states that the second sample (subsample B) is to be taken from 0.5 – 1.0 m of the core. Below 1 m, if contamination is known or suspected to be present the core should also be sub-sampled at 0.5 m intervals. If there is no suspicion of contamination below 1 m depth in the core, the remainder of the core, can be composited as a single sample (subsample C).

Acid Sulphate Soil Testing

Acid sulphate soil field sampling was completed for each core (except for QA/QC replicates) in accordance with the *Sampling and Analysis Procedure for Lowland Acid Sulphate Soils in Queensland* (Ahern et al. 1998). Methodology was as per Section H of the *Acid Sulphate Soils Laboratory Method Guidelines* (Ahern et al. 2004), produced by the Queensland Acid Sulphate Soils Investigation Team (QASSIT).

Field pH and field pH after oxidation with 30% peroxide was measured every 0.25 m along the core profile at each site (this encompassed measuring any horizons present). Subsamples were collected every 0.5 m for analysis of acid sulphate soils, in accordance with the ASS guidelines.

Laboratory Analyses

Subsamples were analysed for the physical parameters outlined in Table 1 of Appendix A in the NAGD, as presented in Table 1.4. The concentration of nutrients and potential contaminants was analysed in the subsamples, as outlined in Table 1.5 and Table 1.6.

Samples were analysed by NATA-accredited Advanced Analytical Pty Ltd (and sub-contractors). For quality assurance / quality control purposes, one subsample was split into three, with one of these three split samples sent to NATA-accredited Australian Laboratory Services (ALS) for analysis.

Table 1.4 Physical parameters analysed.

Parameter	Practical Quantitation Limit (PQL)
Moisture content	0.1%
Total organic carbon	0.1%
Particle size distribution	NA (use of sieve + hydrometer method)
Settling rate	NA

Table 1.5 Nutrient parameters analysed.

Parameter	Practical Quantitation Limit (PQL)
Total nitrogen	0.4 (mg/kg) [A]
Total phosphorus	0.1 (mg/kg)

A Does not meet the PQL indicated in Table 1 of Appendix A in the NAGD. However, there are no guideline values for nutrients, and a result of <0.04 mg/kg total nitrogen would be considered low, based on our experience of nitrogen concentrations in sediments along the Queensland coast.

Table 1.6 Potential contaminants analysed.

Parameter	Practical Quantitation Limit (PQL)
Total petroleum hydrocarbons (TPH)	100 (mg/kg)
Phenols (speciated) [1]	1 (mg/kg)
Volatile chlorinated hydrocarbons (VCHs)	0.05 – 5 (mg/kg)
Chlorobenzenes	50 (µg/kg)
Organochlorines including:	1 (µg/kg)
Total chlordane, oxychlordane, dieldrin, heptachlor, heptachlor epoxide, methoxychlor, endrin, DDD, DDE, DDT, alpha and beta BHC, endosulfan (total alpha, beta and sulphate), hexachlorobenzene, lindane, aldrin [A]	(each individual species)
Total Polychlorinated Biphenyls (PCBs) [A]	5 (µg/kg)
Polynuclear Aromatic Hydrocarbons (PAHs) including: Naphthalene, 2-methylnaphthalene, acenaphthalene (each individual species), acenaphthene, fluorene, phenanthene, benzo[b]fluoranthene, fluoranthene, indeno[1,2,3-cd]pyrene, benzo[k]fluoranthene, chrysene, coronene, dibenz[a,h]anthracene, benzo[e]pyrene, benzo[a]pyrene, perylene, pyrene [A]	5 (µg/kg) (each individual species)
Total PAHs [A]	100 (µg/kg)
Benzene, toluene, ethylbenzene, xylene (BTEX)	200 (µg/kg)
Dioxins [B]	0.02 (µg/kg)
Non-organochlorine pesticides, including: Organophosphates, carbamates, pyrethroids, and herbicides [A]	10 – 100 (µg/kg) (each individual species)

Parameter	Practical Quantitation Limit (PQL)
Organotin compounds (monobutyltin, dibutyltin, tributyltin) [A]	1 (µgSn/kg)
Metals and metalloids (mg/kg)	
copper	1
lead	1
zinc	1
chromium	1
nickel	1
cadmium	0.1
mercury	0.01
arsenic	1
silver	0.1
manganese	10
aluminium	200
cobalt	0.5
iron	100
vanadium	2
selenium	0.1
antimony	0.5
Total cyanide	0.25 (mg/kg)

[A] As these contaminants were not expected to be found in levels above the screening level, they were analysed at five sites only in the first instance to confirm this assessment (i.e. 20% of the sampling sites for a pilot study, as per the NAGD). The QAQC laboratory and field replicates were also analysed for these contaminants.

[B] Note that as dioxins were not expected to be present at harmful levels, and as there is no screening level for dioxins in the NAGD, dioxins in Subsample A samples from 20% of the sampling sites were analysed in the first instance.

Acid Sulphate Soils

As the sediments were not expected to be acid sulphate soils (ASS), samples from approximately 20% of the collected cores (i.e. five cores) were analysed for acid sulphate soils (using the SPOCAS analysis), as detailed in the *Acid Sulphate Soils Laboratory Methods Guidelines 2004* (Ahern et al. 2004). The cores were analysed based on the results of the field tests (i.e. those cores that represented the highest risk with respect to ASS were analysed). The remaining subsamples have been stored frozen. Where the results indicate that potential acid sulphate soils are present, the remaining subsamples will be analysed. This staged approach to analysis of samples is considered acceptable under the ASS guidelines.

Data Analysis

The assessment of sediment quality in the marine footprint followed the approach outlined in Section 4.2 of the NAGD.

Any results less than the practical quantification limit (PQL) were entered as half the PQL, for statistical and analytical purposes (DEWHA 2009). The concentration of detected organic compounds was normalised to total organic carbon (TOC) content, as outlined in Section 4.2.3 of the NAGD.

1.3 Regional Context

The marine sediment quality of the region was described through literature review, to provide a regional context for the condition of the project area. Available literature and sediment quality data was sourced from researchers, government agencies and consultancies to provide a regional description of sediment quality for the project area and region.

2 Existing Environment

2.1 Surface Sediments

Particle Size Distribution

All samples were dominated by sand (0.075 to 2 mm diameter) together with some silt and clay (<0.075 mm diameter). Gravel (>2 mm diameter) was sampled from sites PC (Putney Creek), MI1 (Marina 1), MI2 (Marina 2), PR (Passage Rocks), TS (The Spit), LCM (Leeke's Creek Mouth), LB (Long Beach) and WB (Wreck Beach).

Nutrients

Total Nitrogen

There is no ISQG trigger value for the concentration of total nitrogen in sediment (ANZECC & ARMCANZ 2000). The concentration of total nitrogen was variable between sites and surveys. The highest concentration of total nitrogen was at site PC (Putney Creek) in the pre-wet survey and at sites FB (Fishermans Beach) and CB (Clam Bay) in the post-wet survey (Figure 2.1).

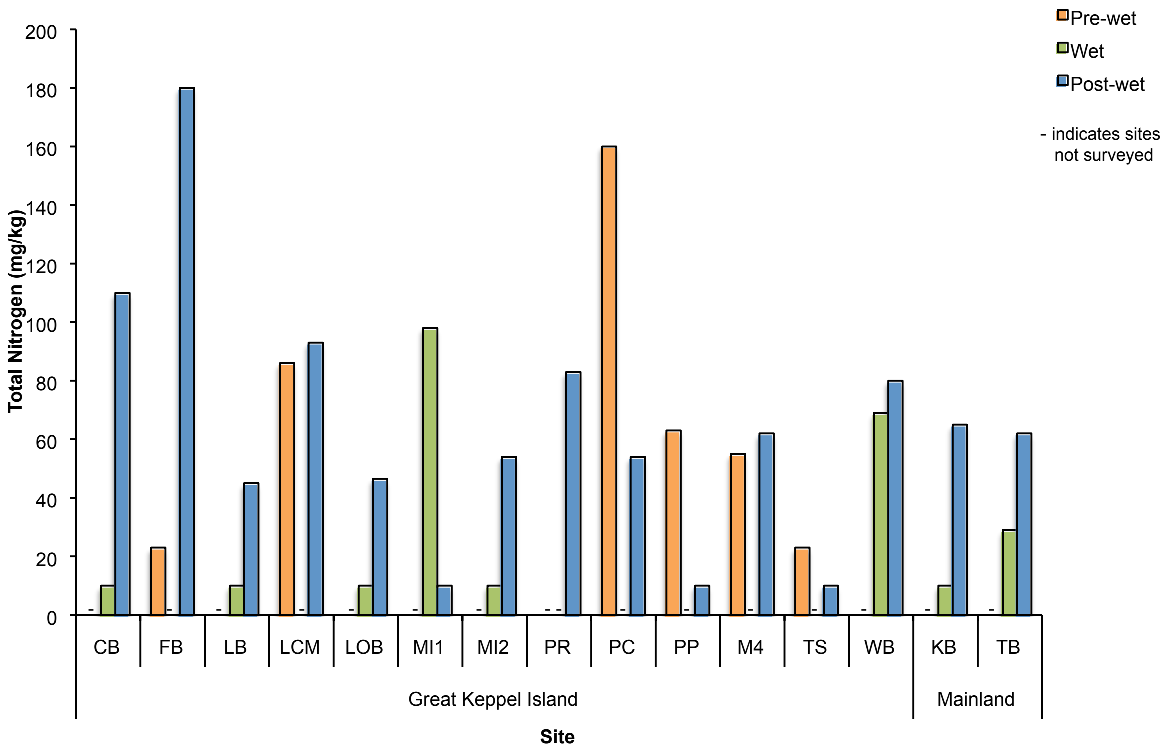

Figure 2.1 Total nitrogen concentration at each site in each survey.

Total Phosphorus

There is no ISQG trigger value for the concentration of total phosphorus in sediment (ANZECC & ARMCANZ 2000). The concentration of total phosphorus was highest at site MI1 (Middle Island) during both surveys, and also relatively high at the mainland sites during both surveys. At each site, the concentration was generally similar between surveys (Figure 2.2).

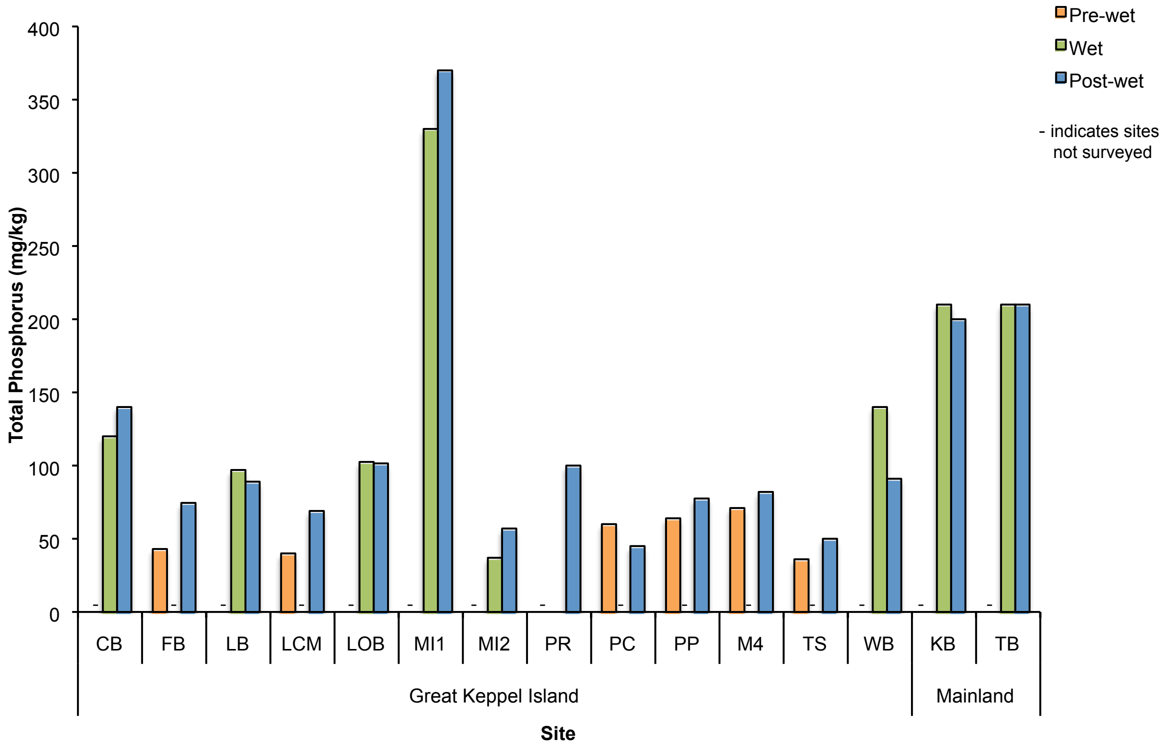

Figure 2.2 Total phosphorus concentration at each site in each survey.

Metals and Metalloids

Arsenic

The concentration of total arsenic was below the ISQG-low trigger value at all sites during all surveys. The concentrations at the mainland sites were relatively high during both surveys. The concentration at each site was generally similar between surveys, although it was higher site MI1 (Middle Island) at the mainland sites during the post-wet survey (Figure 2.3).

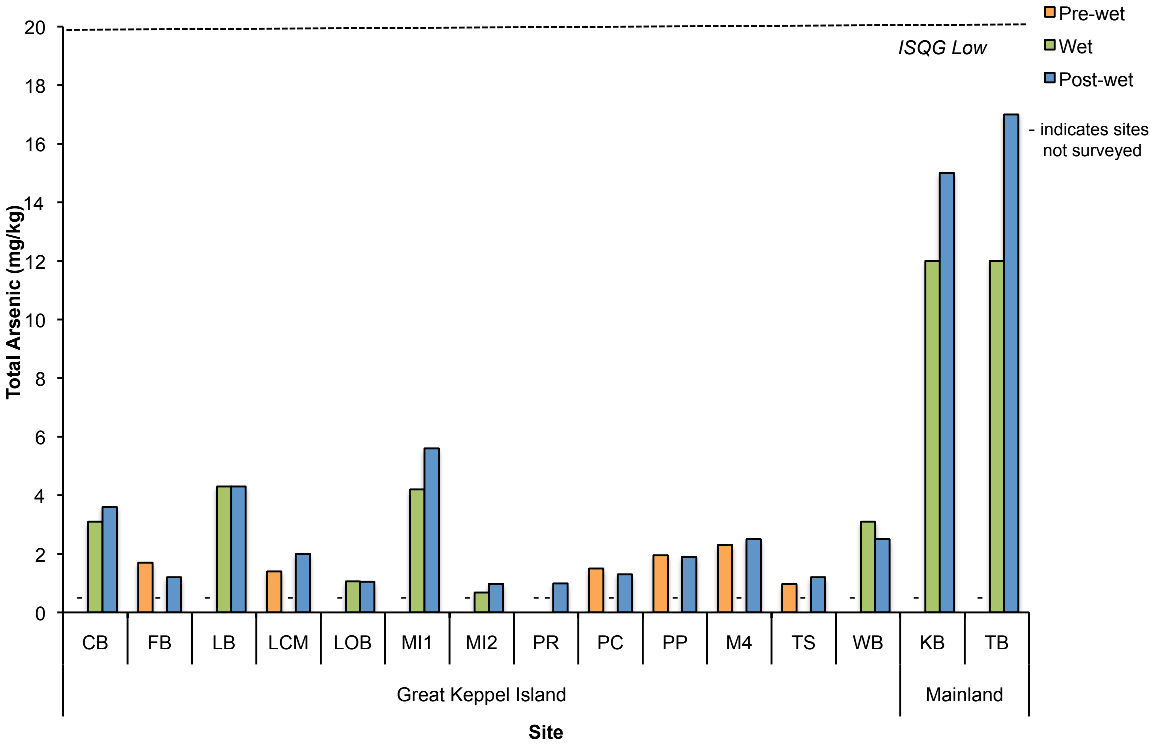

Figure 2.3 Total arsenic concentration at each site in each survey.

Chromium

The concentration of total chromium was substantially lower than the ISQG-low trigger value (80 mg/kg) at all sites during all surveys. The concentration was highest at site MI1 (Middle Island 1) and relatively high at the mainland sites during both surveys. The concentration at each site was generally similar between surveys (Figure 2.4).

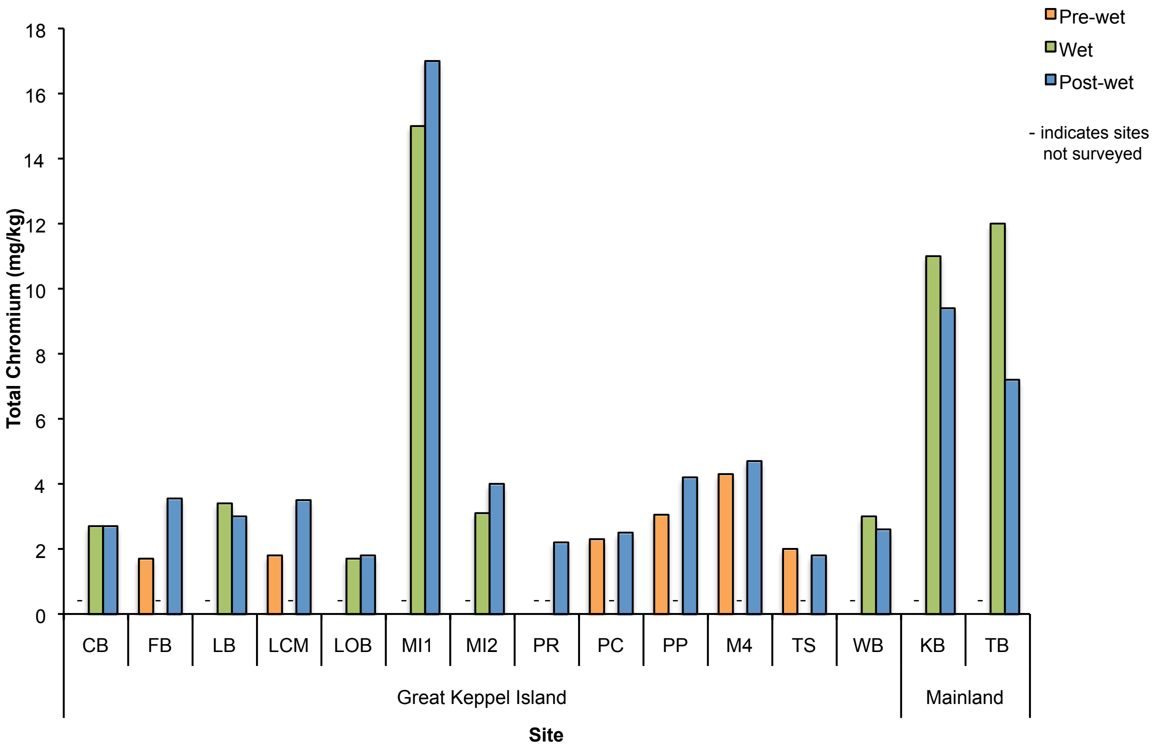

Figure 2.4 Total chromium concentration at each site in each survey.

Copper

The concentration of total copper was substantially lower than the ISQG-low trigger value (65 mg/kg) at all sites during all surveys. The concentration was highest at site LCM (Leeke's Creek Mouth) during the post-wet survey, and relatively high at site MI1 (Middle Island) and the mainland sites during both surveys. The concentration at each site was generally similar between surveys, except at site LCM where it was substantially higher on the post-wet than pre-wet (Figure 2.5).

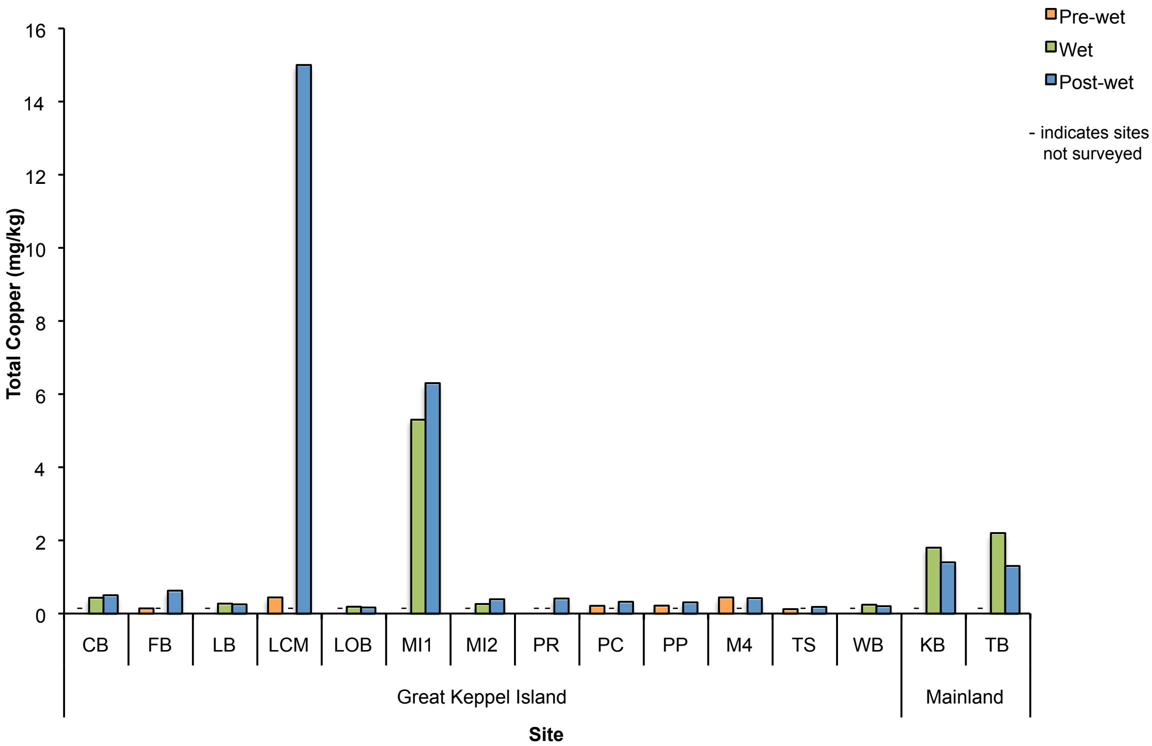

Figure 2.5 Total copper concentration at each site in each survey.

Lead

The concentration of total lead at site LCM (Leeke's Creek Mouth) exceeded the ISQG-low trigger value during the post-wet survey. All other sites were substantially lower than the trigger value in all surveys (Figure 2.6). The extremely high concentration at site LCM in post-wet could be related to boat usage. The coefficient of variation (CoV) for the laboratory sub-samples was very low (<3.8%) during all surveys hence the extremely high concentration at site LCM it is unlikely to be related to laboratory processing[2].

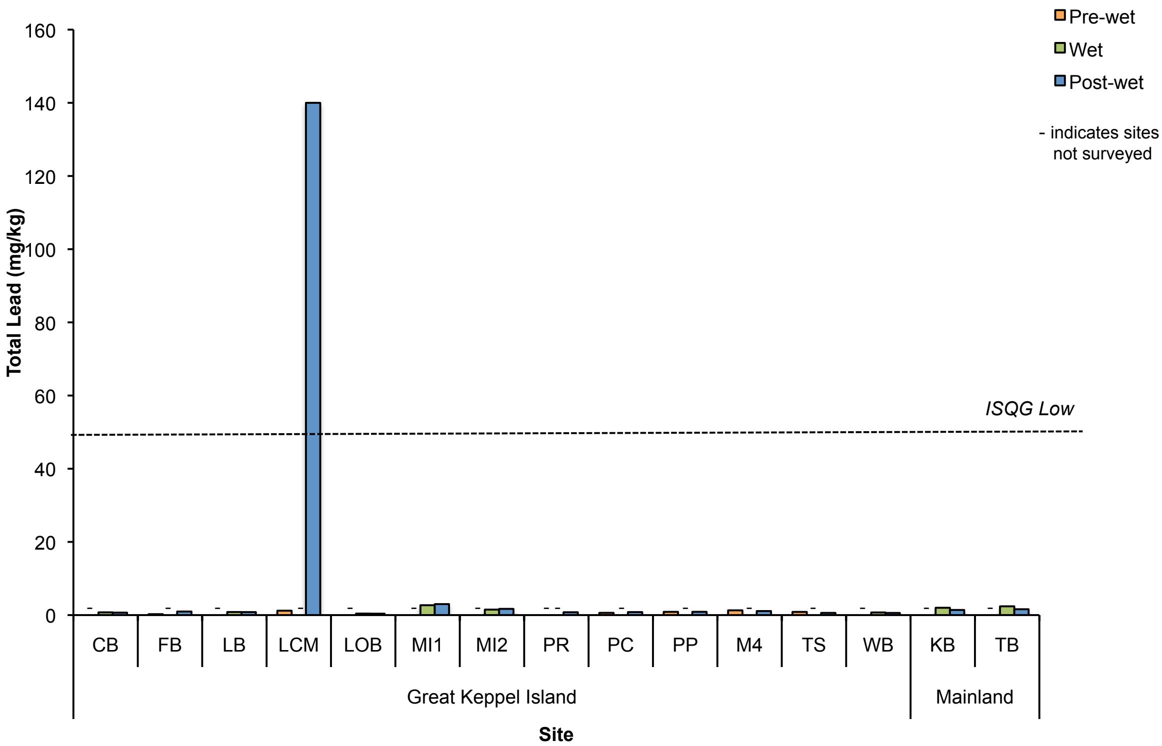

Figure 2.6 Total lead concentration at each site in each survey.

Mercury

The concentration of total mercury was below the ISQG-low trigger value (0.15 mg/kg) at all sites during all survey. The concentration was below the laboratory detection limit (0.1 mg/kg) at all sites during all surveys, except at site LCM (Leeke's Creek Mouth) where it was 0.1 mg/kg during the post-wet survey.

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[2] The CoV for replicate field samples was approximately 50%, however this is not a true indication of the level of variation because the concentration was below the laboratory detection limit (0.5 mg/kg) in one of the samples and therefore halved for the calculation.

Zinc

The concentration of total zinc was substantially lower than the ISQG-low trigger value (200 mg/kg) at all sites during all surveys. The concentration was highest at site MI1 (Middle Island) and relatively high at the mainland sites, during both surveys. It was also relatively high at site M4 (Marina 4) during the pre-wet season and LCM (Leeke's Creek Mouth) during the post-wet survey. The concentration at each site was generally similar between surveys, except at site M4 where it was substantially higher in the pre-wet than post-wet survey (Figure 2.7).

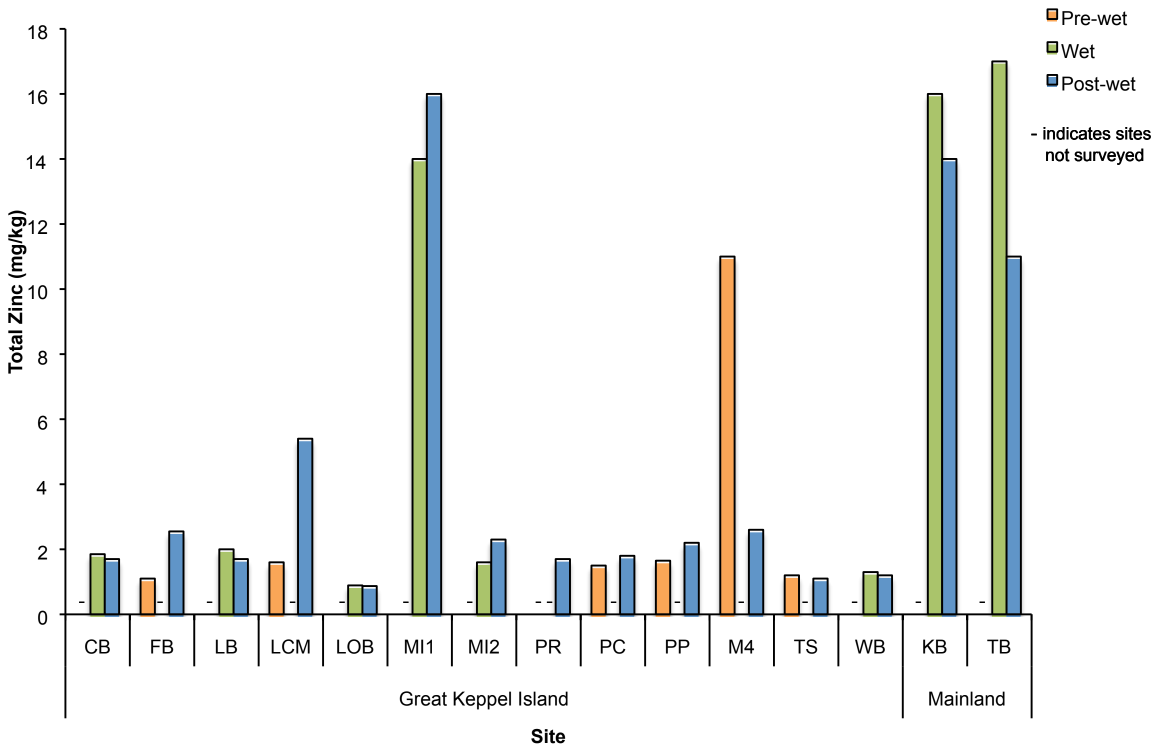

Figure 2.7 Total zinc concentration at each site in each survey.

Pesticides

The concentration of organochlorine pesticides was below the laboratory detection limit (1 µg/kg) and ISQG-low trigger values (where available) at all sites in all surveys.

2.2 Sediments of the Marina Footprint

The sediments were sampled between the 15th and 18th of June 2011. The weather was generally fine and the water was calm throughout sampling. No litter was seen in the dredge area or was collected in the cores.

Settling Rate in Seawater

Settling rates of sediments from subsample A were slightly faster than for deeper sediments (Table 2.1). Approximately 90% of the sediment (by volume) settled within 9.64 minutes for subsample A. In contrast, it took 10.71 minutes for 90% of the volume to settle for subsamples B, and 12.67 minutes for 90% of the volume to settle for subsamples C.

Table 2.1 Time required to settle approximately 90% (volume) of the total sediment.

Settling rate	Units	Mean	SD	95% UCL[A]
Subsample A (the top 0.5 m of sediment).	Minutes	9.64	2.37	10.89
Subsample B (0.5 m deep to 1.0 m deep).	Minutes	10.71	3.31	12.45
Subsample C (sediment deeper than 1.0 m deep down to 0.5 m below the maximum dredge depth).	Minutes	12.67	5.30	15.35

[A] 95% UCL - upper 95% confidence limit of the mean

Note that settling rates do not typically correlate well to particle size distributions determined using a sieve and hydrometer method (Gasparon, M. [University of Queensland], pers. comm. 2008).

Particle Size Distribution

Sands comprised the greatest proportion of the sediments in subsamples A, B, and C (Table 2.2 to Table 2.4), and for the dredge area as a whole. Subsample A samples (the top 0.5 m of sediment) had a slightly higher proportion of sand, and lower proportion of silt and clay, than deeper sediments.

Nutrients

There are no NAGD Guidelines for sediment nutrient concentrations. Nutrient concentrations were highest at site 1 in the proposed entrance channel (see the laboratory reports presented in Appendix K for site-specific results).

Total Organic Carbon

Mean total organic carbon concentration was substantially higher in subsample B samples from 0.5 to 1 m deep (18.64%), than in surface (subsample A; 0.08%) or deeper (subsample C; 0.04%) sediments (Table 2.2. to Table 2.4).

Total Nitrogen

The mean total nitrogen concentration was highest in the surface sediments (subsample A), with a mean concentration of 49.21 mg/kg. This is substantially lower than total nitrogen concentrations in the sediment at nearby boat harbours such as Rosslyn Bay (frc environmental 2008) and Bowen Boat Harbour (frc environmental 2004), and in sediments from Moreton Bay in south east Queensland (frc environmental 2006; 2007b; a; 2009) (Table 2.2. to Table 2.4).

Total Phosphorus

The mean total phosphorus concentration was highest in the deeper sediments (subsample C), with a mean concentration of 0.14 mg/kg. This is substantially lower than total phosphorus concentrations in the sediment at nearby boat harbours such as Rosslyn Bay (frc environmental 2008) and Bowen Boat Harbour (frc environmental 2004), and in sediments from Moreton Bay in south east Queensland (frc environmental 2006; 2007b; a; 2009) (Table 2.2. to Table 2.4).

Contaminants

Metals and Metalloids

The mean concentrations (and the 95% upper confidence limits of means) of all metals were below the NAGD screening levels, where available (Table 2.2 to Table 2.4).

Hydrocarbons

Concentrations of BTEX and individual fractions of petroleum hydrocarbons (C6-C9, C10-C14, C15–28 and C29-C36) and polynuclear aromatic hydrocarbons (PAHs) were below the laboratory LORs in all samples analysed (Table 2.2 to Table 2.4).

Phenols

Concentrations of phenols were all below the NAGD PQLs and laboratory LORs for all samples analysed (Table 2.2 to Table 2.4).

Herbicides and Pesticides

Concentrations of herbicides and pesticides were below the laboratory LORs for all samples analysed (Table 2.2 to Table 2.4).

Organotin

Levels of organotins were below laboratory LORs for all samples analysed (Table 2.2 to Table 2.4).

Poly-chlorinated Biphenyls

Total poly-chlorinated biphenyl (PCB) concentrations were below the laboratory LORs and screening level for all samples analysed (Table 2.2 to Table 2.4).

Cyanide

Concentrations of total cyanide were all below the NAGD PQLs and laboratory LORs for all samples analysed (Table 2.2 to Table 2.4).

Dioxins

There are no screening levels for dioxins. Trace amounts of dioxins were detected in sediments from each of the five assessed for dioxins (sites 1, 3, 8, 15, 20). The concentration of total dioxins detected in the surface sediment (subsample A samples) varied from 52.57 pg/g (picograms per gram) at site 20 to 1 687.70 pg/g at site 1. The dioxin toxic equivalency was calculated for each group of dioxin congeners analysed, based on the World Health Organisation toxicity equivalency factors (WHO_{05}-TEFs). The results were summed to derive a total toxicity equivalent for total dioxins. The total toxicity equivalent for each sample ranged from 0.001 µg/kg to 0.019 µg/kg, which is below the PQL of 0.02 µg/kg in the NAGD (Table 2.2. to Table 2.4).

Table 2.2 Summary of analyses for subsample A samples (the top 0.5 m of sediment).

Parameter	Units	SL[1]	SQG-high[2]	Mean	SD	95% UCL[3]
Moisture Content	%	–	–	19.53	1.31	20.21
Particle Size Analysis						
Gravel (+2 mm)	%	–	–	4.21	5.58	7.14
Sand (2 mm – 0.06 mm)	%	–	–	92.64	7.35	96.50
Silt and clay (<0.06 mm)	%	–	–	3.14	2.44	4.42
Nutrients						
Total Organic Carbon	%	–		0.08	0.01	0.09
Nitrate as N	mg/kg	–	–	0.07	0.07	0.10
Nitrite as N	mg/kg	–	–	<0.1	0.00	<0.1
Total Kjeldahl Nitrogen	mg/kg	–	–	49.21	11.87	55.43
Total Nitrogen	mg/kg	–	–	49.21	11.87	55.43
Total Phosphorus	mg/kg	–	–	0.09	0.05	0.12
Metals						
Silver	mg/kg	1	3.7	0.10	0.06	0.13
Aluminium	mg/kg	–	–	1368.57	660.42	1714.51
Arsenic	mg/kg	20	70	2.69	1.66	3.56
Cadmium	mg/kg	1.5	10	<0.1	0.00	<0.1
Cobalt	mg/kg	–	–	0.59	0.12	0.65
Chromium	mg/kg	80	370	4.56	1.01	5.09
Copper	mg/kg	65	270	0.62	0.50	0.88
Iron	mg/kg	–	–	2035.71	1699.14	2925.76
Mercury	mg/kg	0.15	1	<0.01	0.00	<0.01
Manganese	mg/kg	–	–	52.50	6.60	55.95
Nickel	mg/kg	21	52	1.32	0.26	1.46
Lead	mg/kg	50	220	1.07	0.24	1.19

Parameter	Units	SL[1]	SQG-high[2]	Mean	SD	95% UCL[3]
Antimony	mg/kg	2	–	<0.5	0.00	<0.5
Selenium	mg/kg	–	–	0.06	0.02	0.07
Vanadium	mg/kg	–	–	5.14	4.33	7.40
Zinc	mg/kg	200	410	2.24	0.53	2.51
BTEX						
Benzene	mg/kg	–	–	<0.2	0.00	<0.2
Toluene	mg/kg	–	–	<0.2	0.00	<0.2
Ethyl Benzene	mg/kg	–	–	<0.2	0.00	<0.2
meta- & para- xylenes	mg/kg	–	–	<0.4	0.00	<0.4
ortho-Xylene	mg/kg	–	–	<0.2	0.00	<0.2
Total BTEX	mg/kg	–	–	<1.2	0.00	<1.2
Volatile Chlorinated Hydrocarbons						
Dichlorodifluoromethane	mg/kg	–	–	<1	0.00	<1
Vinyl Chloride	mg/kg	–	–	<1	0.00	<1
Trichlorofluoromethane	mg/kg	–	–	<1	0.00	<1
1,1-Dichloroethene	mg/kg	–	–	<0.2	0.00	<0.2
Iodomethane	mg/kg	–	–	<1	0.00	<1
Methylene chloride	mg/kg	–	–	<1	0.00	<1
trans-1,2-Dichloroethene	mg/kg	–	–	<1	0.00	<1
1,1-Dichloroethane	mg/kg	–	–	<0.2	0.00	<0.2
cis-1,2-Dichloroethene	mg/kg	–	–	<0.2	0.00	<0.2
1,1,1-Trichloroethane	mg/kg	–	–	<0.2	0.00	<0.2
1,1-Dichloropropene	mg/kg	–	–	<0.2	0.00	<0.2
Carbon tetrachloride	mg/kg	–	–	<0.2	0.00	<0.2
1,2-Dichloroethane	mg/kg	–	–	<0.2	0.00	<0.2
Trichloroethene	mg/kg	–	–	<0.2	0.00	<0.2
Dibromomethane	mg/kg	–	–	<0.2	0.00	<0.2
1,1,2-Trichloroethane	mg/kg	–	–	<0.2	0.00	<0.2
Tetrachloroethene	mg/kg	–	–	<0.2	0.00	<0.2
1,1,1,2-Tetrachloroethane	mg/kg	–	–	<0.2	0.00	<0.2
trans-1,4-Dichloro-2-butene	mg/kg	–	–	<0.2	0.00	<0.2
1,1,2,2-Tetrachloroethane	mg/kg	–	–	<0.2	0.00	<0.2

Parameter	Units	SL[1]	SQG-high[2]	Mean	SD	95% UCL[3]
1,2,3-Trichloropropane	mg/kg	–	–	<0.2	0.00	<0.2
Pentachloroethane	mg/kg	–	–	<0.2	0.00	<0.2
1,2-Dibromo-3-chloropropane	mg/kg	–	–	<0.2	0.00	<0.2
Hexachlorobutadiene	mg/kg	–	–	<0.2	0.00	<0.2
Chlorobenzenes						
Chlorobenzene	mg/kg	–	–	<0.2	0.00	<0.2
Bromobenzene	mg/kg	–	–	<0.2	0.00	<0.2
2-Chlorotoluene	mg/kg	–	–	<0.2	0.00	<0.2
4-Chlorotoluene	mg/kg	–	–	<0.2	0.00	<0.2
1,3-Dichlorobenzene	mg/kg	–	–	<0.2	0.00	<0.2
1,4-Dichlorobenzene	mg/kg	–	–	<0.2	0.00	<0.2
1,2-Dichlorobenzene	mg/kg	–	–	<0.2	0.00	<0.2
1,2,4-Trichlorobenzene	mg/kg	–	–	<0.2	0.00	<0.2
1,2,3-Trichlorobenzene	mg/kg	–	–	<0.2	0.00	<0.2
Total Petroleum Hydrocarbons						
TPH C6-C9 Fraction	mg/kg	–	–	<10	0.00	<10
TPH C10-14 Fraction	mg/kg	–	–	<10	0.00	<10
TPH C15-28 Fraction	mg/kg	–	–	<50	8.44	<50
TPH C29-36 Fraction	mg/kg	–	–	<50	0.00	<50
TPH	mg/kg	550	–	<120	8.44	<120
Polycyclic Aromatic Hydrocarbons (PAHs)						
Naphthalene	µg/kg	–	–	<10	0.04	<10
1-Methylnaphthalene	µg/kg	–	–	<10	0.00	<10
2-Methylnaphthalene	µg/kg	–	–	<5	0.00	<5
Acenaphthylene	µg/kg	–	–	<5	0.00	<5
Acenaphthene	µg/kg	–	–	<5	0.00	<5
Fluorene	µg/kg	–	–	<5	0.00	<5
Phenanthrene	µg/kg	–	–	<5	0.00	<5
Anthracene	µg/kg	–	–	<5	0.82	<5
Fluoranthene	µg/kg	–	–	<5	0.82	<5
Pyrene	µg/kg	–	–	<5	1.70	<5
Benzo (a) anthracene	µg/kg	–	–	<5	0.00	<5

Parameter	Units	SL[1]	SQG-high[2]	Mean	SD	95% UCL[3]
Chrysene	µg/kg	–	–	<5	0.00	<5
Benzo (b) & (k) fluoranthene	µg/kg	–	–	<10	0.00	<10
Benzo (a) pyrene	µg/kg	–	–	<5	0.00	<5
Indeno (1,2,3-cd) pyrene	µg/kg	–	–	<5	0.00	<5
Dibenz (a,h) anthracene	µg/kg	–	–	<5	0.00	<5
Benzo (g,h,i) perylene	µg/kg	–	–	<5	0.00	<5
Coronene	µg/kg	–	–	<10	0.00	<10
Benzo (e) pyrene	µg/kg	–	–	<5	0.00	<5
Total PAHs (as above)	µg/kg	10000	50000	<100	0.00	<100
Phenols						
Phenol	mg/kg	–	–	<0.5	0.00	<0.5
2-Chlorophenol	mg/kg	–	–	<0.5	0.00	<0.5
2-Methylphenol	mg/kg	–	–	<0.5	0.00	<0.5
3-&4-Methylphenol	mg/kg	–	–	<1	0.00	<1
2-Nitrophenol	mg/kg	–	–	<0.5	0.00	<0.5
2,4-Dimethylphenol	mg/kg	–	–	<0.5	0.00	<0.5
2,4-Dichlorophenol	mg/kg	–	–	<0.5	0.00	<0.5
2,6-Dichlorophenol	mg/kg	–	–	<0.5	0.00	<0.5
4-Chloro-3-Methylphenol	mg/kg	–	–	<0.5	0.00	<0.5
2,4,6-Trichlorophenol	mg/kg	–	–	<0.5	0.00	<0.5
2,4,5-Trichlorophenol	mg/kg	–	–	<0.5	0.00	<0.5
2,3,4,6-Tetrachlorophenol	mg/kg	–	–	<0.5	0.00	<0.5
Pentachlorophenol	mg/kg	–	–	<1	0.00	<1
Organochlorine Pesticides						
Aldrin	µg/kg	–	–	<0.5	0.00	<0.5
alpha-BHC	µg/kg	–	–	<0.5	0.00	<0.5
beta-BHC	µg/kg	–	–	<0.5	0.00	<0.5
gamma-BHC (Lindane)[4]	µg/kg	0.32	1	<1	0.00	<1
delta-BHC	µg/kg	–	–	<0.5	0.00	<0.5
cis-Chlordane[4]	µg/kg	0.5	6	<0.5	0.00	<0.5
trans-Chlordane[4]	µg/kg	0.5	6	<0.5	0.00	<0.5
p,p'-DDD	µg/kg	2	20	<1	0.00	<1

Parameter	Units	SL[1]	SQG-high[2]	Mean	SD	95% UCL[3]
p,p'-DDE	µg/kg	2.2	27	<1	0.00	<1
p,p'-DDT	µg/kg	1.6	46	<1	0.00	<1
Dieldrin	µg/kg	280	620	<1	0.00	<1
alpha-Endosulfan	µg/kg	–	–	<1	0.00	<1
beta-Endosulfan	µg/kg	–	–	<1	0.00	<1
Endosulfan Sulphate	µg/kg	–	–	<1	0.00	<1
Endrin	µg/kg	10	220	<1	0.00	<1
Endrin ketone	µg/kg	–	–	<1	0.00	<1
Endrin aldehyde	µg/kg	–	–	<1	0.00	<1
Heptachlor	µg/kg	–	–	<1	0.00	<1
Heptachlor epoxide	µg/kg	–	–	<1	0.00	<1
Hexachlorobenzene	µg/kg	–	–	<1	0.00	<1
Methoxychlor	µg/kg	–	–	<1	0.00	<1
Organophosphorus Pesticides						
Dichlorvos	µg/kg	–	–	<20	0.00	<20
Demeton-S-methyl	µg/kg	–	–	<20	0.00	<20
Dimethoate	µg/kg	–	–	<20	0.00	<20
Diazinon	µg/kg	–	–	<20	0.00	<20
Chlorpyrifos-methyl	µg/kg	–	–	<20	0.00	<20
Parathion-methyl	µg/kg	–	–	<20	0.00	<20
Pirimiphos-methyl	µg/kg	–	–	<20	0.00	<20
Fenitrothion	µg/kg	–	–	<20	0.00	<20
Malathion	µg/kg	–	–	<20	0.00	<20
Chlorpyrifos	µg/kg	–	–	<20	0.00	<20
Fenthion	µg/kg	–	–	<20	0.00	<20
Parathion	µg/kg	–	–	<20	0.00	<20
Chlorfenvinphos	µg/kg	–	–	<20	0.00	<20
Bromophos-ethyl	µg/kg	–	–	<20	0.00	<20
Methidathion	µg/kg	–	–	<20	0.00	<20
Fenamiphos	µg/kg	–	–	<20	0.00	<20
Prothiofos	µg/kg	–	–	<20	0.00	<20
Ethion	µg/kg	–	–	<20	0.00	<20
Carbophenothion	µg/kg	–	–	<20	0.00	<20

Parameter	Units	SL[1]	SQG-high[2]	Mean	SD	95% UCL[3]
Phosalone	µg/kg	–	–	<20	0.00	<20
Azinphos-methyl	µg/kg	–	–	<20	0.00	<20
Herbicides, Carbamates						
Aldicarb	mg/kg	–	–	<0.01	0.00	<0.01
Atrazine	mg/kg	–	–	<0.01	0.00	<0.01
Bendiocarb	mg/kg	–	–	<0.01	0.00	<0.01
Carbaryl	mg/kg	–	–	<0.01	0.00	<0.01
Fenoxycarb	mg/kg	–	–	<0.01	0.00	<0.01
Fluroxypyr	mg/kg	–	–	<0.01	0.00	<0.01
Methiocarb	mg/kg	–	–	<0.01	0.00	<0.01
Pirimicarb	mg/kg	–	–	<0.01	0.00	<0.01
Prometryn	mg/kg	–	–	<0.01	0.00	<0.01
Simazine	mg/kg	–	–	<0.01	0.00	<0.01
Synthetic Pyrethoids						
Bifenthrin	mg/kg	–	–	<0.05	0.00	<0.05
Bioresmethrin	mg/kg	–	–	<0.05	0.00	<0.05
Cyfluthrin (total)	mg/kg	–	–	<0.05	0.00	<0.05
Cyhalothrin (total)	mg/kg	–	–	<0.05	0.00	<0.05
Cypermethrin (total)	mg/kg	–	–	<0.05	0.00	<0.05
Deltamethrin (cis & trans)	mg/kg	–	–	<0.05	0.00	<0.05
Fenvalerate (& Es-)	mg/kg	–	–	<0.05	0.00	<0.05
Fluvalinate (& tau-)	mg/kg	–	–	<0.05	0.00	<0.05
Permethrin (cis & trans)	mg/kg	–	–	<0.05	0.00	<0.05
Phenothrin (cis & trans)	mg/kg	–	–	<0.05	0.00	<0.05
Polychlorinated Biphenyls (PCBs)						
Mono-PCB congeners	mg/kg	–	–	<5	0.0	<5
Di-PCB congeners	mg/kg	–	–	<5	0.0	<5
Tri-PCB congeners	mg/kg	–	–	<5	0.0	<5
Tetra-PCB congeners	mg/kg	–	–	<5	0.0	<5
Penta-PCB congeners	mg/kg	–	–	<5	0.0	<5
Hexa-PCB congeners	mg/kg	–	–	<5	0.0	<5
Hepta-PCB congeners	mg/kg	–	–	<5	0.0	<5

Parameter	Units	SL[1]	SQG-high[2]	Mean	SD	95% UCL[3]
Octa-PCB congeners	mg/kg	–	–	<5	0.0	<5
Nona-PCB congeners	mg/kg	–	–	<5	0.0	<5
Deca-PCB congeners	mg/kg	–	–	<5	0.0	<5
Total PCB congeners	mg/kg	23	–	<5	0.0	<5
Organotin Compounds						
Monobutyl tin	µgSn/kg	–	–	<0.5	0.00	<0.5
Dibutyl tin	µgSn/kg	–	–	<0.5	0.00	<0.5
Tributyl tin	µgSn/kg	9	70	<0.5	0.00	<0.5
Phenoxy Acid Herbicides						
2,4 D	mg/kg	–	–	<0.5	0.00	<0.5
2,4 DB	mg/kg	–	–	<0.5	0.00	<0.5
2,4,5 T	mg/kg	–	–	<0.5	0.00	<0.5
2,4,5 TP (Silvex)	mg/kg	–	–	<0.5	0.00	<0.5
Clopyralid	mg/kg	–	–	<0.5	0.00	<0.5
Dicamba	mg/kg	–	–	<0.5	0.00	<0.5
MCPA	mg/kg	–	–	<0.5	0.00	<0.5
Triclopyr	mg/kg	–	–	<0.5	0.00	<0.5
Fluroxypyr	mg/kg	–	–	<0.5	0.00	<0.5
Picloram	mg/kg	–	–	<0.5	0.00	<0.5
Dichlorprop	mg/kg	–	–	<0.5	0.00	<0.5
Mecoprop	mg/kg	–	–	<0.5	0.00	<0.5
Dinoseb	mg/kg	–	–	<0.5	0.00	<0.5
Cyanides						
Cyanide	mg/kg	–	–	<0.1	0.00	<0.1
Dioxins						
Dioxin toxic equivalency (total)	µg/kg	–	–	0.007	0.007	0.013

1 SL – screening level from the NAGD

2 SQG-High – sediment quality high values for contamination from the NAGD

3 95% UCL – upper 95% confidence limit of the mean

4 As stated in the NAGD, the screening level for these analytes is lower than the detection limit. If detected, these substances are present at above the SL and must be assesses accordingly.

Table 2.3 Summary of analyses for subsample B samples (sediment 0.5 m deep to 1.0 m deep).

Parameter	Units	SL[1]	SQG-high[2]	Mean	SD	95% UCL[3]
Moisture Content	**%**	–	–	18.64	2.64	20.02
Particle Size Analysis						
Gravel (+2 mm)	%	–	–	4.50	4.00	6.59
Sand (2 mm – 0.06 mm)	%	–	–	89.93	4.95	92.52
Silt and clay (<0.06 mm)	%	–	–	5.57	3.72	7.52
Nutrients						
Total Organic Carbon	%	–		18.64	2.64	20.02
Nitrate as N	mg/kg	–	–	0.06	0.04	0.09
Nitrite as N	mg/kg	–	–	<0.1	0.00	<0.1
Total Kjeldahl Nitrogen	mg/kg	–	–	38.79	18.78	48.62
Total Nitrogen	mg/kg	–	–	38.79	18.78	48.62
Total Phosphorus	mg/kg	–	–	0.08	0.05	0.11
Metals						
Silver	mg/kg	1	3.7	0.08	0.06	0.11
Aluminium	mg/kg	–	–	1823.57	889.77	2289.65
Arsenic	mg/kg	20	70	2.37	1.45	3.13
Cadmium	mg/kg	1.5	10	<0.1	0.00	<0.1
Cobalt	mg/kg	–	–	0.08	0.06	0.11
Chromium	mg/kg	80	370	3.93	1.02	4.46
Copper	mg/kg	65	270	0.69	0.46	0.93
Iron	mg/kg	–	–	2014.29	2083.21	3105.52
Mercury	mg/kg	0.15	1	0.01	0.00	0.01
Manganese	mg/kg	–	–	31.02	17.34	40.11
Nickel	mg/kg	21	52	1.33	0.34	1.51
Lead	mg/kg	50	220	2014.29	2083.21	3105.52
Antimony	mg/kg	2	–	0.01	0.00	0.01
Selenium	mg/kg	–	–	0.06	0.02	0.07
Vanadium	mg/kg	–	–	5.26	2.81	6.73
Zinc	mg/kg	200	410	2.04	0.49	2.29

Parameter	Units	SL[1]	SQG-high[2]	Mean	SD	95% UCL[3]
BTEX						
Benzene	mg/kg	–	–	<0.2	0.00	<0.2
Toluene	mg/kg	–	–	<0.2	0.00	<0.2
Ethyl Benzene	mg/kg	–	–	<0.2	0.00	<0.2
meta- & para- xylenes	mg/kg	–	–	<0.4	0.00	<0.4
ortho-Xylene	mg/kg	–	–	<0.2	0.00	<0.2
Total BTEX	mg/kg	–	–	<1.2	0.00	<1.2
Volatile Chlorinated Hydrocarbons						
Dichlorodifluoromethane	mg/kg	–	–	<1	0.00	<1
Vinyl Chloride	mg/kg	–	–	<1	0.00	<1
Trichlorofluoromethane	mg/kg	–	–	<1	0.00	<1
1,1-Dichloroethene	mg/kg	–	–	<0.2	0.00	<0.2
Iodomethane	mg/kg	–	–	<1	0.00	<1
Methylene chloride	mg/kg	–	–	<1	0.00	<1
trans-1,2-Dichloroethene	mg/kg	–	–	<1	0.00	<1
1,1-Dichloroethane	mg/kg	–	–	<0.2	0.00	<0.2
cis-1,2-Dichloroethene	mg/kg	–	–	<0.2	0.00	<0.2
1,1,1-Trichloroethane	mg/kg	–	–	<0.2	0.00	<0.2
1,1-Dichloropropene	mg/kg	–	–	<0.2	0.00	<0.2
Carbon tetrachloride	mg/kg	–	–	<0.2	0.00	<0.2
1,2-Dichloroethane	mg/kg	–	–	<0.2	0.00	<0.2
Trichloroethene	mg/kg	–	–	<0.2	0.00	<0.2
Dibromomethane	mg/kg	–	–	<0.2	0.00	<0.2
1,1,2-Trichloroethane	mg/kg	–	–	<0.2	0.00	<0.2
Tetrachloroethene	mg/kg	–	–	<0.2	0.00	<0.2
1,1,1,2-Tetrachloroethane	mg/kg	–	–	<0.2	0.00	<0.2
trans-1,4-Dichloro-2-butene	mg/kg	–	–	<0.2	0.00	<0.2
1,1,2,2-Tetrachloroethane	mg/kg	–	–	<0.2	0.00	<0.2
1,2,3-Trichloropropane	mg/kg	–	–	<0.2	0.00	<0.2
Pentachloroethane	mg/kg	–	–	<0.2	0.00	<0.2
1,2-Dibromo-3-chloropropane	mg/kg	–	–	<0.2	0.00	<0.2

Parameter	Units	SL[1]	SQG-high[2]	Mean	SD	95% UCL[3]
Hexachlorobutadiene	mg/kg	–	–	<0.2	0.00	<0.2
Chlorobenzenes						
Chlorobenzene	mg/kg	–	–	<0.2	0.00	<0.2
Bromobenzene	mg/kg	–	–	<0.2	0.00	<0.2
2-Chlorotoluene	mg/kg	–	–	<0.2	0.00	<0.2
4-Chlorotoluene	mg/kg	–	–	<0.2	0.00	<0.2
1,3-Dichlorobenzene	mg/kg	–	–	<0.2	0.00	<0.2
1,4-Dichlorobenzene	mg/kg	–	–	<0.2	0.00	<0.2
1,2-Dichlorobenzene	mg/kg	–	–	<0.2	0.00	<0.2
1,2,4-Trichlorobenzene	mg/kg	–	–	<0.2	0.00	<0.2
1,2,3-Trichlorobenzene	mg/kg	–	–	<0.2	0.00	<0.2
Total Petroleum Hydrocarbons						
TPH C6-C9 Fraction	mg/kg	–	–	<10	0.00	<10
TPH C10-14 Fraction	mg/kg	–	–	<10	0.00	<10
TPH C15-28 Fraction	mg/kg	–	–	<50	8.44	<50
TPH C29-36 Fraction	mg/kg	–	–	<50	0.00	<50
TPH	mg/kg	550	–	<120	8.44	<120
Polycyclic Aromatic Hydrocarbons (PAHs)						
Naphthalene	µg/kg	–	–	<10	0.04	<10
1-Methylnaphthalene	µg/kg	–	–	<10	0.00	<10
2-Methylnaphthalene	µg/kg	–	–	<5	0.00	<5
Acenaphthylene	µg/kg	–	–	<5	0.00	<5
Acenaphthene	µg/kg	–	–	<5	0.00	<5
Fluorene	µg/kg	–	–	<5	0.00	<5
Phenanthrene	µg/kg	–	–	<5	0.00	<5
Anthracene	µg/kg	–	–	<5	0.82	<5
Fluoranthene	µg/kg	–	–	<5	0.82	<5
Pyrene	µg/kg	–	–	<5	1.70	<5
Benzo (a) anthracene	µg/kg	–	–	<5	0.00	<5
Chrysene	µg/kg	–	–	<5	0.00	<5
Benzo (b) & (k) fluoranthene	µg/kg	–	–	<10	0.00	<10
Benzo (a) pyrene	µg/kg	–	–	<5	0.00	<5

Parameter	Units	SL[1]	SQG-high[2]	Mean	SD	95% UCL[3]
Indeno (1,2,3-cd) pyrene	µg/kg	–	–	<5	0.00	<5
Dibenz (a,h) anthracene	µg/kg	–	–	<5	0.00	<5
Benzo (g,h,i) perylene	µg/kg	–	–	<5	0.00	<5
Coronene	µg/kg	–	–	<10	0.00	<10
Benzo (e) pyrene	µg/kg	–	–	<5	0.00	<5
Total PAHs (as above)	µg/kg	10000	50000	<100	0.00	<100
Phenols						
Phenol	mg/kg	–	–	<0.5	0.00	<0.5
2-Chlorophenol	mg/kg	–	–	<0.5	0.00	<0.5
2-Methylphenol	mg/kg	–	–	<0.5	0.00	<0.5
3-&4-Methylphenol	mg/kg	–	–	<1	0.00	<1
2-Nitrophenol	mg/kg	–	–	<0.5	0.00	<0.5
2,4-Dimethylphenol	mg/kg	–	–	<0.5	0.00	<0.5
2,4-Dichlorophenol	mg/kg	–	–	<0.5	0.00	<0.5
2,6-Dichlorophenol	mg/kg	–	–	<0.5	0.00	<0.5
4-Chloro-3-Methylphenol	mg/kg	–	–	<0.5	0.00	<0.5
2,4,6-Trichlorophenol	mg/kg	–	–	<0.5	0.00	<0.5
2,4,5-Trichlorophenol	mg/kg	–	–	<0.5	0.00	<0.5
2,3,4,6-Tetrachlorophenol	mg/kg	–	–	<0.5	0.00	<0.5
Pentachlorophenol	mg/kg	–	–	<1	0.00	<1
Organochlorine Pesticides						
Aldrin	µg/kg	–	–	<0.5	0.00	<0.5
alpha-BHC	µg/kg	–	–	<0.5	0.00	<0.5
beta-BHC	µg/kg	–	–	<0.5	0.00	<0.5
gamma-BHC (Lindane)[4]	µg/kg	0.32	1	<1	0.00	<1
delta-BHC	µg/kg	–	–	<0.5	0.00	<0.5
cis-Chlordane[4]	µg/kg	0.5	6	<0.5	0.00	<0.5
trans-Chlordane[4]	µg/kg	0.5	6	<0.5	0.00	<0.5
p,p'-DDD	µg/kg	2	20	<1	0.00	<1
p,p'-DDE	µg/kg	2.2	27	<1	0.00	<1
p,p'-DDT	µg/kg	1.6	46	<1	0.00	<1
Dieldrin	µg/kg	280	620	<1	0.00	<1
alpha-Endosulfan	µg/kg	–	–	<1	0.00	<1

Parameter	Units	SL[1]	SQG-high[2]	Mean	SD	95% UCL[3]
beta-Endosulfan	µg/kg	–	–	<1	0.00	<1
Endosulfan Sulphate	µg/kg	–	–	<1	0.00	<1
Endrin	µg/kg	10	220	<1	0.00	<1
Endrin ketone	µg/kg	–	–	<1	0.00	<1
Endrin aldehyde	µg/kg	–	–	<1	0.00	<1
Heptachlor	µg/kg	–	–	<1	0.00	<1
Heptachlor epoxide	µg/kg	–	–	<1	0.00	<1
Hexachlorobenzene	µg/kg	–	–	<1	0.00	<1
Methoxychlor	µg/kg	–	–	<1	0.00	<1
Organophosphorus Pesticides						
Dichlorvos	µg/kg	–	–	<20	0.00	<20
Demeton-S-methyl	µg/kg	–	–	<20	0.00	<20
Dimethoate	µg/kg	–	–	<20	0.00	<20
Diazinon	µg/kg	–	–	<20	0.00	<20
Chlorpyrifos-methyl	µg/kg	–	–	<20	0.00	<20
Parathion-methyl	µg/kg	–	–	<20	0.00	<20
Pirimiphos-methyl	µg/kg	–	–	<20	0.00	<20
Fenitrothion	µg/kg	–	–	<20	0.00	<20
Malathion	µg/kg	–	–	<20	0.00	<20
Chlorpyrifos	µg/kg	–	–	<20	0.00	<20
Fenthion	µg/kg	–	–	<20	0.00	<20
Parathion	µg/kg	–	–	<20	0.00	<20
Chlorfenvinphos	µg/kg	–	–	<20	0.00	<20
Bromophos-ethyl	µg/kg	–	–	<20	0.00	<20
Methidathion	µg/kg	–	–	<20	0.00	<20
Fenamiphos	µg/kg	–	–	<20	0.00	<20
Prothiofos	µg/kg	–	–	<20	0.00	<20
Ethion	µg/kg	–	–	<20	0.00	<20
Carbophenothion	µg/kg	–	–	<20	0.00	<20
Phosalone	µg/kg	–	–	<20	0.00	<20
Azinphos-methyl	µg/kg	–	–	<20	0.00	<20

Parameter	Units	SL[1]	SQG-high[2]	Mean	SD	95% UCL[3]
Herbicides, Carbamates						
Aldicarb	mg/kg	–	–	<0.01	0.00	<0.01
Atrazine	mg/kg	–	–	<0.01	0.00	<0.01
Bendiocarb	mg/kg	–	–	<0.01	0.00	<0.01
Carbaryl	mg/kg	–	–	<0.01	0.00	<0.01
Fenoxycarb	mg/kg	–	–	<0.01	0.00	<0.01
Fluroxypyr	mg/kg	–	–	<0.01	0.00	<0.01
Methiocarb	mg/kg	–	–	<0.01	0.00	<0.01
Pirimicarb	mg/kg	–	–	<0.01	0.00	<0.01
Prometryn	mg/kg	–	–	<0.01	0.00	<0.01
Simazine	mg/kg	–	–	<0.01	0.00	<0.01
Synthetic Pyrethoids						
Bifenthrin	mg/kg	–	–	<0.05	0.00	<0.05
Bioresmethrin	mg/kg	–	–	<0.05	0.00	<0.05
Cyfluthrin (total)	mg/kg	–	–	<0.05	0.00	<0.05
Cyhalothrin (total)	mg/kg	–	–	<0.05	0.00	<0.05
Cypermethrin (total)	mg/kg	–	–	<0.05	0.00	<0.05
Deltamethrin (cis & trans)	mg/kg	–	–	<0.05	0.00	<0.05
Fenvalerate (& Es-)	mg/kg	–	–	<0.05	0.00	<0.05
Fluvalinate (& tau-)	mg/kg	–	–	<0.05	0.00	<0.05
Permethrin (cis & trans)	mg/kg	–	–	<0.05	0.00	<0.05
Phenothrin (cis & trans)	mg/kg	–	–	<0.05	0.00	<0.05
Polychlorinated Biphenyls (PCBs)						
Mono-PCB congeners	mg/kg	–	–	<5	0.0	<5
Di-PCB congeners	mg/kg	–	–	<5	0.0	<5
Tri-PCB congeners	mg/kg	–	–	<5	0.0	<5
Tetra-PCB congeners	mg/kg	–	–	<5	0.0	<5
Penta-PCB congeners	mg/kg	–	–	<5	0.0	<5
Hexa-PCB congeners	mg/kg	–	–	<5	0.0	<5
Hepta-PCB congeners	mg/kg	–	–	<5	0.0	<5
Octa-PCB congeners	mg/kg	–	–	<5	0.0	<5
Nona-PCB congeners	mg/kg	–	–	<5	0.0	<5

Parameter	Units	SL[1]	SQG-high[2]	Mean	SD	95% UCL[3]
Deca-PCB congeners	mg/kg	–	–	<5	0.0	<5
Total PCB congeners	mg/kg	23	–	<5	0.0	<5
Organotin Compounds						
Monobutyl tin	µgSn/kg	–	–	<0.5	0.00	<0.5
Dibutyl tin	µgSn/kg	–	–	<0.5	0.00	<0.5
Tributyl tin	µgSn/kg	9	70	<0.5	0.00	<0.5
Phenoxy Acid Herbicides						
2,4 D	mg/kg	–	–	<0.5	0.00	<0.5
2,4 DB	mg/kg	–	–	<0.5	0.00	<0.5
2,4,5 T	mg/kg	–	–	<0.5	0.00	<0.5
2,4,5 TP (Silvex)	mg/kg	–	–	<0.5	0.00	<0.5
Clopyralid	mg/kg	–	–	<0.5	0.00	<0.5
Dicamba	mg/kg	–	–	<0.5	0.00	<0.5
MCPA	mg/kg	–	–	<0.5	0.00	<0.5
Triclopyr	mg/kg	–	–	<0.5	0.00	<0.5
Fluroxypyr	mg/kg	–	–	<0.5	0.00	<0.5
Picloram	mg/kg	–	–	<0.5	0.00	<0.5
Dichlorprop	mg/kg	–	–	<0.5	0.00	<0.5
Mecoprop	mg/kg	–	–	<0.5	0.00	<0.5
Dinoseb	mg/kg	–	–	<0.5	0.00	<0.5
Cyanides						
Cyanide	mg/kg	–	–	<0.1	0.00	<0.1

1 SL – screening level from the NAGD

2 SQG-High – sediment quality high values for contamination from the NAGD

3 95% UCL – upper 95% confidence limit of the mean

4 As stated in the NAGD, the screening level for these analytes is lower than the detection limit. If detected, these substances are present at above the SL and must be assesses accordingly.

Table 2.4 Summary of analyses for subsample C samples (sediment deeper than 1.0 m deep down to 0.5 m below the maximum dredge depth).

Parameter	Units	SL[1]	SQG-high[2]	Mean	SD	95% UCL[3]
Moisture Content	**%**	–	–	16.54	1.12	17.10
Particle Size Analysis						
Gravel (+2 mm)	%	–	–	2.80	3.61	4.63
Sand (2 mm – 0.06 mm)	%	–	–	91.60	5.14	94.20
Silt and clay (<0.06 mm)	%	–	–	5.60	2.85	7.04
Nutrients						
Total Organic Carbon	%	–		0.04	0.02	0.05
Nitrate as N	mg/kg	–	–	0.06	0.04	0.09
Nitrite as N	mg/kg	–	–	<0.1	0.00	<0.1
Total Kjeldahl Nitrogen	mg/kg	–	–	28.14	15.50	35.99
Total Nitrogen	mg/kg	–	–	28.14	15.50	35.99
Total Phosphorus	mg/kg	–	–	0.14	0.18	0.23
Metals						
Silver	mg/kg	1	3.7	<0.1	0.00	<0.1
Aluminium	mg/kg	–	–	1555.71	741.97	1931.20
Arsenic	mg/kg	20	70	1.63	0.90	2.09
Cadmium	mg/kg	1.5	10	<0.1	0.00	<0.1
Cobalt	mg/kg	–	–	0.47	0.21	0.58
Chromium	mg/kg	80	370	2.48	0.68	2.82
Copper	mg/kg	65	270	1.03	0.69	1.38
Iron	mg/kg	–	–	1383.57	443.68	1608.10
Mercury	mg/kg	0.15	1	0.01	0.00	0.01
Manganese	mg/kg	–	–	11.69	7.02	15.25
Nickel	mg/kg	21	52	1.46	0.38	1.65
Lead	mg/kg	50	220	1.36	0.42	1.57
Antimony	mg/kg	2	–	<0.5	0.00	<0.5
Selenium	mg/kg	–	–	0.08	0.05	0.10
Vanadium	mg/kg	–	–	3.88	1.09	4.43
Zinc	mg/kg	200	410	1.71	0.55	1.98

Parameter	Units	SL[1]	SQG-high[2]	Mean	SD	95% UCL[3]
BTEX						
Benzene	mg/kg	–	–	<0.2	0.00	<0.2
Toluene	mg/kg	–	–	<0.2	0.00	<0.2
Ethyl Benzene	mg/kg	–	–	<0.2	0.00	<0.2
meta- & para- xylenes	mg/kg	–	–	<0.4	0.00	<0.4
ortho-Xylene	mg/kg	–	–	<0.2	0.00	<0.2
Total BTEX	mg/kg	–	–	<1.2	0.00	<1.2
Volatile Chlorinated Hydrocarbons						
Dichlorodifluoromethane	mg/kg	–	–	<1	0.00	<1
Vinyl Chloride	mg/kg	–	–	<1	0.00	<1
Trichlorofluoromethane	mg/kg	–	–	<1	0.00	<1
1,1-Dichloroethene	mg/kg	–	–	<0.2	0.00	<0.2
Iodomethane	mg/kg	–	–	<1	0.00	<1
Methylene chloride	mg/kg	–	–	<1	0.00	<1
trans-1,2-Dichloroethene	mg/kg	–	–	<1	0.00	<1
1,1-Dichloroethane	mg/kg	–	–	<0.2	0.00	<0.2
cis-1,2-Dichloroethene	mg/kg	–	–	<0.2	0.00	<0.2
1,1,1-Trichloroethane	mg/kg	–	–	<0.2	0.00	<0.2
1,1-Dichloropropene	mg/kg	–	–	<0.2	0.00	<0.2
Carbon tetrachloride	mg/kg	–	–	<0.2	0.00	<0.2
1,2-Dichloroethane	mg/kg	–	–	<0.2	0.00	<0.2
Trichloroethene	mg/kg	–	–	<0.2	0.00	<0.2
Dibromomethane	mg/kg	–	–	<0.2	0.00	<0.2
1,1,2-Trichloroethane	mg/kg	–	–	<0.2	0.00	<0.2
Tetrachloroethene	mg/kg	–	–	<0.2	0.00	<0.2
1,1,1,2-Tetrachloroethane	mg/kg	–	–	<0.2	0.00	<0.2
trans-1,4-Dichloro-2-butene	mg/kg	–	–	<0.2	0.00	<0.2
1,1,2,2-Tetrachloroethane	mg/kg	–	–	<0.2	0.00	<0.2
1,2,3-Trichloropropane	mg/kg	–	–	<0.2	0.00	<0.2
Pentachloroethane	mg/kg	–	–	<0.2	0.00	<0.2
1,2-Dibromo-3-chloropropane	mg/kg	–	–	<0.2	0.00	<0.2

Parameter	Units	SL[1]	SQG-high[2]	Mean	SD	95% UCL[3]
Hexachlorobutadiene	mg/kg	–	–	<0.2	0.00	<0.2
Chlorobenzenes						
Chlorobenzene	mg/kg	–	–	<0.2	0.00	<0.2
Bromobenzene	mg/kg	–	–	<0.2	0.00	<0.2
2-Chlorotoluene	mg/kg	–	–	<0.2	0.00	<0.2
4-Chlorotoluene	mg/kg	–	–	<0.2	0.00	<0.2
1,3-Dichlorobenzene	mg/kg	–	–	<0.2	0.00	<0.2
1,4-Dichlorobenzene	mg/kg	–	–	<0.2	0.00	<0.2
1,2-Dichlorobenzene	mg/kg	–	–	<0.2	0.00	<0.2
1,2,4-Trichlorobenzene	mg/kg	–	–	<0.2	0.00	<0.2
1,2,3-Trichlorobenzene	mg/kg	–	–	<0.2	0.00	<0.2
Total Petroleum Hydrocarbons						
TPH C6-C9 Fraction	mg/kg	–	–	<10	0.00	<10
TPH C10-14 Fraction	mg/kg	–	–	<10	0.00	<10
TPH C15-28 Fraction	mg/kg	–	–	<50	8.44	<50
TPH C29-36 Fraction	mg/kg	–	–	<50	0.00	<50
TPH	mg/kg	550	–	<120	8.44	<120
Polycyclic Aromatic Hydrocarbons (PAHs)						
Naphthalene	µg/kg	–	–	<10	0.04	<10
1-Methylnaphthalene	µg/kg	–	–	<10	0.00	<10
2-Methylnaphthalene	µg/kg	–	–	<5	0.00	<5
Acenaphthylene	µg/kg	–	–	<5	0.00	<5
Acenaphthene	µg/kg	–	–	<5	0.00	<5
Fluorene	µg/kg	–	–	<5	0.00	<5
Phenanthrene	µg/kg	–	–	<5	0.00	<5
Anthracene	µg/kg	–	–	<5	0.82	<5
Fluoranthene	µg/kg	–	–	<5	0.82	<5
Pyrene	µg/kg	–	–	<5	1.70	<5
Benzo (a) anthracene	µg/kg	–	–	<5	0.00	<5
Chrysene	µg/kg	–	–	<5	0.00	<5
Benzo (b) & (k) fluoranthene	µg/kg	–	–	<10	0.00	<10
Benzo (a) pyrene	µg/kg	–	–	<5	0.00	<5

Parameter	Units	SL[1]	SQG-high[2]	Mean	SD	95% UCL[3]
Indeno (1,2,3-cd) pyrene	µg/kg	–	–	<5	0.00	<5
Dibenz (a,h) anthracene	µg/kg	–	–	<5	0.00	<5
Benzo (g,h,i) perylene	µg/kg	–	–	<5	0.00	<5
Coronene	µg/kg	–	–	<10	0.00	<10
Benzo (e) pyrene	µg/kg	–	–	<5	0.00	<5
Total PAHs (as above)	µg/kg	10000	50000	<100	0.00	<100
Phenols						
Phenol	mg/kg	–	–	<0.5	0.00	<0.5
2-Chlorophenol	mg/kg	–	–	<0.5	0.00	<0.5
2-Methylphenol	mg/kg	–	–	<0.5	0.00	<0.5
3-&4-Methylphenol	mg/kg	–	–	<1	0.00	<1
2-Nitrophenol	mg/kg	–	–	<0.5	0.00	<0.5
2,4-Dimethylphenol	mg/kg	–	–	<0.5	0.00	<0.5
2,4-Dichlorophenol	mg/kg	–	–	<0.5	0.00	<0.5
2,6-Dichlorophenol	mg/kg	–	–	<0.5	0.00	<0.5
4-Chloro-3-Methylphenol	mg/kg	–	–	<0.5	0.00	<0.5
2,4,6-Trichlorophenol	mg/kg	–	–	<0.5	0.00	<0.5
2,4,5-Trichlorophenol	mg/kg	–	–	<0.5	0.00	<0.5
2,3,4,6-Tetrachlorophenol	mg/kg	–	–	<0.5	0.00	<0.5
Pentachlorophenol	mg/kg	–	–	<1	0.00	<1
Organochlorine Pesticides						
Aldrin	µg/kg	–	–	<0.5	0.00	<0.5
alpha-BHC	µg/kg	–	–	<0.5	0.00	<0.5
beta-BHC	µg/kg	–	–	<0.5	0.00	<0.5
gamma-BHC (Lindane)[4]	µg/kg	0.32	1	<1	0.00	<1
delta-BHC	µg/kg	–	–	<0.5	0.00	<0.5
cis-Chlordane[4]	µg/kg	0.5	6	<0.5	0.00	<0.5
trans-Chlordane[4]	µg/kg	0.5	6	<0.5	0.00	<0.5
p,p'-DDD	µg/kg	2	20	<1	0.00	<1
p,p'-DDE	µg/kg	2.2	27	<1	0.00	<1
p,p'-DDT	µg/kg	1.6	46	<1	0.00	<1
Dieldrin	µg/kg	280	620	<1	0.00	<1
alpha-Endosulfan	µg/kg	–	–	<1	0.00	<1

Parameter	Units	SL[1]	SQG-high[2]	Mean	SD	95% UCL[3]
beta-Endosulfan	µg/kg	–	–	<1	0.00	<1
Endosulfan Sulphate	µg/kg	–	–	<1	0.00	<1
Endrin	µg/kg	10	220	<1	0.00	<1
Endrin ketone	µg/kg	–	–	<1	0.00	<1
Endrin aldehyde	µg/kg	–	–	<1	0.00	<1
Heptachlor	µg/kg	–	–	<1	0.00	<1
Heptachlor epoxide	µg/kg	–	–	<1	0.00	<1
Hexachlorobenzene	µg/kg	–	–	<1	0.00	<1
Methoxychlor	µg/kg	–	–	<1	0.00	<1
Organophosphorus Pesticides						
Dichlorvos	µg/kg	–	–	<20	0.00	<20
Demeton-S-methyl	µg/kg	–	–	<20	0.00	<20
Dimethoate	µg/kg	–	–	<20	0.00	<20
Diazinon	µg/kg	–	–	<20	0.00	<20
Chlorpyrifos-methyl	µg/kg	–	–	<20	0.00	<20
Parathion-methyl	µg/kg	–	–	<20	0.00	<20
Pirimiphos-methyl	µg/kg	–	–	<20	0.00	<20
Fenitrothion	µg/kg	–	–	<20	0.00	<20
Malathion	µg/kg	–	–	<20	0.00	<20
Chlorpyrifos	µg/kg	–	–	<20	0.00	<20
Fenthion	µg/kg	–	–	<20	0.00	<20
Parathion	µg/kg	–	–	<20	0.00	<20
Chlorfenvinphos	µg/kg	–	–	<20	0.00	<20
Bromophos-ethyl	µg/kg	–	–	<20	0.00	<20
Methidathion	µg/kg	–	–	<20	0.00	<20
Fenamiphos	µg/kg	–	–	<20	0.00	<20
Prothiofos	µg/kg	–	–	<20	0.00	<20
Ethion	µg/kg	–	–	<20	0.00	<20
Carbophenothion	µg/kg	–	–	<20	0.00	<20
Phosalone	µg/kg	–	–	<20	0.00	<20
Azinphos-methyl	µg/kg	–	–	<20	0.00	<20
Herbicides, Carbamates						
Aldicarb	mg/kg	–	–	<0.01	0.00	<0.01

Parameter	Units	SL[1]	SQG-high[2]	Mean	SD	95% UCL[3]
Atrazine	mg/kg	–	–	<0.01	0.00	<0.01
Bendiocarb	mg/kg	–	–	<0.01	0.00	<0.01
Carbaryl	mg/kg	–	–	<0.01	0.00	<0.01
Fenoxycarb	mg/kg	–	–	<0.01	0.00	<0.01
Fluroxypyr	mg/kg	–	–	<0.01	0.00	<0.01
Methiocarb	mg/kg	–	–	<0.01	0.00	<0.01
Pirimicarb	mg/kg	–	–	<0.01	0.00	<0.01
Prometryn	mg/kg	–	–	<0.01	0.00	<0.01
Simazine	mg/kg	–	–	<0.01	0.00	<0.01
Synthetic Pyrethoids						
Bifenthrin	mg/kg	–	–	<0.05	0.00	<0.05
Bioresmethrin	mg/kg	–	–	<0.05	0.00	<0.05
Cyfluthrin (total)	mg/kg	–	–	<0.05	0.00	<0.05
Cyhalothrin (total)	mg/kg	–	–	<0.05	0.00	<0.05
Cypermethrin (total)	mg/kg	–	–	<0.05	0.00	<0.05
Deltamethrin (cis & trans)	mg/kg	–	–	<0.05	0.00	<0.05
Fenvalerate (& Es-)	mg/kg	–	–	<0.05	0.00	<0.05
Fluvalinate (& tau-)	mg/kg	–	–	<0.05	0.00	<0.05
Permethrin (cis & trans)	mg/kg	–	–	<0.05	0.00	<0.05
Phenothrin (cis & trans)	mg/kg	–	–	<0.05	0.00	<0.05
Polychlorinated Biphenyls (PCBs)						
Mono-PCB congeners	mg/kg	–	–	<5	0.0	<5
Di-PCB congeners	mg/kg	–	–	<5	0.0	<5
Tri-PCB congeners	mg/kg	–	–	<5	0.0	<5
Tetra-PCB congeners	mg/kg	–	–	<5	0.0	<5
Penta-PCB congeners	mg/kg	–	–	<5	0.0	<5
Hexa-PCB congeners	mg/kg	–	–	<5	0.0	<5
Hepta-PCB congeners	mg/kg	–	–	<5	0.0	<5
Octa-PCB congeners	mg/kg	–	–	<5	0.0	<5
Nona-PCB congeners	mg/kg	–	–	<5	0.0	<5
Deca-PCB congeners	mg/kg	–	–	<5	0.0	<5
Total PCB congeners	mg/kg	23	–	<5	0.0	<5

Parameter	Units	SL[1]	SQG-high[2]	Mean	SD	95% UCL[3]
Organotin Compounds						
Monobutyl tin	µgSn/kg	–	–	<0.5	0.00	<0.5
Dibutyl tin	µgSn/kg	–	–	<0.5	0.00	<0.5
Tributyl tin	µgSn/kg	9	70	<0.5	0.00	<0.5
Phenoxy Acid Herbicides						
2,4 D	mg/kg	–	–	<0.5	0.00	<0.5
2,4 DB	mg/kg	–	–	<0.5	0.00	<0.5
2,4,5 T	mg/kg	–	–	<0.5	0.00	<0.5
2,4,5 TP (Silvex)	mg/kg	–	–	<0.5	0.00	<0.5
Clopyralid	mg/kg	–	–	<0.5	0.00	<0.5
Dicamba	mg/kg	–	–	<0.5	0.00	<0.5
MCPA	mg/kg	–	–	<0.5	0.00	<0.5
Triclopyr	mg/kg	–	–	<0.5	0.00	<0.5
Fluroxypyr	mg/kg	–	–	<0.5	0.00	<0.5
Picloram	mg/kg	–	–	<0.5	0.00	<0.5
Dichlorprop	mg/kg	–	–	<0.5	0.00	<0.5
Mecoprop	mg/kg	–	–	<0.5	0.00	<0.5
Dinoseb	mg/kg	–	–	<0.5	0.00	<0.5
Cyanides						
Cyanide	mg/kg	–	–	<0.1	0.00	<0.1

1 SL – screening level from the NAGD

2 SQG-High – sediment quality high values for contamination from the NAGD

3 95% UCL – upper 95% confidence limit of the mean

4 As stated in the NAGD, the screening level for these analytes is lower than the detection limit. If detected, these substances are present at above the SL and must be assesses accordingly.

Quality Assurance / Quality Control

The NAGD recommend that for laboratory replicates, a relative standard deviation (RSD[3]) or relative percent difference (RPD[4]) of ± 35% is acceptable (DEWHA 2009). The highest RPD between laboratory replicates was 66.6% (silver) for site 1 subsample A, all other variables had a RPD of <9%. Given that the concentration was below the screening level, this does not affect the interpretation of the results.

There was also high variation between replicates analysed by different laboratories for vanadium and selenium. For vanadium, the concentration recorded by ALS was lower than that recorded by Advanced Analytical, meaning it is possible that vanadium concentrations have been over-estimated. For selenium, the difference was due to high variation between samples analysed by Advanced Analytical, and also an artefact of different laboratory limits of reporting for Advanced Analytical and ALS. There are no screening levels for vanadium and selenium.

The NAGD recommend that for field replicates, an RPD or RSD of ± 50% between field replicates is acceptable (DEWHA 2009). The highest RSD between field replicates was 127.7% (phosphate), 86.6% (nitrate), and 59.4% (copper) for site 12 subsample C. Given that there are no screening levels for phosphate and nitrate, and that the concentration of copper was below the screening level in all samples, this does not affect the interpretation of the results.

Acid Sulphate Soils

Field pH_F values were relatively neutral (usually ~7.0 to 8.0) in most of the samples, and were relatively uniform across the sampling sites at the various depth intervals. pH_{FOX} (pH after oxidation with peroxide) values were usually around 1 to 2 pH units below pH_F, values, but the pH of some samples was lower. These field results indicated that the sediments within parts of the dredge areas may be potential acid sulphate soils (PASS).

[3] RSD = standard deviation ÷ mean x 100
[4] RPD = the difference between two samples ÷ mean x 100

Specifically, possible PASS were detected:

- between 1.25 and 2.25 m at site 1 (except for the 1.5 m strata)
- the 1.75 m strata at site 8 and 11
- between 1.75 and 2.75 m at site 12 (except for the 2.25 and 2.5 m strata)
- below 1.25 m at site 16
- between 2.25 m at site 18 (except for the 2.5 m strata)
- below 0.75 m at site 20 although the potential was highly variable with depth, and
- below 2.0 m at site 22 (except the 2.25 m strata).

Laboratory analyses were performed on collected sediment samples from sites 1, 12, 16, 18 and 22 to confirm the presence of PASS. Field results, along with laboratory results, are presented in Table 2.5.

At each of the sites, titratable actual acidity and titratable peroxide acidity of the soils was below the laboratory LORs. The net acidity of the sediments, which takes into account the acid neutralising capacity of the sediments, is presented in Table 2.6. These results indicate that the net acidity of the sediments is below the action criteria outlined in the *State Planning Policy 2/02*, in most samples. That is, the acid neutralising capacity of the sediments would be sufficient to neutralise any acidity from PASS, and that no treatment would be required, at most sites. Given that sediments will be thoroughly mixed during dredging, no further testing is planned, however several samples are being held, frozen, should further testing be required.

Table 2.5 Results of acid sulphate soil field testing and laboratory analysis using the SPOCAS method.

Field Morphology Summary					Laboratory Results															
		Field pH						TAA	TPA	S_{KCl}	S_P	Ca_{KCl}	Ca_P	Mg_{KCl}	Mg_P	TSA	ANC_E	S_{POS}	Ca_A	Mg_A
Site	Soil Texture	Depth (m)	pH_F	pH_{FOX}	Sample Depth (m)	pH_{KCl}	pH_{OX} [A]	mol H^+/t		%S		%Ca		%Mg		mol H^+/t	% $CaCO_3$	%S	%Ca	%Mg
						23A	23B	23F	23G	23C	23D	23V	23W	23S	23T	23H	23Q	23E	23X	21U
1	smooth, sand	0	7.8	7.1	0-0.5	9.9	7.9	<5	<5	0.04	0.11	0.12	1.50	0.03	0.11	<5	3.70	0.07	1.30	0.07
1	smooth, sand	0.25	7.8	7.2	0-0.5	9.9	7.9	<5	<5	0.04	0.11	0.11	1.30	0.03	0.10	<5	3.30	0.07	1.20	0.06
1	smooth, sand	0.5	8.0	7.3	0.5-1.0	9.9	7.7	<5	<5	0.03	0.06	0.10	0.28	0.02	0.05	<5	0.37	0.02	0.18	0.02
1	smooth, sand	0.75	7.9	7.3	1.0-1.5	9.3	5.5	<5	<5	0.03	0.08	0.03	0.03	0.03	0.06	<5	<0.05	0.04	<0.005	0.03
1	smooth, sand	1	7.9	7.6	1.5-2.0	8.5	6.0	<5	<5	0.02	0.03	0.00	0.00	0.02	0.04	<5	<0.05	<0.005	<0.005	0.01
1	smooth, sand	1.25	7.9	5.8	2.0-2.5	8.5	6.6	<5	<5	0.02	0.01	0.009	0.00	0.02	0.03	<5	0.07	<0.005	<0.005	0.01
1	smooth, sand	1.5	7.8	7.2																
1	smooth, sand	1.75	7.9	3.8																
1	smooth, sand	2	7.8	3.8																
1	smooth, sand	2.25	8.0	6.5																
1	smooth, sand	2.5	7.9	6.5																
3	smooth, sand	0	8.1	7.1																
3	smooth, sand	0.25	8.1	7.2																
3	smooth, sand	0.5	8.0	7.2																
3	smooth, sand	0.75	7.9	7.2																
3	smooth, sand	1	7.8	6.7																
3	smooth, sand	1.25	7.9	6.9																
3	smooth, sand	1.5	7.9	7.5																
3	smooth, sand	1.75	8.0	7.0																
3	smooth, sand	2	7.8	6.4																
3	smooth, sand	2.25	6.6	5.9																
6	smooth, sand	0	6.8	6.7																
6	smooth, sand	0.25	7.1	7.0																
6	smooth, sand	0.5	7.3	7.4																
6	smooth, sand	0.75	7.2	7.1																
6	smooth, sand	1	7.3	7.3																
6	smooth, sand	1.25	7.4	7.3																
6	smooth, sand	1.5	7.5	7.5																
6	smooth, sand	1.75	7.5	7.0																

Field Morphology Summary					Laboratory Results															
		Field pH						TAA	TPA	S_{KCl}	S_P	Ca_{KCl}	Ca_P	Mg_{KCl}	Mg_P	TSA	ANC_E	S_{POS}	Ca_A	Mg_A
Site	Soil Texture	Depth (m)	pH_F	pH_{FOX}	Sample Depth (m)	pH_{KCl}	pH_{OX} A	mol H^+/t		%S		%Ca		%Mg		mol H^+/t	% $CaCO_3$	%S	%Ca	%Mg
						23A	23B	23F	23G	23C	23D	23V	23W	23S	23T	23H	23Q	23E	23X	21U
6	smooth, sand	2	7.3	5.9																
6	smooth, sand	2.25	7.3	5.9																
6	smooth, sand	2.5	7.2	6.0																
6	smooth, sand	2.75	7.2	6.3																
6	smooth, sand	3	7.4	7.0																
6	smooth, sand	3.25	7.3	6.1																
8	smooth, sand	0	7.3	6.9																
8	smooth, sand	0.25	7.6	7.0																
8	smooth, sand	0.5	7.7	7.1																
8	rough, sand	0.75	7.9	6.9																
8	rough, sand	1	7.9	7.0																
8	smooth, sand	1.25	7.5	6.7																
8	smooth, sand	1.5	7.9	7.2																
8	smooth, sand	1.75	8.0	3.8																
8	clay	2	8.2	6.5																
8	clay	2.25	7.9	6.5																
11	smooth, sand	0	8.0	7.0																
11	smooth, sand	0.25	8.1	7.1																
11	smooth, sand	0.5	8.1	7.1																
11	rough, sand	0.75	8.2	7.1																
11	smooth, sand	1	8.1	7.2																
11	smooth, sand	1.25	8.0	6.5																
11	smooth, sand	1.5	8.0	7.1																
11	smooth, sand	1.75	8.1	3.3																
12	smooth, sand	0	8.0	6.9	0-0.5	10.0	7.8	<5	<5	0.04	0.07	0.12	2.60	0.03	0.15	<5	7.70	0.03	2.50	0.11
12	smooth, sand	0.25	7.8	7.0	0.5-1.0	10.0	7.8	<5	<5	0.03	0.05	0.10	0.57	0.01	0.05	<5	1.20	0.02	0.47	0.03
12	smooth, sand	0.5	7.3	7.1	1.0-1.5	9.9	7.5	<5	<5	0.05	0.06	0.10	0.23	0.03	0.04	<5	0.29	0.01	0.13	0.01
12	smooth, sand	0.75	7.5	7.1	1.5-2.0	9.9	7.1	<5	<5	0.04	0.05	0.08	0.11	0.03	0.04	<5	0.14	<0.005	0.02	0.01
12	smooth, sand	1	7.5	6.9	2.0-2.5	9.5	6.7	<5	<5	0.02	0.04	0.04	0.05	0.02	0.05	<5	0.08	0.02	<0.005	0.03
12	smooth, sand	1.25	7.5	7.0	2.5-3.0	7.2	6.4	<5	<5	0.02	0.01	0.01	0.01	0.02	0.05	<5	<0.05	<0.005	<0.005	0.02
12	smooth, sand	1.5	7.5	6.5																

Field Morphology Summary					Laboratory Results															
		Field pH						TAA	TPA	S_{KCl}	S_P	Ca_{KCl}	Ca_P	Mg_{KCl}	Mg_P	TSA	ANC_E	S_{POS}	Ca_A	Mg_A
Site	Soil Texture	Depth (m)	pH_F	pH_{FOX}	Sample Depth (m)	pH_{KCl}	pH_{OX} A	mol H^+/t		%S		%Ca		%Mg		mol H^+/t	% $CaCO_3$	%S	%Ca	%Mg
						23A	23B	23F	23G	23C	23D	23V	23W	23S	23T	23H	23Q	23E	23X	21U
12	smooth, sand	1.75	7.3	3.9																
12	smooth, sand	2	7.2	2.4																
12	smooth, sand	2.25	7.8	6.7																
12	smooth, sand	2.5	8.0	6.2																
12	smooth, sand	2.75	7.8	5.6																
12	clay	3	7.8	6.4																
14	smooth, sand	0	7.9	6.8																
14	smooth, sand	0.25	7.9	7.0																
14	smooth, sand	0.5	8.0	7.0																
14	smooth, sand	0.75	7.8	6.9																
14	smooth, sand	1	8.0	7.0																
14	smooth, sand	1.25	7.9	6.9																
14	rough, sand	1.5	8.3	6.9																
14	smooth, sand	1.75	8.1	6.6																
14	smooth, sand	2	7.9	6.2																
14	smooth, sand	2.25	7.8	6.3																
14	smooth, sand	2.5	7.8	6.2																
15	smooth, sand	0	7.9	7.0																
15	smooth, sand	0.25	7.9	7.0																
15	rough, sand	0.5	8.1	7.0																
2	rough, sand	0.75	8.1	7.1																
15	smooth, sand	1	7.9	7.1																
15	smooth, sand	1.25	8.1	7.3																
15	smooth, sand	1.5	7.9	7.2																
15	smooth, sand	1.75	8.1	6.9																
15	smooth, sand	2	7.8	6.3																
15	smooth, sand	2.25	7.6	6.5																
15	smooth, sand	2.5	7.6	6.8																
15	smooth, sand	2.75	7.6	6.0																
16	smooth, sand	0	7.8	6.9	0-0.5	9.7	7.8	<5	<5	0.04	0.05	0.17	2.20	0.03	0.12	<5	7.30	0.02	2.00	0.08
16	smooth, sand	0.25	8.0	6.9	0-0.5	9.9	7.7	<5	<5	0.03	0.06	0.11	2.50	0.03	0.14	<5	7.00	0.03	2.40	0.11

Field Morphology Summary					Laboratory Results															
		Field pH						TAA	TPA	S_{KCl}	S_P	Ca_{KCl}	Ca_P	Mg_{KCl}	Mg_P	TSA	ANC_E	S_{POS}	Ca_A	Mg_A
Site	Soil Texture	Depth (m)	pH_F	pH_{FOX}	Sample Depth (m)	pH_{KCl}	pH_{OX} [A]	mol H^+/t		%S		%Ca		%Mg		mol H^+/t	% $CaCO_3$	%S	%Ca	%Mg
						23A	23B	23F	23G	23C	23D	23V	23W	23S	23T	23H	23Q	23E	23X	21U
16	smooth, sand	0.5	8.0	6.5	0.5-1.0	9.8	7.8	<5	<5	0.04	0.06	0.12	1.00	0.03	0.08	<5	2.40	0.01	0.89	0.04
16	smooth, sand	0.75	7.4	6.2	1.0-1.5	9.7	7.3	<5	<5	0.03	0.04	0.08	0.14	0.02	0.03	<5	0.20	0.01	0.05	0.01
16	smooth, sand	1	7.4	6.2	1.5-2.0	9.4	5.6	<5	<5	0.04	0.05	0.04	0.04	0.02	0.03	<5	<0.05	0.008	<0.005	<0.005
16	smooth, sand	1.25	7.4	2.6	2.0-2.5	8.7	3.0	<5	<5	0.03	0.08	0.03	0.03	0.02	0.02	<5	<0.05	0.05	<0.005	<0.005
16	smooth, sand	1.5	7.3	2.7																
16	smooth, sand	1.75	7.1	1.6																
16	smooth, sand	2	7.1	1.6																
16	smooth, sand	2.25	7.1	1.6																
16	smooth, sand	2.5	7.1	4.6																
16	smooth, sand	2.7	7.1	1.8																
18	smooth, sand	0	7.2	6.0	0-0.5	9.8	7.8	<5	<5	0.04	0.05	0.13	2.90	0.04	0.16	<5	9.00	0.009	2.80	0.12
18	smooth, sand	0.25	7.6	6.3	0.5-1.0	9.8	7.8	<5	<5	0.03	0.09	0.12	4.10	0.02	0.23	<5	12.00	0.05	4.00	0.20
18	smooth, sand	0.5	7.8	6.4	1.0-1.5	9.7	7.8	<5	<5	0.07	0.10	0.14	3.40	0.04	0.21	<5	10.00	0.03	3.30	0.16
18	smooth, sand	0.75	8.0	6.4	1.5-2.0	9.6	7.9	<5	<5	0.07	0.17	0.12	0.94	0.03	0.09	<5	2.00	0.10	0.81	0.06
18	smooth, sand	1	7.9	6.3	2.0-2.5	9.1	4.0	<5	<5	0.05	0.15	0.08	0.11	0.02	0.05	<5	<0.05	0.10	0.036	0.02
18	smooth, sand	1.25	8.0	6.4	2.5-3.0	9.0	7.3	<5	<5	0.04	0.13	0.08	0.19	0.02	0.04	<5	0.13	0.09	0.11	0.02
18	rough, sand	1.5	7.7	6.3	3.0-3.5	9.4	6.9	<5	<5	0.03	0.04	0.07	0.06	0.03	0.03	<5	0.1	0.006	<0.005	<0.005
18	smooth, sand	1.75	7.8	6.2	3.0-3.5	9.4	6.9	<5	<5	0.03	0.04	0.08	0.06	0.03	0.03	<5	0.1	<0.005	<0.005	<0.005
18	smooth, sand	2	7.8	6.2																
18	smooth, sand	2.25	7.8	4.8																
18	smooth, sand	2.5	7.7	5.9																
18	smooth, sand	2.75	7.8	2.3																
18	smooth, sand	3	7.6	1.9																
18	clay	3.25	7.7	5.3																
20	smooth, sand	0	8.0	6.4																
20	smooth, sand	0.25	8.1	6.4																
20	smooth, sand	0.5	8.1	6.4																
20	smooth, sand	0.75	8.3	6.1																
20	smooth, sand	1	8.2	6.4																
20	smooth, sand	1.25	8.2	6.3																
20	smooth, sand	1.5	8.4	6.3																

Field Morphology Summary					Laboratory Results															
		Field pH						TAA	TPA	S_{KCl}	S_P	Ca_{KCl}	Ca_P	Mg_{KCl}	Mg_P	TSA	ANC_E	S_{POS}	Ca_A	Mg_A
Site	Soil Texture	Depth (m)	pH_F	pH_{FOX}	Sample Depth (m)	pH_{KCl}	pH_{OX} [A]	mol H^+/t		%S		%Ca		%Mg		mol H^+/t	% $CaCO_3$	%S	%Ca	%Mg
						23A	23B	23F	23G	23C	23D	23V	23W	23S	23T	23H	23Q	23E	23X	21U
20	smooth, sand	1.75	8.3	6.2																
20	smooth, sand	2	8.2	6.3																
20	smooth, sand	2.25	8.2	6.2																
20	smooth, sand	2.5	8.1	5.9																
20	smooth, sand	2.75	7.8	5.9																
20	smooth, sand	3	8.0	6.2																
20	smooth, sand	3.25	7.9	6.2																
20	smooth, sand	3.5	8.0	6.2																
20	smooth, sand	3.7	7.8	3.4																
22	smooth, sand	0	8.2	6.5	0-0.5	9.7	7.8	<5	<5	0.04	0.06	0.10	2.80	0.03	0.15	<5	8.60	0.03	2.70	0.11
22	smooth, sand	0.25	8.0	6.6	0.5-1.0	9.8	7.7	<5	<5	0.04	0.06	0.10	2.70	0.03	0.14	<5	8.10	0.02	2.60	0.11
22	smooth, sand	0.5	8.1	6.6	1.0-1.5	9.8	7.7	<5	<5	0.05	0.06	0.10	1.10	0.03	0.07	<5	2.60	0.01	0.96	0.03
22	rough, sand	1	8.2	6.5	1.5-2.0	9.7	7.5	<5	<5	0.04	0.04	0.08	0.22	0.028	0.03	<5	0.37	<0.005	0.14	0.006
22	rough, sand	1.25	8.0	6.6	2.0-2.5	8.7	3.5	<5	<5	0.02	0.05	0.02	0.02	0.022	0.02	<5	<0.05	0.02	<0.005	0.005
22	rough, sand	1.5	8.1	6.4	2.5-3.0	8.4	2.9	<5	17	0.04	0.08	0.03	0.02	0.042	0.03	17	<0.05	0.03	<0.005	<0.005
22	smooth, sand	1.75	8.2	6.5																
22	smooth, sand	2	8.1	6.0																
22	smooth, sand	2.25	7.8	6.0																
22	smooth, sand	2.5	8.0	1.7																
22	smooth, sand	2.75	7.8	1.6																
22	smooth, sand	3	7.7	1.7																

[A] Shaded cells provide an indication of the possible presence of potential acid sulphate soils (PASS), i.e. where the pH_F is more than two pH units below the pH_{FOX} value.

Table 2.6 Acid base accounting results for net acidity for each sample analysed.

Site	Sample Depth (m)	Percent Clay [A]	Action Criteria for Acidity [B] mol H^+/t	Net Acidity (with ANCE) mol H^+/t	Liming Rate without ANCE kg $CaCo_3/m^3$	Liming Rate with ANCE kg $CaCo_3/m^3$
1	0-0.5	5	18	<10	3.4	<0.75
1	0-0.5	5	18	<10	3.3	<0.75
1	0.5-1.0	8	18	<10	1.1	<0.75
1	1.0-1.5	8	18	27	NA	2
1	1.5-2.0	8	18	<10	NA	<0.75
1	2.0-2.5	8	18	<10	<0.75	<0.75
12	0-0.5	<3	18	<10	1.2	<0.75
12	0.5-1.0	<3	18	<10	0.8	<0.75
12	1.0-1.5	2	18	<10	<0.75	<0.75
12	1.5-2.0	2	18	<10	<0.75	<0.75
12	2.0-2.5	2	18	<10	<0.75	<0.75
12	2.5-3.0	2	18	<10	NA	<0.75
16	0-0.5	<3	18	<10	0.81	<0.75
16	0-0.5	<3	18	<10	1.4	<0.75
16	0.5-1.0	<3	18	<10	<0.75	<0.75
16	1.0-1.5	<3	18	<10	<0.75	<0.75
16	1.5-2.0	<3	18	<10	NA	<0.75
16	2.0-2.5	<3	18	13	NA	1
18	0-0.5	<2	18	<10	<0.75	<0.75
18	0.5-1.0	<4	18	<10	2.6	<0.75
18	1.0-1.5	2	18	<10	1.5	<0.75
18	1.5-2.0	2	18	<10	4.6	<0.75
18	2.0-2.5	2	18	62	NA	4.6
18	2.5-3.0	2	18	<10	NA	<0.75
18	3.0-3.5	2	18	<10	<0.75	<0.75
18	3.0-3.5	2	18	<10	<0.75	<0.75

Site	Sample Depth (m)	Percent Clay [A]	Action Criteria for Acidity [B] mol H^+/t	Net Acidity (with ANCE) mol H^+/t	Liming Rate without ANCE kg $CaCo_3/m^3$	Liming Rate with ANCE kg $CaCo_3/m^3$
22	0-0.5	<3	18	<10	1.3	<0.75
22	0.5-1.0	<4	18	<10	0.92	<0.75
22	1.0-1.5	<3	18	<10	<0.75	<0.75
22	1.5-2.0	<3	18	<10	<0.75	<0.75
22	2.0-2.5	<3	18	<10	NA	<0.75
22	2.5-3.0	<3	18	19	NA	1.4

[A] Percent of Clay – where figures are < both silt and clay are combined.

[B] Based on texture-based acid sulphate soil action criteria for disturbances to more than 1000t of material (State Planning Policy 2/02); net acidity of the shaded cells exceeds the criteria.

NA denotes test not required.

3 Regional Context

Keppel Bay has been shaped through macrotidal currents, and wind and wave regimes, with continental islands, relict seabed morphology, and sediment input from terrestrial and marine sources. Terrestrial sediment from the Fitzroy Basin mostly accumulates in the mouth of the Fitzroy River estuary, with river sediment reaching the offshore reefs of Keppel Bay during major flood events (Ryan et al. 2007) together with tidal exchange.

Sands accumulate in the south of Keppel Bay and are transported onshore by tidal currents, while outer Keppel Bay is dominated by the shoreward transport of older material from the continental shelf (Ryan et al. 2006). Sediments surrounding Great Keppel Island are dominated by sand (grain size predominantly greater than 63 µm) (Ryan et al. 2007).

Agricultural and mining activities throughout the Fitzroy Basin introduce contaminants to the waterways and ultimately to the offshore areas during flood events. Contaminants include fertilisers which can contain nutrients and metals as phosphate salts (particularly cadmium), ‘cattle dip’ which can contain arsenic compounds for parasite control, and mining activities which can introduce metals such as copper, gold and coal compounds (Vicente-Beckett et al. 2006).

3.1 Metals and Metalloids

Metal contamination in the sediment of the region appears to be low. Sediment metal concentrations data indicate that concentrations of most metals in the Fitzroy River estuary are consistent with those in a range of un-impacted Queensland estuaries. However elevated concentrations have been recorded for nickel, chromium and antimony, which is likely to reflect the geology of the central Queensland region rather than anthropogenic influences (particularly for nickel and chromium) (Moss & Costanzo 1998; Rolfe et al. 2004). High nickel and mercury concentrations have been reported throughout the estuary, suggesting possible diffuse anthropogenic sources. High antimony and gold concentrations have been reported in Keppel Bay, suggesting some historical accumulation of these metals. (Rolfe et al. 2004).

3.2 Hydrocarbons

Polynuclear aromatic hydrocarbons (PAHs) are persistent organic pollutants that may be introduced to coastal systems by natural (e.g. fossil fuels, oil shales, natural forest fires, volcanoes) and anthropogenic sources (e.g. oil spills, runoff, stormwater, atmospheric deposition and combustion) (Vicente-Beckett et al. 2006). They are likely to elevated in the project area from time to time, particularly following flood events.

3.3 Nutrients

The Fitzroy River estuary and inshore coastal waters of the region contain weathered sediments that are naturally nutrient-rich. The organic carbon to nitrogen ratio of sediment in the Fitzroy River estuary indicate that the organic matter in the sediment is mainly derived from marine phytoplankton and / or bacterial sources (Radke et al. 2005). Dissolved and particulate nutrients reach Keppel Bay via the Fitzroy River plume during flood events, or during the dry season by tidal flows when fine sediments and water are exchanged within the Fitzroy River estuary.

4 Potential Impacts

Cumulative impacts of the proposed development on marine sediment quality, including nearby tourism developments, climate change and ecosystem functioning, are discussed in Appendix C (Marine Water Quality).

5 Measures to Avoid, Minimise and Mitigate Impacts

Mitigation measures associated with the potential impacts of the development on marine sediment quality are discussed in Appendix C (Marine Water Quality).

6 Summary and Conclusions

6.1 Existing Environment

Surface Sediments

Surface sediments were largely composed of sands.

The concentration of total nitrogen was variable between sites and surveys. The highest concentration of total nitrogen was in Putney Creek during the pre-wet survey and at Fishermans Beach and Clam Bay during in the post-wet survey. The concentration of total phosphorus was highest at Middle Island during both surveys, and also relatively high at the mainland sites during both surveys; the concentration was generally similar at each site during each survey.

The concentration of total arsenic, chromium, copper, mercury and zinc was below the ISQG-low trigger value at all sites during all surveys. The concentration of total lead at the Leeke's Creek mouth exceeded the ISQG-low trigger value during the post-wet survey; all other sites were substantially lower than the trigger value in all surveys. Overall, concentrations of metals and metalloids were higher at Leeke's Creek mouth, near the underwater observatory on Middle Island and at the mainland sites. Relatively high levels could be related to the (decommissioned) underwater observatory, boating activity in Leeke's Creek and terrestrial run-off (e.g. fertilisers and mining activities) at the mainland sites.

Sediments of the Marina Footprint

Sediments of the marina footprint were largely composed of sands. The concentration of nutrients in the sediments was substantially lower than other locations in Queensland. The concentrations of all contaminants were below the laboratory LORs and NAGD screening levels (where available). The sediments are therefore considered to be uncontaminated.

No treatment of acid sulphate soils is likely to be required, as net acidity (including acid neutralising capacity) was low and mostly below the laboratory limits of reporting.

The results of quality assurance / quality control analyses were generally acceptable, with the exception of the laboratory replicates of silver and field replicates of phosphate, nitrate and copper. Given that there are no screening levels for phosphate and nitrate, and that concentrations of copper in all samples were below the screening level, this does not affect the interpretation of the results.

Regional Context

Keppel Bay has been shaped through macrotidal currents, and wind and wave regimes, with continental islands, relict seabed morphology, and sediment input from terrestrial and marine sources. Terrestrial sediment from the Fitzroy Basin mostly accumulates in the mouth of the Fitzroy River estuary, with river sediment reaching the offshore reefs of the Keppel Islands during major flood events.

Agricultural and mining activities throughout the Fitzroy Basin introduce contaminants to waterways and ultimately to the offshore areas during flood events. Contaminants include fertilisers which can contain nutrients and metals as phosphate salts (particularly cadmium), ‘cattle dip’ which can contain arsenic compounds for parasite control, and mining activities which can introduce metals such as copper, gold and coal compounds.

Metal contamination in the sediment of the region appears to be low. Sediment metal concentrations data indicate that concentrations of most metals in the Fitzroy River estuary are consistent with those in a range of un-impacted Queensland estuaries. However elevated concentrations have been recorded for nickel, chromium and antimony, which are likely to reflect the geology of the central Queensland region rather than anthropogenic influences (particularly for nickel and chromium). High nickel and mercury concentrations have been reported throughout the estuary, suggesting possible diffuse anthropogenic sources. High antimony and gold concentrations have been reported in Keppel Bay, suggesting some historical accumulation of these metals.

The Fitzroy River estuary and inshore coastal waters of the region contain weathered sediments that are naturally nutrient-rich. Dissolved and particulate nutrients reach Keppel Bay via the Fitzroy River plume during flood events, or during the dry season by tidal flows when fine sediments and water are exchanged within the Fitzroy River estuary.

6.2 Potential Impacts

The potential impacts of the development on marine sediment quality are discussed in Appendix C (Marine Water Quality).

6.3 Mitigation Measures

Mitigation measures associated with the potential impacts of the development on marine sediment quality are discussed in Appendix C (Marine Water Quality).

7 Field Core Logs

Site 1

Client: Tower Holdings
Location: Putney Beach, Great Keppel Island
Date: 15th June 2011 Weather: Sunny
Corer Type: Vibracorer Sea State: Calm
Scientist: CF / CAC Core Taken By: Abyss
Composite subsample taken by: CF Core Cleaned By: CF

Easting (WGS84, Zone 56)	Northing (WGS84, Zone 56)	Time (24 hrs)	Water Depth (m)	Core Length (m)	Tide wrt AHD	Top of Core wrt AHD	Bottom of Core wrt AHD
288438	7436075	16:00	3.3	2.6	-1.64	-4.94	-7.54

Depth (m)	Colour	Particle Size	Texture	Mottles	Plasticity	Odour	Shell %
0.00	Dark Grey	Sand	Smooth	Nil	Low	Nil	0%
0.25	Dark Grey	Sand	Smooth	Nil	Low	Nil	0%
0.50	Dark Grey	Sand	Smooth	Nil	Low	Nil	0%
0.75	Dark Grey	Sand	Smooth	Nil	Low	Nil	0%
1.00	Dark Grey	Sand	Smooth	Nil	Low	Nil	0%
1.25	Dark Grey	Sand	Smooth	Nil	Low	Nil	0%
1.50	Dark Grey	Sand	Smooth	Nil	Low	Nil	0%
1.75	Dark Grey	Sand	Smooth	Nil	Low	Nil	0%
2.00	Dark Grey	Sand	Smooth	Nil	Low	Nil	0%
2.25	Light Grey	Sand	Smooth	Nil	Low	Nil	0%
2.50	Light Grey	Sand	Smooth	Nil	Low	Nil	0%

Site 2

Client: Tower Holdings
Location: Putney Beach, Great Keppel Island
Date: 15th June 2011 Weather: Sunny
Corer Type: Vibracorer Sea State: Calm
Scientist: CF / CAC Core Taken By: Abyss
Composite subsample taken by: CF Core Cleaned By: CF

Easting (WGS84, Zone 56)	Northing (WGS84, Zone 56)	Time (24 hrs)	Water Depth (m)	Core Length (m)	Tide wrt AHD	Top of Core wrt AHD	Bottom of Core wrt AHD
288405	7436174	15:15	2.4	2.6	-1.78	-4.18	-6.78

Depth (m)	Colour	Particle Size	Texture	Mottles	Plasticity	Odour	Shell %
0.00	Grey	Sand	Rough	Nil	Low	Nil	50%
0.25	Grey	Sand	Rough	Nil	Low	Nil	50%
0.50	Grey	Sand	Smooth	Nil	Low	Nil	0%
0.75	Grey	Sand	Smooth	Nil	Low	Nil	0%
1.00	Brown	Sand	Smooth	Nil	Low	Nil	0%
1.25	Brown	Sand	Smooth	Nil	Low	Nil	0%
1.50	Grey	Sand/clay	Smooth	Nil	High	Nil	0%
1.75	Grey	Sand/clay	Smooth	Nil	High	Nil	0%
2.00	Grey	Sand/clay	Smooth	Nil	High	Nil	0%
2.25	Grey	Sand/clay	Smooth	Nil	High	Nil	0%
2.50	Grey	Sand/clay	Smooth	Nil	High	Nil	0%

Site 3

Client: Tower Holdings
Location: Putney Beach, Great Keppel Island
Date: 15th June 2011
Weather: Sunny/windy
Corer Type: Vibracorer
Sea State: Calm
Scientist: CF / CAC
Core Taken By: Abyss
Composite subsample taken by: CF
Core Cleaned By: CF

Easting (WGS84, Zone 56)	Northing (WGS84, Zone 56)	Time (24 hrs)	Water Depth (m)	Core Length (m)	Tide wrt AHD	Top of Core wrt AHD	Bottom of Core wrt AHD
288438	7436043	13:30	2.5	2.5	-1.52	-4.02	-6.52

Depth (m)	Colour	Particle Size	Texture	Mottles	Plasticity	Odour	Shell %
0.00	Grey	Sand	Smooth	Nil	Low	Nil	0%
0.25	Grey	Sand	Smooth	Nil	Low	Nil	0%
0.50	Grey	Sand	Smooth	Nil	Low	Nil	0%
0.75	Grey	Sand	Smooth	Nil	Low	Nil	0%
1.00	Grey	Sand	Smooth	Nil	Low	Nil	0%
1.25	Grey	Sand	Smooth	Nil	Low	Nil	0%
1.50	Grey	Sand	Smooth	Nil	Low	Nil	0%
1.75	Orange	Clay	Smooth	Nil	High	Nil	0%
2.00	Orange	Clay	Smooth	Nil	High	Nil	0%
2.25	Orange	Clay	Smooth	Nil	High	Nil	0%
2.50	Orange	Clay	Smooth	Nil	High	Nil	0%

Site 4

Client: Tower Holdings
Location: Putney Beach, Great Keppel Island
Date: 17th June 2011 Weather: Sunny/windy
Corer Type: Vibracorer Sea State: Calm
Scientist: CF / CAC Core Taken By: Abyss
Composite subsample taken by: CF Core Cleaned By: CF

Easting (WGS84, Zone 56)	Northing (WGS84, Zone 56)	Time (24 hrs)	Water Depth (m)	Core Length (m)	Tide wrt AHD	Top of Core wrt AHD	Bottom of Core wrt AHD
288563	7436016	13:00	3.5	2.7	0.49	-3.01	-5.71

Depth (m)	Colour	Particle Size	Texture	Mottles	Plasticity	Odour	Shell %
0.00	Grey	Sand	Smooth	Nil	Low	Nil	0%
0.25	Grey	Sand	Smooth	Nil	Low	Nil	0%
0.50	Grey	Sand	Smooth	Nil	Low	Nil	25%
0.75	Grey	Sand	Smooth	Nil	Low	Nil	0%
1.00	Grey	Sand	Smooth	Nil	Low	Nil	0%
1.25	Grey	Sand	Smooth	Nil	Low	Nil	0%
1.50	Grey	Sand	Smooth	Nil	Low	Nil	0%
1.75	Grey	Sand	Smooth	Nil	Low	Nil	0%
2.00	Dark Grey	Sand/clay	Smooth	Nil	Moderate	Nil	0%
2.25	Light Brown	Clay	Smooth	Nil	Moderate	Nil	0%
2.50	Light Brown	Clay	Smooth	Nil	Moderate	Nil	0%
2.70	Light Grey	Clay	Smooth	Nil	Moderate	Nil	0%

Site 5

Client: Tower Holdings
Location: Putney Beach, Great Keppel Island
Date: 17th June 2011
Weather: Sunny/windy
Corer Type: Vibracorer
Sea State: Calm
Scientist: CF / CAC
Core Taken By: Abyss
Composite subsample taken by: CF
Core Cleaned By: CF

Easting (WGS84, Zone 56)	Northing (WGS84, Zone 56)	Time (24 hrs)	Water Depth (m)	Core Length (m)	Tide wrt AHD	Top of Core wrt AHD	Bottom of Core wrt AHD
288479	7435978	13:55	4.4	2.7	0.80	-3.60	-6.30

Depth (m)	Colour	Particle Size	Texture	Mottles	Plasticity	Odour	Shell %
0.00	Dark Grey	Sand	Smooth	Nil	Low	Nil	0%
0.25	Dark Grey	Sand	Smooth	Nil	Low	Nil	0%
0.50	Dark Grey	Sand	Smooth	Nil	Low	Nil	0%
0.75	Dark Grey	Sand	Smooth	Nil	Low	Nil	0%
1.00	Grey	Sand	Smooth	Nil	Low	Nil	0%
1.25	Grey	Sand	Smooth	Nil	Low	Nil	0%
1.50	Light Grey	Sand	Smooth	Nil	Low	Nil	0%
1.75	Light Grey	Sand	Smooth	Nil	Low	Nil	0%
2.00	Light Grey	Sand	Smooth	Nil	Low	Nil	0%
2.25	Light Grey	Sand	Smooth	Nil	Low	Nil	0%
2.50	Tan	Sand	Smooth	Nil	Low	Nil	0%

Site 6

Client: Tower Holdings
Location: Putney Beach, Great Keppel Island
Date: 17th June 2011 Weather: Sunny/windy
Corer Type: Vibracorer Sea State: Calm
Scientist: CF / CAC Core Taken By: Abyss
Composite subsample taken by: CF Core Cleaned By: CF

Easting (WGS84, Zone 56)	Northing (WGS84, Zone 56)	Time (24 hrs)	Water Depth (m)	Core Length (m)	Tide wrt AHD	Top of Core wrt AHD	Bottom of Core wrt AHD
288506	7435896	14:50	1.8	3.6	-1.41	-3.21	-6.81

Depth (m)	Colour	Particle Size	Texture	Mottles	Plasticity	Odour	Shell %
0.00	Dark Grey	Sand	Smooth	Nil	Low	Nil	0%
0.25	Dark Grey	Sand	Rough	Nil	Low	Nil	30%
0.50	Dark Grey	Sand	Rough	Nil	Low	Nil	60%
0.75	Dark Grey	Sand	Rough	Nil	Low	Nil	30%
1.00	Dark Grey	Sand	Smooth	Nil	Low	Nil	0%
1.25	Dark Grey	Sand	Smooth	Nil	Low	Nil	0%
1.50	Dark Grey	Sand	Smooth	Nil	Low	Nil	0%
1.75	Dark Grey	Sand	Smooth	Nil	Low	Nil	0%
2.00	Dark Grey	Sand	Smooth	Nil	Low	Nil	0%
2.25	Light Grey	Sand	Smooth	Nil	Low	Nil	0%
2.50	Light Grey	Sand	Smooth	Nil	Low	Nil	0%
3.00	Tan	Sand	Smooth	Nil	Low	Nil	0%
3.50	Orange	Sand	Smooth	Nil	Low	Nil	0%

Site 7

Client: Tower Holdings
Location: Putney Beach, Great Keppel Island
Date: 17th June 2011 Weather: Sunny/windy
Corer Type: Vibracorer Sea State: Calm
Scientist: CF / CAC Core Taken By: Abyss
Composite subsample taken by: CF Core Cleaned By: CF

Easting (WGS84, Zone 56)	Northing (WGS84, Zone 56)	Time (24 hrs)	Water Depth (m)	Core Length (m)	Tide wrt AHD	Top of Core wrt AHD	Bottom of Core wrt AHD
288598	7435933	13:33	4	2.5	0.25	-3.75	-6.25

Depth (m)	Colour	Particle Size	Texture	Mottles	Plasticity	Odour	Shell %
0.00	Grey	Sand	Smooth	Nil	Low	Nil	1%
0.25	Grey	Sand	Smooth	Nil	Low	Nil	0%
0.50	Grey	Sand	Smooth	Nil	Low	Nil	0%
0.75	Grey	Sand	Smooth	Nil	Low	Nil	0%
1.00	Light Grey	Sand	Smooth	Nil	Low	Nil	0%
1.25	Light Grey	Sand	Smooth	Nil	Low	Nil	0%
1.50	Light Grey	Sand	Smooth	Nil	Low	Nil	0%
1.75	Light Grey	Sand	Smooth	Nil	Low	Nil	0%
2.00	Red/Brown	Clay	Smooth	Nil	High	Nil	0%
2.25	Red/Brown	Clay	Smooth	Nil	High	Nil	0%
2.50	Red/Brown	Clay	Smooth	Nil	High	Nil	0%

Site 8

Client: Tower Holdings
Location: Putney Beach, Great Keppel Island
Date: 17th June 2011
Corer Type: Vibracorer
Scientist: CF / CAC
Composite subsample taken by: CF

Weather: Sunny/windy
Sea State: Calm
Core Taken By: Abyss
Core Cleaned By: CF

Easting (WGS84, Zone 56)	Northing (WGS84, Zone 56)	Time (24 hrs)	Water Depth (m)	Core Length (m)	Tide wrt AHD	Top of Core wrt AHD	Bottom of Core wrt AHD
288654	7435953	13:50	1.4	2.3	-1.08	-2.48	-4.78

Depth (m)	Colour	Particle Size	Texture	Mottles	Plasticity	Odour	Shell %
0.00	Grey	Sand	Smooth	Nil	Low	Nil	0%
0.25	Grey	Sand	Smooth	Nil	Low	Nil	0%
0.50	Grey	Sand	Smooth	Nil	Low	Nil	5%
0.75	Light Grey	Sand	Rough	Nil	Low	Nil	10%
1.00	Light Grey	Sand	Rough	Nil	Low	Nil	10%
1.25	Light Grey	Sand	Smooth	Nil	Low	Nil	5%
1.50	Light Grey	Sand	Smooth	Nil	Low	Nil	0%
1.75	Light Grey	Sand	Smooth	Nil	Low	Nil	0%
2.00	Brown	Clay	Smooth	Nil	High	Nil	0%
2.25	Red/Grey	Clay	Smooth	Nil	High	Nil	0%

Site 9

Client: Tower Holdings
Location: Putney Beach, Great Keppel Island
Date: 17th June 2011
Weather: Sunny/windy
Corer Type: Vibracorer
Sea State: Calm
Scientist: CF / CAC
Core Taken By: Abyss
Composite subsample taken by: CF
Core Cleaned By: CF

Easting (WGS84, Zone 56)	Northing (WGS84, Zone 56)	Time (24 hrs)	Water Depth (m)	Core Length (m)	Tide wrt AHD	Top of Core wrt AHD	Bottom of Core wrt AHD
288572	7435905	12:02	4.4	2.4	1.25	-3.15	-5.55

Depth (m)	Colour	Particle Size	Texture	Mottles	Plasticity	Odour	Shell %
0.00	Grey	Rock/Sand	Rough	Nil	Low	Nil	0%
0.25	Grey	Sand	Smooth	Nil	Low	Nil	0%
0.50	Grey	Sand	Smooth	Nil	Low	Nil	0%
0.75	Grey	Sand	Smooth	Nil	Low	Nil	0%
1.00	Light Grey	Sand	Smooth	Nil	Low	Nil	0%
1.25	Brown	Sand	Smooth	Nil	Low	Nil	0%
1.50	Brown	Sand	Smooth	Nil	Low	Nil	0%
1.75	Brown	Sand	Smooth	Nil	Low	Nil	0%
2.00	Light Grey	Sand	Smooth	Nil	Low	Nil	0%
2.25	Light Grey	Sand	Smooth	Nil	Low	Nil	0%
2.40	Light Grey	Sand	Smooth	Nil	Low	Nil	0%

Site 10

Client: Tower Holdings
Location: Putney Beach, Great Keppel Island
Date: 17th June 2011
Corer Type: Vibracorer
Scientist: CF / CAC
Composite subsample taken by: CF

Weather: Sunny/windy
Sea State: Calm
Core Taken By: Abyss
Core Cleaned By: CF

Easting (WGS84, Zone 56)	Northing (WGS84, Zone 56)	Time (24 hrs)	Water Depth (m)	Core Length (m)	Tide wrt AHD	Top of Core wrt AHD	Bottom of Core wrt AHD
288461	7435804	12:30	4.3	2.2	1.14	-3.17	-5.37

Depth (m)	Colour	Particle Size	Texture	Mottles	Plasticity	Odour	Shell %
0.00	Dark Grey	Sand	Smooth	Nil	Low	Nil	2%
0.25	Dark Grey	Sand	Smooth	Nil	Low	Nil	2%
0.50	Dark Grey	Sand	Smooth	Nil	Low	Nil	2%
0.75	Dark Grey	Sand	Smooth	Nil	Low	Nil	2%
1.00	Dark Grey	Sand	Smooth	Nil	Low	Nil	0%
1.25	Black	Sand	Smooth	Nil	Low	Slight	0%
1.50	Brown	Sand	Smooth	Nil	Low	Nil	0%
1.75	Brown	Sand	Smooth	Nil	Low	Nil	0%
2.00	Brown	Sand	Smooth	Nil	Low	Nil	0%
2.20	Brown	Sand	Smooth	Nil	Low	Nil	0%

Site 11

Client: Tower Holdings
Location: Putney Beach, Great Keppel Island
Date: 16th June 2011
Weather: Sunny/windy
Corer Type: Vibracorer
Sea State: Calm
Scientist: CF / CAC
Core Taken By: Abyss
Composite subsample taken by: CF
Core Cleaned By: CF

Easting (WGS84, Zone 56)	Northing (WGS84, Zone 56)	Time (24 hrs)	Water Depth (m)	Core Length (m)	Tide wrt AHD	Top of Core wrt AHD	Bottom of Core wrt AHD
288605	7435880	16:45	1.3	1.75	-1.73	-3.03	-4.78

Depth (m)	Colour	Particle Size	Texture	Mottles	Plasticity	Odour	Shell %
0.00	Dark Grey	Sand	Smooth	Nil	Low	Nil	0%
0.25	Dark Grey	Sand	Smooth	Nil	Low	Nil	0%
0.50	Dark Grey	Sand	Smooth	Nil	Low	Nil	0%
0.75	Dark Grey	Sand	Rough	Nil	Low	Nil	30%
1.00	Dark Grey	Sand	Smooth	Nil	Low	Nil	0%
1.25	Dark Brown	Sand	Smooth	Nil	Low	Nil	0%
1.50	Grey	Sand	Smooth	Nil	Low	Nil	0%
1.75	Grey	Sand	Smooth	Nil	Low	Nil	0%

Site 12

Client: Tower Holdings
Location: Putney Beach, Great Keppel Island
Date: 16th June 2011
Corer Type: Vibracorer
Scientist: CF / CAC
Composite subsample taken by: CF

Weather: Sunny/windy
Sea State: Calm
Core Taken By: Abyss
Core Cleaned By: CF

Easting (WGS84, Zone 56)	Northing (WGS84, Zone 56)	Time (24 hrs)	Water Depth (m)	Core Length (m)	Tide wrt AHD	Top of Core wrt AHD	Bottom of Core wrt AHD
288673	7435850	15:50	0.8	2.9	-1.80	-2.60	-5.50

Depth (m)	Colour	Particle Size	Texture	Mottles	Plasticity	Odour	Shell %
0.00	Dark Grey	Sand	Smooth	Nil	Low	Nil	0%
0.25	Dark Grey	Sand	Smooth	Nil	Low	Nil	0%
0.50	Dark Grey	Sand	Smooth	Nil	Low	Nil	0%
0.75	Dark Grey	Sand	Smooth	Nil	Low	Nil	0%
1.00	Dark Grey	Sand	Smooth	Nil	Low	Nil	0%
1.25	Grey	Sand	Smooth	Nil	Low	Nil	0%
1.50	Grey	Sand	Smooth	Nil	Low	Nil	0%
1.75	Grey	Sand	Smooth	Nil	Low	Nil	0%
2.00	Grey	Sand	Smooth	Nil	Low	Nil	0%
2.25	Grey	Sand	Smooth	Nil	Low	Nil	0%
2.50	Light Grey	Sand	Smooth	Nil	Low	Nil	0%
2.75	Light Grey	Sand	Smooth	Nil	Low	Nil	0%
2.90	Red Brown	Clay	Smooth	Nil	High	Nil	0%

Site 13

Client: Tower Holdings
Location: Putney Beach, Great Keppel Island
Date: 17th June 2011
Weather: Sunny/windy
Corer Type: Vibracorer
Sea State: Calm
Scientist: CF / CAC
Core Taken By: Abyss
Composite subsample taken by: CF
Core Cleaned By: CF

Easting (WGS84, Zone 56)	Northing (WGS84, Zone 56)	Time (24 hrs)	Water Depth (m)	Core Length (m)	Tide wrt AHD	Top of Core wrt AHD	Bottom of Core wrt AHD
288598	7435832	10:45	4.2	2.7	1.27	-2.93	-5.63

Depth (m)	Colour	Particle Size	Texture	Mottles	Plasticity	Odour	Shell %
0.00	Dark Grey	Sand	Smooth	Nil	Low	Nil	0%
0.25	Dark Grey	Sand	Course	Nil	Low	Nil	30%
0.50	Dark Grey	Sand	Smooth	Nil	Low	Nil	0%
0.75	Dark Grey	Sand	Smooth	Nil	Low	Nil	0%
1.00	Brown	Sand	Smooth	Nil	Low	Nil	0%
1.25	Brown	Sand	Smooth	Nil	Low	Nil	0%
1.50	Brown	Sand	Smooth	Nil	Low	Nil	0%
1.75	Light Grey	Sand	Smooth	Nil	Low	Nil	0%
2.00	Light Grey	Sand	Smooth	Nil	Low	Nil	0%
2.25	Light Grey	Sand	Smooth	Nil	Low	Nil	0%
2.50	Light Grey	Sand	Smooth	Nil	Low	Nil	0%

Site 14

Client: Tower Holdings
Location: Putney Beach, Great Keppel Island
Date: 17th June 2011
Corer Type: Vibracorer
Scientist: CF / CAC
Composite subsample taken by: CF

Weather: Sunny/windy
Sea State: Calm
Core Taken By: Abyss
Core Cleaned By: CF

Easting (WGS84, Zone 56)	Northing (WGS84, Zone 56)	Time (24 hrs)	Water Depth (m)	Core Length (m)	Tide wrt AHD	Top of Core wrt AHD	Bottom of Core wrt AHD
288783	7435812	9:35	2.5	2.5	1.31	-1.19	-3.69

Depth (m)	Colour	Particle Size	Texture	Mottles	Plasticity	Odour	Shell %
0.00	Grey	Sand	Smooth	Nil	Low	Slight	0%
0.25	Grey	Sand	Smooth	Nil	Low	Slight	0%
0.50	Grey	Sand	Smooth	Nil	Low	Slight	0%
0.75	Grey	Sand	Smooth	Nil	Low	Slight	0%
1.00	Grey	Sand	Smooth	Nil	Low	Nil	0%
1.25	Grey	Sand	Smooth	Nil	Low	Nil	0%
1.50	Grey	Sand	Rough	Nil	Low	Nil	20%
1.75	Brown	Clay	Smooth	Nil	High	Nil	20%
2.00	Brown	Clay	Smooth	Nil	High	Nil	20%
2.25	Red	Clay	Smooth	Nil	High	Nil	20%
2.50	Grey	Clay	Smooth	Nil	High	Nil	20%

Site 15

Client: Tower Holdings
Location: Putney Beach, Great Keppel Island
Date: 17h June 2011
Weather: Sunny/windy
Corer Type: Vibracorer
Sea State: Calm
Scientist: CF / CAC
Core Taken By: Abyss
Composite subsample taken by: CF
Core Cleaned By: CF

Easting (WGS84, Zone 56)	Northing (WGS84, Zone 56)	Time (24 hrs)	Water Depth (m)	Core Length (m)	Tide wrt AHD	Top of Core wrt AHD	Bottom of Core wrt AHD
288633	7435772	10:55	3.7	2.9	1.03	-2.67	-5.57

Depth (m)	Colour	Particle Size	Texture	Mottles	Plasticity	Odour	Shell %
0.00	Grey	Sand	Smooth	Nil	Low	Nil	0%
0.25	Grey	Sand	Smooth	Nil	Low	Nil	0%
0.50	Grey	Sand	Rough	Nil	Low	Nil	40%
0.75	Grey	Sand	Rough	Nil	Low	Nil	40%
1.00	Grey	Sand	Smooth	Nil	Low	Nil	0%
1.25	Grey	Sand	Smooth	Nil	Low	Nil	0%
1.50	Grey	Sand	Smooth	Nil	Low	Nil	0%
1.75	Grey	Sand	Smooth	Nil	Low	Nil	0%
2.00	Light Brown	Sand	Smooth	Nil	Low	Nil	0%
2.25	Light Brown	Sand	Smooth	Nil	Low	Nil	0%
2.50	Light Brown	Sand	Smooth	Nil	Low	Nil	0%
2.75	Light Grey	Sand	Smooth	Nil	Low	Nil	0%
2.90	Light Grey	Sand	Smooth	Nil	Low	Nil	0%

Site 16

Client: Tower Holdings
Location: Putney Beach, Great Keppel Island
Date: 17th June 2011
Weather: Sunny/windy
Corer Type: Vibracorer
Sea State: Calm
Scientist: CF / CAC
Core Taken By: Abyss
Composite subsample taken by: CF
Core Cleaned By: CF

Easting (WGS84, Zone 56)	Northing (WGS84, Zone 56)	Time (24 hrs)	Water Depth (m)	Core Length (m)	Tide wrt AHD	Top of Core wrt AHD	Bottom of Core wrt AHD
288550	7435732	8:25	3.1	2.75	-0.03	-3.13	-5.88

Depth (m)	Colour	Particle Size	Texture	Mottles	Plasticity	Odour	Shell %
0.00	Grey	Sand	Smooth	Nil	Low	Nil	10%
0.25	Grey	Sand	Smooth	Nil	Low	Nil	5%
0.50	Grey	Sand	Smooth	Nil	Low	Nil	5%
0.75	Grey	Sand	Smooth	Nil	Low	Nil	1%
1.00	Grey	Sand	Smooth	Nil	Low	Nil	1%
1.25	Grey	Sand	Smooth	Nil	Low	Nil	5%
1.50	Grey	Sand	Smooth	Nil	Low	Nil	1%
1.75	Grey	Sand	Smooth	Nil	Low	Nil	0%
2.00	Grey	Sand	Smooth	Nil	Low	Nil	0%
2.25	Grey	Sand	Smooth	Nil	Low	Nil	0%
2.50	Grey	Sand	Smooth	Nil	Low	Nil	0%
2.75	Grey	Sand	Smooth	Nil	Low	Nil	0%

Site 17

Client: Tower Holdings
Location: Putney Beach, Great Keppel Island
Date: 17th June 2011
Corer Type: Vibracorer
Scientist: CF / CAC
Composite subsample taken by: CF

Weather: Sunny/windy
Sea State: Calm
Core Taken By: Abyss
Core Cleaned By: CF

Easting (WGS84, Zone 56)	Northing (WGS84, Zone 56)	Time (24 hrs)	Water Depth (m)	Core Length (m)	Tide wrt AHD	Top of Core wrt AHD	Bottom of Core wrt AHD
288574	7435732	9:10	3.3	2.75	0.26	-3.04	-5.79

Depth (m)	Colour	Particle Size	Texture	Mottles	Plasticity	Odour	Shell %
0.00	Grey	Sand	Smooth	Nil	Low	Nil	1%
0.25	Grey	Sand	Smooth	Nil	Low	Nil	1%
0.50	Grey	Sand	Smooth	Nil	Low	Nil	2%
0.75	Grey	Sand	Smooth	Nil	Low	Nil	2%
1.00	Grey	Sand	Smooth	Nil	Low	Nil	0%
1.25	Grey	Sand	Smooth	Nil	Low	Nil	0%
1.50	Grey	Sand	Smooth	Nil	Low	Nil	1%
1.75	Grey	Pebble	Rough	Nil	Low	Nil	0%
2.00	Grey	Pebble	Rough	Nil	Low	Nil	0%
2.25	Grey	Sand	Smooth	Nil	Low	Nil	0%
2.50	Grey	Sand	Smooth	Nil	Low	Nil	0%
2.75	Grey	Sand	Smooth	Nil	Low	Nil	0%

Site 18

Client: Tower Holdings
Location: Putney Beach, Great Keppel Island
Date: 16th June 2011
Corer Type: Vibracorer
Scientist: CF / CAC
Composite subsample taken by: CF

Weather: Sunny/windy
Sea State: Calm
Core Taken By: Abyss
Core Cleaned By: CF

Easting (WGS84, Zone 56)	Northing (WGS84, Zone 56)	Time (24 hrs)	Water Depth (m)	Core Length (m)	Tide wrt AHD	Top of Core wrt AHD	Bottom of Core wrt AHD
288779	7435788	9:15	2.5	3.3	1.27	-1.23	-4.53

Depth (m)	Colour	Particle Size	Texture	Mottles	Plasticity	Odour	Shell %
0.00	Dark Grey	Sand	Smooth	Nil	Low	Slight	0%
0.25	Dark Grey	Sand	Smooth	Nil	Low	Slight	0%
0.50	Dark Grey	Sand	Smooth	Nil	Low	Slight	0%
0.75	Dark Grey	Sand	Smooth	Nil	Low	Slight	0%
1.00	Dark Grey	Sand	Smooth	Nil	Low	Slight	0%
1.25	Dark Grey	Sand	Smooth	Nil	Low	Nil	0%
1.50	Dark Grey	Sand	Rough	Nil	Low	Nil	50%
1.75	Dark Grey	Sand	Smooth	Nil	Low	Nil	0%
2.00	Dark Grey	Sand	Smooth	Nil	Low	Nil	0%
2.25	Dark Grey	Sand	Smooth	Nil	Low	Nil	0%
2.50	Dark Grey	Sand	Smooth	Nil	Low	Nil	0%
2.75	Dark Grey	Sand	Smooth	Nil	Low	Nil	0%
3.00	Brown Red	Sand	Smooth	Nil	Low	Nil	0%
3.25	Brown Red	Clay	Smooth	Nil	High	Nil	0%

Site 19

Client: Tower Holdings
Location: Putney Beach, Great Keppel Island
Date: 17th June 2011
Weather: Sunny/windy
Corer Type: Vibracorer
Sea State: Calm
Scientist: CF / CAC
Core Taken By: Abyss
Composite subsample taken by: CF
Core Cleaned By: CF

Easting (WGS84, Zone 56)	Northing (WGS84, Zone 56)	Time (24 hrs)	Water Depth (m)	Core Length (m)	Tide wrt AHD	Top of Core wrt AHD	Bottom of Core wrt AHD
288733	7435735	9:27	2.4	2	0.66	-1.75	-3.75

Depth (m)	Colour	Particle Size	Texture	Mottles	Plasticity	Odour	Shell %
0.00	Dark Grey	Sand	Smooth	Nil	Low	Nil	0%
0.25	Dark Grey	Sand	Smooth	Nil	Low	Nil	0%
0.50	Dark Grey	Sand	Smooth	Nil	Low	Nil	0%
0.75	Dark Grey	Sand	Smooth	Nil	Low	Nil	0%
1.00	Dark Grey	Sand	Course	Nil	Low	Nil	10%
1.25	Dark Grey	Sand	Rough	Nil	Low	Nil	40%
1.50	Dark Grey	Sand	Course	Nil	Low	Nil	5%
1.75	Dark Grey	Sand	Smooth	Nil	Low	Nil	0%
2.00	Dark Grey	Sand	Smooth	Nil	Low	Nil	0%

Site 20

Client: Tower Holdings
Location: Putney Beach, Great Keppel Island
Date: 16th June 2011 Weather: Sunny/windy
Corer Type: Vibracorer Sea State: Calm
Scientist: CF / CAC Core Taken By: Abyss
Composite subsample taken by: CF Core Cleaned By: CF

Easting (WGS84, Zone 56)	Northing (WGS84, Zone 56)	Time (24 hrs)	Water Depth (m)	Core Length (m)	Tide wrt AHD	Top of Core wrt AHD	Bottom of Core wrt AHD
288747	7435700	8:30	2.3	3.7	1.15	-1.16	-4.86

Depth (m)	Colour	Particle Size	Texture	Mottles	Plasticity	Odour	Shell %
0.00	Grey	Sand	Smooth	Nil	Low	Nil	0%
0.25	Grey	Sand	Smooth	Nil	Low	Nil	0%
0.50	Grey	Sand	Smooth	Nil	Low	Nil	0%
0.75	Grey	Sand	Smooth	Nil	Low	Nil	0%
1.00	Grey	Sand	Smooth	Nil	Low	Nil	0%
1.25	Grey	Sand	Smooth	Nil	Low	Nil	0%
1.50	Dark Grey	Sand	Smooth	Nil	Low	Nil	0%
1.75	Dark Grey	Sand	Smooth	Nil	Low	Nil	35%
2.00	Dark Grey	Sand	Smooth	Nil	Low	Nil	10%
2.25	Dark Grey	Sand	Smooth	Nil	Low	Nil	5%
2.50	Dark Grey	Sand	Smooth	Nil	Low	Nil	0%
2.75	Dark Grey	Sand	Smooth	Nil	Low	Nil	0%
3.00	Grey	Sand	Smooth	Nil	Low	Nil	0%

Depth (m)	Colour	Particle Size	Texture	Mottles	Plasticity	Odour	Shell %
3.25	Grey	Sand	Smooth	Nil	Low	Nil	0%
3.50	Grey	Sand	Smooth	Nil	Low	Nil	0%
3.70	Grey	Sand	Smooth	Nil	Low	Nil	0%

Site 21

Client: Tower Holdings
Location: Putney Beach, Great Keppel Island
Date: 17th June 2011
Corer Type: Vibracorer
Scientist: CF / CAC
Composite subsample taken by: CF

Weather: Sunny/windy
Sea State: Calm
Core Taken By: Abyss
Core Cleaned By: CF

Easting (WGS84, Zone 56)	Northing (WGS84, Zone 56)	Time (24 hrs)	Water Depth (m)	Core Length (m)	Tide wrt AHD	Top of Core wrt AHD	Bottom of Core wrt AHD
288643	7435677	10:00	3.2	3	0.86	-2.34	-5.34

Depth (m)	Colour	Particle Size	Texture	Mottles	Plasticity	Odour	Shell %
0.00	Dark Grey	Sand	Smooth	Nil	Low	Slight	0%
0.25	Dark Grey	Sand	Smooth	Nil	Low	Slight	0%
0.50	Dark Grey	Sand	Smooth	Nil	Low	Slight	0%
0.75	Dark Grey	Sand	Course	Nil	Low	Slight	20%
1.00	Dark Grey	Sand	Course	Nil	Low	Slight	20%
1.25	Dark Grey	Sand	Smooth	Nil	Low	Nil	0%
1.50	Grey	Sand	Smooth	Nil	Low	Nil	0%
1.75	Grey	Sand	Smooth	Nil	Low	Nil	0%
2.00	Grey	Sand	Smooth	Nil	Low	Nil	0%
2.25	Grey	Sand	Smooth	Nil	Low	Nil	0%
2.50	Grey	Sand	Smooth	Nil	Low	Nil	0%
2.75	Grey	Sand	Smooth	Nil	Low	Nil	0%
3.00	Grey	Sand	Smooth	Nil	Low	Nil	0%

Site 22

Client: Tower Holdings
Location: Putney Beach, Great Keppel Island
Date: 16th June 2011 Weather: Sunny/windy
Corer Type: Vibracorer Sea State: Calm
Scientist: CF / CAC Core Taken By: Abyss
Composite subsample taken by: CF Core Cleaned By: CF

Easting (WGS84, Zone 56)	Northing (WGS84, Zone 56)	Time (24 hrs)	Water Depth (m)	Core Length (m)	Tide wrt AHD	Top of Core wrt AHD	Bottom of Core wrt AHD
288635	7435652	11:48	2.7	3	0.72	-1.98	-4.98

Depth (m)	Colour	Particle Size	Texture	Mottles	Plasticity	Odour	Shell %
0.00	Grey	Sand	Smooth	Nil	Low	Slight	0%
0.25	Grey	Sand	Smooth	Nil	Low	Slight	5%
0.50	Grey	Sand	Smooth	Nil	Low	Slight	10%
0.75	Grey	Sand	Smooth	Nil	Low	Slight	15%
1.00	Light Grey	Sand/shell	Course	Nil	Low	Nil	20%
1.25	Light Grey	Sand/shell	Course	Nil	Low	Nil	20%
1.50	Light Grey	Sand/shell	Course	Nil	Low	Nil	20%
1.75	Light Grey	Sand	Smooth	Nil	Low	Nil	0%
2.00	Light Grey	Sand	Smooth	Nil	Low	Nil	0%
2.25	Light Grey	Sand	Smooth	Nil	Low	Nil	0%
2.50	Light Grey	Sand	Smooth	Nil	Low	Nil	0%
2.75	Light Grey	Sand	Smooth	Nil	Low	Nil	0%
3.00	Light Grey	Sand	Smooth	Nil	Low	Nil	0%
3.25	Light Grey	Sand	Smooth	Nil	Low	Nil	0%

Site 23

Client: Tower Holdings
Location: Putney Beach, Great Keppel Island
Date: 17th June 2011 Weather: Sunny
Corer Type: Vibracorer Sea State: Calm
Scientist: CF / CAC Core Taken By: Abyss
Composite subsample taken by: CF Core Cleaned By: CF

Easting (WGS84, Zone 56)	Northing (WGS84, Zone 56)	Time (24 hrs)	Water Depth (m)	Core Length (m)	Tide wrt AHD	Top of Core wrt AHD	Bottom of Core wrt AHD
288686	7435647	11:16	3	3	1.12	-1.88	-4.88

Depth (m)	Colour	Particle Size	Texture	Mottles	Plasticity	Odour	Shell %
0.00	Grey	Sand	Smooth	Nil	Low	Nil	10%
0.25	Grey	Sand	Smooth	Nil	Low	Nil	30%
0.50	Slight Brown	Sand	Smooth	Nil	Low	Nil	30%
0.75	Slight Brown	Sand	Smooth	Nil	Low	Nil	5%
1.00	Grey	Sand	Smooth	Nil	Low	Nil	1%
1.25	Grey	Sand	Smooth	Nil	Low	Nil	0%
1.50	Greg	Sand	Smooth	Nil	Low	Nil	0%
1.75	Grey	Sand	Smooth	Nil	Low	Nil	0%
2.00	Grey	Sand	Smooth	Nil	Low	Nil	0%
2.25	Cream/Grey	Sand	Smooth	Nil	Low	Nil	0%
2.50	Cream/Grey	Sand	Smooth	Nil	Low	Nil	0%

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Appendix E Marine Flora

Contents

Tables

Figures

1 Methods

1.1 Definition of Marine Plants

All marine plants are protected under the *Fisheries Act 1994* (Fisheries Act). Under the Fisheries Act, marine plants are defined as:

- plants that usually grow on or adjacent to tidal land, whether living, dead, standing or fallen
- the material of a tidal plant, or other plant material on tidal land, and
- a plant, or material of a plant, prescribed under a regulation or management plan to be a marine plant.

Tidal land is defined as all land below the theoretical level of highest astronomical tide.

Plants of high significance to fisheries are plants that usually grow on or next to tidal land, including mangroves, seagrasses, marine algae, saltcouch and samphires. These are protected as marine plants, whether or not they are on tidal land (Couchman & Beumer 2007).

Plants that usually grow next to tidal lands include some *Melaleuca* and *Casuarina* species. These plants are valuable to fisheries productivity and are protected under the Fisheries Act; particularly *Melaleuca* communities next to tidal areas that are either permanently or periodically connected to tides, and Casuarina communities that have saltcouch or samphires in the understory (Couchman & Beumer 2007).

In a Fisheries Tribunal decision it was determined that it was an error of law to decide whether land is tidal (or not) by the presence (or absence) of marine plants, and that a decision must first be made whether the land is tidal or not (Couchman & Beumer 2007).

Consequently, to map marine plant communities on the proposed development site, the position of HAT was determined, and plant communities next to and below this were mapped.

Estimation of Highest Astronomical Tide

The extent of tidal inundation over the proposed development site was mapped following methods adapted from Paul (2004) and the Surveyors Board of Queensland (2002). Tidal inundation was mapped on 18 to 19 February [1] (fine days, with no rain the night before).

Before the high tide, stakes were positioned at approximately 10 m intervals along the high tide mark. Stakes were continuously checked and repositioned as the tide came in, until the tide began to ebb at 5:11 pm. The position of the stakes was recorded using a GPS (accurate to ± 4 m), and subsequently geo-referenced by Gassman Surveyors; and the data was plotted using GIS software (MapInfo).

1.2 Mangrove Forest and Saltmarsh

Survey Details

Mangrove communities were surveyed during the following seasons [2]:

- pre-wet – 15 to 19 November 2010
- wet – 17 to 21 January 2011, and
- post-wet – 30 March to 2 April and 30 April to 2 May 2011.

Mangroves were surveyed at two sites on Great Keppel Island and at one mainland site, which were respectively (Figure 1.3 to Figure 1.5):

- Leeke's Creek
- Putney Creek, and
- Kinka Beach.

Details of the survey area are presented in Appendix A.

[1] HAT was 18 February 2011; the difference in tidal height between 18 and 19 February 2011 was 0.01 m.

[2] Great Keppel Island mangroves communities were surveyed in the pre-wet and post-wet season surveys. Kinka Beach mangrove communities were surveyed during the wet survey (as they were added to the project area after the pre-wet survey, to consider impacts of the submarine cable crossing) and post-wet survey.

Distribution and Community Composition

The boundaries of different mangrove and saltmarsh communities were marked using a GPS (accurate to ±4 m). Survey points were established at regular intervals, or when a change in mangrove community structure or ecological health (condition) was noted. At each survey point, species composition (% cover of each species), canopy height (m), canopy cover (%), and the structural formation of the mangroves were recorded. Structural formation followed the classification system used by the Queensland Herbarium (Dowling & Stephens 2001).

Data points and field survey data were superimposed onto rectified aerial photographs using GIS software (MapInfo). Maps of the vegetation communities were created from data, and from interpretation of aerial photography.

Ecological Health

At each survey point, ecological health (condition) was assessed within a 10 x 10 m quadrat (Figure 1.1, Figure 1.2, Table 1.1).

In addition, the abundance of macroalgae, macrofauna and seedlings was recorded at each site. Each survey point was assessed for signs of disturbance, including:

- damage by insects
- anthropogenic or natural disturbances, and
- erosion of the foreshore.

Extremely dense foliage and spatially extensive forests prevented access to some mid-forest areas.

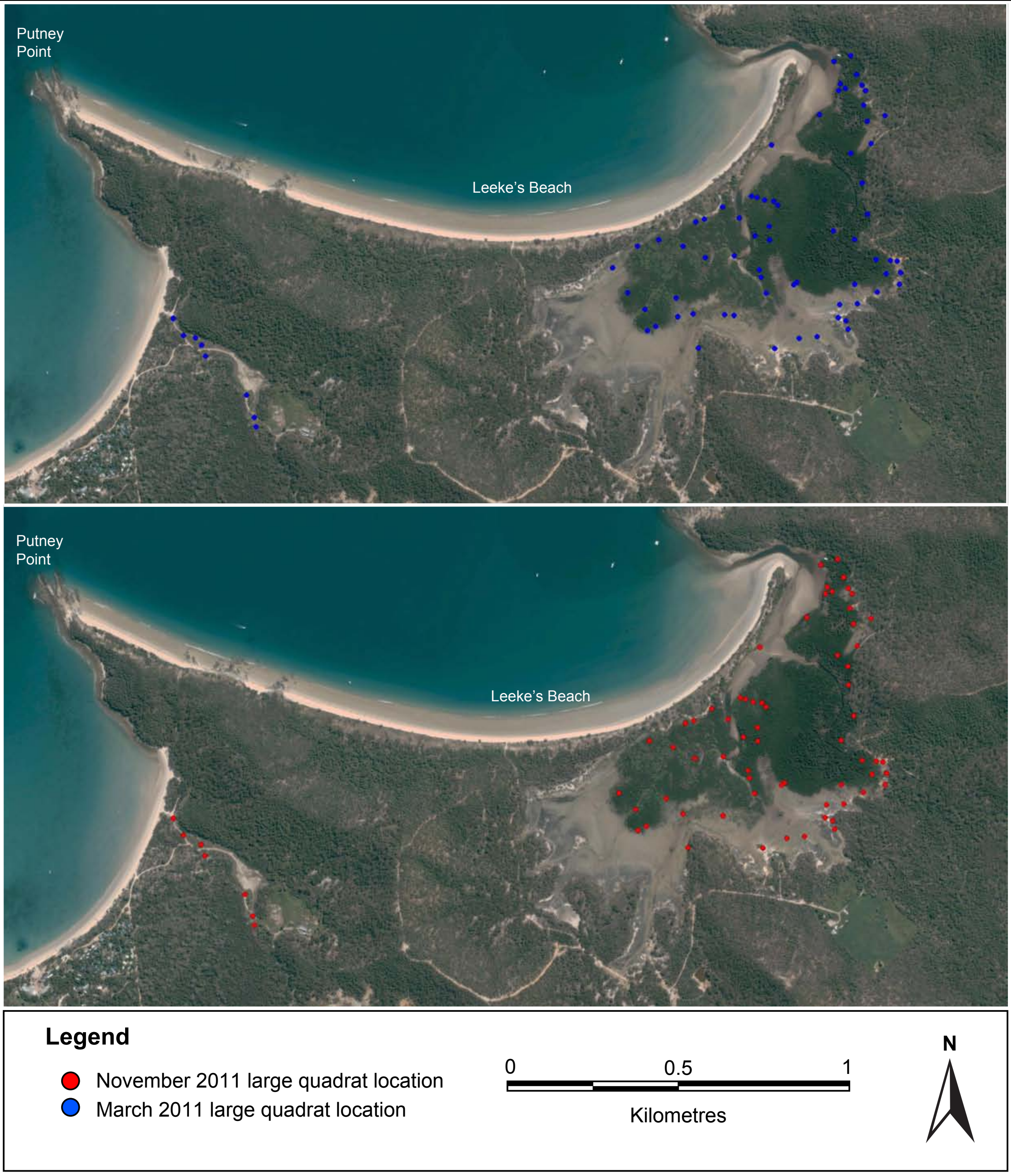
Table 1.1 Mangrove health criteria.

Mangrove Health Category	Visual Criteria
Good (1)	• green leaves with no yellowing / curling and little evidence of damage by insects
	• little or no epicormic growth
	• no abnormal leaf loss
	• few dead branches or trees
Fair (2)	• mainly green leaves with <20% of the canopy affected by yellowing / curling or damage by insects
	• some epicormic growth
	• some dead trees and branches
Poor (3)	• many yellowing / curled leaves, reduced canopy cover, high insect damage
	• abundant epicormic growth
	• more than 30% of trees or branches dead
Dead (4)	• leaves brown or absent with no new growth apparent
	• dominated by dead trees
Regrowth (5)	• canopy cover low but new trees present
	• previous disturbance sometimes evident

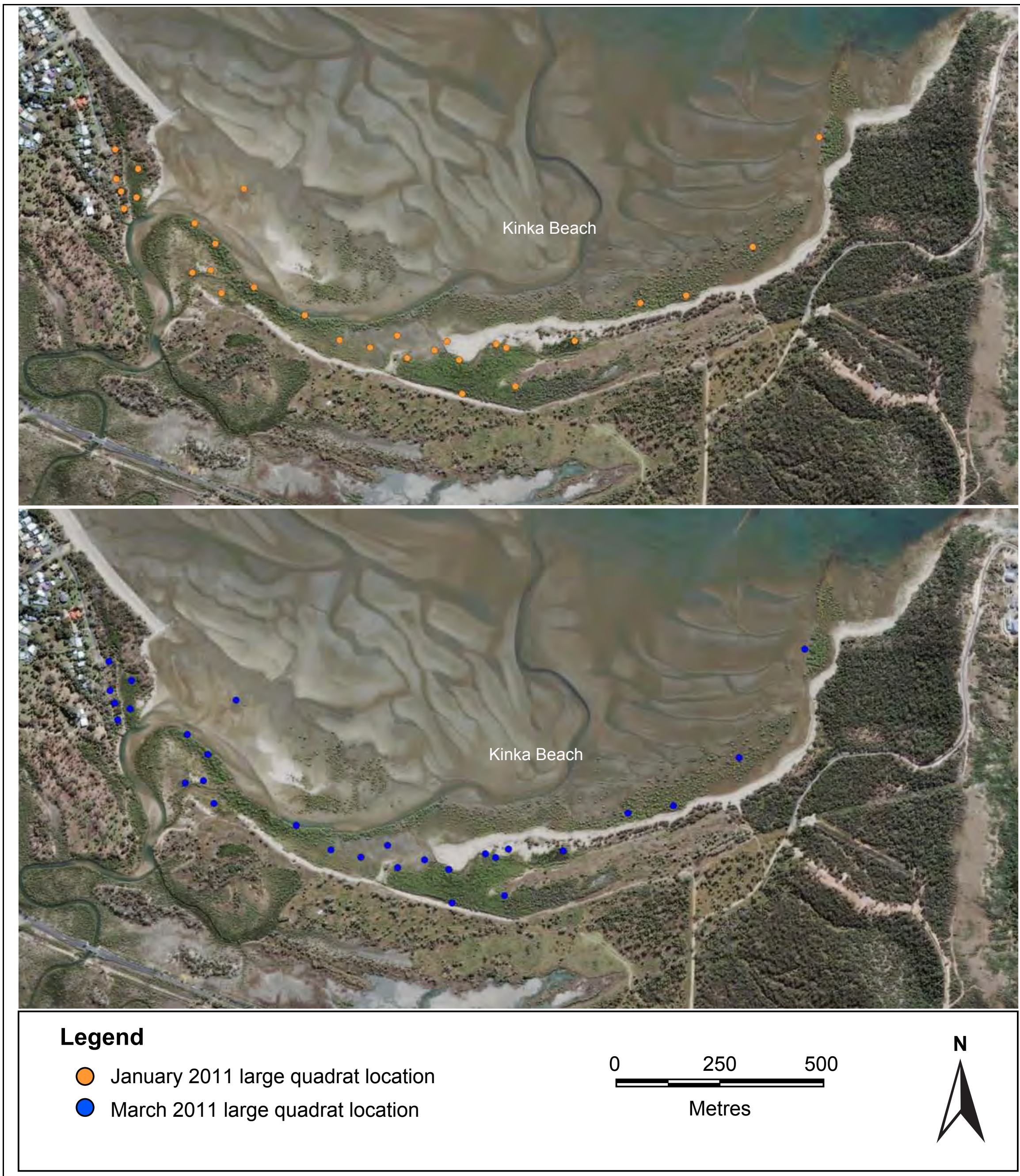
Fisheries Habitat Values

The value of the mangrove forests to fisheries was assessed in three randomly placed 1 x 1 m quadrats in selected larger (10 x 10 m) quadrats that were assessed for ecological health, at:

- three sites in Putney Creek,
- ten sites in Leeke's Creek and
- two sites at Kinka Beach (Figure 1.3 to Figure 1.5).



frc environmental AQUATIC ECOLOGISTS deep thinking. science.	Great Keppel Island Revitalisation EIS	
	Figure 1.1 Quadrat locations for assessment of mangrove distribution, community composition and condition in Leeke's and Putney creeks.	
	Microsoft Bing © 2010 Microsoft Corporation	May 2012

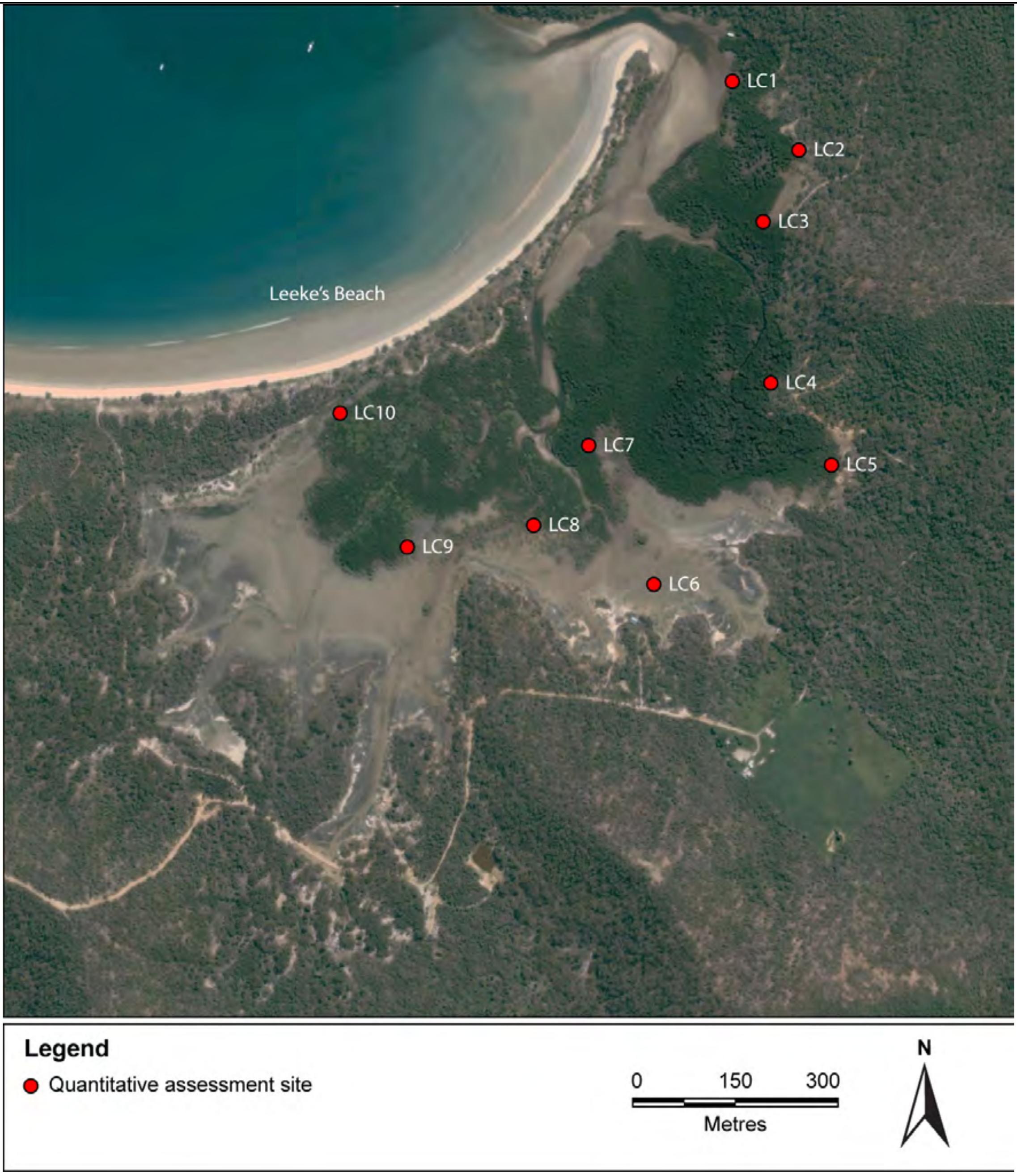


frc environmental AQUATIC ECOLOGISTS deep thinking. science.	Great Keppel Island Revitalisation EIS
	Figure 1.2 Quadrat locations for assessment of mangrove distribution, community composition and condition at Kinka Beach.
	Microsoft Bing © 2010 Microsoft Corporation — May 2012

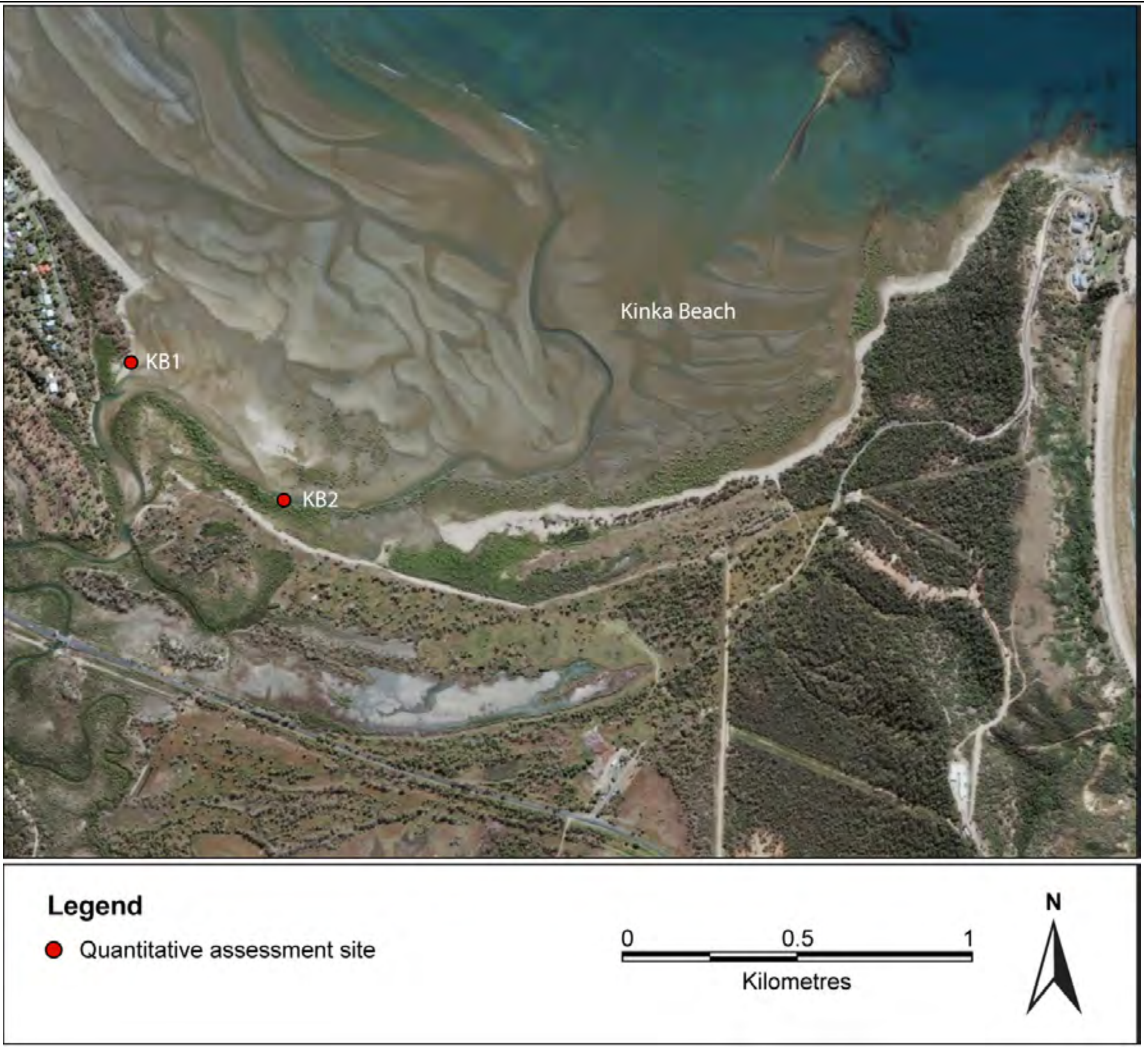
Great Keppel Island Revitalisation EIS

Figure 1.3 Quadrat locations for quantitative assessment of mangrove values to fisheries in Putney Creek.

Microsoft Bing © 2010 Microsoft Corporation | July 2011



frc environmental AQUATIC ECOLOGISTS deep thinking. science.	Great Keppel Island Revitalisation EIS	
	Figure 1.4 Quadrat locations for quantitative assessment of mangrove values to fisheries in Leeke's Creek.	
	Microsoft Bing © 2010 Microsoft Corporation	July 2011



frc environmental AQUATIC ECOLOGISTS deep thinking. science.	Great Keppel Island Revitalisation EIS	
	Figure 1.5 Quadrat locations for quantitative assessment of mangrove values to fisheries at Kinka Beach.	
	Microsoft Bing © 2010 Microsoft Corporation	July 2011

The value of the mangrove forests to fisheries was evaluated using the:

- abundance of crab burrows and molluscs (e.g. whelks and nerites)
- availability and complexity of physical habitat for fauna (e.g. pneumatophores, prop roots, leaf litter and large debris such as fallen branches), and the
- relative proximity of each site to permanent water at low tide (to assess likely frequency of tidal inundation) (Table 1.2).

Table 1.2 Criteria used to assess the value of mangroves to fisheries.

Fisheries Value Category	**Criteria**
Excellent (5)	• high abundance of fauna / crab burrows • very complex structural habitat for fauna • likely to be regularly inundated
Very good (4)	• high abundance of fauna / crab burrows • complex structural habitat for fauna • likely to be regularly inundated • some disturbance
Good (3)	• some fauna / crab burrows • periodical tidal inundation • some structural habitat for fauna
Fair (2)	• low abundance of fauna / crab burrows • little structural habitat for fauna • infrequent tidal inundation
Poor (1)	• little to no fauna • little / no structural habitat for fauna • infrequent / no tidal inundation • poorly flushed • only opportunistic species present

Structural elements provide habitat for marine organisms in mangrove forests, such as:

- trees
- seedlings
- aerial roots
- pneumatophores
- litter on the forest floor (e.g. fallen mangrove leaves), and
- large debris (e.g. dead tree trunks).

However, very high cover of litter (>50%) indicates an area is infrequently inundated by the tide, and is poorly flushed, reducing its value to fisheries.

Smaller structures (e.g. pneumatophores, seedlings and small aerial roots) provide habitat for certain species, while larger structures (e.g. tree trunks and large aerial roots) provide habitat for other species. Different sized structural elements:

- provide heterogeneity of habitat
- offer a greater range of habitat types to a larger number of different species of fish and crustaceans, and
- generally support a more diverse community of marine organisms.

The abundance of infauna (e.g. crabs and molluscs) is a direct indicator of habitat use and food availability. Relative densities of crab burrows also provide an indication of use; however, the number of burrows does not necessarily equate to the number of individual crabs using the habitat, as some species create more than one burrow while others share burrows. Crabs and molluscs are food for fishes and large crustaceans.

1.3 Seagrass Meadows and Macroalgae

Survey Details

Seagrass communities were surveyed during the following seasons[3]:

- pre-wet – 15 to 19 November 2010
- wet – 17 to 21 January 2011
- post-wet – 30 March to 2 April and 30 April to 2 May 2011, and
- winter (to quantify community 'recovery' following flooding) – 11 to 14 July 2011.

Seagrass communities were surveyed at nine sites around Great Keppel Island (Figure 1.6):

- Putney Beach
- Fishermans Beach
- Leeke's Beach
- Leeke's Creek Mouth
- The Spit
- Middle Island
- Long Beach
- Clam Bay, and
- Monkey Beach.

The locations chosen for survey were based on meadows mapped by the Department of Primary Industries & Fisheries (DEEDI 2011) and aerial photographs of the area, together with the location of the proposed development components (e.g. marina and wastewater wet weather outfall).

[3] Seagrass meadows of Putney Beach, Fishermans Beach and The Spit were surveyed during the pre-wet, post-wet and winter season surveys. Seagrass meadows of Long Beach, Middle Island, Leeke's Beach and Monkey Beach were surveyed during the wet survey (as they were not accessible during the pre-wet survey), post-wet and winter surveys. Leeke's Creek mouth and Clam Bay was surveyed during the wet survey; there was no seagrass and these locations were not re-surveyed.

Seagrass communities of the submarine cable alignment were surveyed by Marine & Earth Sciences Pty Ltd, from 1 to 3 March 2011 (as organised by Water Technology). The survey used:

- sub-bottom profiling to map sub-bottom conditions, and
- side scan sonar to map sea floor features (e.g. sand ripples, seagrass meadows and rocky / coral outcrop).

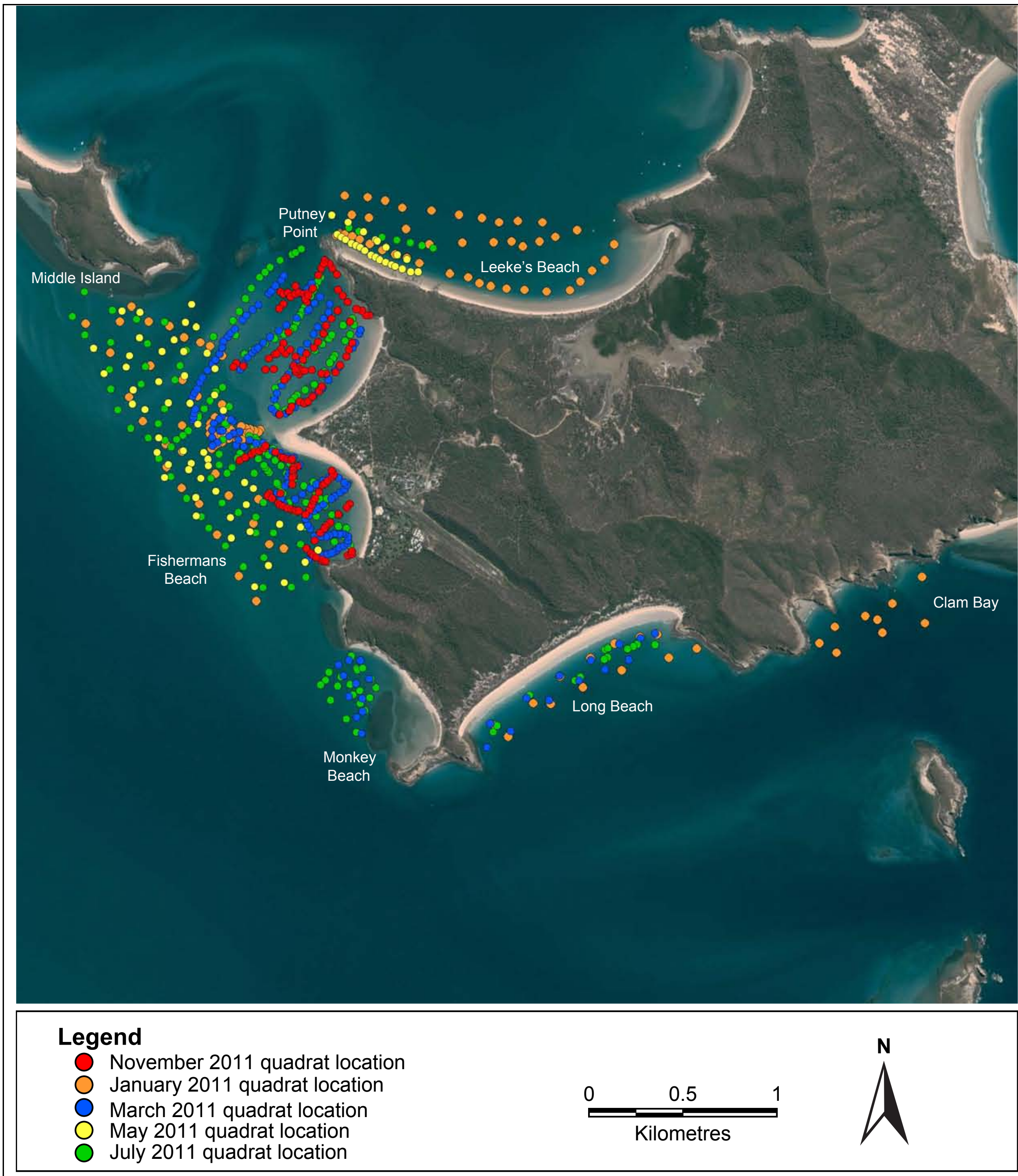
Distribution and Community Composition

The distribution and community composition of seagrass meadows were recorded during surveys undertaken on snorkel within 1 x 1 m quadrats at each location (Figure 1.7). The following variables were recorded:

- seagrass species
- percent cover of each seagrass species
- seagrass morphology (small, medium and large)
- seagrass above ground biomass rank
- epiphytic cover
- benthic epifaunal invertebrates
- vertebrates such as stingrays and their feeding pits, and
- water depth.

Epiphyte load (percent cover of seagrass covered with algae or fauna) was estimated visually. It included both true epiphytes (i.e. attached to the seagrass), and free-floating algae / cyanobacteria that catch on seagrass blades, as the ecological impacts of both forms are likely to be similar.

Great Keppel Island Revitalisation EIS	
Figure 1.6 Great Keppel Island seagrass assessment locations.	
Microsoft Bing © 2010 Microsoft Corporation	July 2011



frc environmental AQUATIC ECOLOGISTS deep thinking. science.	Great Keppel Island Revitalisation EIS	
	Figure 1.7 Quadrat locations for assessment of seagrass meadows around Great Keppel Island.	
	Microsoft Bing © 2010 Microsoft Corporation	May 2012

Aboveground Biomass

Data and Sample Collection

Aboveground biomass was determined by visually estimating biomass and correlating this with data from collected samples (Mellors 1991). Seagrass meadows were first classified according to dominant species and morphology. Within these classifications, seagrass biomass was estimated in 1 x 1 m quadrats during the snorkel surveys.

In the pre-wet and winter recovery survey, seagrass biomass was also estimated in representative samples of each category. These samples were collected and weighed, and the relative proportion of each species was recorded. The biomass estimates were then correlated with the actual biomass.

Laboratory and Data Analysis

Each seagrass sample was sorted, dried and weighed, and the density of aboveground dry weight was determined (g/m^2). To calculate aboveground biomass estimates, seagrass biomass visual estimates were calibrated against seagrass biomass samples collected from 0.25 x 0.25 m quadrats. Linear regression analysis was used to compare estimated seagrass biomass to the actual seagrass biomass (if linear regression analyses are significant, i.e. have an r value close to 1, the data can be confidently used to predict aboveground biomass).

Historical Changes to Seagrass Meadows

A description of the historical changes to the seagrass meadows of Putney Beach was based on available aerial photos and information sourced from government agencies, local residents, community-based groups (e.g. Seagrass Watch) and researchers (where available).

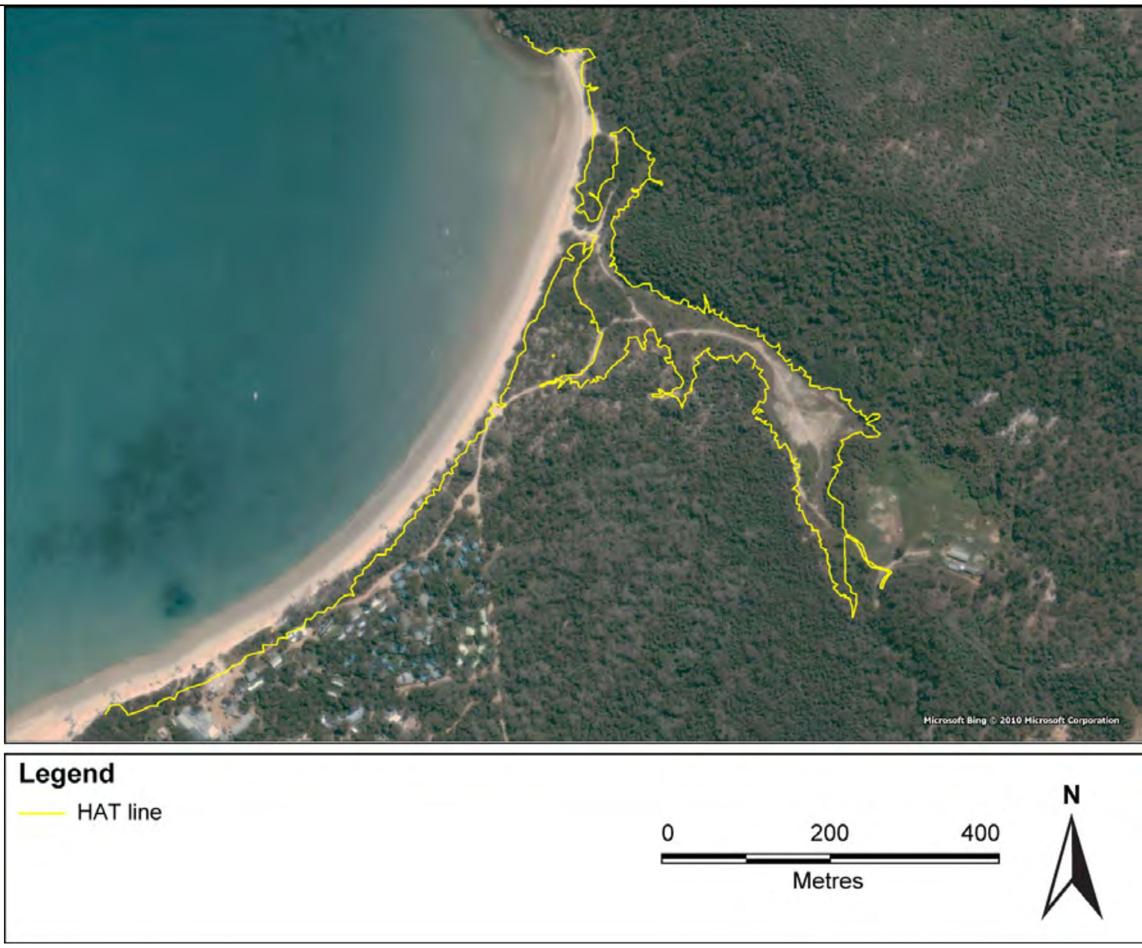
Regional and Ecological Context

Aquatic flora of the project area (existing environment) and region were described through literature review and database searches, specifically: the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act), *Protected Matters Search Tool* (DSEWPC 2011); and the *Queensland WildNet database* (DERM 2011c). The search area included a 10 km buffer around the project as well as within the wider project area (from Shoalwater Bay to Curtis Island). Information was also sourced from researchers, government agencies and consultancies to provide a description of flora communities, including ecologically significant species, near the proposed development and of the region. The extent (hectares) of regional seagrass was calculated from McKenzie et al (2006-2012).

2 Existing Environment

2.1 Estimation of Highest Astronomical Tide

The estimated level of highest astronomical tide (HAT) at Putney Beach is presented in Figure 2.1.



frc environmental AQUATIC ECOLOGISTS deep thinking. science.	Great Keppel Island Revitalisation EIS	
	Figure 2.1 The estimated level of highest astronomical tide at Putney Beach.	
	Microsoft Bing © 2010 Microsoft Corporation	July 2011

2.2 Mangrove Forests and Saltmarsh

Community Composition

The distribution and community composition of mangrove and saltmarsh communities of the survey area are presented in Figure 2.2 to Figure 2.4. The estimated area of mangrove forest and saltmarsh at Putney Creek was 1 ha and 12 ha respectively (Figure 2.2). The estimated area of mangrove forest and saltmarsh at Leeke's Creek was 30 ha and 19 ha respectively (Figure 2.3). The estimated area of mangrove forest at Kinka Beach was 31 ha (Figure 2.4).

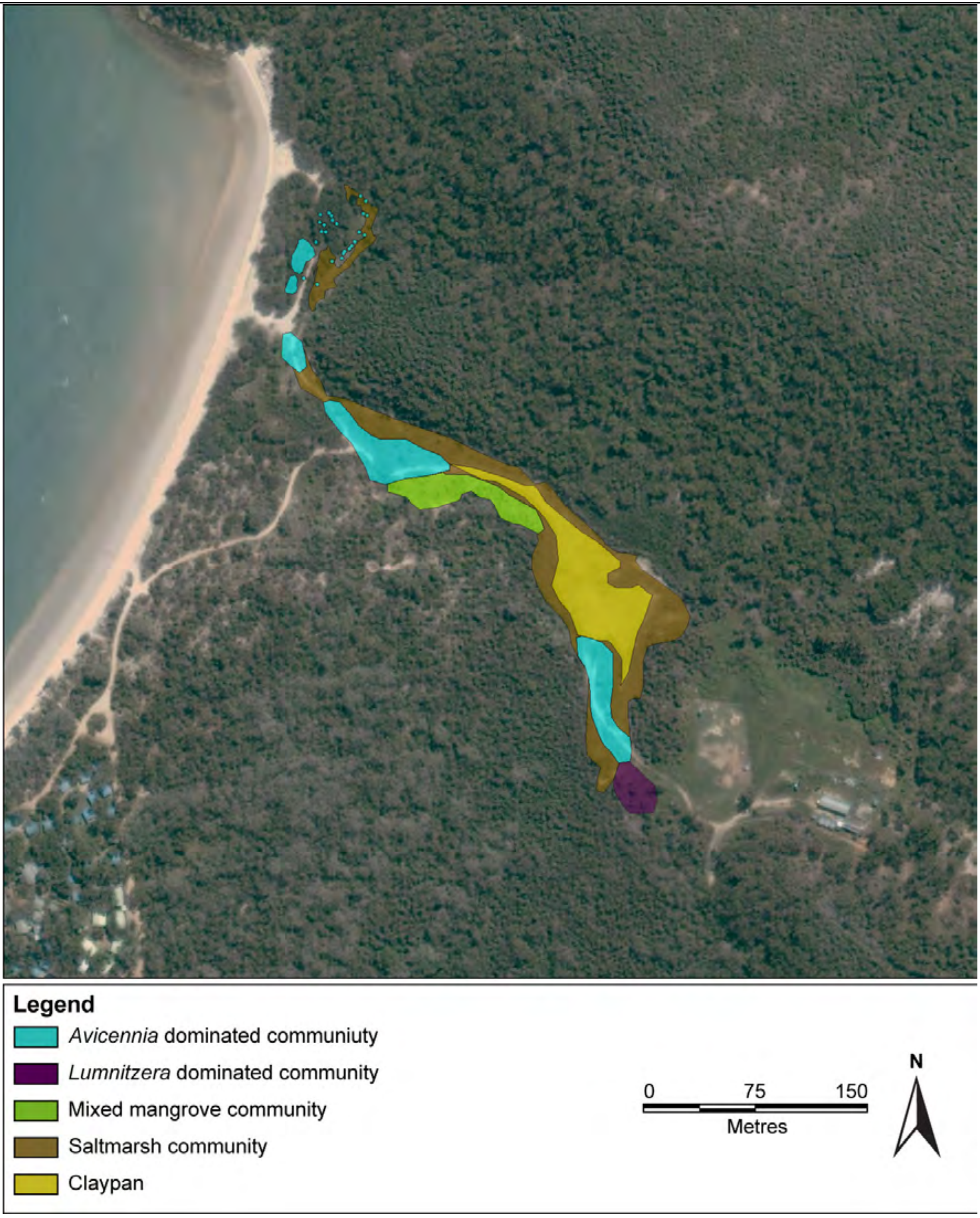
Ten species of mangrove were recorded on Great Keppel Island and seven species at Kinka Beach. *Aegialitis annulata* was recorded at Kinka Beach but not on Great Keppel Island. Several species were recorded on Great Keppel Island but not at Kinka Beach (Table 2.1).

Mangrove communities were dominated by:

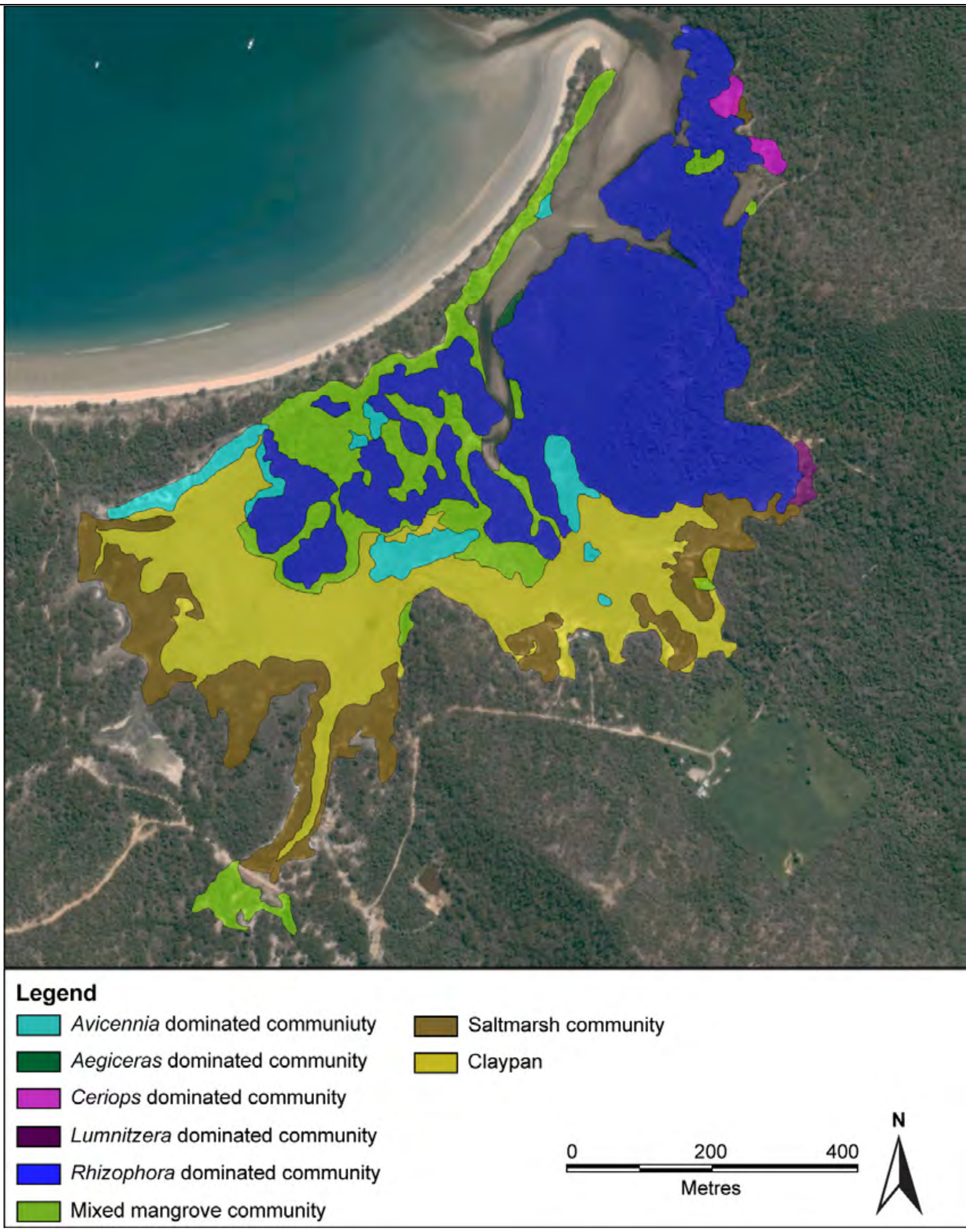
- *Rhizophora* spp. (predominantly *Rhizophora stylosa* and *Rhizophora apiculata*)
- *Avicennia marina*
- *Aegiceras corniculatum*
- *Lumnitzera racemosa*, and
- *Ceriops australis* (Figure 2.6 to Figure 2.11).

Six species of saltmarsh were recorded on Great Keppel Island and at Kinka Beach; only two of these species were recorded in both areas (Table 2.2). Saltmarsh communities were dominated by *Sarcocornia quinqueflora*, *Sporobolus virginicus* and *Suaeda australis* (Figure 2.12). Several sedge species, including *Fimbristylis* sp. and *Juncus* sp., grew next to the mangrove and saltmarsh communities at Leeke's Creek.

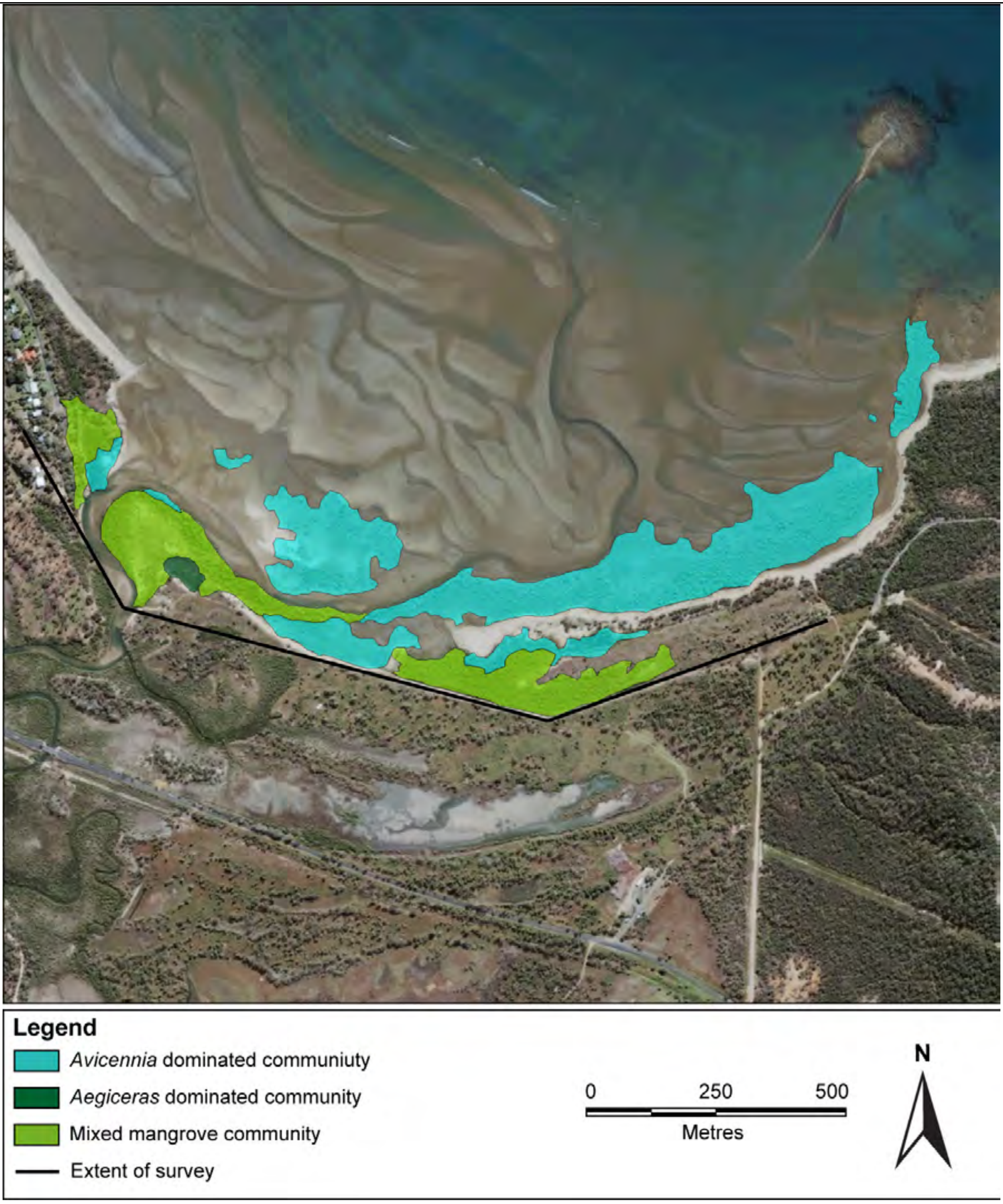
The mangrove communities of Putney Creek were not mapped during surveys by the Department of Primary Industries and Fisheries between 1992 and 2003 (DEEDI 2011). The distribution of the mangrove communities of Leeke's creek and Kinka Beach were similar in this study to previous studies by DPI&F (Figure 2.5).



frc environmental AQUATIC ECOLOGISTS deep thinking. science.	Great Keppel Island Revitalisation EIS	
	Figure 2.2 Mangrove communities at Putney Creek.	
	Microsoft Bing © 2010 Microsoft Corporation	August 2011



frc environmental AQUATIC ECOLOGISTS deep thinking. science.	Great Keppel Island Revitalisation EIS	
	Figure 2.3 Mangrove communities at Leeke's Creek.	
	Microsoft Bing © 2010 Microsoft Corporation	August 2011



Great Keppel Island Revitalisation EIS

Figure 2.4 Mangrove communities at Kinka Beach.

Microsoft Bing © 2010 Microsoft Corporation

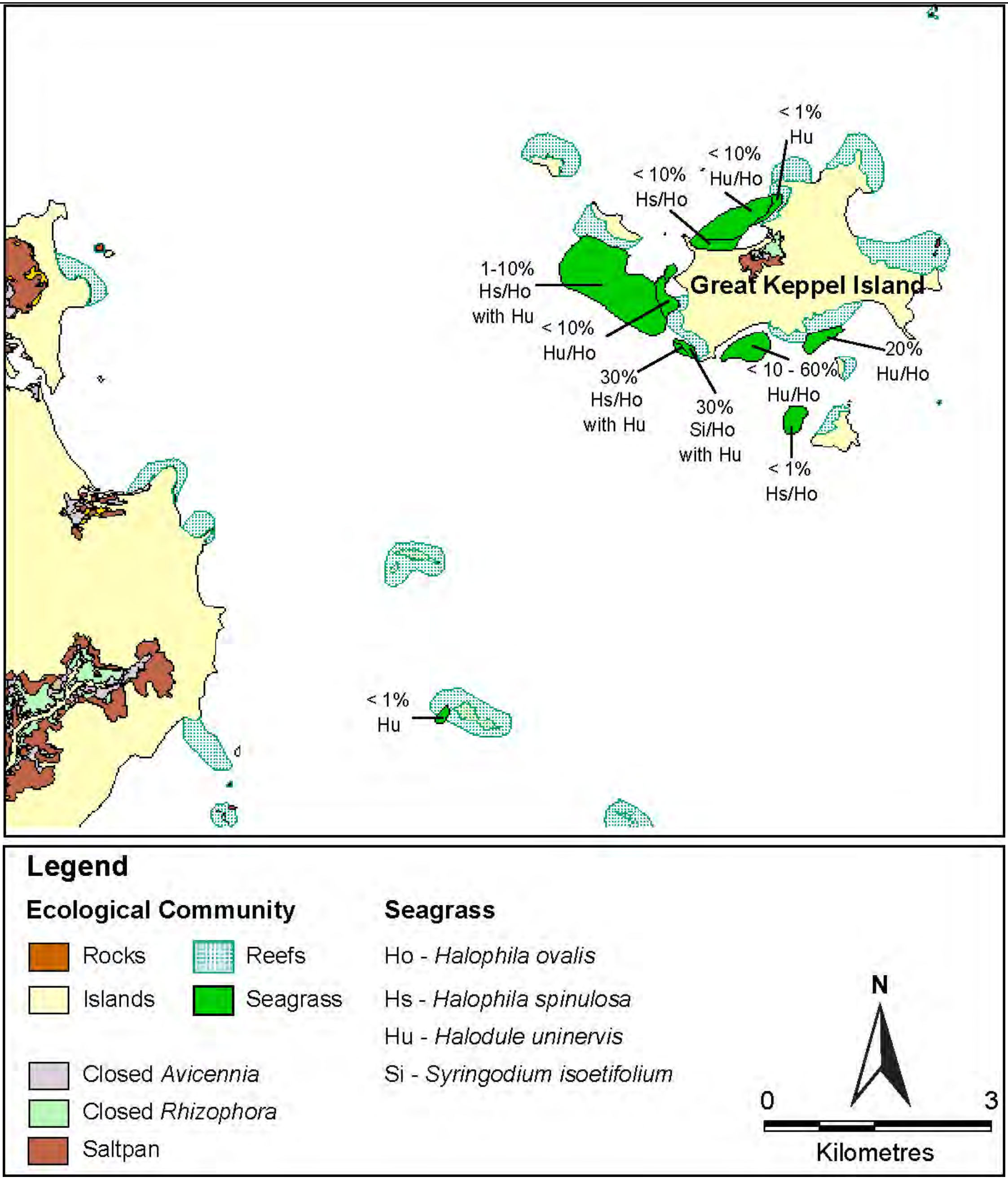
August 2011

Table 2.1 Mangrove species on Great Keppel Island and at Kinka Beach.

Family	Scientific Name	Common Name	Great Keppel Island	Kinka Beach
Plumbaginaceae	*Aegialitis annulata*	club mangrove	–	✓
Myrsinaceae	*Aegiceras corniculatum*	river mangrove	✓	✓
Acanthaceae	*Avicennia marina*	grey mangrove	✓	✓
Rhizophoraceae	*Bruguiera gymnorrhiza*	large-leafed orange mangrove	✓	–
Rhizophoraceae	*Ceriops australis*	smooth-fruited yellow mangrove	✓	✓
Euphorbiaceae	*Excoecaria agallocha*	milky mangrove	✓	–
Combretaceae	*Lumnitzera racemosa*	white-flowered black mangrove	✓	✓
Myrtaceae	*Osbornia octodonta*	myrtle mangrove	✓	✓
Rhizophoraceae	*Rhizophora* spp.	stilt mangrove	✓	✓
Meliaceae	*Xylocarpus granatum*	cannonnball mangrove	✓	–

Table 2.2 Saltmarsh species on Great Keppel Island and Kinka Beach.

Family	Scientific Name	Common Name	Great Keppel Island	Kinka Beach
Aizoaceae	*Sesuvium portulacastrum*	sea purslane	–	✓
Amaranthaceae	*Suaeda australis*	Austral seablite	✓	✓
Chenopodiaceae	*Enchylaena tomentosa*	ruby saltbush	–	✓
Chenopodiaceae	*Sarcocornia quinqueflora*	bead weed	✓	–
Plumbaginaceae	*Limonium austral*	sea lavender	✓	–
Phocaea	*Sporobolus virginicus*	marine couch	✓	✓



frc environmental AQUATIC ECOLOGISTS deep thinking.science.	Great Keppel Island Revitalisation EIS	
	Figure 2.5 Marine plant communities in the vicinity of the project.	
	Microsoft Bing © 2010 Microsoft DEEDI 2011	March 2011

Figure 2.6

Rhizophora dominated community at Leeke's Creek.

Figure 2.7

Avicennia dominated community at Putney Creek.

Figure 2.8

Aegiceras dominated community at Kinka Beach.

Figure 2.9

Lumnitzera dominated community at Putney Creek.

Figure 2.10

Ceriops dominated community at Leeke's Creek.

Figure 2.11

Mixed mangrove community at Leeke's Creek.

Figure 2.12

Sporobolus virginicus dominated community at Leeke's Creek.

Ecological Health

Mangrove forests were in poor to good ecological health (condition). Most trees showed few signs of stress; the major exceptions to this were at Putney Creek, where the community was assessed as being in poor health, exhibiting:

- low canopy cover (generally less than 15%)
- a relatively high percentage of dead branches (generally greater than 20%), and
- dead mangroves (Figure 2.13).

There were also a few areas in Leeke's Creek where mangroves were in poor ecological health due to occasional dead trees, trees being stunted, and epicormic growth (Figure 2.14 to Figure 2.16).

Figure 2.13

Dead mangroves at Putney Creek.

Figure 2.14

Stunted *Avicennia marina* at Leeke's Creek.

Figure 2.15

Dead mangrove trees at Leeke's Creek.

Figure 2.16

Epicormic shoots of *Avicennia marina* at Leeke's Creek.

Other evidence of poor health included minor insect damage, floating macroalgae and dense seedling growth in response to an open forest canopy (generally associated with the death of mature trees or branches). Insect damage was most common at Kinka Beach and Leeke's Creek. Floating macroalgae was most common at Putney Creek. Increased seedling density was most common at Kinka Beach but also evident at Leeke's Creek (Figure 2.17 to Figure 2.19).

Figure 2.17

Minor insect damage to mangrove leaves at Leeke's Creek.

Figure 2.18

Macroalgae covering pneumatophores at Putney Creek.

Figure 2.19

High seedling density at Leeke's Creek.

Value to Fisheries

Most of the mangrove communities provide good to very good fisheries habitat, with moderate amounts of structural habitat for fauna, and frequent tidal inundation. Fisheries habitat values were generally higher at Leeke's Creek, than at Putney Creek and Kinka Beach, due to abundant fauna, complex structural habitat and regular tidal inundation.

The mean number of aerial roots varied between sites and within some sites, ranging from 0 to 23 roots/m^2. The majority of Leeke's Creek sites had relatively high numbers of aerial roots because they were dominated by *Rhizophora* spp. (which have aerial roots), while other sites were dominated by species without aerial roots (e.g. *Avicennia marina* or *Ceriops tagal*) (Figure 2.20).

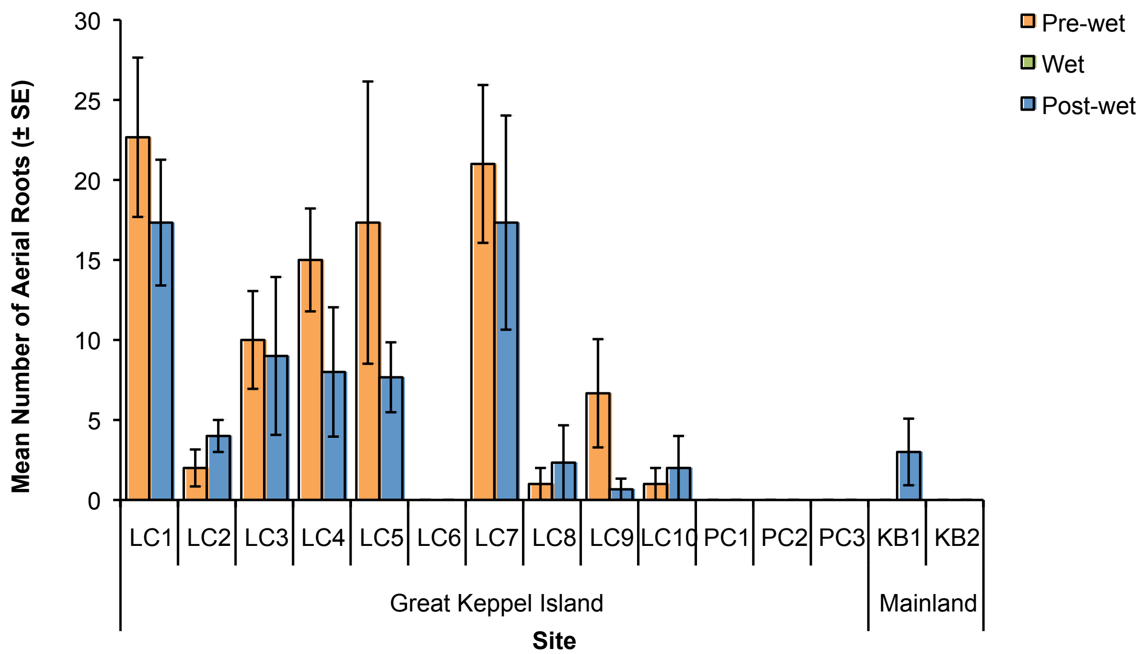


Figure 2.20 Mean number of aerial roots (± SE) at each site.

Large debris was only present at five of the 15 sites surveyed. The mean percent cover of large debris varied within a site and between sites, ranging from 0.3 to 13.5%. The percent cover of large debris was generally less in the post-wet survey, than other surveys (Figure 2.21 and Figure 2.22).

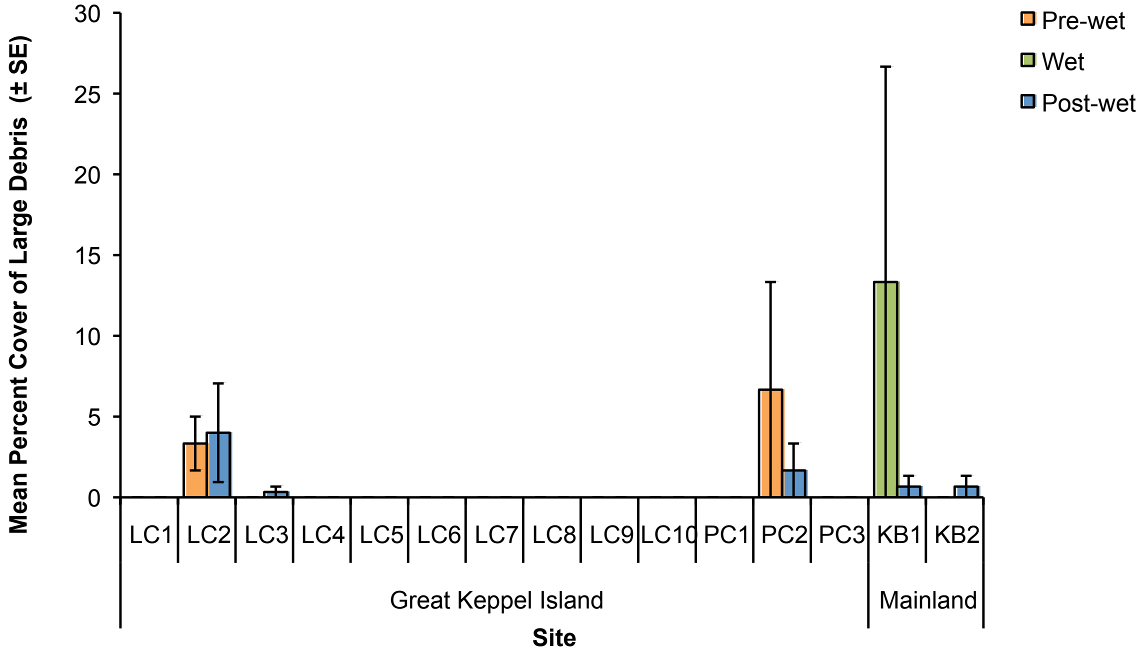


Figure 2.21 Mean percent cover of large debris (± SE) at each site.

Figure 2.22

Woody debris at site KB1.

Most sites had some leaf litter. The mean cover of leaf litter varied within a site and between sites, ranging from 0 to 10%. There was generally less leaf litter in the post-wet survey, than the other surveys, which is likely to be a result of heavy rainfall and flooding in the wet season flushing the leaves out of the mangrove forests (Figure 2.23 and Figure 2.24).

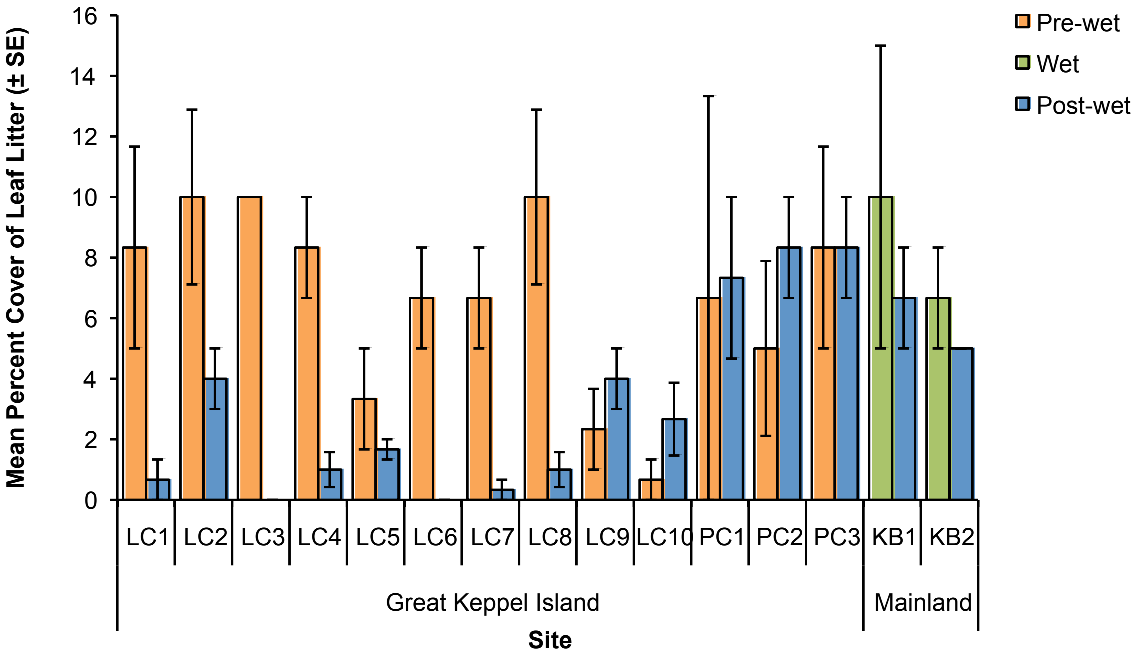


Figure 2.23 Mean percent cover of leaf litter (± SE) at each site.

Figure 2.24

A patch of relatively dense leaf litter at site LC8 during the pre-wet survey.

The density of crab burrows was highly variable between sites, and within some sites. Crab burrow density ranged from 3 to 243 burrows/m^2. At the sites on Great Keppel Island crab burrow density was generally stable, however it was substantially lower at Kinka Beach in the post-wet survey than in the wet survey (Figure 2.25 and Figure 2.26).

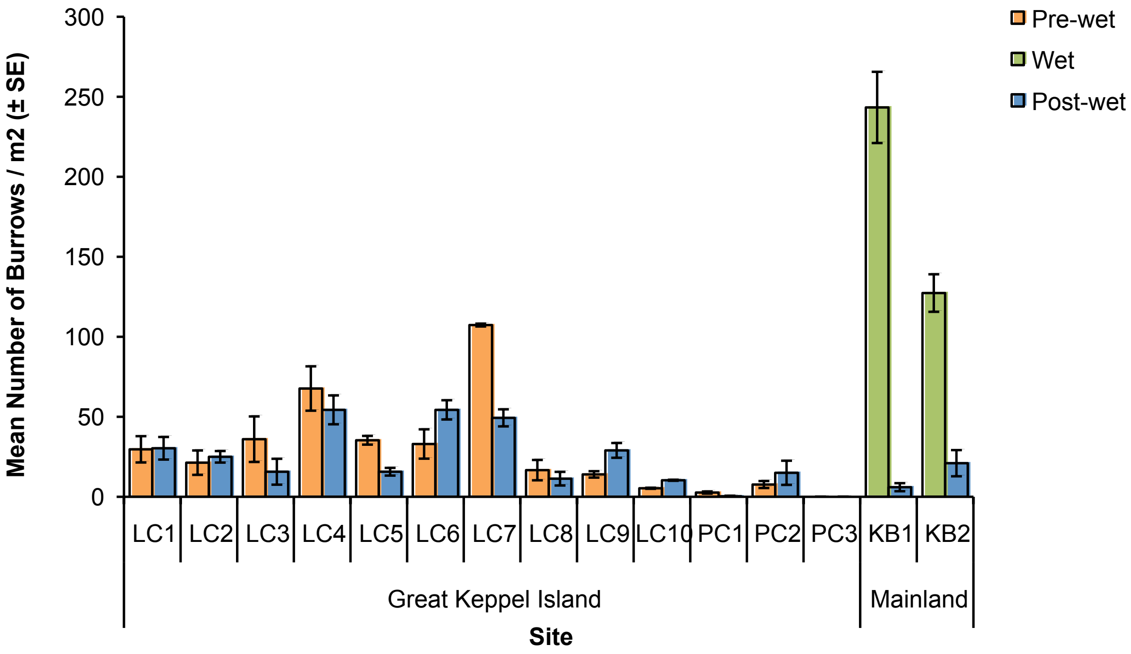


Figure 2.25 Mean number of burrows/m^2 (± SE) at each site.

Figure 2.26

Sesarma sp. in burrow at site KB1.

Gastropods were only present at six of the 15 sites surveyed. The mean gastropod density varied within a site and between sites, ranging from 0 to 10 individuals/m^2 (Figure 2.27 and Figure 2.28).

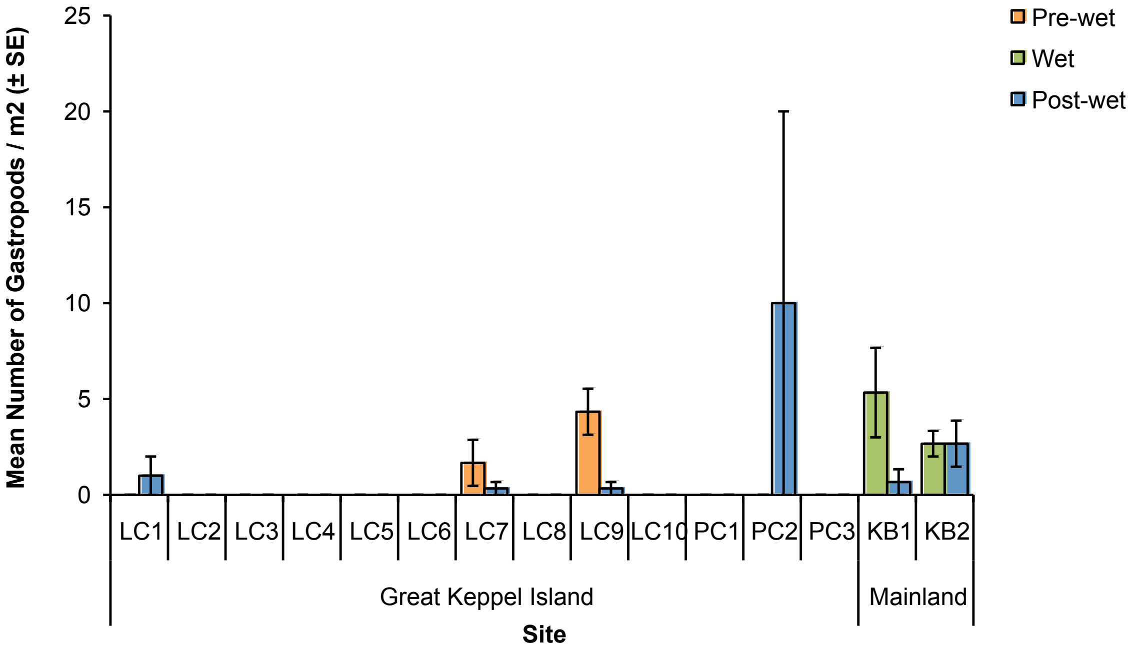


Figure 2.27 Mean number of gastropods/m^2 (± SE) at each site.

Figure 2.28

Nerita articulata at site KB1.

2.3 Seagrass Meadows and Macroalgae

Community Composition

Four species of seagrass from three families were recorded around Great Keppel Island (Table 2.3). The seagrass communities were dominated by *Halophila ovalis* and *Halodule uninervis*, with a small morphology (*H. uninervis* leaves less than 3 mm wide and 70 mm long and *H. ovalis* leaves less than 7 mm wide and 20 mm long).

Table 2.3 Seagrass species in this survey.

Family	Scientific Name	Common Name
Cymodoceaceae	*Halodule uninervis*	narrowleaf seagrass
Hydrocharitaceae	*Halophila ovalis*	paddle weed
Hydrocharitaceae	*Halophila spinulosa*	fern seagrass
Potamogetonaceae	*Syringodium isoetifolium*	noodle seagrass

Halophila ovalis was less widespread than *H. uninervis*, which is likely to be related to environmental conditions such as turbidity and sedimentation. *Halophila ovalis* and *H. uninervis* commonly colonises when conditions are good, and disappear when conditions are poor. Both species produce large numbers of seeds and can therefore rapidly re-colonise when conditions improve (Longstaff & Dennison 1999; Waycott et al. 2005). *Halophila spinulosa* and *Syringodium isoetifolium* were least widespread and not recorded during the winter recovery survey.

Seagrass communities typically had overall cover of <5% with sparse, patchy distribution (e.g. up to 15% cover in patches separated by large areas of bare sand at Fishermans Beach during the pre-wet survey). The sediment was dominated by sand (Figure 2.29 and Figure 2.30).

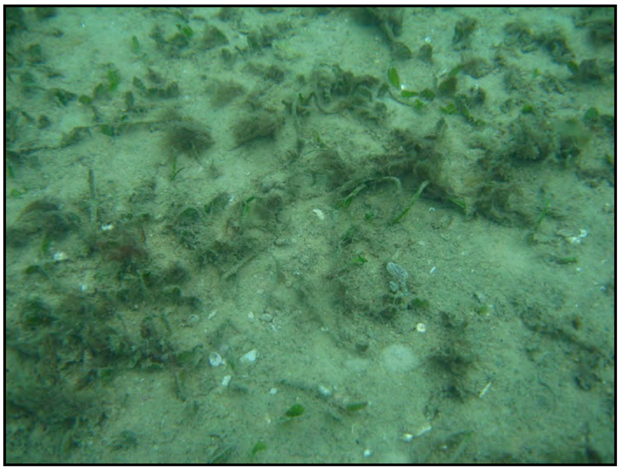
These results are consistent with the most recent (pre-wet season 2009) Seagrass Watch survey, which recorded <4% cover of mostly *H. uninervis* at the Monkey Beach site on Great Keppel Island (Seagrass Watch 2011b).

Figure 2.29

Typical cover of *Halodule uninervis*.

Figure 2.30

A small patch of relatively dense *Halodule uninervis* and *Halophila ovalis*.



There were few algal or faunal epiphytes on the seagrasses meadows. The cyanobacteria, *Lyngbya majuscula* was recorded on the seagrass at several locations in each survey, with dense cover at some locations (e.g. Fishermans and Putney Beach) (Figure 2.31). Abundant *Lyngbya* can lead to a decrease in the distribution of seagrass and may negatively impact turtle and dugong communities (e.g. Watkinson et al. 2005). The reason for *Lyngbya* blooms is not clear; an ecological and regional context is provided in Section 3.2.

Figure 2.31

Dense *Lyngbya majuscula* growing on sparse seagrass.

The macroalgae, *Caulerpa taxifolia*, was relatively common, growing in small isolated patches at all locations. *Caulerpa taxifolia* is typically found in areas of low light and high nutrients (Burfield & Udy 2009) and provides diverse habitat for a range of different epi- and infauna (Tanner 2011). *Laurencia* spp., *Halimeda* spp., *Hypnea* spp. and *Padina* spp. also grew in small, isolated patches at some locations (Figure 2.32 and Figure 2.33).

Figure 2.32

Caulerpa taxifolia at Putney Beach.

Figure 2.33

Halimeda sp. at Putney Beach.

Seagrass was not recorded along the submarine cable alignment. The sea floor along the alignment was dominated by [4]:

- sand ripples of fine to medium grained sands
- irregular hummocks
- a few low-relief, unknown features, and
- anchor or trawl board scours (Marine and Earth Sciences 2011).

Distribution

The distribution of seagrass in each survey is presented in Figure 2.34 to Figure 2.36. The overall cover, extent and diversity in each meadow in each survey are presented in Table 2.4.

[4] Marine & Earth Sciences 2011 recommend investigation of four locations using a drop-camera, to confirm the nature of the sea floor surface, and collection of grab samples (with a Van Veen grab sampler or similar) at close intervals along the alignment to ground truth their interpretation.

frc environmental AQUATIC ECOLOGISTS deep thinking. science.	Great Keppel Island Revitalisation EIS
	Figure 2.34 Seagrass meadows during the pre-wet season survey.
	Microsoft Bing © 2010 Microsoft Corporation / July 2011

frc environmental AQUATIC ECOLOGISTS deep thinking. science.	Great Keppel Island Revitalisation EIS
	Figure 2.35 Seagrass meadows during the post-wet season survey.
	Microsoft Bing © 2010 Microsoft Corporation / July 2011

Great Keppel Island Revitalisation EIS	
Figure 2.36 Seagrass meadows during the winter recovery survey.	
Microsoft Bing © 2010 Microsoft Corporation	July 2011

Table 2.4 Overall cover, extent and diversity of each seagrass meadow in this survey.

	Percent Cover (%)	Approximate Area (ha)	Species Present [a]			
			Hu	Ho	Hs	Si
Pre-wet and wet season survey						
Putney Beach	5	24	✓	✓	✓	✓
Fishermans Beach	10	23	✓	✓	–	✓
Leeke's Beach	<5	<1	–	–	–	✓
The Spit	5	30	✓	✓	✓	✓
Middle Island	5	5	✓	✓	✓	–
Long Beach	5	14	✓	✓	✓	–
Clam Bay	0	0	–	–	–	–
Leeke's Creek Mouth	0	0	–	–	–	–
Monkey Beach	NS	NS	NS	NS	NS	NS
Post-wet season survey						
Putney Beach	<5	<1	✓	–	–	–
Fishermans Beach	<5	2	✓	✓	✓	–
Leeke's Beach	0	0	–	–	–	–
The Spit	0	0	–	–	–	–
Middle Island	<5	<1	✓	–	–	✓
Long Beach	<5	4	✓	✓	✓	–
Clam Bay	NS	NS	NS	NS	NS	NS
Leeke's Creek Mouth	NS	NS	NS	NS	NS	NS
Monkey Beach	<5	8	✓	✓	✓	–
Winter recovery survey						
Putney Beach	<5	10	✓	✓	–	–
Fishermans Beach	<5	7	✓	✓	–	–
Leeke's Beach	0	0	–	–	–	–
The Spit	0	0	–	–	–	–
Middle Island	<5	<1	–	✓	–	–
Long Beach	<5	2	✓	✓	–	–
Clam Bay	NS	NS	NS	NS	NS	NS
Leeke's Creek Mouth	NS	NS	NS	NS	NS	NS
Monkey Beach	<5	2	✓	✓	–	–

[a] Hu (Halodule uninervis), Ho (Halophila ovalis), Hs (Halophila spinulosa) and Si (Syringodium isoetifolium)

NS site not surveyed

Pre-wet and Wet Season Survey

Overall, percent cover during the pre-wet / wet season survey [5] was relatively low, with patches of seagrass with 5 to 15% cover, and the overall cover of seagrass between 5 and 10%; however cover and extent was higher than during other (later) surveys. All four species were recorded during the pre-wet / wet survey. There was no seagrass recorded at Leeke's Creek mouth or Clam Bay in the wet season survey.

Seagrass meadows typically increase in extent and cover in clearer water associated with low rainfall conditions, and decrease in turbid water associated with high rainfall and floods. The relatively large area of seagrass recorded in this survey is likely to be a result of the low rainfall in the preceding months, compared to the post-wet and winter recovery survey.

Post-wet Season Survey

Overall, seagrass communities had lower cover (<5% at all locations) and covered a smaller area during the post-wet survey than in the pre-wet / wet survey. All four species were recorded during the post-wet survey. Natural seasonal changes are common in seagrass communities (Rasheed et al. 2007). These reductions in cover and area are most likely a result of extensive flooding in January 2011.

Winter Recovery Survey

Overall, seagrass meadows had lower cover (<5% at all locations) and covered a smaller area in the winter recovery survey than in the pre-wet / wet survey. Species diversity was also less than in the pre-wet season survey. Only two species, *H. ovalis* and *H. uninervis,* were recorded in the winter survey; both of which were the dominant species prior to the wet season and are fast-growing colonising species. These types of changes are typical of inshore seagrass meadows of the region following large rainfall events.

There was no seagrass at The Spit and Leeke's Beach in the winter survey.

[5] Seagrass meadows of Putney Beach, Fishermans Beach and The Spit were surveyed during the pre-wet, post-wet and winter season surveys. Seagrass meadows of Long Beach, Middle Island, Leeke's Beach and Monkey Beach were surveyed during the wet survey (as they were not accessible during the pre-wet survey due to permit and boat constraints), post-wet and winter surveys. Leeke's Creek mouth and Clam Bay was surveyed during the wet survey; there was no seagrass and these locations were not re-surveyed.

Aboveground Biomass

Linear regression results showed a significant correlation between observer estimates of seagrass biomass and actual seagrass biomass (r^2 = 0.99). That is, our observed estimates can be used to accurately describe actual seagrass biomass. Above ground biomass ranged from 0.008 to 0.548 g/m^2.

Faunal Communities

Benthic epifaunal communities of the seagrass meadows were dominated by:

- echinoderms such as sea stars (*Protoreaster* spp.), sand dollars, urchins, sea cucumbers and crinoids
- acorn worms (*Balanoglossus carnosus*)
- obese sea pens (*Cavernularia obesa*), and
- moon snails (*Polinices lewisssi*) (Figure 2.37 to Figure 2.40).

Echinoderms were observed during every survey; sea stars (*Protoreaster* spp.) were particularly abundant at The Spit during the winter recovery survey. Acorn worms were abundant during every survey. Sea pens and moon snails were less common

Stingrays, and their feeding-pits, were observed during every survey (Figure 2.41). The blue-spotted stingray (*Dasyatis kuhlii*), cowtail stingray (*Taeniura melanospila*) and common shovel-nosed ray (*Rhinobatos batillum*) were recorded in the seagrass beds.

Figure 2.37

Sea stars and a crinoid at The Spit.

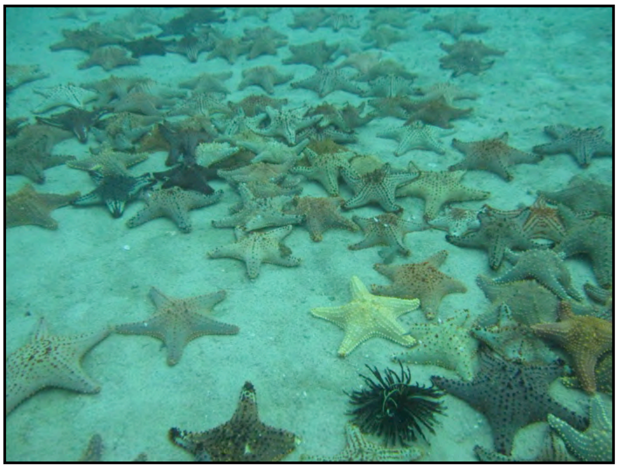


Figure 2.38

Acorn worms within the sediment at Putney Beach.

Figure 2.39

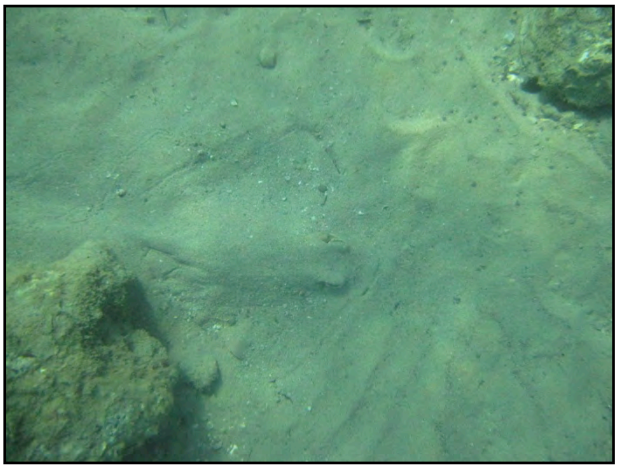
Obese sea pen at Fishermans Beach.

Figure 2.40

Moon snail at Fishermans Beach.

Figure 2.41

Stingray at Fishermans Beach.



Factors Affecting Seagrass Distribution and Abundance of the Project Area

A review of the factors affecting seagrass distribution and cover is provided in Section 3.2.

Around Great Keppel Island, seagrass colonises shallow, open areas of sand and the edges of coral and rocky reefs. Consequently, the areas available for colonisation are naturally determined by a combination of many environmental and anthropogenic factors. The seasonal changes recorded during this survey are likely to be associated with sediment-laden run-off associated with heavy rainfall, turbidity, sedimentation and smothering of seagrass. Extended heavy rainfall, from November 2010 to January 2011 (BOM 2011) increased run-off, turbidity and sedimentation, leading to reduced distribution and cover of seagrass communities. Rainfall in this wet season was unusually high, and resulted in extensive sediment plumes from the Fitzroy River, which is approximately 40 km south-west of Great Keppel Island (Table 2.5).

Table 2.5 Monthly rainfall at Rockhampton airport, leading up to and during the surveys.

Date	Total Monthly Rainfall (mm)	Highest Daily Rainfall (mm)
2010		
October	50.6	25.4
November	120.6	47.0
December	523.8	140.4
2011		
January	115.6	42.2
February	65.0	15.4
March	315.4	57.2
April	41.8	22.0
May	19.4	8.4
June	23.4	10.6
July	9.0	9.0

Putney and Fishermans beaches have been designated erosion-prone by the Department of Environment and Resource Management (DERM) (DERM 2011a). Severe erosion along Putney Beach has introduced large volumes of sand into adjacent waters, which can increase sedimentation and smothering of seagrass communities. Low seagrass cover may reduce trapping of sand (i.e. allowing it to be more mobile) and subsequently lower the substrate level (Water Tecnology 2011). The area of erosion is next to urban dwellings that can also contribute to increased run-off of pollutants and elevated nutrients (Figure 2.42).

Figure 2.42

Erosion and dwellings at Putney Beach.

Historical Changes to Seagrass Meadows

Previous Surveys of Great Keppel Island

Ongoing monitoring of seagrass communities around Great Keppel Island has shown communities are composed predominately of *H. uninervis,* on sandy substrate. A survey around Great Keppel Island in 1988 recorded:

- *Halophila ovalis*
- *Halophila spinulosa*
- *Halodule uninervis*, and
- *Syringodium isoetifolium* (Lee Long et al. 1992).

Between 1984 and 1988, there were large meadows of seagrass along Leeke's Beach, and between Fishermans Beach and Middle Island (DEEDI 2011; Figure 2.5). Meadows in this area had low cover of <10% and included:

- *Halophila spinulosa*
- *H. uninervis*, and
- *H. ovalis* (DEEDI 2011)

Meadows along Leeke's Beach had low cover (1 to 10%) and included:

- *H. uninervis*, and
- *H. ovalis* (DEEDI 2011)

Meadows near Middle Island had <1% cover and consists of *H. uninervis.* The meadows of Fishermans Beach had <10% cover and included:

- *H. spinulosa*
- *H. uninervis*, and
- *H. ovalis* (DEEDI 2011)

Communities along the southern shoreline of Great Keppel Island (Monkey Beach, Long Beach and Clam Bay) had a higher density. The communities at Monkey Beach had up to 30% cover and were dominated by:

- *H. spinulosa*
- *H. uninervis*
- *H. ovalis*, and
- *Syringodium isoetifolium.*

The communities of Long Beach had up to 60% cover, and consist of:

- *H. ovalis*, and
- *H. uninervis* (DEEDI 2011)

The communities of Clam Bay had up to 20% cover, and consist of:

- *H. ovalis*, and
- *H. uninervis* (DEEDI 2011)

Seagrass, to the west of Humpy Island, was relatively sparse with <1% cover, and consists of:

- *H. spinulosa*, and
- *H. ovalis* (DEEDI 2011)

Between 2007 and 2009, Seagrass Watch (2011b) recorded the same four species and a decline from approximately 6% to 3% cover at Monkey Beach. The meadows of Great Keppel Island typically have lower cover and shorter seagrass leaves than at other sites in the region. Macroalgal abundance was generally low, with slightly higher abundances in the dry season of each year. Epiphyte abundance varied from survey to survey and was generally higher in the late wet season (Seagrass Watch 2011a).

Analysis of Aerial Photographs

Aerial photographs show that in 1961 there were extensive seagrass meadows at Putney and Fishermans Beach (Figure 2.44). The community composition of these meadows is unknown.

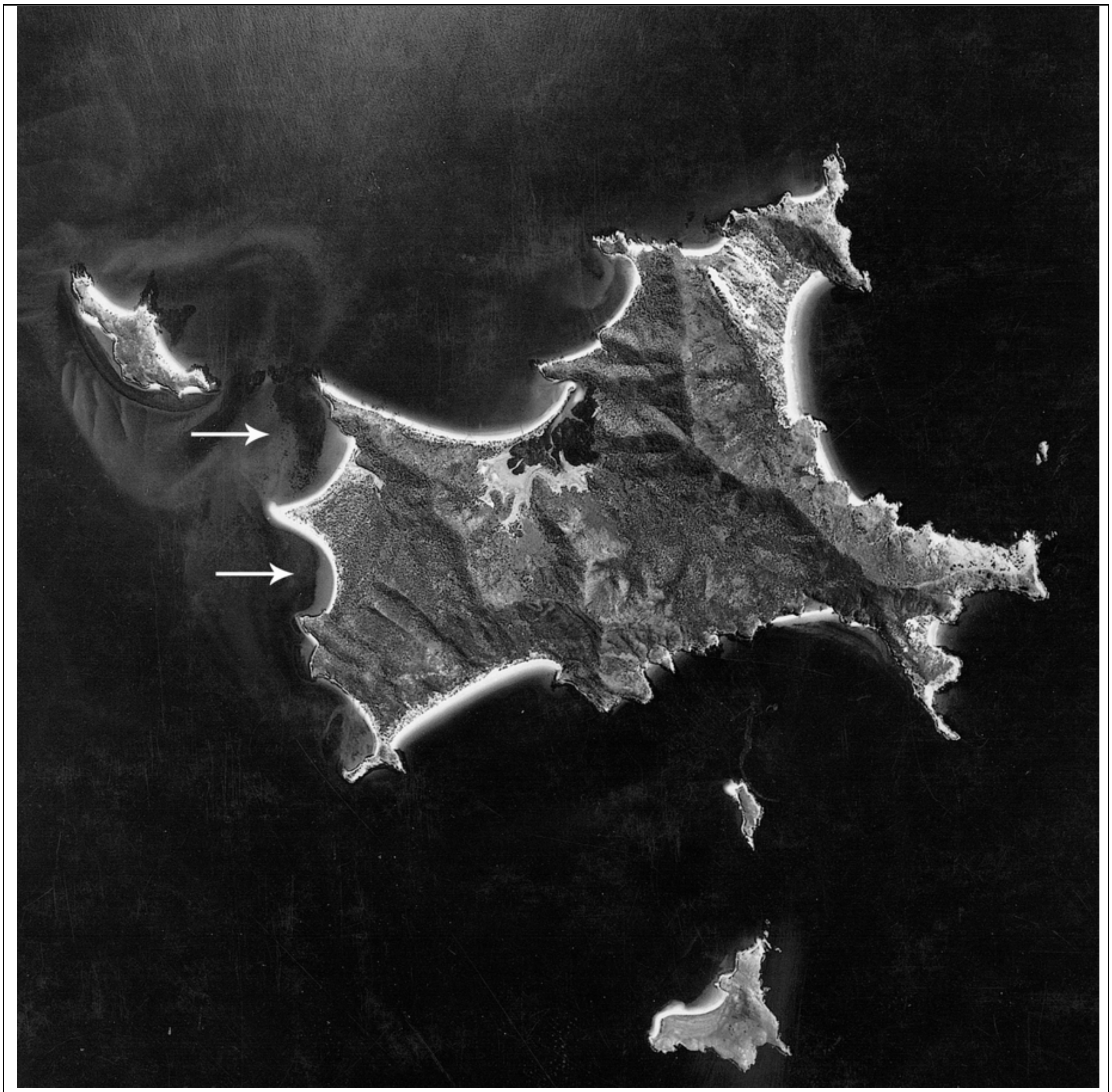
By 1973 the seagrass meadows had largely disappeared, however the cause of this decline was not documented (Figure 2.45). There were no major cyclones between 1961 and 1973, therefore extreme weather was unlikely to have been the cause. The airstrip on the island was built between 1966 and 1970 and may have changed run-off patterns into Putney Creek (K Christie [local resident] pers. comm., July 2011). The change in freshwater flows from Putney Creek may have impacted the seagrass communities.

In the most recent aerial photographs there are no extensive seagrass meadows around Great Keppel Island (Figure 2.46 and Figure 2.47). The reason for the decline is not clear but it is likely to be related to cyclone activity, sedimentation and / or elevated nutrient levels.

In 1975 and 1980, cyclones impacted the island causing erosion at Fishermans Beach and sediment transportation towards Putney Beach (Water Tecnology 2011). The Keppel Haven Resort, located near Putney Beach, expanded in the late 1970s (K Christie [local resident] pers. comm., July 2011), which would have cleared vegetation and may have increased sediment-laden run-off, and is likely to have increased wastewater output and therefore nutrient levels. A wastewater outfall located along Putney Point released nutrients over seagrass meadows during this period (Figure 2.43). Algae are typically more effective at absorbing nutrients from the water column than seagrasses, and can therefore out-compete seagrass (as discussed in Section 3.2).

Figure 2.43

Aerial photograph of Putney Beach showing wastewater outfall in 1999.



frc environmental AQUATIC ECOLOGISTS deep thinking. science.	Great Keppel Island Revitalisation EIS	
	Figure 2.44 Aerial photograph of Great Keppel Island in 1961.	
	Supplied by Water Technology	August 2011

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	Figure 2.45 Aerial photograph of Great Keppel Island in 1973.
	Supplied by Water Technology / August 2011

	Great Keppel Island Revitalisation EIS
frc environmental AQUATIC ECOLOGISTS deep thinking. science.	Figure 2.46 Aerial photograph of Great Keppel Island in 1999.
	Supplied by Water Technology — August 2011

frc environmental AQUATIC ECOLOGISTS deep thinking. science.	Great Keppel Island Revitalisation EIS	
	Figure 2.47 Aerial photograph of Great Keppel Island in 2005.	
	Google Earth © 2010	August 2011

3 Regional and Ecological Context

3.1 Mangrove Forests and Saltmarsh

Distribution and Community Composition

Twenty species of mangroves have been reported within the region (from the Keppel Islands in the north to Rodd's Bay in the south) (Lovelock 1993; Table 2.2; DEEDI 2011). Regionally, between Shoalwater Bay and Hervey Bay, there are approximately 3875 patches of mangroves covering an area of 20 300 ha (Manson et al. 2005), with 41 114 ha in the Central Queensland Coast Bioregion, (DERM 2011b). Within the Great Barrier Reef, mangroves increase in diversity from south to north, while saltmarsh diversity increases from north to south (Lovelock & Ellison) (Table 3.1). Mangroves and saltmarsh communities of the region are shown in Figure 3.1

Table 3.1 Mangrove species of the region.

Family	Scientific Name	Common Name
Acanthaceae	*Acanthus ilicifolius*	holly leaf mangrove
Pteridaceae	*Acrostichum speciosum*	mangrove fern
Plumbaginaceae	*Aegialitis annulata*	club mangrove
Myrsinaceae	*Aegiceras corniculatum*	river mangrove
Acanthaceae	*Avicennia marina*	grey mangrove
Acanthaceae	*Avicennia marina* subsp. *australasica*	eastern white mangrove
Acanthaceae	*Avicennia marina* subsp. *eucalyptifolia*	northern grey mangrove
Rhizophoraceae	*Bruguiera exaristata*	orange mangrove
Rhizophoraceae	*Bruguiera gymnorrhiza*	large-leafed orange mangrove
Rhizophoraceae	*Bruguiera parviflora*	small-leafed orange mangrove
Rhizophoraceae	*Ceriops tagal*	yellow mangrove
Euphorbiaceae	*Excoecaria agallocha*	milky mangrove
Sterculiaceae	*Heritiera littoralis*	red mangrove
Combretaceae	*Lumnitzera littorea*	red-flowered black mangrove
Combretaceae	*Lumnitzera racemosa*	mangrove
Myrtaceae	*Osbornia octodonta*	myrtle mangrove
Rhizophoraceae	*Rhizophora stylosa*	red mangrove
Sonneratiaceae	*Sonneratia alba*	mangrove apple
Rubiaceae	*Scyphiphora hydrophylacea*	yam-stick mangrove
Meliaceae	*Xylocarps granite*	cannonnball mangrove

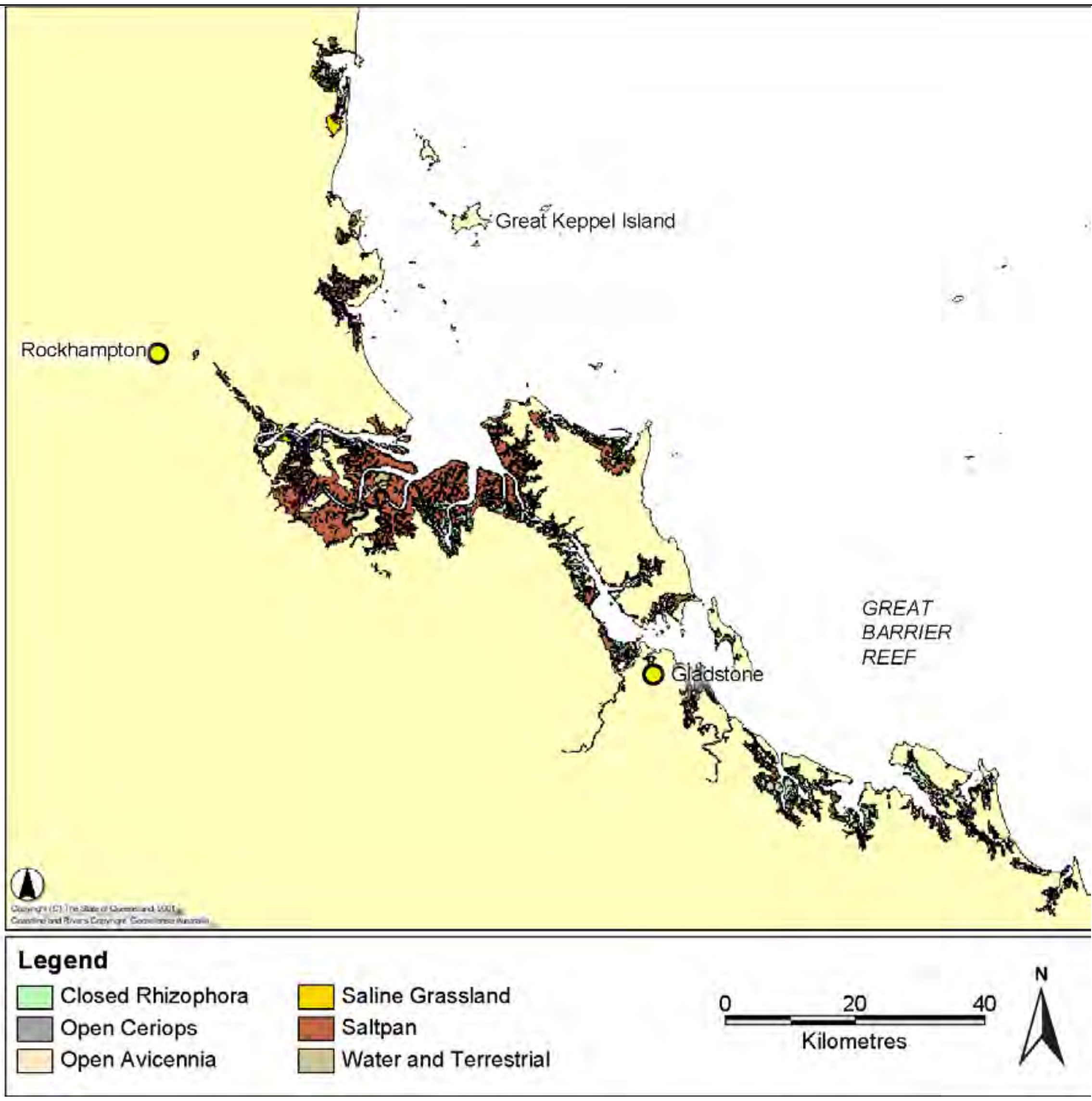

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	Figure 3.1 Mangrove and saltmarsh communities of the region.	
	Microsoft Bing © 2010 Microsoft Corporation; DEEDI 2011	July 2011

Factors Affecting Mangrove and Saltmarsh Distribution

Factors that influence the distribution of mangrove forest and saltmarsh in Queensland include:

- temperature
- sediment type
- salinity of the interstitial water (i.e. in the sediment / soil)
- drainage / aeration of the sediment / soil
- degree and frequency of tidal inundation
- exposure to water currents, and
- exposure to freshwater.

Mangrove species are limited by their tolerance to low temperatures; most species prefer tropical environments with mean winter temperatures above 20 °C (Duke et al. 2003). Diversity, based on temperature, is evident on the Queensland coastline with:

- 36 species recorded from Cape York
- 14 species recorded in the Curtis Coast region, and
- nine species recorded in southeast Queensland.

Mangrove communities grow on a diverse range of sediments from rocky outcrops and coarse sand, to fine silts and mud. However, they develop best in sheltered, depositional environments on fine silts and clays (Hutchings & Saenger 1987). Drainage and aeration depend on sediment characteristics, frequency and period of fresh and saltwater inundation and elevation. Mangrove species differ in their ability to withstand poorly drained or poorly aerated soils. Hutchings & Saenger (1987) produced a tentative grouping of mangroves based on the soil water content in which they grow. The height of some mangroves (e.g. *Avicennia marina*) appears to depend on drainage properties of the soil, with the tallest trees growing in well-drained banks, close to streams. Saltmarshes cannot remain vigorous on waterlogged, anaerobic soils, and this is likely to be a major factor limiting their seaward distribution (Hutchings & Saenger 1987).

Salinity of interstitial water is an important factor regulating growth, height, survival and zonation of mangroves and saltmarsh plants (Hutchings & Saenger 1987). Salinity of interstitial water is dependent on the:

- salinity of the ocean or estuarine water
- period and frequency of inundation
- volume and frequency of freshwater inputs
- evaporation due to high temperature or wind
- soil type, and
- plant cover.

In general, saltmarsh species are more tolerant of high salinities than mangroves, and saltmarsh grow on ground that is less-frequently tidally inundated than most mangroves. Of the mangroves:

- *A. marina* grows over the largest salinity range
- *Aegiceras corniculatum* grows over a broad range, although not as great as *A. marina*, and
- *Rhizophora stylosa, Bruguiera gymnorrhiza* and *Ceriops tagal* grow at salinities three to four times the concentration of seawater (Hutchings & Saenger 1987).

Wetland Functioning

Estuarine wetlands, including mangrove and saltmarsh communities, provide valuable habitat and food sources for a variety of vertebrate and invertebrate species. Some of these are of conservational significance (e.g. marine turtles and the water mouse), while others are recreationally and / or commercially important. The majority of commercially and recreationally important fish species from eastern Australia depend upon estuarine environments (Pollard 1976; Quinn 1992; Robertson & Blaber 1992; Laegdsgaard & Johnson 1995; Halliday & Young 1996; Blaber 1997; Zeller 1998; refer to Appendix G for discussion of fisheries). For example, juveniles of seven of the ten commercially harvested fish species in Moreton Bay occur most abundantly in mangrove ecosystems (Laegdsgaard & Johnson 1995). Further, Morton (1990) reported that 46% by species and 94% by weight, of fishes associated with an *Avicennia marina* forest in Moreton Bay were of direct commercial significance (Morton 1990). Shallow water and intertidal habitats, such as mangrove ecosystems, are among the most productive environments for fisheries (Quinn 1992).

Mangrove lined creeks are particularly important habitats as they support a variety of fish species which appear to display habitat-specific distributions according to individual species requirements for food and shelter (Zeller 1998).

Wetland functioning is discussed further in Appendix H (Commercial and Recreational Fisheries) with regard to species of fisheries importance.

Mangrove forests can act as carbon sources for estuarine, inshore, and offshore waters, through the export of leaf and fruit material (Lee 1995b). Decomposing mangrove material provides both soluble nutrients and detrital fragments that are eaten by crustacea such as prawns and crabs, and some fish. Decaying plant and animal matter are consumed by juvenile and adult greasy back prawn, and juvenile banana prawns, both of which are obligate residents of mud banks adjacent to mangroves (Staples et al. 1985). Adult banana prawns eat both small benthic invertebrates feeding on detritus in channels draining mangroves, and benthic algae on adjacent mud flats (Newell et al. 1995).

Mangroves also trap, accumulate and release nutrients (and in some cases pollutants) and particulate matter (silt) from surrounding land, thus acting as a buffer to the direct effects of runoff. They also protect the shoreline from erosion from the water (waves, boat wash) or the land (runoff) and contribute to the establishment of islands and the extension of shorelines (Blamey 1992).

Mangroves in central Queensland are unlikely to have strong seasonal changes in either distribution or standing biomass. Litter fall from *Avicennia marina* trees is typically much greater during wet summer months than in the remainder of the year (Mackey & Smail 1995). Increased litter fall is likely to increase the amount of carbon available for local food webs, and can lead to an increase in carbon outwelling to near-shore and offshore food webs (Lee 1995a). Periods of high rainfall may lead to seedling colonisation of hypersaline mudflats (McTainsh et al. 1986), leading to rapid increases in the distribution of mangrove forests. However, this can only occur where suitable habitat is available forcolonisation, and it is unlikely to occur in the relatively stable system within the study area.

The effects of prolonged dry periods and wet periods are likely to have significant impacts on the health and functioning of mangrove forests subjected to anthropogenically pollution. For example, in a mangrove forest near Wynnum in Moreton Bay prolonged dry conditions led to a reduction in the buffering capacity of the sediments as the water table fell (Clarke et al. 1997). That is, the ability of the sediments to immobilise metals close to their source was reduced (Clarke et al. 1997). Where desiccation was extreme, acid sulphate soils developed and metals were mobilised down the hydraulic gradient.

3.2 Seagrass Meadows and Macroalgae

Seagrass Meadows

Distribution and Community Composition

Nine species of seagrass have been recorded in the Gladstone Region, from the Keppel Islands in the north to Rodd's Bay in the south (Lee Long et al. 1997; Sheppard et al. 2006, Table 2.1). There are approximately 4 600 000 ha of seagrass in the Great Barrier Reef, with 45,910 ha in Central Queensland from Mackay to Gladstone (including Rodds Bay), 17,940 ha from Shoalwater Bay to the Fitzroy River mouth (inclusive) and 40 ha around the islands of the Keppel Group McKenzie et al (2006-2012).

Table 3.2 Seagrass species of the region.

Family	Scientific Name	Common Name
Cymodoceaceae	*Halodule uninervis*	narrowleaf seagrass
Hydrocharitaceae	*Halophila decipiens*	paddle grass
Hydrocharitaceae	*Halophila minor*	ovate seagrass
Hydrocharitaceae	*Halophila ovalis*	paddle weed
Hydrocharitaceae	*Halophila spinulosa*	fern seagrass
Zosteraceae	*Zostera muelleri*	eelgrass
Cymodoceaceae	*Halodule pinifolia*	turtlegrass
Cymodoceaceae	*Cymodocea serrulata*	cymodocea
Potamogetonaceae	*Syringodium isoetifolium*	noodle seagrass

The extent and condition of seagrass in the region is highly variable. Species composition of meadows differs between habitats (e.g. between inshore coastal, estuarine and coral reef areas). In general, inshore coastal meadows are dominated by *Zostera muelleri* [6] with some *Halodule uninervis*, estuarine meadows are dominated by *Z. muelleri* and coral reef-associated meadows are dominated by *H. uninervis* (Seagrass Watch 2011b).

[6] Previously called *Zostera capricorni.*

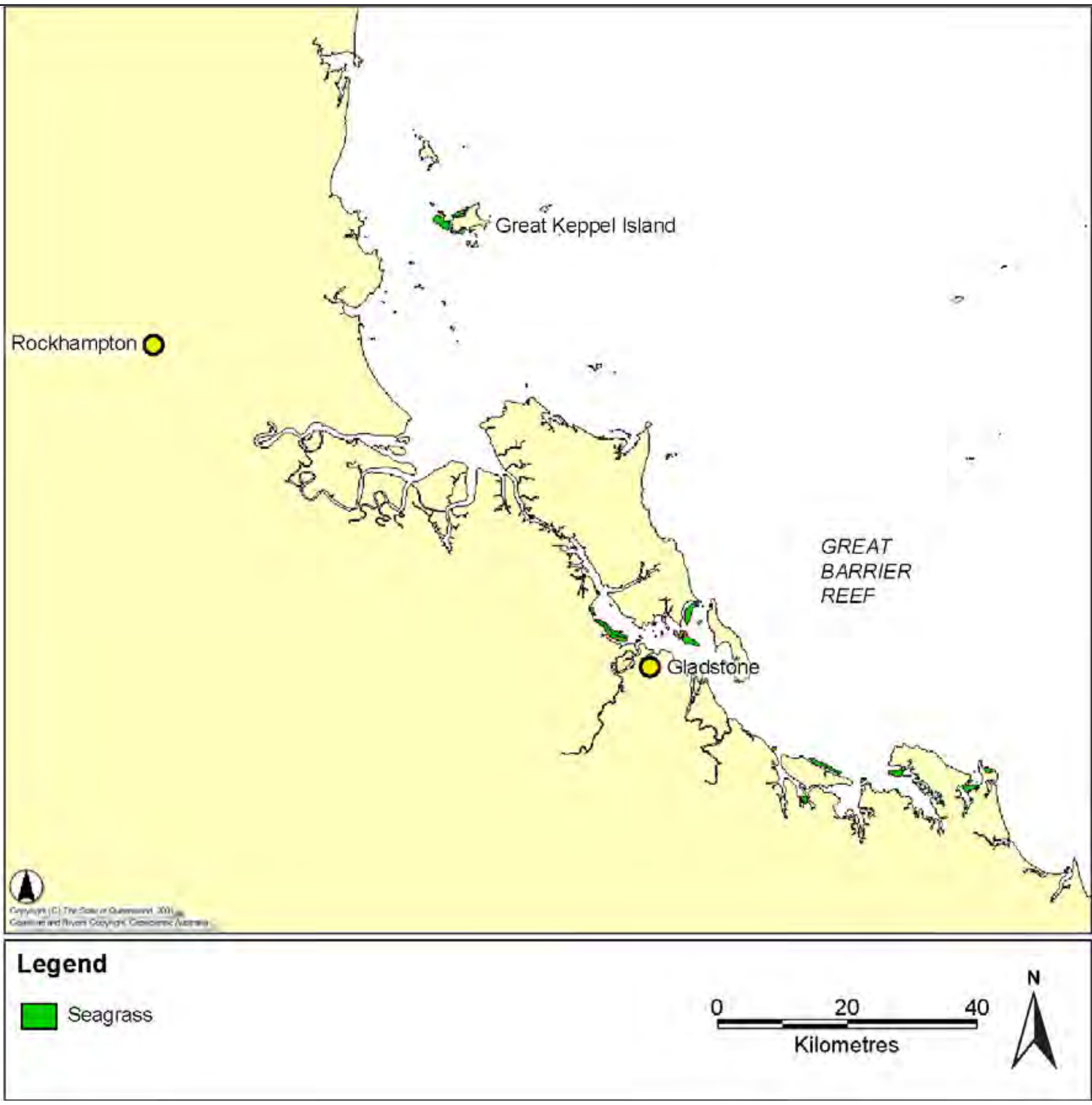

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	Figure 3.2 Seagrass meadows of the region.
	Microsoft Bing © 2010 Microsoft Corporation; DEEDI 2011 — August 2011

In Shoalwater Bay, seagrass communities comprise:

- *Cymodocea serrulata*
- *Halophila decipiens*
- *Halophila minor*
- *H. ovalis*
- *H. uninervis,* and
- *Z. muelleri* (DEEDI 2011).

Around Curtis Island, seagrass communities comprise:

- *Z. muelleri*
- *H. ovalis*
- *H. uninervis*
- *H. spinulosa,* and
- *H. decipiens* (DEEDI 2011).

Variability between habitats is likely to be related to light and nutrient levels. Epiphyte coverage on seagrass is generally seasonal, with macroalgal cover typically lower on inshore coastal and reef meadows, and highly variable in estuarine environments (e.g. Gladstone Harbour) (Prange et al. 2009; Johnson et al. 2010).

Dominant seagrass species in the area (*H. uninervis* and *Z. muelleri*) are characterised by abundant seed production, fast growth rates, and the ability to rapidly recolonise areas. This suggests that these species may be able to rapidly colonise following a disturbance.

Factors Affecting Seagrass Distribution and Abundance

The most important environmental factors limiting seagrasses distribution are:

- turbidity
- salinity
- temperature
- currents
- exposure
- sediment characteristics

- nutrients in the water column, and
- nutrients in the sediment.

Like all plants, seagrasses require light to photosynthesise. Light that reaches a seagrass meadow is a combination of the:

- light intensity at the surface
- depth at which the seagrass is growing
- turbidity of the water, and
- presence or absence of epiphytes on the seagrass.

The turbidity of water above a seagrass bed can be increased either directly, by adding or re-suspending fine sediment in the water column, or indirectly through enhanced nutrients which increase phytoplankton density (Shepherd et al. 1989). Water turbidity can increase for several reasons, including:

- flooding
- dredging
- sludge discharge
- upstream fertilisation of terrestrial land, and
- increased sediment loads from land clearing and / or fires (Abal & Dennison 1996).

Light availability, or specifically the duration of light intensity that exceeds the photosynthetic light saturation point, controls the depth distribution of seagrasses (Dennison & Alberte 1985; Dennison 1987; Abal & Dennison 1996). The depth range of seagrasses is depends on water clarity (e.g. *H. ovalis* has a particularly low tolerance to light deprivation, caused by pulsed turbidity such as floods and dredging) (Longstaff & Dennison 1999).

Availability of light also affects productivity of seagrasses. Grice et al. (1996) found that seagrass exposed to higher light intensity was more productive than seagrass in less intense light environments. Therefore, dredging may result in temporarily lowered productivity of seagrasses. Light has also been shown to control (under particular circumstances) the population dynamics of macroalgae (Lukatelich and McComb 1986; cited in Lavery & McComb 1991).

Seagrass can absorb nutrients through both the leaves and roots. Moderate amounts of additional nutrients in either the water column or in the sediment can increase seagrass growth (McRoy & Helfferich 1980). However, increased nutrient loads may lead to an increase in phytoplankton densities, which will reduce water clarity and seagrass depth distribution (Dennison et al. 1993).

Increased nutrients may also lead to an increase in macroalgae, at the expense of the seagrass. Macroalgae are more efficient at absorbing nutrients from the water column than seagrass (Wheeler & Weidner 1983; Zimmerman & Kremer 1986). So benthic macroalgae may overgrow and displace seagrass, while drift and epiphytic algae may physically shade seagrass and reduce its growth and distribution (Twilley et al. 1985; Silberstein et al. 1986; Maier & Pregnall 1990; Tomasko & Lapointe 1991). Epiphytic algae may also reduce diffusive exchange of dissolved nutrients and gases at leaf surfaces (Twilley et al. 1985; Neckles et al. 1993).

Changes to sediment characteristics and / or currents may also lead to changes in seagrass distribution and species composition. Sub-tropical seagrasses, in general, grow in areas of low current, usually in embayments or estuaries, or on sheltered coastlines; each species has different capabilities of withstanding different currents. Changes to sediment and currents may also result in changes to the length of exposure of seagrass meadows. With increasing exposure, desiccation and temperature are likely to increase; increased exposure, particularly during summer, may result in decreased distribution and density, and altered community composition.

Seagrass ecosystem functioning is discussed further in Appendix H (Commercial and Recreational Fisheries) with regard to species of fisheries importance.

Macroalgae Communities

Macroalgae are a commonly overlooked component of the marine environment, which may significantly contribute to an area's ability to support marine life, particularly fish and crustacea. The macroalgal component of estuarine floral communities may consist of several elements:

- loose lying or drift algae
- rhizophytic or benthic macroalgae, and
- epiphytic algae on seagrass or other algae (den Hartog 1979).

An understanding of the seasonal occurrence and standing crop dynamics is necessary to evaluate the community role of macroalgae in the ecosystem (Benz et al. 1979). While the distribution of macroalgae is variable and has not been mapped, it is expected to occur throughout the project area, with the greatest diversity and biomass near the mouths of creeks and rivers.

Macroalgal communities can play a role similar to other macrobenthic plants, and provide oxygen, food and habitat for small fauna. Macroalgae are likely to perform the following functions:

- provide shelter and refuge for resident and transient adult and juvenile animals, many of which are of commercial and recreational importance
- trap, stabilise and hold bottom sediments
- slow and retard water movement promoting sedimentation of particulate matter and inhibiting re-suspension of organic and inorganic matter
- supply and fix biogenic calcium carbonate
- produce and trap detritus and secrete dissolved organic matter that tends to internalise nutrient cycles within the system, and
- provide food for many species including the green turtle (*Chelonia mydas*) (Jenkins & Wheatley 1998; Zeller 1998).

Macroalgal ecosystem functioning is discussed further in Appendix H (Commercial and Recreational Fisheries) with regard to species of fisheries importance.

Cyanobacteria *Lyngbya*

Lyngbya majuscula is a naturally-occurring, toxic, filamentous, cyanobacteria (blue-green algae), that is found worldwide in tropical and subtropical estuarine and coastal habitats (EPA 2002; Arthur et al. 2006). *Lyngbya* grows epiphytically on rock, coral, seagrass, macroalgae, and anthropogenic structures, and it forms matted masses of dark filamentous material (Humm and Wicks 1980, cited in Arthur et al. 2006; Dennison et al. 1999, cited in Arthur et al. 2006). Gas bubbles, formed from rapid photosynthesis, can accumulate in the matted mass and cause *Lyngbya* to float to the surface and form large surface aggregations (EPA 2002; Albert et al. 2005).

Lyngbya growth has resulted in the loss of seagrass meadows, and may have reduced turtle and dugong feeding grounds in Moreton Bay (Watkinson et al. 2005). *Lyngbya* can also cause severe eye and skin irritations to humans, as well as asthma-like symptoms (Osborne et al. 2001). *Lyngbya* can affect the economics of commercial and recreational fisheries and tourism.

The exact cause of *Lyngbya* blooms is unknown but factors that can contribute to a bloom are:

- warm water
- high light intensity
- enhanced nutrient loading, and
- availability of essential metals (EPA 2002; Albert et al. 2005; Arthur et al. 2006).

Changes in catchment land use (as seen at Deception Bay near Brisbane) or seabird distributions (as seen at Hardy Reef) can lead to alterations of the inputs of dissolved organics, iron, and phosphorus into a system, which can lead to *Lyngbya* blooms (Arthur et al. 2006). Ahern et al. (2007) found that nutrients, particularly organically chelated iron, phosphorus, and nitrogen promotes prolific growth of *Lyngbya*. These studies and others indicate that there is commonly an association between *Lyngbya* blooms and development of coastal catchments (Ahern et al. 2007)

Nuisance *Lyngbya* blooms have been recorded along the east coast of Queensland at:

- Moreton Bay
- Hervey Bay
- Shoalwater Bay
- Whitsundays
- Hinchinbrook Island
- Cape Kimberly, and
- coral outcrops near Great Keppel Island (Albert et al. 2005; Powell & Martens 2005).

3.3 Exotic Species

No introduced marine species have been reported outside of designated ports in the Great Barrier Reef (GBRMPA 2011).

4 Potential Impacts

This section describes the potential direct impact on marine flora. Indirect impacts on marine flora are discussed in Appendix C (Marine Water Quality). Some impacts may be permanent while others will be temporary and reversible.

4.1 Description of Project

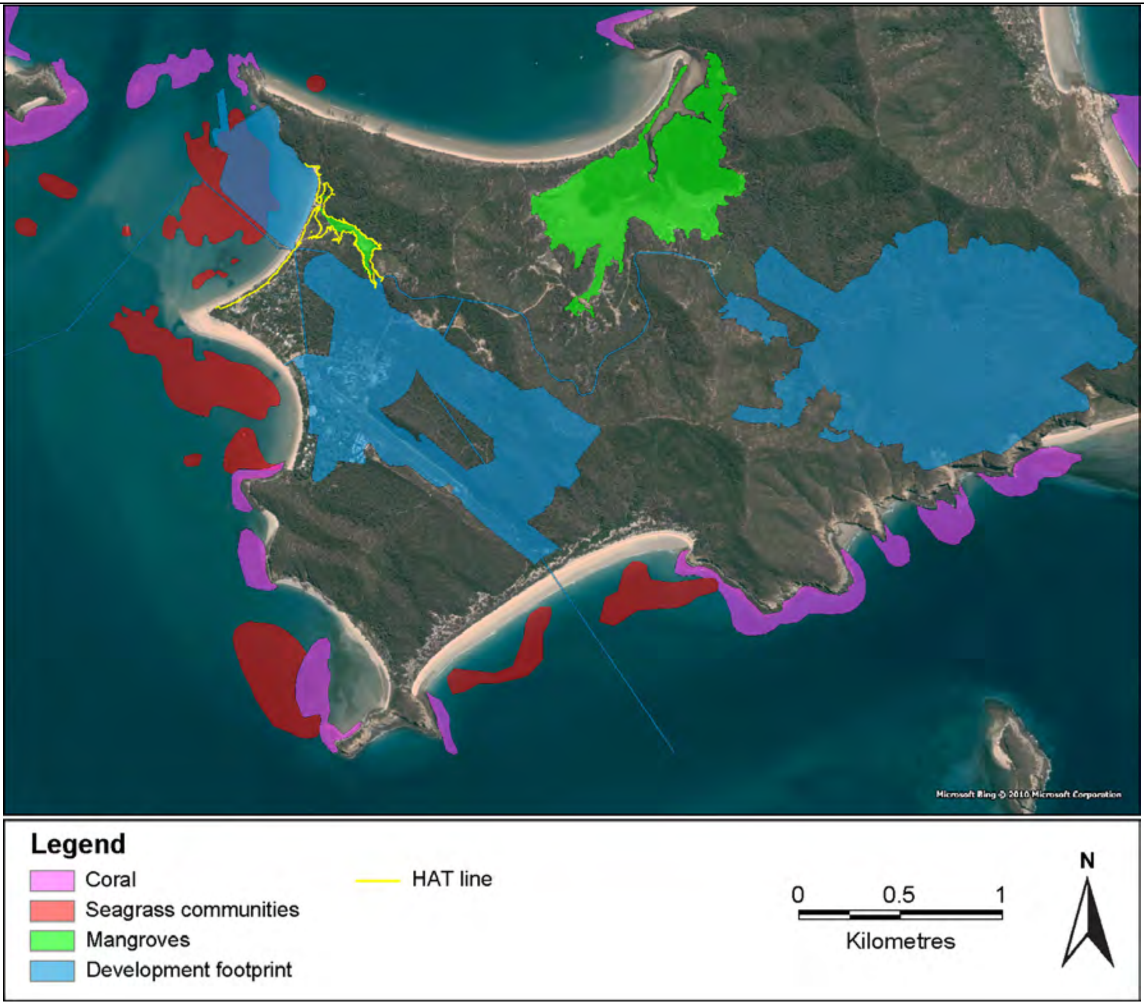
The revised proposal for the Great Keppel Island Resort Revitalisation Plan 2010 includes the following components that have the potential to impact on marine flora:

- dredging for construction of the marina and re-nourishment of Putney Beach using dredge spoil
- development of a marina at Putney Beach comprising 250 berths, emergency services facilities, ferry terminal, yacht club, dry dock storage, and retail area (mix of cafes, restaurants and clothing shops)
- development of an 18-hole golf course, integrated with essential habitats and ecological corridors, and located on previously disturbed grazing lands
- development of associated service facilities and utilities (e.g. fuel storage and wastewater treatment plant)
- establishment of a Water Management Plan to mitigate effects of stormwater run-off and golf course run-off into the Great Barrier Reef Marine Park (GBRMP), and
- installation of a submarine connection of services (e.g. power, telecommunications and potable water) line between Great Keppel Island and Kinka Beach on the mainland.

Construction and operation activities associated with the following components of the development have the potential to impact on marine surface water (and sediment) quality:

- marina precinct
- wastewater treatment plant wet weather outfall
- golf course precinct, and
- submarine connection of services to the mainland.

Figure 4.1 and Figure 4.2 show ecological communities and the proposed development on Great Keppel Island and the mainland, respectively. Further details regarding each of the potentially impacting activities are provided in Appendix C.



frc environmental AQUATIC ECOLOGISTS deep thinking. science.	Great Keppel Island Revitalisation EIS	
	Figure 4.1 Ecological communities and the proposed development on Great Keppel Island.	
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frc environmental AQUATIC ECOLOGISTS deep thinking. science.	Great Keppel Island Revitalisation EIS	
	Figure 4.2 Ecological communities and the proposed submarine cable alignment on the mainland.	
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4.2 Marina Construction

Marina construction activities including excavation, dredging, spoil handling, and pile driving have the potential to result in:

- loss of marine flora
- gain of habitat for marine flora (and fauna)
- increased suspended sediment levels (turbidity) and consequent sediment deposition
- altered hydrodynamics and consequently altered flushing and patterns of sediment deposition and erosion
- spills of hydrocarbons and other contaminants including litter and waste
- release of contaminants from the disturbed sediments
- disturbance of acid sulphate or potential acid sulphate sediments (ASS / PASS), and
- associated ecosystem functioning.

The potential for indirect impacts on marine flora, such as turbidity, sediment deposition and contaminants, are discussed in Appendix C. Direct impacts are discussed below.

Loss of Marine Flora

Seagrass and Macroalgae

Construction of the marina will result in the direct loss of patches of seagrass within an area of approximately 9.60 ha. These patches cover less than 10% of the seabed and the cover within the patches ranges from <5% to 15%. A total area of less than 0.96 ha of seagrass will be lost.

Installation of the submarine cables along the marina breakwall will remove an additional approximately 0.004 ha (based on a 1 m wide installation corridor through an area of 0.04 ha that contains patches covering less than 10%) of seagrass. A hydrographic survey was undertaken to inform route alignment, and avoid sensitive ecologically communities including coral reefs, seagrass meadows and mangrove forests (where practical). Seagrass was not recorded along the submarine cable alignment [7], however prior to the

[7] Marine & Earth Sciences 2011 recommend investigation of four locations using a drop-camera, to confirm the nature of the sea floor surface, and collection of grab samples (with a Van Veen grab sampler or similar) at close intervals along the alignment to ground truth their interpretation.

installation, the contractor will undertake an additional hydrographic survey to confirm there is no seagrass.

These calculations are based on the maximum extent of seagrass distribution recorded during this study (the pre-wet season survey in November 2010), and consequently the calculated loss is likely to over-estimate the loss averaged over time. This is equivalent to less than 0.1% of the seagrass recorded in the region, that is:

- 0.0005% of the 17,940 ha recorded from Shoalwater Bay to the Fitzroy River mouth (inclusive)
- 0.0002% of the 45,910 ha recorded in central Queensland from Mackay to Gladstone (including Rodds Bay), or
- 0.000002% of the 4 600 000ha recorded or the Great Barrier Reef Marine Park.

Seagrass as Habitat for Fauna

Seagrasses provide shelter and refuge for resident and transient adult and juvenile finfish, crustaceans and cephalopods. Many of these species are of commercial and recreational importance, and others are the preferred foods of these species (Dredge et al. 1977; Hutchings 1982; McNeill et al. 1992; Coles et al. 1993; Edgar & Shaw 1995; Gray et al. 1996; Connolly 1997). While juvenile abundance of many fish and crustacean species is commonly higher in seagrass habitats than over bare sand or mud, there are significant differences in abundance between seagrass beds (e.g. Gray et al. 1996). Some sites have consistently higher recruitment (McNeill et al. 1992), while other sites may only periodically or temporarily have higher abundances (Gray et al. 1996; Connolly et al. 1999). This may be due to the structural complexity of the seagrass beds; location of the seagrass beds with respect to currents and the dispersal of larvae; and natural fluctuations (patchiness) in population sizes (Gray et al. 1996; Connolly et al. 1999).

Macroalgae are a commonly overlooked component of the marine environment. Macroalgae are likely to provide shelter and refuge for resident and transient adult and juvenile animals, many of which are of commercial and recreational importance. Macroalgae stabilise and hold bottom sediments, supply and fix biogenic calcium carbonate, produce and trap detritus and provide food for many species. Macroalgae are major primary producers within coastal waters, with 10% (kelp communities) and 60% to 97% (algal turf communities) of algal production entering grazing food chains (Carpenter 1986; Klumpp and McKinnon 1989 - each cited in Phillips 1998). Even in seagrass meadows, herbivores consume 20% to 62% of algal epiphytes on seagrass leaves compared to a maximum of 10% of seagrass (Klumpp et al. 1992; Orth 1995 - both cited in Phillips 1998).

Loss of seagrass has the potential to affect species of conservation significance, as seagrass provides an important food source for several important species, e.g. marine turtles, dugong and syngnathids.

Given that the meadows within and adjacent to the proposed marina are sparse and patchy, and typical of the region, the potential loss is unlikely to have a measurable ecological impact beyond the marina footprint.

Mangroves

Construction of the marina will not involve mangrove removal.

Mainland connection of the submarine cables along the current proposed alignment may remove approximately 0.04 ha (based on a 2.5 m wide installation corridor) of mangrove forest. This is less than 9.7 $\times 10^{-7}$% of the mangroves in the Central Queensland Coast Bioregion. There are several gaps in the forest (up to 67 m wide) and removal of mangroves will not be required where the alignment is modified to extend through one of the gaps.

Gain of Habitat for Flora and Fauna

Artificial Structures as Habitat within the Marina Basin

The proposed marina will add a significant degree of physical complexity to the intertidal and shallow subtidal habitat of Putney Beach, and hence to the local diversity of habitat and productivity of associated flora and fauna. Habitats that provide structural and topographical relief, such as woody debris, rock and oyster reefs and rubble, play an important role in the recruitment and survival of many commercially important species (Skilleter & N.R. 2003 and references therein). Each habitat provides a characteristic combination of hard surfaces, voids and shading, and may alter both the water quality and sediment characteristics in the immediate vicinity.

Construction of the proposed marina will result in a mosaic of habitats associated with breakwalls, pontoons, piles and other intertidal and subtidal structures, together with moored vessels. The hard surfaces of these structures may provide substrate for many species of algae, hard and soft corals, sponges, ascidians and a variety of other invertebrates; the hard surfaces of the submarine cables and wastewater outfall will also provide a recruitment surface for a variety of benthic flora and fauna. In turn, this sessile benthic community may provide shelter and food for a variety of fishes and other fauna (vis. the nearby Rosslyn Bay Marina, pers. obs.). The structures associated with the proposed development will also provide a high degree of shade, important in attracting many fish species (de la Moriniere et al. 2004; Verweii et al. 2006).

Studies of natural and artificial habitat have shown that both typically support a fish community with a similar number of species, yet with different (but often overlapping) assemblages (Fujita et al. 1996; Clark & Edwards 1999). For example, in Botany Bay (Sydney, New South Wales) a seagrass meadow within a small, constructed harbour supported abundant post-larval and juvenile bream, tarwhine and blackfish, up to 73-times more than nearby meadows (McNeill et al. 1992). Fish abundance generally increases with increasing rugosity (structural complexity) and fouling (Rooker et al. 1997). Whilst larger artificial structures are likely to attract both a greater abundance and diversity of organisms; small structures support a disproportionately high diversity of biota (Bohnsack et al. 1991).

Other studies have shown that breakwalls can have negative ecological impacts, including (Dugan & Hubbard 2006):

- loss and / or reduction of intertidal zone
- altered deposition and retention of debris, and
- reduced diversity and abundance of invertebrates and birds.

In the current design, the marina will include a rip-rap breakwall approximately 700 m long. This structure will provide a variety of interstitial spaces to accommodate different species and life history stages (United States Army Corps of Engineers 1995, cited in Derbyshire 2006). The limited area of rocky substrate at Putney Beach (and other rocky shores in the project area) supports relatively diverse communities of marine flora (algae) and fauna, whereas the soft sediment substrate supports relatively depauperate communities (refer to Appendix E and F for a discussion of marine flora and fauna). It is expected that the hard structures of the proposed development, particularly the marina, will support similarly diverse communities as those currently found on rocky substrate at Putney Beach and throughout the survey area.

Little attention has been given to the habitat value provided by moored vessels, although the concept of floating, moored fish-attracting devices is well appreciated by fishers and fisheries managers worldwide. Pontoons and moored boats are a common feature in the region, and are capable of supporting communities similar to those associated with rocky reefs, pylons and concrete revetments (Holloway & Connell 2002).

Investigations of zooplankton in the canal estates of Raby Bay (south-east Queensland) showed that the canal system supported higher densities of zooplankton taxa than the

adjoining waters (Moreton Bay). These aggregations could provide relatively rich foraging patches for zoo-planktivorous larval and juvenile fishes (King & Williamson 1995). The man-made foreshores of Raby Bay support a similar fish fauna to the remaining mangrove lined shores (Williamson et al. 1994).
The waters and sediment of the marina basin are likely to have relatively low ecological value, primarily as waters are likely to be too deep and / or turbid to support substantial floral communities and the soft sediment community will be similar to those recorded in the proposed footprint (infauna dominated by polychaete worms and sparse epifauna). Habitat, and consequently ecological value, could be enhanced with the addition of fish-friendly structures.

The Queensland Government publication *Fisheries Guidelines for Fish-Friendly Structures* describe a number of artificial structures that may enhance fish habitat, including (Derbyshire 2006):

- the Fish Hab
- Aqua Crib
- Reef Ball
- Plastic Mesh Structures
- Mushroom Hats
- Stake Beds
- Log Cribs
- Wooden Cross-pieces Structures
- Wooden Pallets, and
- Spawning Structures (see Derbyshire 2006 for a comprehensive review).

The primary value of these artificial habitats arise from the provision of complex structural habitat, which may serve as substrate for epibiota, nursery habitat for juvenile fish, general habitats and spawning areas for adult fish habitat. Several of these modules, or other similarly complex engineered structures, could be incorporated into the current marina design to provide additional habitat for fish and other fauna (Derbyshire 2006), and will be considered at the detailed design stage.

The *Fisheries Guidelines for Fish-Friendly Structures* (Derbyshire 2006) outlines several general and specific fish-friendly design features intended for developments that require aquatic infrastructure. Specific design guidelines are included for several features included in the proposed marina development, including guidelines for general small boat harbours and marinas, jetties and pontoons, boat ramps, stabilisation structures, dredge spoil, and mooring buoys. Opportunities to enhance the habitat value of the proposed marina will be considered at the detailed design stage.

Mangroves of Putney Creek

Opening of the Putney Creek mouth would change the flood regime with the potential to positively impact water and sediment quality (as discussed in Appendix C). Improved water and sediment quality would facilitate improved condition of the mangrove and saltmarsh communities in Putney Creek, which are currently in relatively poor condition and provide relatively poor habitat for fauna compared to forests with better flushing and hence water and sediment quality (e.g. Leeke's Creek and Kinka Beach).

4.3 Marina Operation

Potential impacts associated with marina operation and associated infrastructure are likely to be primarily linked to human activity, e.g. marine pests (primarily marine fauna but potentially marine flora also), increased boat traffic, refuelling operations, antifoul leaching and increased litter, together with stormwater run-off (which will be mitigated using retention basins). Maintenance dredging is unlikely to be required due to the design of the marina.

The potential for indirect impacts on marine flora, such as hydrocarbon contamination and litter, are discussed in Appendix C. The direct impact of increased marine pests is discussed below.

Introduction of Marine Pests

The introduction of exotic flora and fauna can threaten the integrity of natural communities, the existence of rare and endangered species, the viability of living resource-based industries and pose risks to human health (Hutchings et al. 2002; Hayes et al. 2005). Of the 338 exotic marine species that have been recorded in Australian waters, 15 species are regarded as pests and a further 32 are considered as potential pests (CRC 2004; Hayes et al. 2005).

Introductions of marine species in ballast water and via hull fouling have been identified in virtually all regions of the world. Introductions causing substantial deleterious impacts appear to occur more extensively in temperate (Hewitt 2002) than tropical regions (Hilliard

& Raaymakers 1997). A survey of 12 tropical ports in eastern Australia revealed far fewer exotic marine species than in temperate ports of Australia (Hilliard & Raaymakers 1997). However, the lack of baseline surveys and the poor taxonomic status of many tropical groups may have hindered detection (Hewitt 2002). The recent incursion of the black striped mussel (*Mytilopsis sallei*) in northern Australia was due to hull fouling on a recreational vessel (CRC 2004). However, many of the species that are translocated with hull fouling have minimal effects on receiving environments, which are often limited to the nuisance fouling of hard structures (Hayes et al. 2005).

Marine pests have not been reported in the waters of the Great Barrier Reef outside of designated ports. Nine introduced marine species have been recorded in the nearby Port Curtis region, including:

- bryozoans (*Amathia distans, Bugula neritina, Cryptosula pallasiana,* and *Watersporia subtoraquata*),
- ascidians (*Botrylloides leachi* and *Styela plicata*),
- isopod crustaceans (*Paracerceis sculpta*),
- hydrozoans (*Obelia longissima*), and
- dinoflagellates (*Alexandrium* sp.).

The proposed marina will not serve as a point of entry to Australia and will not service international commercial shipping, hence the risk of introductions via ballast water is minor.

The risk of fouling-based TBT introduction is also very low, as international vessels will be required to clear quarantine, and potentially be subject to inspection, at their port of entry.

4.4 Wastewater Wet Weather Outfall

There may be short-term indirect impacts to marine flora during construction of the wastewater treatment plant wet weather outfall, including increased turbidity (and subsequent sedimentation) associated with disturbing the substrate or shallow dredging, hydrocarbon spills, and increased litter.

Potential indirect impacts to marine flora during operation of the wastewater treatment plant include the potential for nutrient enrichment following release via the wet weather outfall. However impacts to marine plants and ecosystem functioning are likely to be negligible as the wastewater will, as a minimum, be treated to meet section 135(4) of the

Great Barrier Reef Marine Park Regulations 1983 (Opus International Consultants (Australia) Pty Ltd 2011).

The potential indirect impacts of the wet weather outfall on marine flora are discussed in Appendix C.

4.5 Submarine Cables

There may be short-term indirect impacts to marine flora associated with the installation of the submarine cables, including increased turbidity (and subsequent sedimentation) associated with shallow dredging (to 1.2 m), hydrocarbon spills, and increased litter.

Potential negative impacts to marine flora, and associated ecosystem functioning, during operation are likely to be negligible.

The potential indirect impacts of submarine cable construction such as turbidity, sediment deposition and contaminants on marine flora are discussed in Appendix C. Potential direct impacts associated with the loss or gain of marine flora / habitat are discussed above in the marina construction section.

4.6 Golf Course Precinct

Indirect impacts to marine flora during operation of the golf course include nutrient enrichment following stormwater run-off or water / wastewater storage overflow, and changes to environmental flows.

Short-term impacts to marine flora during operation of the golf course include the potential for nutrient enrichment following stormwater run-off or water storage overflow. However impacts to ecosystem functioning are likely to be negligible as the wastewater will, as a minimum, be treated to meet section 135(4) of the *Great Barrier Reef Marine Park Regulations 1983* (Opus International Consultants (Australia) Pty Ltd 2011). None the less, potential impacts associated with nutrient enrichment on mangrove forests are discussed in Appendix C (Water Quality).

Capture of stormwater run-off on the golf course, for retention and treatment, is likely to reduce environmental flows in downstream freshwater and estuarine (i.e. mangrove forests) ecosystems. Reduced environmental flows have the potential to negatively affect marine flora as discussed in Appendix C (Water Quality).

4.7 Cumulative Impacts

Cumulative impacts of the proposed development on marine flora, including nearby tourism developments, climate change and ecosystem functioning, are discussed in Appendix C (Marine Water Quality).

5 Measures to Avoid, Minimise and Mitigate Impacts

5.1 Risk Assessment

A risk assessment of potential impacts has been undertaken in accordance with a standard risk assessment matrix (Table 5.1), as presented in Table 5.2. Mitigation measures associated with potential indirect impacts are discussed in Appendix C (Marine Water Quality), those associated with direct impacts are discussed below.

Table 5.1 Risk assessment matrix.

Probability	**Consequence** Catastrophic Irreversible Permanent (5)	Major Long-term (4)	Moderate Medium-term (3)	Minor Short-term Manageable (2)	Insignificant Manageable (1)
Almost Certain (5)	(25) Extreme	(20) Extreme	(15) High	(10) Medium	(5) Medium
Likely (4)	(20) Extreme	(16) High	(10) Medium	(8) Medium	(4) Low
Possible (3)	(15) High	(12) High	(9) Medium	(6) Medium	(3) Low
Unlikely (2)	(10) Medium	(8) Medium	(6) Medium	(4) Low	(2) Low
Rare (1)	(5) Medium	(4) Low	(3) Low	(2) Low	(1) Low

Table 5.2 Summary of potential impacts on marine flora.

Design	Construction	Operation	Potential Impact	Mitigation Measure	Monitoring	Significance of Impact (Unmitigated)	Significance of Residual (Mitigated Impact)
●	●		Loss of marine flora	• development locations chosen to avoid sensitive ecological communities wherever possible • marina design including reduced overall footprint compared to original plan • minimise the area of disturbance required for the submarine cables through best practice construction methods including water jetting and burying-in-excavated-trench method	• an annual (pre-wet) seagrass and mangrove monitoring program would provide the opportunity to assess the severity of predicted impacts and inform management of potential issues, including construction and operational EMPs and remediation • during dredging / sediment disturbance, the extent of the turbidity plume can be monitored to confirm that plumes do not have a negative long-term impact on seagrass condition	Mangroves (4) Low Seagrass (15) High Coral reef (15) High Mobile biota (10) Medium Listed species (10) Medium	Mangroves (4) Low Seagrass (15) High Coral reef (15) High Mobile biota (10) Medium Listed species (10) Medium

Design	Construction	Operation	Potential Impact	Mitigation Measure	Monitoring	Significance of Impact (Unmitigated)	Significance of Residual (Mitigated Impact)
●		●	Gain of habitat (positive impact)	• the hard surfaces of development structures may provide substrate for many species of algae, hard and soft corals, sponges, ascidians and a variety of other invertebrates (in turn, this sessile benthic community may provide shelter and food for a variety of fishes and other fauna) • habitat, and consequently ecological value, of the marina could be enhanced with the addition of fish-friendly structures • Improved water and sediment quality would facilitate improved condition of the mangrove and saltmarsh communities in Putney Creek, which are currently in relatively poor condition and provide relatively poor habitat	• an annual (pre-wet) seagrass and mangrove monitoring program would provide the opportunity to assess the severity of predicted impacts and inform management of potential issues, including construction and operational EMPs and remediation	NA	NA
●		●	Introduction of marine pests	• the proposed marina will not serve as a point of entry to Australia and will not service international commercial shipping hence the risk of introductions via ballast water is manageable • AQIS has developed strict new biofouling laws to protect Australia, including an assessment of risk and the mandatory inspection (of high-risk vessels • the International Convention for the Control and Management of Ships Ballast Water & Sediments requires that international ships undertake ballast water exchange at sea, or apply an alternative ballast water management measure	• annual monitoring during operation	Mangroves (4) Low Seagrass (4) Low Coral reef (6) Medium Mobile biota (6) Medium Listed species (6) Medium	Mangroves (3) Low Seagrass (3) Low Coral reef (4) Medium Mobile biota (4) Medium Listed species (4) Medium

5.2 Mitigation Measures

Current 'best practice' assessment and engineering practices offer significant opportunities to minimise the impacts associated with both construction and operation of the proposed development.

Loss of Marine Flora

Loss of marine flora has been reduced through the marina design, i.e. the reduction in overall size compared to earlier proposals. Unavoidable loss of marine flora can be mitigated through the creation of habitat that serves a similar ecological function, or through the enhancement of similar habitat elsewhere (as discussed below in the offsets section). The contribution of funding (cash or in-kind) to habitat-related research has also been recently recognised as an appropriate form of mitigation for habitat loss (Dixon & Beumer 2002). A habitat loss compensation strategy should be developed in support of the marine plant permit application.

Monitoring of seagrass condition and the use of water quality 'trigger levels' can also be used to inform on site daily management decisions, which contribute to effectively controlling suspended solids concentrations in adjoining waters during dredging. This method was successful used by the Department of Transport and Main Roads (DTMR) to protect sensitive ecological communities during recent dredging of nearby Rosslyn Bay boat harbour (frc environmental 2009).

Potential Offsets

An environmental offset is an action taken to counterbalance unavoidable, negative environmental impacts resulting from an activity or development. An offset differs from mitigation in that it addresses remaining impacts, after attempts to reduce (or mitigate) the impact have been undertaken (EPA 2008). There are three specific-issue offset policies, including a policy for offsets for marine fish habitat (Dixon & Beumer 2002). This policy applies to all proposed work that may result in permanent or temporary loss of fisheries resources and habitats. Offsets for the loss of marine fish habitat can include:

- fish habitat enhancement
- fish habitat restoration, rehabilitation or creation
- fish habitat exchange and secured where the lands proposed for exchange contribute similar fish habitat, and

- contribution of an offset amount constituting financial support for one or more of the following where associated with fish habitats:
  - applied research
  - enhancement, restoration, rehabilitation or creation
  - education, training or extension, or
  - fish habitat acquisition or exchange (QPIF 2010).

Queensland Fisheries provide indicative guidelines for monetary compensation for unavoidable loss of marine plant habitat (Table 5.3). These guidelines are based on the ecosystem service value estimates provided by Costanza et al. (1997), and allow for an economic evaluation of the contribution that these habitats would make to local and regional fisheries over a 20 year production cycle, if left undisturbed. These guidelines are only indicative and are designed to form the basis for initial discussions. These guidelines were used to estimate the monetary compensation required for the areas to be lost (Table 5.4).

Table 5.3 Ecosystem services values of mangroves, saltmarsh and bare areas.[8]

Fish Habitat Type	Ecosystem Services Rate ($/ha/yr), 2011	Temporal Loss / Gain Over a 20 Year Production Cycle
Seagrass		
Impact (Permanent)	41 310	20
Impact (Temporary)	41 310	2
Created Area	41 310	18
Mangrove and Saltmarsh		
Impact (Permanent)	21 716	20
Impact (Temporary)	21 716	2
Created Area	21 716	18
Bare Substrate		
Impact (Permanent)	8 808	20
Impact (Temporary)	8 808	2
Created Area	8 808	18

[8] Queensland Fisheries pers. com., 2011.

Impacts of the proposed development will result in:

- a permanent loss of less than 0.964 ha of seagrass (Section 4.2), and
- a loss of up to 0.04 ha of mangroves, which may or may not be permanent (Section 4.5).

This will be offset by a gain of approximately 2.02 ha of marina wall (based on the height of the wall under HAT, and a slope of 1.5), and the gain of approximately 0.55 ha associated with walkways and pontoons (total length of 3674 m nominal width of 1.5 m) of 'bare' substrate. This substrate is likely to be colonised by a variety of flora and fauna including: many species of algae, hard and soft corals, sponges, ascidians, molluscs and a variety of other invertebrates. This sessile benthic community will provide shelter and food for a variety of fishes and other fauna.

Table 5.4 Value of loss and gain of marine plant habitat, based on Queensland Fisheries valuations.

Fish Habitat Type	Ecosystem Services Rate ($/ha/yr), 2011	Temporal Loss / Gain Over a 20 Year Production Cycle	Area Lost or Gained (ha)	Offset Value ($)
Seagrass				
Impact (Permanent)	41 310	20	-0.10	796 457
Mangrove				
Impact (Permanent)	21 716	20	-0.04	17 373
Bare Substrate				
Impact (Temporary)	8 808	2	-20.08	353 729
Created Area	8 808	18	+2.57	407 458

In addition to the offset created by the infrastructure associated with the marina, a number of other offsets are proposed including:

- Construction of the first specialised Research Centre in the Keppels on Great Keppel Island. The Research Centre will be used to conduct research programs and conservation activities on the Island and within the marine park monitor fringing coral and marine plant communities, and facilitate student research activities. Students from local schools and universities will have access to the Centre to advance their learning through practical application, and it will be available for scientists, government departments and other interested parties (Tower Holdings 2010), and
- A biodiversity conservation fund to provide significant and ongoing funding for the Research Centre. A proportion of all revenue generated from the resort operations will be collected for this fund. The funds will be managed through a research partnership with key environmental associations and the Reef and Rainforest Research Centre. The funds will be directly spent on research and conservation works on the Island and throughout the Keppels.

Innovative approaches to the design of the marina are being considered, and will be detailed in the marine plant offset plan including:

- Vegetating the internal side and top of the marina revetment wall, above high tide with marine plants such as *Sporobolus virginicus*. This vegetation will be monitored to determine if it can be successfully used in other marine applications.
- Incorporation of fish friendly structures into the design of the marina (Derbyshire 2006) and monitoring of these structures to determine if they do enhance the abundance and species diversity of fish habitats and communities in the area.

5.3 Monitoring Requirements

Undertaking an annual (pre-wet) seagrass, mangrove and marine pest monitoring program will provide the opportunity to assess the accuracy of predicted impacts and inform management (and construction and operation Environmental Management Plans (EMPs), of potential issues and the need for responsive action. Regular monitoring will provide increased opportunity to identify the source of impacts and as required, distinguish them from the *perceived* source of impact.

Monitoring will focus of the distribution and health of communities in the vicinity of the development footprint (including around the island and adjacent to the mainland), and in areas where altered hydrodynamics are likely to impact on the marine floral community structure. Likely indicators of marine floral condition include distribution mapping and community description, condition (health) and physiological indicators.

During dredging / sediment disturbance, the extent of the turbidity plume will be monitored to confirm that plumes do not have a negative long-term impact on seagrass condition.

6 Summary and Conclusions

6.1 Existing Environment

Mangrove Forests and Saltmarsh

The estimated area of mangrove forest and saltmarsh at Putney Creek was 1 ha and 12 ha respectively. The estimated area of mangrove forest and saltmarsh at Leeke's Creek was 30 ha and 19 ha respectively. The estimated area of mangrove forest at Kinka Beach was 31 ha.

Ten species of mangrove were recorded on Great Keppel Island and seven species at Kinka Beach. Mangrove communities were dominated by:

- *Rhizophora spp.* (predominantly *Rhizophora stylosa* and *Rhizophora apiculata*)
- *Avicennia marina*
- *Aegiceras corniculatum*
- *Lumnitzera racemosa*, and
- *Ceriops australis*.

Six species of saltmarsh were recorded on Great Keppel Island and at Kinka Beach; only two of these species were recorded in both areas. Saltmarsh communities were dominated by *Sarcocornia quinqueflora*, *Sporobolus virginicus* and *Suaeda australis*. Several sedge species, including *Fimbristylis* sp. and *Juncus* sp., grew next to the mangrove and saltmarsh communities at Leeke's Creek.

Mangrove forests were in poor to good ecological health. Most trees showed few signs of stress; the major exceptions to this were at Putney Creek, where the community was assessed as being in poor health, exhibiting:

- reduced canopy cover (generally <15%)
- a relatively high percentage of dead branches (generally >20%), and
- dead mangroves.

Most of the mangrove communities provide good to very good fisheries habitat, and had reasonable amounts of structural habitat for fauna, and frequent tidal inundation. Fisheries habitat values were generally higher at Leeke's Creek, than Putney Creek and Kinka Beach.

Seagrass Meadows and Macroalgae

Four species of seagrass were recorded around Great Keppel Island. Communities were dominated by *Halophila ovalis* and *Halodule uninervis*. *Halophila ovalis* was less widespread than *H. uninervis*, which is likely to be related to environmental conditions such as turbidity and sedimentation. *Halophila spinulosa* and *Syringodium isoetifolium* were least widespread and not evident during the winter recovery survey. Seagrass communities typically had an overall cover of <5% with sparse, patchy distribution. The sediment was dominated by sand. These results are consistent with the most recent (pre-wet season 2009) Seagrass Watch survey, which recorded <4% cover of mostly *H. uninervis* at the Great Keppel Island site of Monkey Beach (Seagrass Watch 2011b).

There were few algal or faunal epiphytes on the seagrasses meadows. The cyanobacteria, *Lyngbya majuscule*, was recorded on the seagrass at several locations in each survey, with dense cover at some locations. The macroalgae, *Caulerpa taxifolia*, was relatively common, growing in small isolated patches at all locations. *Laurencia* sp., *Halimeda* sp., *Hypnea* sp. and *Padina* sp. grew in small, isolated patches at some locations.

Benthic epifaunal communities were dominated by echinoderms (e.g. sea stars *Protoreaster* spp. and crinoids), acorn worms (*Balanoglossus carnosus*), obese sea pens (*Cavernularia obesa*) and moon snails (*Polinices lewisssi*). Stingrays, and their feedings pits, were recorded in each survey, including the blue-spotted stingray (*Dasyatis kuhlii*), cowtail stingray (*Taeniura melanospila*) and common shovel-nosed ray (*Rhinobatos batillum*).

Overall, seagrass meadows had lower cover and covered a smaller area in the post-wet and winter recovery surveys than the pre-wet / wet survey. Diversity was also lower in the winter survey, with only two species recorded (*H. ovalis* and *H. uninervis*). These types of changes are typical of inshore seagrass meadows of the region following large rainfall events.

There has been a substantial decrease in the cover and the extent of seagrass since the 1970s. This is likely to be related to cyclone activity, sedimentation and / or elevated nutrient levels.

Regional and Ecological Context

Mangrove Forests and Saltmarsh

Twenty species of mangroves have been reported within the region (from the Keppel Islands in the north to Rodd's Bay in the south). Regionally, between Shoalwater Bay and Hervey Bay, there are approximately 3875 patches of mangroves covering an area of 20 300 ha.

Mangrove communities grow on a diverse range of sediments from rocky outcrops and coarse sand, to fine silts and mud. However, they develop best in sheltered, depositional environments on fine silts and clays. Drainage and aeration depend on sediment characteristics, frequency and period of fresh and saltwater inundation and elevation. Mangrove species differ in their ability to withstand poorly drained or poorly aerated soils. Saltmarshes cannot remain vigorous on waterlogged, anaerobic soils, and this is likely to be a major factor limiting their seaward distribution.

Estuarine wetlands, including mangrove and saltmarsh communities, provide valuable habitat and food sources for a variety of vertebrate and invertebrate species. Some of these are of conservational significance (e.g. marine turtles and the water mouse), while others are recreationally and / or commercially important. The majority of commercially and recreationally important fish species from eastern Australia depend upon estuarine environments. Shallow water and intertidal habitats are among the most productive environments for fisheries.

Seagrass Meadows

Nine species of seagrass have been recorded in the region. There are approximately 4 600 000 ha of seagrass in the Great Barrier Reef, with 45 910 ha in Central Queensland from Mackay to Gladstone (including Rodds Bay), 17 940 ha from Shoalwater Bay to the Fitzroy River mouth (inclusive) and 40 ha around the islands of the Keppel Group.

The extent and condition (e.g. reproductive health) of seagrass in the region is highly variable; species composition of meadows differs between habitats. In general, inshore coastal meadows are dominated by *Zostera muelleri* [9] with some *Halodule uninervis*, estuarine meadows are dominated by *Z. muelleri* and coral reef-associated meadows are dominated by *H. uninervis.* Variability between habitats is likely to be related to light and nutrient levels. Epiphyte coverage on seagrass is generally seasonal, with macroalgal cover typically lower on inshore coastal and reef meadows, and highly variable in

[9] This species was previously described as *Zostera capricorni.*

estuarine environments. Dominant seagrass species in the area (*H. uninervis* and *Z. muelleri*) are characterised by abundant seed production, fast growth rates, and the ability to rapidly recolonise areas. This suggests that these species may be able to rapidly colonise following a disturbance.

Macroalgae are a commonly overlooked component of the marine environment, which may significantly contribute to an area's ability to support marine life, particularly fish and crustacea. While the distribution of macroalgae is variable and has not been mapped, it is expected to occur throughout the project area, with the greatest diversity and biomass near the mouths of creeks and rivers.

Cyanobacteria **Lyngbya**

Lyngbya majuscula is a naturally occurring, toxic, filamentous, cyanobacteria (blue-green algae), which is found worldwide in tropical and subtropical estuarine and coastal habitats. *Lyngbya* growth has resulted in the loss of seagrass meadows, and may have reduced turtle and dugong feeding grounds in Moreton Bay. *Lyngbya* can also cause severe eye and skin irritations to humans, as well as asthma-like symptoms. *Lyngbya* can affect the economics of commercial and recreational fisheries and tourism.

Changes in catchment land use or seabird distributions can lead to alterations of the inputs of dissolved organics, iron, and phosphorus into a system, which can lead to *Lyngbya* blooms. There is commonly an association between *Lyngbya* blooms and development of coastal catchments. Nuisance *Lyngbya* blooms have been recorded on coral outcrops near Great Keppel Island by other studies.

6.2 Potential Impacts

Indirect impacts on marine flora are discussed in Appendix C (Marine Water Quality). Direct impacts to marine flora are discussed below.

Loss of Marine Flora

Seagrass and Macroalgae

Construction of the marina will result in the direct loss of patches of seagrass within an area of approximately 9.60 ha. These patches cover less than 10% of the of seabed, the cover within the patches ranges from <5% to 15%. A total area of less than 0.96 ha of seagrass will be lost.

Installation of the submarine cables along the marina breakwall will remove an additional approximately 0.004 ha (based on a 1 m wide installation corridor through an area of 0.04 ha that contains patches covering less than 10%) of seagrass. A hydrographic survey was undertaken to inform route alignment, and avoid sensitive ecologically communities including coral reefs, seagrass meadows and mangrove forests (where practical).

Seagrass as Habitat for Fauna

Seagrasses provide shelter and refuge for resident and transient adult and juvenile finfish, crustaceans and cephalopods. Many of these species are of commercial and recreational importance, and others are the preferred foods of these species. While juvenile abundance of many fish and crustacean species is commonly higher in seagrass habitats than over bare sand or mud, there are significant differences in abundance between seagrass beds. Some sites have consistently higher recruitment, while other sites may only periodically or temporarily have higher abundances. This may be due to the structural complexity of the seagrass beds; location of the seagrass beds with respect to currents and the dispersal of larvae; and natural fluctuations (patchiness) in population sizes.

Loss of seagrass has the potential to affect species of conservation significance, as seagrass provides an important food source for several important species, e.g. marine turtles, dugong and syngnathids.

Given that the meadows within and adjacent to the proposed marina are sparse and patchy, and typical of the region, the potential loss is unlikely to have a measurable ecological impact beyond the marina footprint.

Mangroves

Mainland connection of the submarine cables along the current proposed alignment may result in the direct loss of approximately 0.04 ha (based on a 2.5 m wide installation corridor) of mangrove forest. There are several gaps in the forest (up to 67 m wide) and removal of mangroves will not be required where the alignment is modified to extend through one of the gaps.

Gain of Habitat

Artificial Structures as Habitat within the Marina Basin

Construction of the proposed marina will result in a mosaic of habitats associated with breakwalls, pontoons, piles and other intertidal and subtidal structures, together with moored vessels. The hard surfaces of these structures will provide substrate for many species of algae, hard and soft corals, sponges, ascidians and a variety of other invertebrates and wastewater outfall will also provide a recruitment surface for a variety of benthic flora and fauna. In turn, this sessile benthic community may provide shelter and food for a variety of fishes and other fauna. The structures associated with the proposed development will also provide a high degree of shade, important in attracting many fish species.

The waters of the marina basin are likely to have relatively low ecological value, primarily as waters are likely to be too deep to support substantial floral communities and the soft sediment community will be similarly depauperate to those recorded in the proposed footprint (dominated by polychaete worms). Habitat, and consequently ecological value, could be enhanced with the addition of fish-friendly structures. The *Fisheries Guidelines for Fish-Friendly Structures* describe a number of artificial structures that may enhance fish habitat (Derbyshire 2006).

Mangroves of Putney Creek

Opening of the Putney Creek mouth would change the flood regime with the potential to positively impact water and sediment quality. Improved water and sediment quality would facilitate improved condition of the mangrove and saltmarsh communities in Putney Creek, which are currently in relatively poor condition and provide relatively poor habitat for fauna compared to forests with better flushing and hence water and sediment quality (e.g. Leeke's Creek and Kinka Beach).

Introduction of Marine Pests

The introduction of exotic flora and fauna can threaten the integrity of natural communities, the existence of rare and endangered species, the viability of living resource-based industries and pose risks to human health (Hutchings et al. 2002; Hayes et al. 2005). The proposed marina will not serve as a point of entry to Australia and will not service international commercial shipping, hence the risk of introductions via ballast water is negligible.

6.3 Mitigation Measures

Current 'best practice' assessment and engineering practices offer significant opportunities to minimise the impacts associated with both construction and operation of the proposed development. Table 5.2 provides a summary of mitigation measures and the associated residual risk for direct impacts; indirect impacts are discussed in Appendix C.

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Appendix F Marine Fauna

Contents

Figures

Tables

1 Methods

1.1 Sites Surveyed

Coral communities and benthic macroinvertebrate communities were surveyed in the following seasons[1]:

- pre-wet – 16 to 19 November 2010
- wet – 17 to 21 January 2011
- post-wet – 28 March to 1 April 2011 and 30 April to 2 May 2011, and
- winter (to quantify community 'recovery' following flooding) – 12 to 14 July 2011.

Coral communities were surveyed at ten sites around Great Keppel Island (Figure 1.1):

- Clam Bay West (CBW)
- Clam Bay Centre (CBC)
- Fishermans Beach (FB)
- Monkey Beach (MB)
- Long Beach (LOB)
- Middle Island (MI1)
- Middle Island Observatory (MI2)
- Passage Rocks (PR)
- Putney Beach (PB), and
- Wreck Beach (WB).

[1] Faunal communities of Fishermans Beach, Passage Rocks and Putney Beach were surveyed during the pre-wet, post-wet and winter surveys. Faunal communities of Clam Bay, Monkey Beach, Long Beach, Middle Island and Wreck Beach were surveyed during the wet survey (as they were not accessible during the pre-wet season due to permit and boat constraints), post-wet and winter surveys. Coral was surveyed at Clam Bay east during the wet survey; there was no live coral and this site was not re-surveyed. Invertebrate communities of the mainland were surveyed during the wet survey (as they were added to the project area after the pre-wet survey, to consider impacts of the submarine cable crossing), post-wet and winter survey.

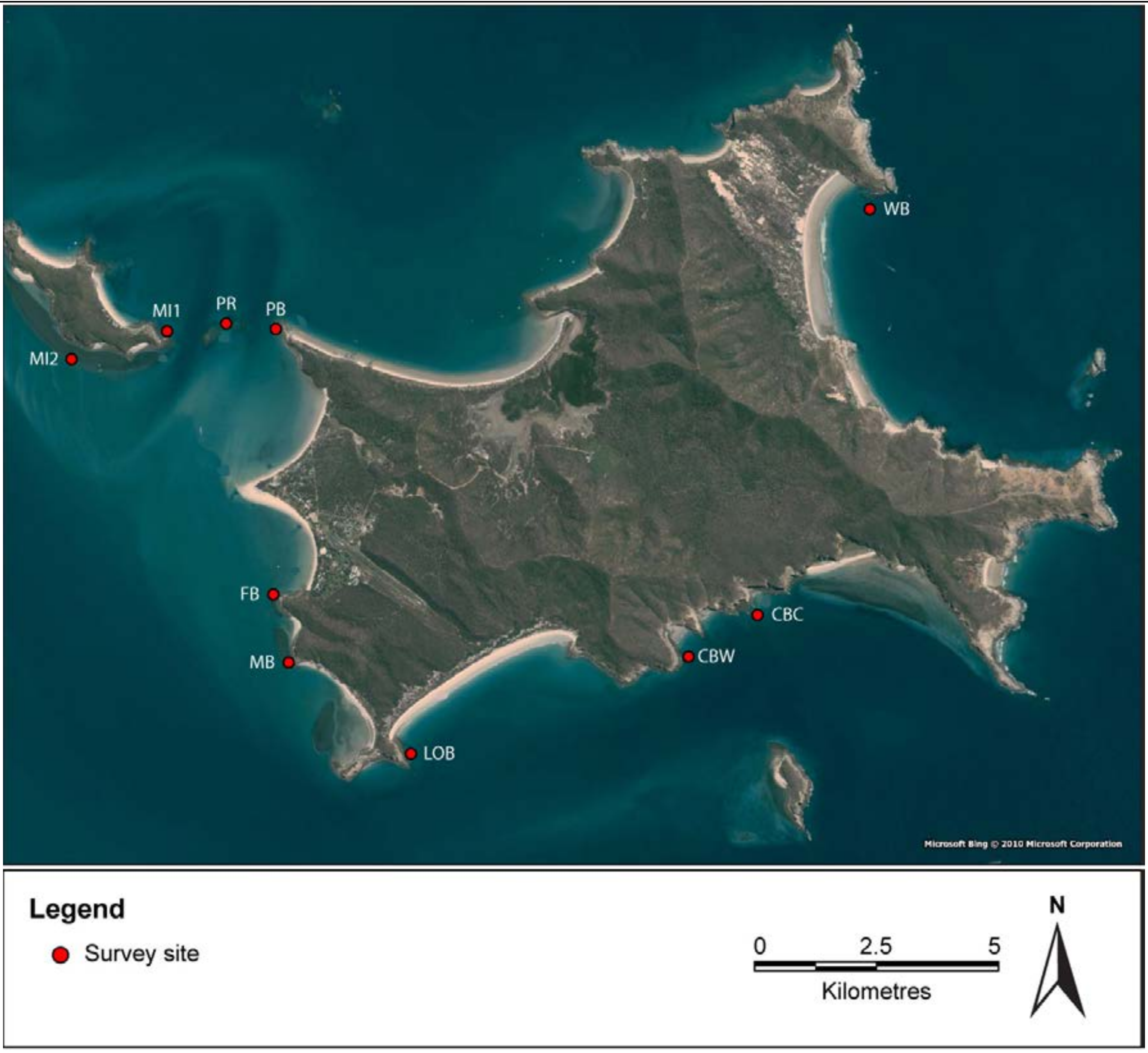

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	Figure 1.1 Coral survey sites.	
	Microsoft Bing © 2010 Microsoft Corporation	July 2011

Benthic infaunal invertebrate communities were surveyed at ten sites around Great Keppel Island (Figure 1.2):

- Clam Bay (CB)
- Fisherman's Beach (FB)
- Leeke's Beach (LB)
- Leeke's Creek Mouth (LCM)
- Long Beach (LOB)
- Putney Beach (PB1, PB2, PB3 and PB4)
- The Spit (TS),
- Wreck Beach (WB), and

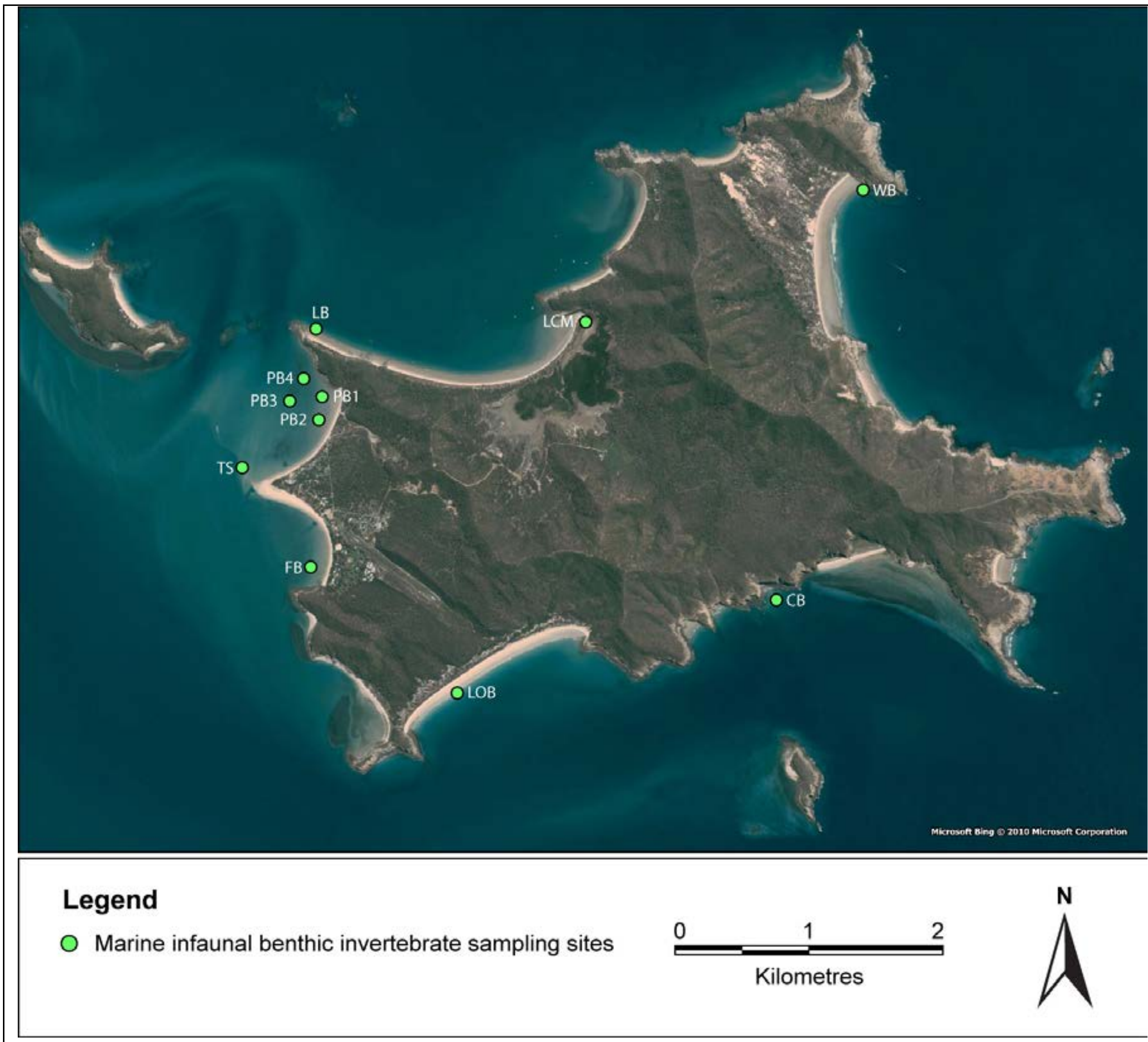
at two mainland sites (Figure 1.3):

- Tanby Beach (TB), and
- Kinka Beach (KB).

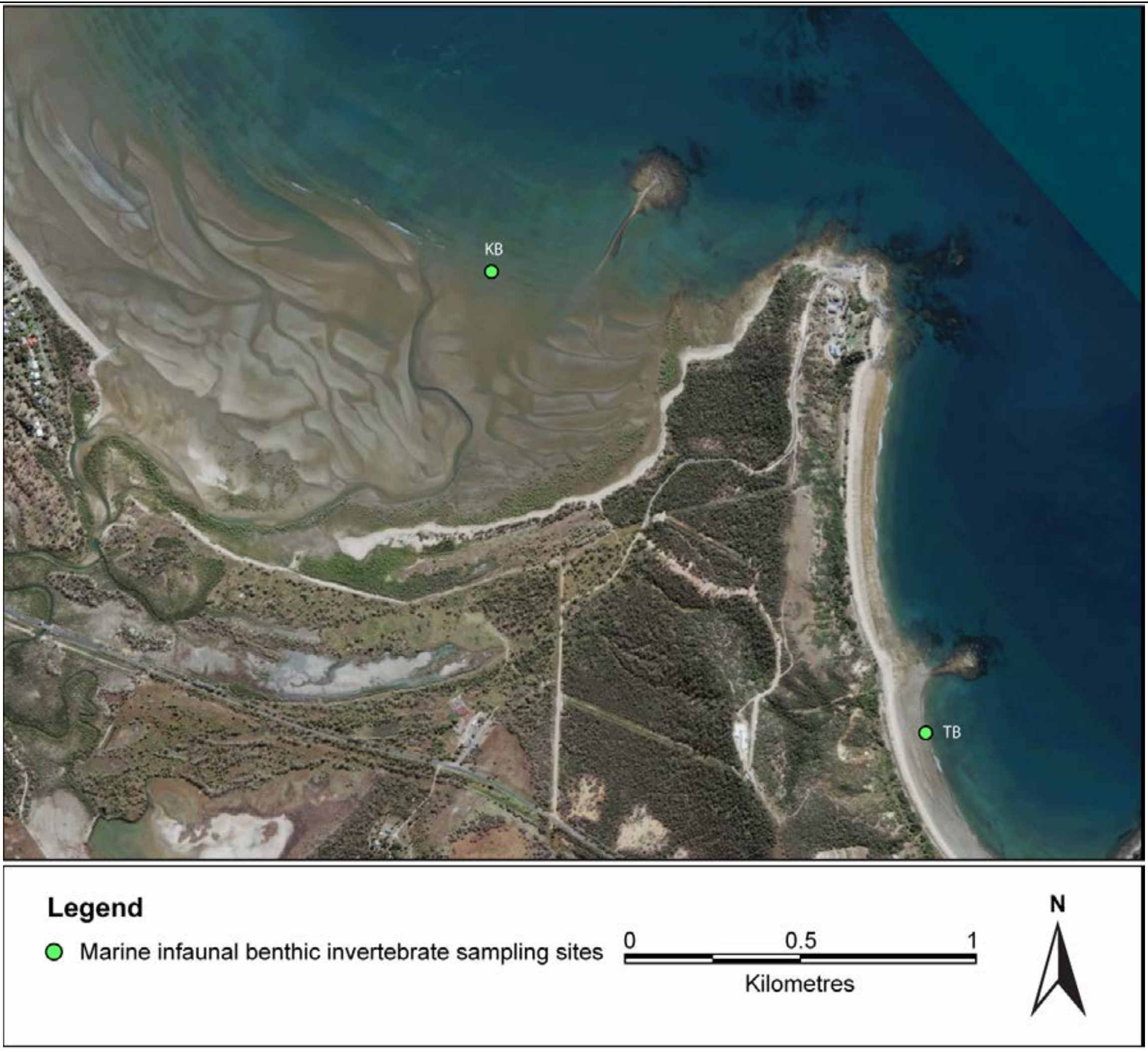
The intertidal rocky shores were surveyed at Putney and Fishermans beaches during the pre-wet survey.

Macrocrustaceans, fishes, marine reptiles and marine mammals were recorded opportunistically during all surveys.

Marine turtle nesting was surveyed at Putney, Fishermans and Long beaches during the 2010-11 nesting season.



frc environmental AQUATIC ECOLOGISTS deep thinking. science.	Great Keppel Island Revitalisation EIS	
	Figure 1.2 Great Keppel Island benthic infaunal invertebrate sites.	
	Microsoft Bing © 2010 Microsoft Corporation	June 2011



frc environmental AQUATIC ECOLOGISTS deep thinking. science.	Great Keppel Island Revitalisation EIS	
	Figure 1.3 Mainland benthic infaunal invertebrate sites.	
	Microsoft Bing © 2010 Microsoft Corporation	June 2011

1.2 Coral Communities

Distribution

The distribution of coral communities around Great Keppel Island was determined using aerial photographs and ground-truthing on snorkel using a floating GPS (accurate to ±4 m).

Cover and Community Composition

Coral cover and community composition were recorded using a modified version of the photo transect method used by the Australian Institute of Marine Science (AIMS) and the University of Queensland (Roelfsema et al. 2006).

Data Collection

A transect was established at each coral survey site at 1 to 3 m below lowest astronomical tide, running along the reef crest. Each transect was approximately 300 to 500 m long, with length dependent on the length of reef at each site. Before starting each transect, a slate was labelled with the date and site number, and photographed. The benthic community was photographed every 5 to 10 m along each transect, with photo locations chosen haphazardly. Each photo included an approximate area of 35 x 35 cm; the camera lens was parallel to the substrate. The start and end points of each transect were recorded using GPS (accurate to ±4 m). Evidence of disease was recorded.

Data Analysis

Photographs were analysed using the Coral Point Count with Excel extensions (CPCe Version 3.6) software developed by the National Coral Reef Institute in the USA (Kohler & Gill 2006). Fifty random points were overlain on each photograph (distributed using a stratified random approach), providing a total of up to 1000 points per transect (i.e. 50 points x 20 photos[2]). This Australian Institute of Marine Science (AIMS) long term monitoring program, uses a total of 200 points per transect (Page et al. 2001).

[2] 15 photos were assessed at some sites during the wet season survey due to issues with visibility and capturing high quality photos.

The percent cover of live coral (by growth form), severely bleached coral, macroalgae, epifaunal invertebrates (e.g. ascidians and sponges) and rubble / sediment was determined for each site. Life form categories and descriptions are detailed in Table 1.1.

Table 1.1 Life form categories and descriptions used for assessing coral communities in Coral Point Count analysis.

Category	Description
Coral	
Branching or digitate	>1º branching (e.g. *Acropora robusta, A. formosa, Seriatopora hystrix*)
Encrusting or sub-massive	Major portion attached to substratum as a laminar plate (e.g. *Montipora undata*, *Acropora palifera* [juvenile]), or forms small columns, knobs, or wedges (e.g. *Acropora palifera, Porites lichen*, *Psammocora digitata*)
Massive	Solid boulder or mound (e.g. *Platygyra daedalea*)
Mushroom	Solitary, free living corals of the family Fungiidae
Plate or foliose	Horizontal flattened plates or foliose form (e.g. *A. hyacinthus*)
Soft coral	Soft bodied coral (e.g. *Sarcophyton*, *Sinularia*)
Severely bleached Coral	Still standing, white to dirty white in colour; severely bleached or recently dead coral tissue (no algal or faunal growth)
Algae	
Halimeda	Macroalgae of the genus *Halimeda*
Padina	Macroalgae of the genus *Padina*
Coralline	Encrusting coralline algae (e.g. *Lithothamnion prolifer*, *Neogoniolithon brassica*)
Turf	Filamentous algae with a canopy height of 1–10 mm
Other	Other macroalgae including *Caulerpa* sp., *Chlorodesmis fastigiata*, *Dictyota* sp., *Padina gymnospora*, *Turbinaria* sp.
Sponge	Animals of the phylum Porifera
Zoanthid or corallimorph	Anemone-like animals of the families Zoanthidae or Discomatidae
Other epifauna	Other epifaunal invertebrates (e.g. anemone, ascidian, barnacle, bivalve, bryozoan, gastropod, gorgonian, polychaete, other echinoderms)
Sediment	
Rubble	Dead, unstable coral pieces often colonised with macroalgae
Sand	Sediment with a particle size of 62.5µm to 2 mm
Fine sediment	Sediment that had been retained on turf algae or dead coral
Unknown	Any object that cannot be identified
Other	Other objects (e.g. mangrove leaf)

1.3 Intertidal Rocky Shores

The benthic communities of the intertidal rocky headland at Putney and Fishermans beaches were surveyed on foot at low tide. Each species present was recorded, and taxonomic richness (i.e. the number of species at each location) calculated.

Field observations were supplemented with literature review and database searches, specifically: the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) *Protected Matters Search Tool* (DSEWPC 2011); and the *Queensland WildNet database* (DERM 2011b) with a search area that included a 10 km buffer around the project area.

1.4 Benthic Infaunal Invertebrate Communities

A suite of factors, including nutrient loads, sediment grain size and turbidity, influence the structure of benthic infaunal invertebrate communities. Changes in community structure can be used as a tool to assess the ecological health of ecosystems, to identify characteristics of pressures acting on those waterways, and to assess the potential impacts of a development.

Sample Collection

Benthic infaunal invertebrates were collected using a 2 L stainless steel Eyre's corer and sieved in the field through a 1 mm sieve. The benthic fauna, sediment and detritus retained by the sieve were frozen and sent to the frc environmental biological laboratory. Five samples were collected at each site, with the exception of Putney Beach where three cores[3] were collected from each of four sites

Laboratory Analysis

All samples were stained with Rose Bengal and invertebrates were picked, counted and identified to typically family level. The total abundance of each taxa was recorded for each sample.

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3 Fewer cores were collected as these sites would be lost to the proposed development and not included in monitoring.

Data Analysis

Mean abundance (i.e. the average number of individuals in the samples from each site), mean taxonomic richness (i.e. the average number of taxa in the five samples from each site) and mean abundance of abundant taxa (i.e. the average number of individuals from each abundant taxa in the five samples from each site) were calculated and graphed.

Taxonomic richness is the number of taxa (in this assessment, families). Taxonomic richness is a basic, unambiguous and effective diversity measure. It is however, affected by arbitrary choice of sample size. Where all samples are of equal size, taxonomic richness is a useful tool when used in conjunction with other indices. Richness does not take into account the relative abundance of each taxa, so rare and common taxa are considered equally.

1.5 Macrocrustaceans, Fishes, Marine Reptiles and Marine Mammals

Macrocrustaceans and fishes (fin-fish and elasmobrachs) of the project area were recorded during the coral, seagrass and mangrove surveys. Other marine vertebrates, including marine mammals and reptiles, were surveyed opportunistically during all surveys.

Field observations were supplemented with literature review and database searches, specifically: the EPBC Act *Protected Matters Search Tool* (DSEWPC 2011); and the *Queensland Wildnet database* (DERM 2011b) for a search area that included a 10 km buffer around the project area.

Marine Turtle Nesting

Marine turtle nesting on Putney, Fishermans, Leeke’s and Long beaches was surveyed during the 2010-11 nesting season (from November to early February) by an island resident mentored by frc environmental. Surveys were undertaken in accordance with best practice and agency guidelines (WADEC 2010; DERM 2011a). Where possible, surveys coincided with a high tide around dusk or dawn; the time most likely for turtles to come ashore to nest. Surveys comprised a visual census of turtle tracks or turtles emerging from the water. Turtles or tracks were identified to species level where possible. Marine turtle nesting data provided by a second island resident was also discussed.

1.6 Regional and Ecological Context

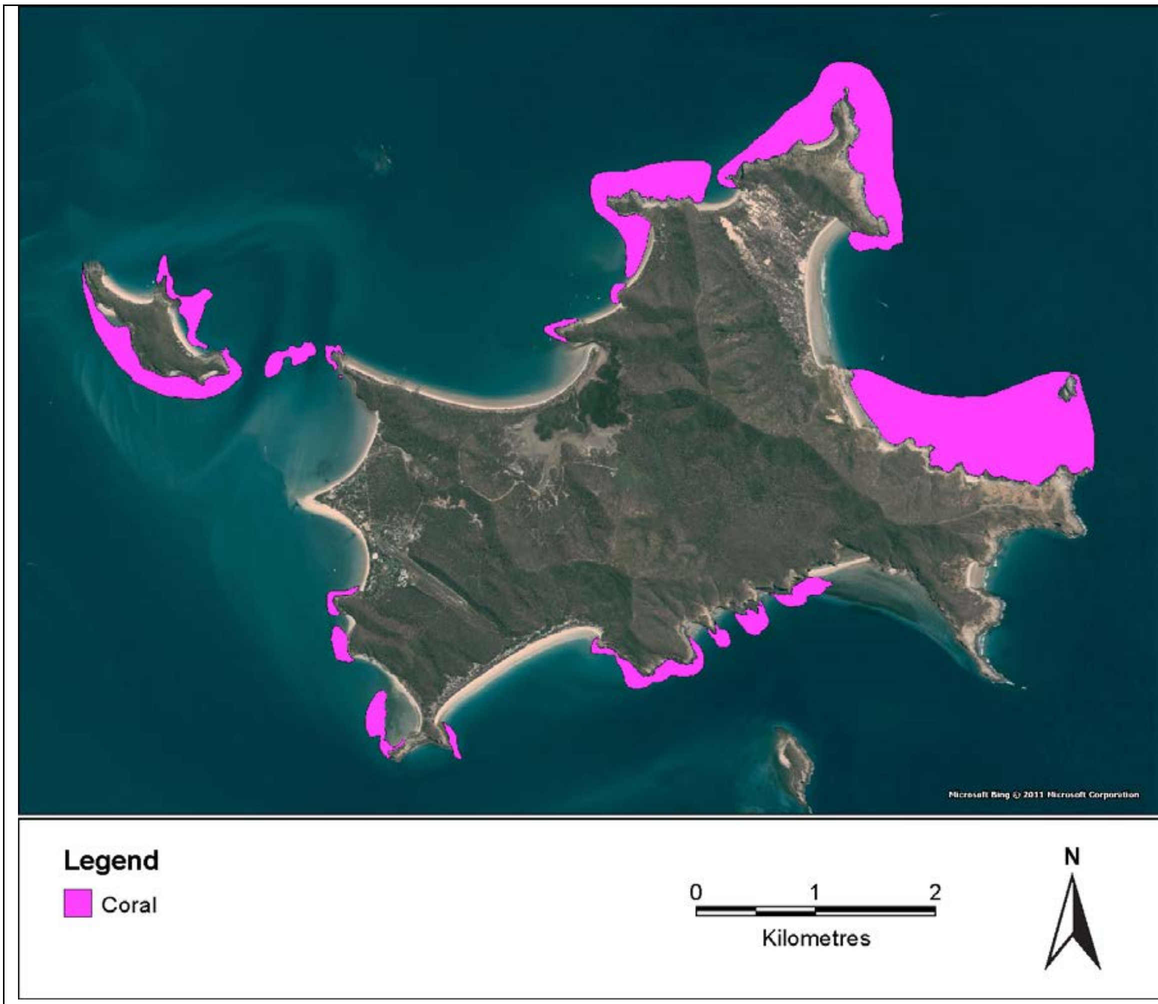
Marine fauna of the region were described through literature review and database searches, specifically: the Commonwealth EPBC Act *Protected Matters Search Tool* (DSEWPC 2011); and the *Queensland WildNet database* (DERM 2011b) for a search area that extended from Shoalwater Bay to Curtis Island. Where available, information was also sourced from researchers, government agencies and consultancies to provide a description of faunal communities, including ecologically significant species in the vicinity of the proposed development and of the region.

2 Existing Environment

2.1 Coral Communities

Distribution

The distribution of communities that are dominated by coral is presented in Figure 2.1.



frc environmental AQUATIC ECOLOGISTS deep thinking.science.	Great Keppel Island Revitalisation EIS	
	Figure 2.1 Coral communities of Great Keppel Island.	
	Microsoft Bing © 2010 Microsoft Corporation	August 2011

Coral Cover

Coral cover varied between sites and within most sites (Figure 2.2)[4]. Cover was consistently high (>41%) at sites MI1 (Middle Island) and consistently low (<16%) at site MI2 (Middle Island Observatory). Cover was relatively high, but varied between surveys, at site PR (Passage Rocks). Coral cover ranged from 1% at site FB (Fishermans Beach) during the post-wet survey to 50% at site PR (Passage Rocks) during the pre-wet survey.

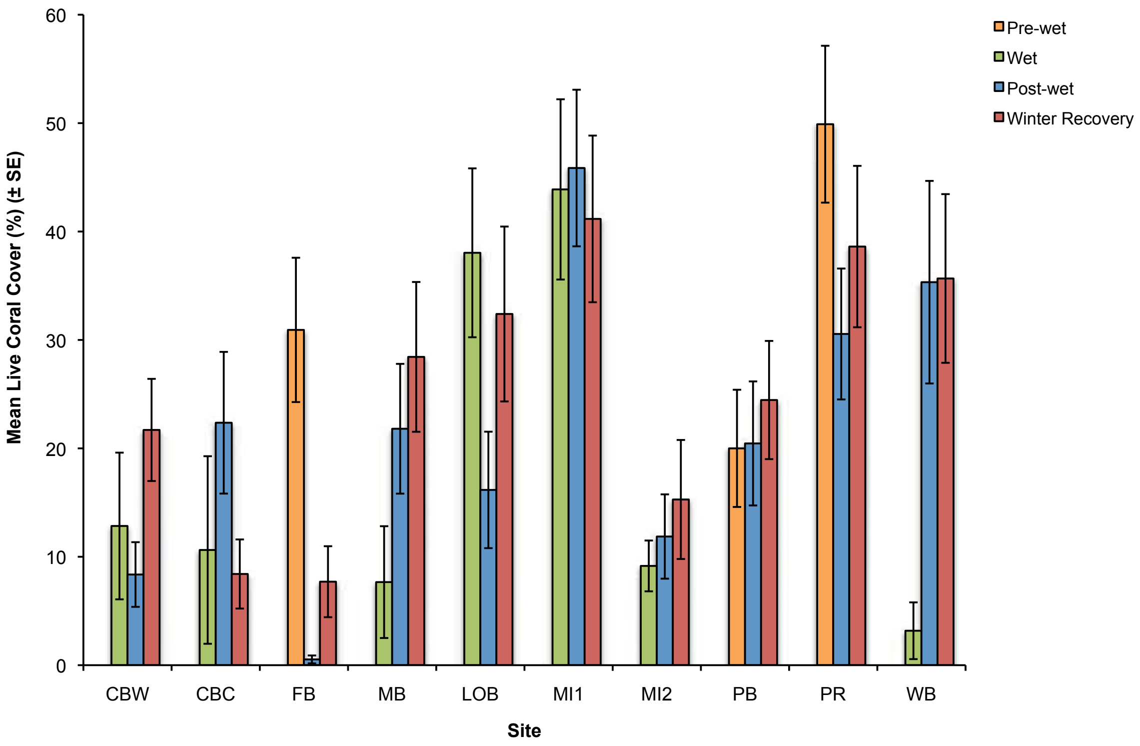


Figure 2.2 Mean percent cover of live coral (± SE) at each site.

Jones et al (2011) reported that mean coral cover on reefs of the Keppel Group ranged from 29 to 94%, with mean cover of 52%. The highest mean cover was on nearby Humpy Island (>80%[5]), with moderate cover at Passage Rocks (>50%) and Middle Island (>45%), Wreck reef (>45%) and relatively low cover at Monkey and Shelving beaches (>30%).

[4] Coral communities of Fishermans Beach, Passage Rocks and Putney Beach were surveyed during the pre-wet, post-wet and winter surveys. Coral communities of Clam Bay, Monkey Beach, Long Beach, Middle Island and Wreck Beach were surveyed during the wet survey (as they were not accessible during the pre-wet season), post-wet and winter surveys. Clam Bay east was surveyed during the wet survey; there was no live coral and this location was not re-surveyed.

[5] Approximate cover based on graphs.

Coral Bleaching

The cover of severely bleached coral was highly variable between sites and within some sites. Cover was highest (up to 17%) at Clam Bay sites (CBW and CBC), particularly during the wet survey. Overall, cover of severely bleached corals was highest during the wet survey; however several sites had little (<2% cover) recently dead or severely bleached corals in any of the surveys (FB, MI2, PB and PR). Cover of severely bleached coral ranged from 0% at several sites to 17% at site CBW (Clam Bay West) during the wet survey (Figure 2.3 to Figure 2.5). The bleaching was primarily associated with flooding of the Fitzroy River during the 2010-11 wet season, which exposed corals to freshwater and contaminants.

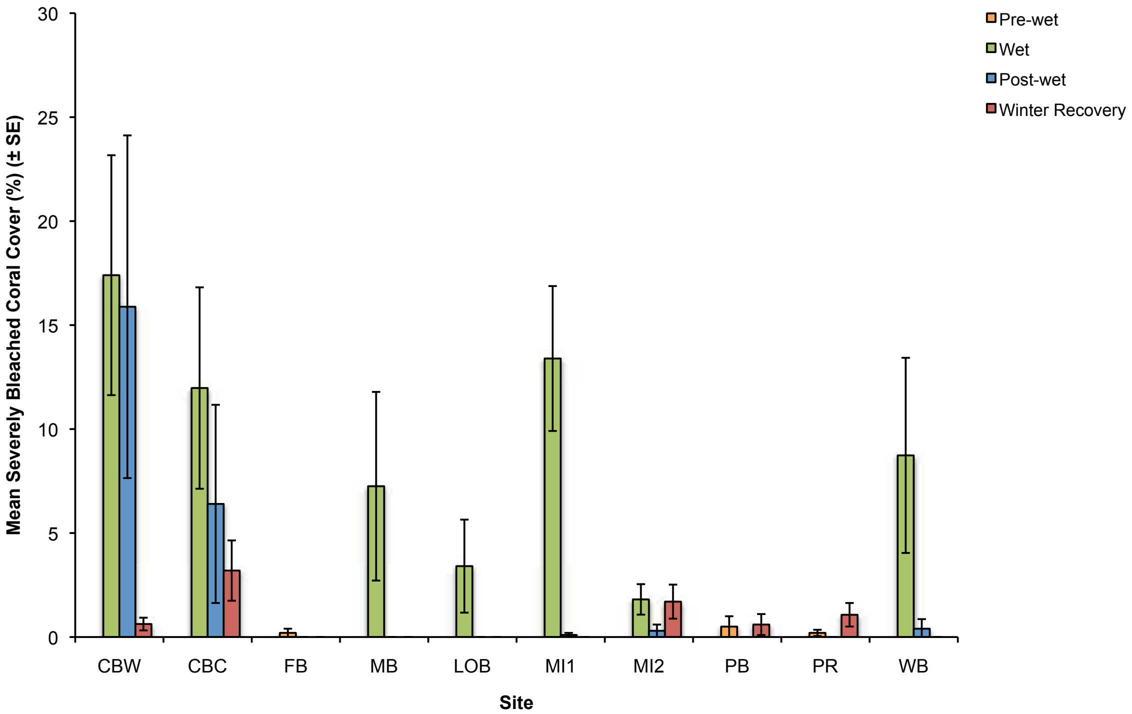


Figure 2.3 Mean percent cover of severely bleached coral (± SE) at each site.

Figure 2.4

Bleached coral at Putney Beach.

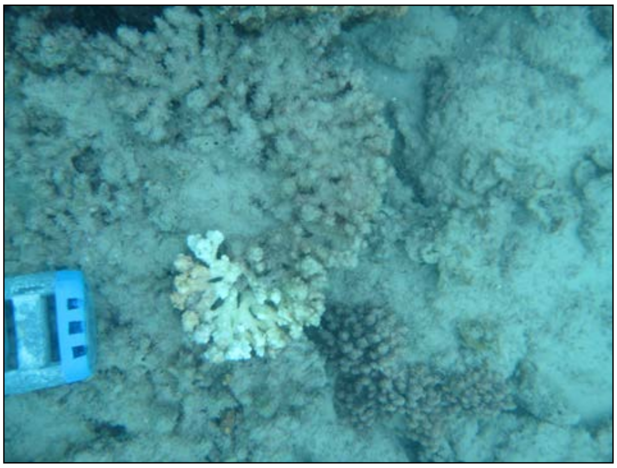
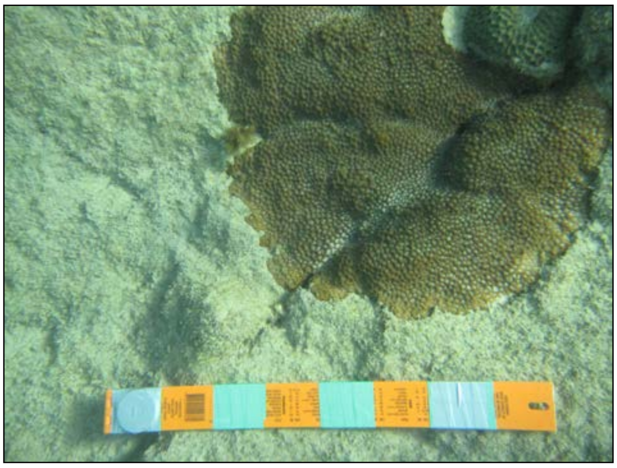


Figure 2.5

Healthy coral at Putney Beach.



Bleaching is common on the reefs of Great Keppel Island (e.g. Berkelmans et al. 2004; Elvidge et al. 2004; Weeks et al. 2008; Diaz-Pulido et al. 2009). After the major flood event in January 1991, the large freshwater input from the Fitzroy River resulted in reduced coral cover and increased bleaching. Approximately 85% of coral in the area died and was overgrown by turf algae, with shallow reefs most affected. For example, at Clam Bay, shallow coral slopes were reduced from 93% cover at approximately 1 m below low water, to no live coral at approximately 1 m below low water and 9% cover at approximately 2 m below low water. Mortality was greatest for acroporids and pocilloporids, while faviids, *Turbinaria* spp., *Porites* spp., *Psammocora* sp. and *Coscinaraea* sp. survived in shallow habitats (Van Woesik 1991).

In January 2006, 100% of corals in Keppel Bay were bleached with approximately 40% mortality by May 2006 (GBRMPA 2007; Weeks et al. 2008). At Middle Island, 60 to 70% of corals were impacted by bleaching during the summer of 2006, coral communities at this time were dominated by fast growing *Acropora* species including *A. formasa, A. microphthalma*, and *A. millepora*. Middle Island is vulnerable to bleaching due to the dominance of mono-specific strands of *Acropora* (on both upper and lower reef slopes) as these corals species are most susceptible to thermal stress (GBRMPA 2007). However, reefs of the Keppel Group have recently demonstrated resilience to bleaching and strong recovery following severe bleaching (Diaz-Pulido et al. 2009).

Coral disease was not observed during the surveys.

Dominant Growth Forms

Communities were dominated by branching growth forms from the family Acroporidea (mostly *Acropora* spp. and *Montipora* spp.) and massive growth forms from the families Faviidae (mostly *Favia* spp., *Favites* spp., *Gonisterea* spp. and *Platygyra* spp.) and Poritidae (mostly *Porites* spp.), together with some plate / foliose, soft, mushroom and encrusting growth forms. The corals of Putney Beach were dominated by *Turbinaria* sp. and the soft coral *Sarcophyton* sp..

These results are consistent with other studies of the area. Jones et al (2011) reported that reefs of the Keppel Group were dominated by coral from the family *Acroporidea* (61 species) and *Faviidae* (57 species), together with *Mussidae* (12 species) and *Poritidae* (approximately 10 species). GBRMPA (2007) report that Middle Island reefs were dominated by *Acropora* species, including branching and tabulate forms, with low species richness, high coral cover, and slopes restricted by a shallow silt base.

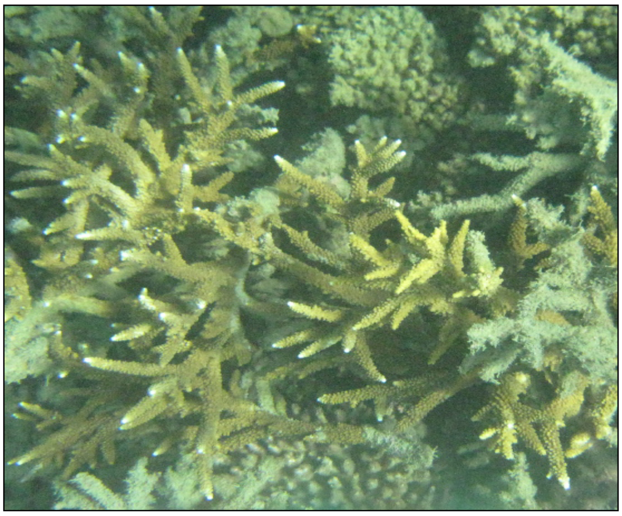
Branching Growth Forms

The dominant branching growth forms were from the families:

- Acroporidae (*Acropora* spp. and *Montipora* spp.), and
- Pocilloporidae (*Pocillopora* spp.) (Figure 2.6).

Figure 2.6

Branching (*Acropora* sp.) coral at Middle Island.



Cover of coral with a branching growth form varied between sites and within most sites. Cover of branching growth forms was consistently high (>32%) at site MI1 (Middle Island) and consistently low (<5%) at sites MB (Monkey Beach) and PB (Putney Beach). Cover of branching coral growth forms ranged from 0% at several sites to 45% at site MI1 (Middle Island) during the post-wet survey (Figure 2.7).

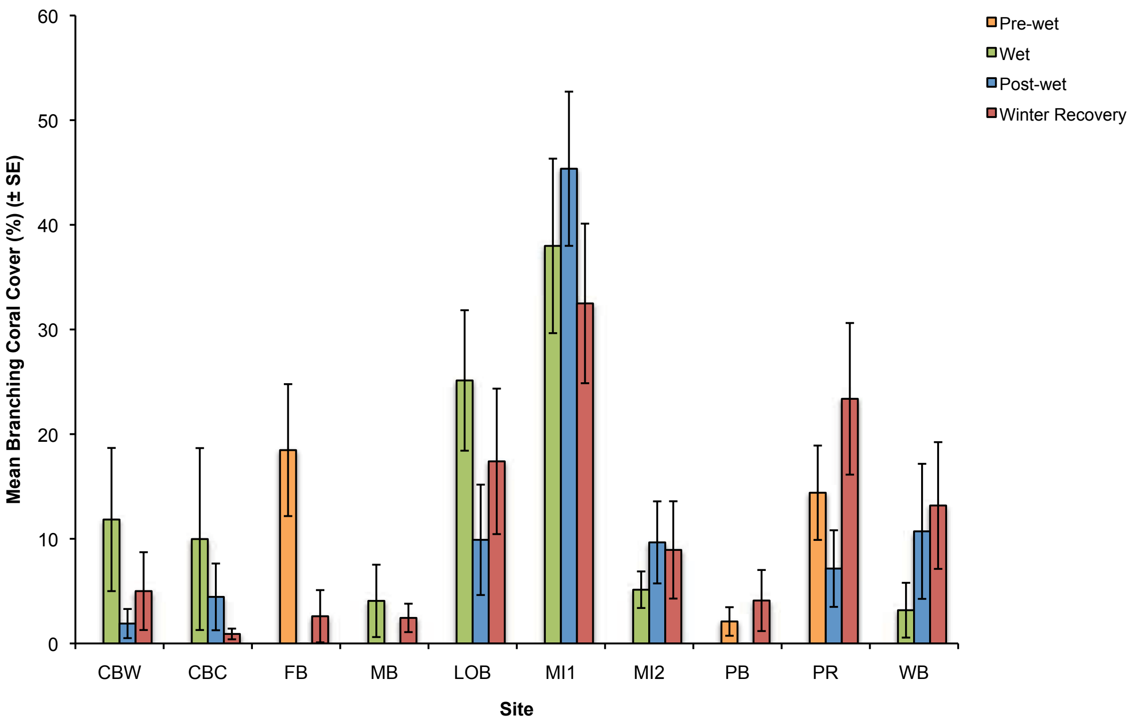


Figure 2.7 Mean percent cover of branching coral (± SE) at each site.

Massive Growth Forms

The dominant massive growth forms were the families:

- Agariciidae (*Coelosceris* spp.)
- Faviidae (*Favia* spp., *Favites* spp., *Gonisterea* spp. and *Platygyra* spp.), and
- Mussidae (*Acanthastrea* spp. and *Lobophyllia* spp.), and
- Poritidae (*Portites* spp.) (Figure 2.8 and Figure 2.9).

Figure 2.8

Massive (*Favia* sp.) coral at site Long Beach

Figure 2.9

Massive (*Goniastrea* sp.) coral at site Long Beach.

Cover of coral with a massive growth form varied between sites and within sites, but was generally low (<10% at most sites during most surveys). Corals with a massive growth form were not recorded at site MI2 (Middle Island Observatory), and cover was consistently low (<6%) at sites FB (Fishermans Beach) and PR (Passage Rocks). Cover of massive growth forms ranged from 0% at Middle Island Observatory to 18% at site CBC (Clam Bay Central) during the post-wet survey and sites MB (Monkey Beach) and PB (Putney Beach) during the winter survey (Figure 2.10).

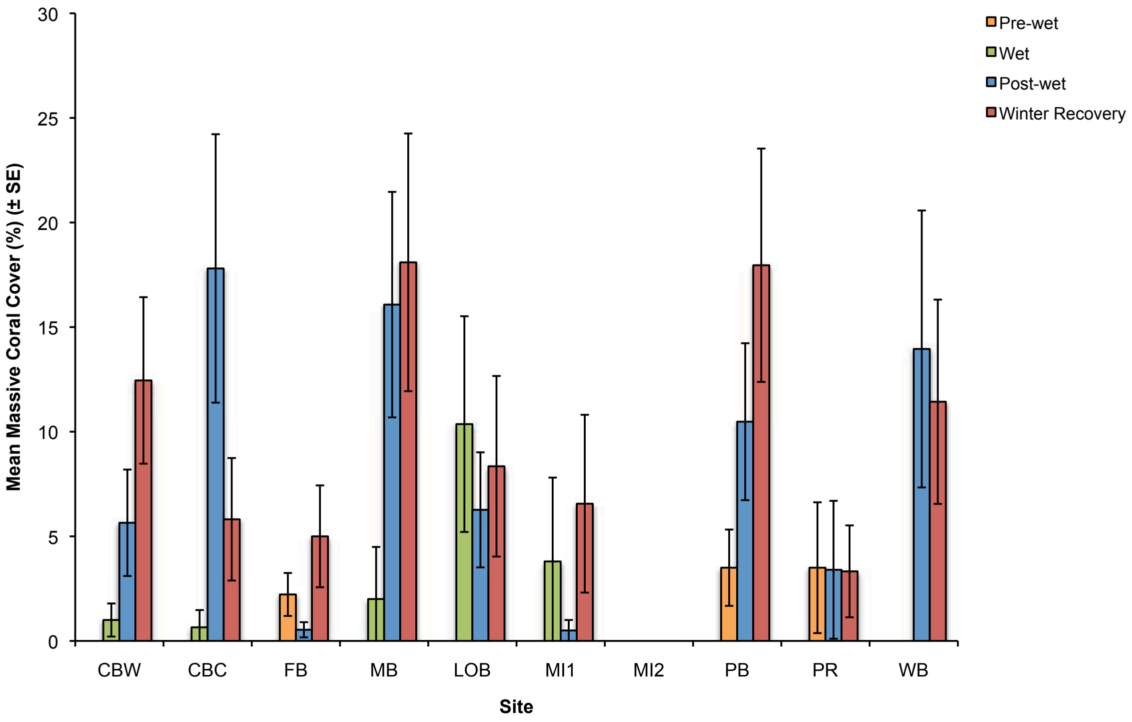


Figure 2.10 Mean percent cover of massive coral (± SE) at each site.

Other Growth Forms

Other growth forms (e.g. soft, foliose / plate, mushroom and encrusting) were less widespread and included the families:

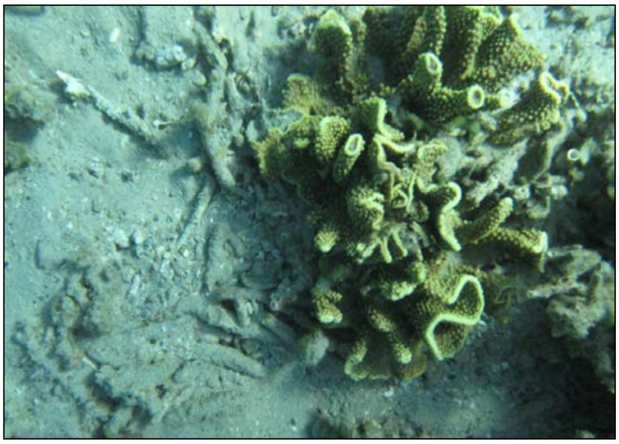
- Alcyoniidae (e.g. *Lobophytum* spp.)
- Dendrophylliidae (e.g. *Turbinaria* spp.)
- Fungiidae (e.g. *Fungia* spp.)
- Pectiniidae (e.g. *Echinophyllia* spp. and *Oxypora* spp.), and
- Sidastreiidae (e.g. *Coscinaraea* spp.) (Figure 2.11 and Figure 2.12).

Figure 2.11

Mixed community at Passage Rocks including mushroom (*Fungia* sp.) and soft (*Lobophytum* sp.) coral.

Figure 2.12

Foliose (*Turbinaria* sp.) coral at Clam Bay West.



Dominant Taxa

In 2009, 167 species from 48 genera in 13 families were recorded from 19 sites in Keppel Bay, with an average of 39 species per reef. The highest number of species (richness) was recorded on nearby Humpy Island (70 species), with relatively high richness at Passage Rocks and Middle Island (up to 53 species) and relatively low richness at Leeke's Creek mouth and Monkey Beach (up to 38 species[6]) (Jones et al. 2011).

Coral families at each site are presented in Table 2.1.

6 Approximate richness based on graphs.

Table 2.1 Coral families at each site.

Family	Site									
	CBW	CBC	FB	MB	LOB	MI1	MI2	PB	PR	WB
Acroporidae	✓	✓	–	–	✓	✓	✓	✓	✓	✓
Alcyoniidae	✓	✓	✓	✓	✓	✓	–	✓	✓	–
Dendrophyllidae	–	–	–	–	–	–	–	✓	–	–
Faviidae	✓	✓	✓	✓	✓	✓	–	✓	✓	✓
Fungiidae	✓	✓	–	–	–	–	✓	–	✓	–
Mussidae	–	–	–	✓	✓	–	–	✓	✓	✓
Pectiniidae	–	–	–	–	✓	✓	✓	–	–	✓
Pocilloporidae	✓	✓	–	–	–	✓	✓	✓	✓	✓
Poritidae	✓	✓	–	–	–	✓	–	✓	✓	✓
Sidastreiidae	✓	✓	–	–	–	–	–	✓	✓	✓

Epifauna

Coral-associated epifauna (e.g. ascidians, barnacles, bivalves, echinoderms, polychaetes and zoanthids) were rare, covering <10% of the substrate at any one site. Sponges and bivalves were the most common coral-associated epifauna. Sea cucumbers (*Holothuria leucospilota*) were relatively widespread and abundant at site PB (Putney Beach) in all of the surveys (Figure 2.13).

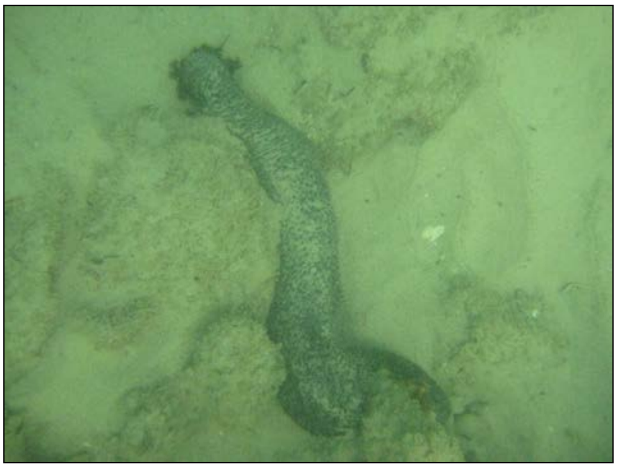


Figure 2.13

Sea cucumber (*Holothuria leucospilota*) at Putney Beach.

Macroalgae

Turf algae dominated the macroalgal communities, and typically grew on dead branching corals. There was low cover (typically <10%) of crustose coralline algae and larger growth forms from the genera *Lobophora*, *Padina* and *Halimeda* at most sites in most of the surveys.

Total macroalgal cover (including turf algae, crustose coralline algae and larger growth forms) varied between sites and within most sites. Cover was consistently high (>82%) at site MI2 (Middle Island Observatory; mostly turf algae) and relatively low, but variable between surveys, at sites FB (Fishermans Beach) and PB (Putney Beach). Macroalgal cover ranged from 0% at site PB (Putney Beach) during the post-set survey to 88% at site MI2 (Middle Island Observatory) during the wet season (Figure 2.14 and Figure 2.16).

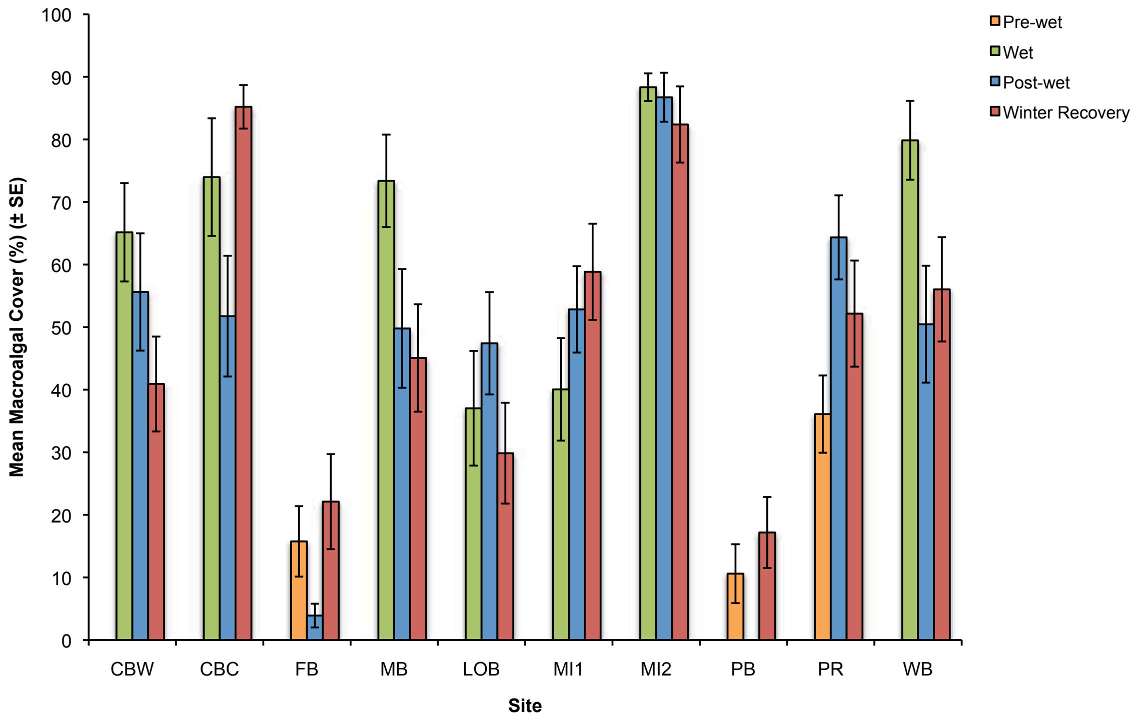


Figure 2.14 Mean percent cover of macroalgae (± SE) at each site.

Figure 2.15

Turf algae on dead coral near the Middle Island Observatory.

Jones et al (2011) reported low cover of crustose coralline algae (typically <10%[7]) on reefs in Keppel Bay. However there was moderate cover (typically <20%) of the macroalgae *Lobophora variegata* at some sites. Cover was relatively high (up to 45%) at Monkey Beach and Shelving Beach, moderate (up to 20%) at Passage Rocks and very low (<5%) at Middle Island and Wreck Beach. *Lobophora variegate* is reported to compete with corals for space on reefs in Keppel Bay following severe bleaching (Diaz-Pulido et al. 2009).

7 Approximate cover based on graphs.

Turf Algae

Cover of turf algae varied between sites and within most sites. Cover of turf algae was consistently high (>77%) at site MI2 (Middle Island Observatory), and to a lesser extent at site MB (Monkey Beach), and consistently low (<14%) at sites FB (Fishermans Beach) and PB (Putney Beach), although it varied between surveys. Cover of turf algae was relatively high at sites CBC (Clam Bay Central) and WB (Wreck Bay). Cover ranged from 0% at site PB (Putney Beach) during the post-wet survey to 85% at site CBC (Clam Bay Central) during the winter survey (Figure 2.16).

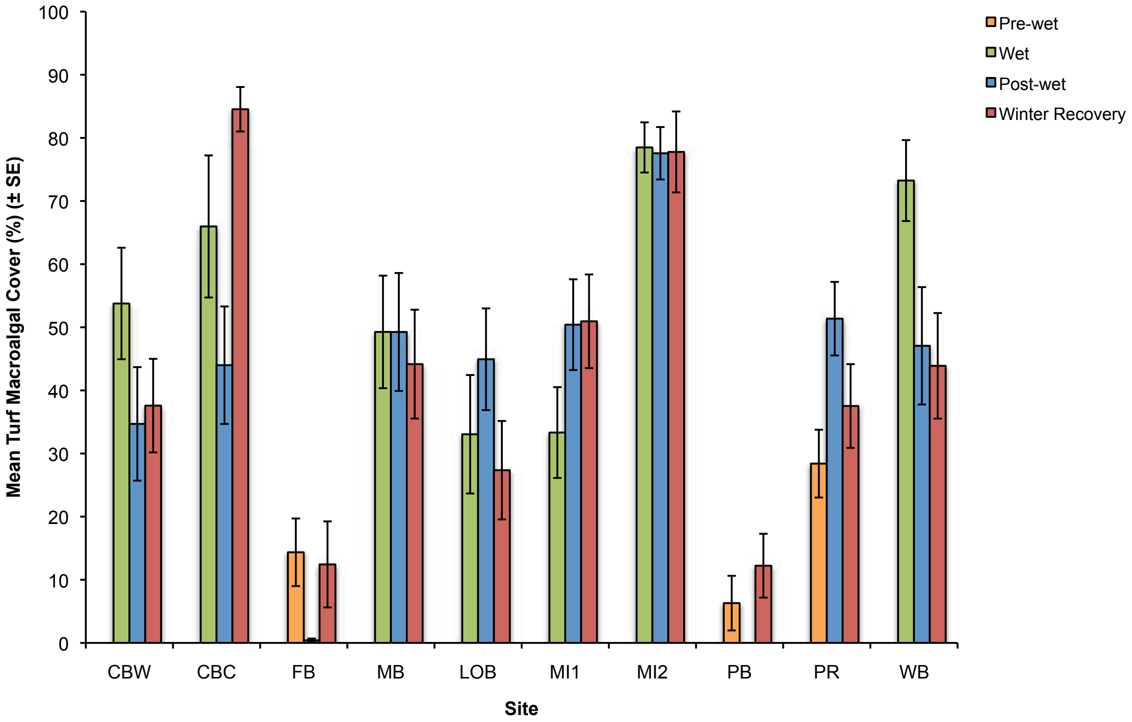


Figure 2.16 Mean percent cover of turf algae (± SE) at each site.

Crustose Coralline Algae

Cover of crustose coralline algae varied between sites and within sites. Cover ranged from 0% at site PB (Putney Beach) during the post-wet survey to 24% at site MB (Monkey Beach) during the wet survey (Figure 2.17 and Figure 2.18).

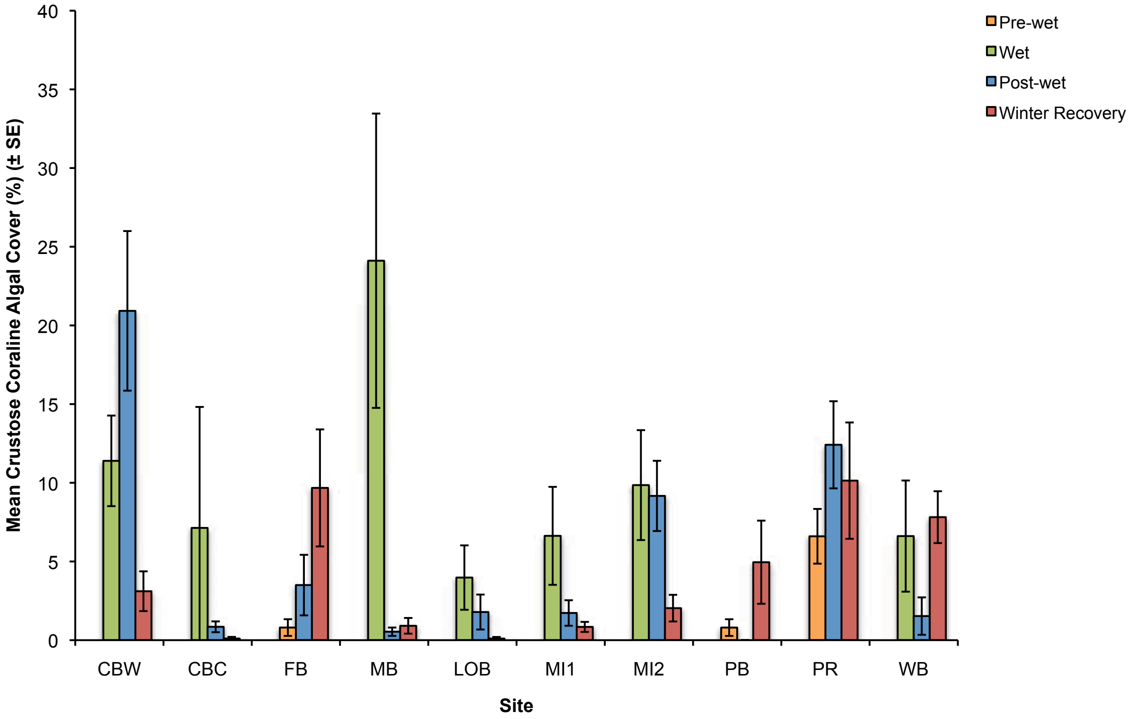
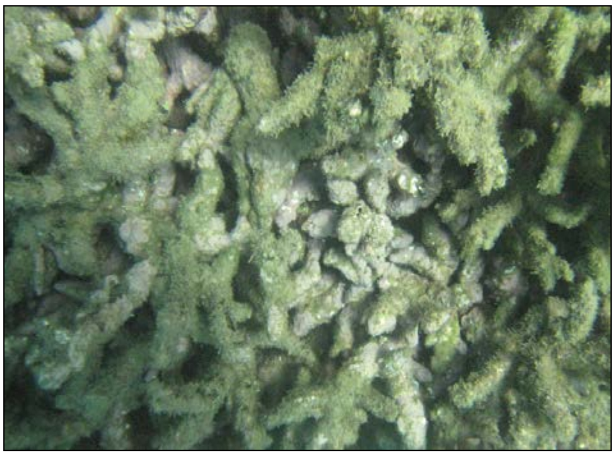


Figure 2.17 Mean percent cover of crustose coralline algae (± SE) at each site.

Figure 2.18

Crustose coralline algae (centre of photo) and turf algae on dead coral at the Clam Bay West site.



Sediment

Cover of sediment (rubble, sand and fine sediment) varied between sites and within most sites. Cover was consistently high (>47%) at site FB (Fishermans Beach) and PB (Putney Beach), and consistently low (<3%) at Middle Island sites and to a lesser extent (<13%) sites PR (Passage Rocks) and WB (Wreck Bay). Cover ranged from 0% at site MI1 (Middle Island) during the post-wet and winter surveys to 89% at site FB (Fishermans Beach) during the post-wet survey (Figure 2.19).

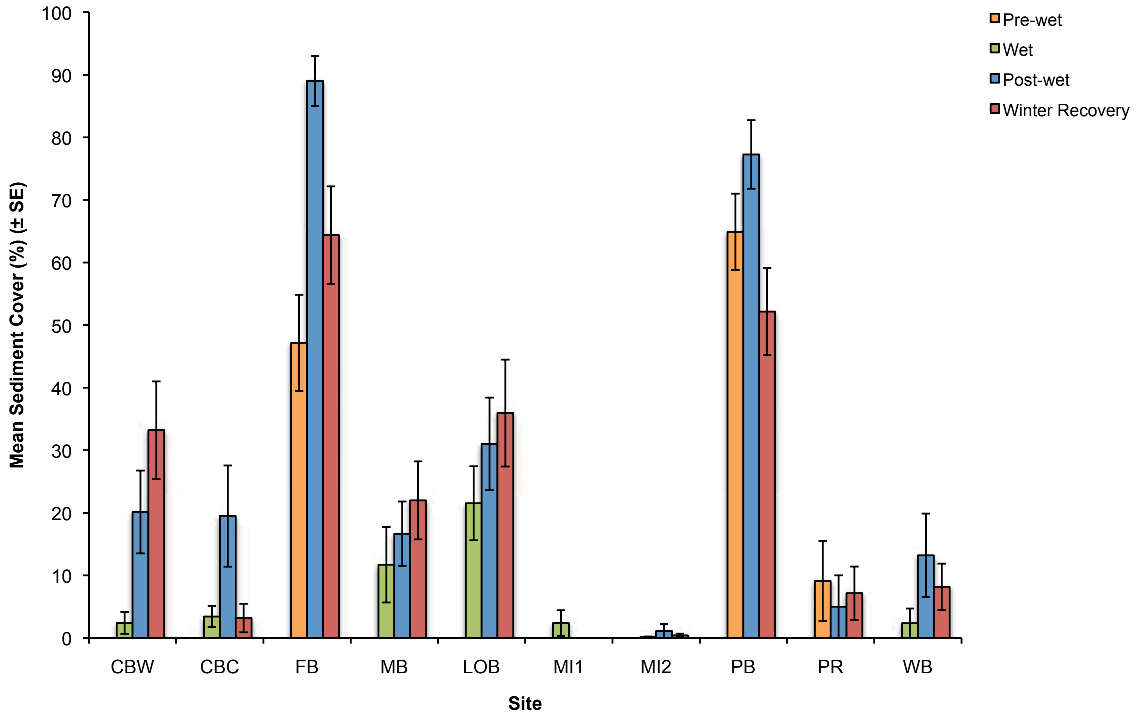


Figure 2.19 Mean percent cover of sediment (± SE) at each site.

Rubble

The amount of substrate covered with rubble varied between sites and within most sites. Cover was consistently high (>12%) at site LOB (Long Beach) and consistently low (<3%) at Middle Island sites (MI1 and MI2) and sites PB (Putney Beach) and PR (Passage Rocks). Cover ranged from 0% at several sites to 19% at site FB (Fishermans Beach) during the post-wet survey (Figure 2.20 and Figure 2.21).

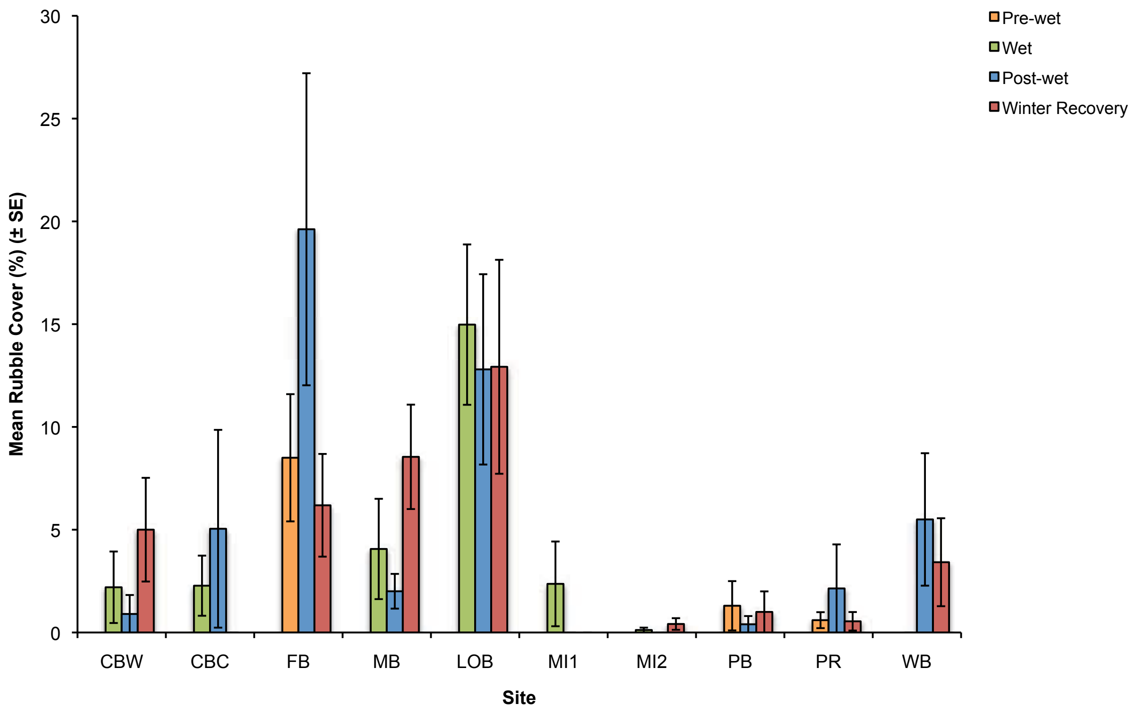
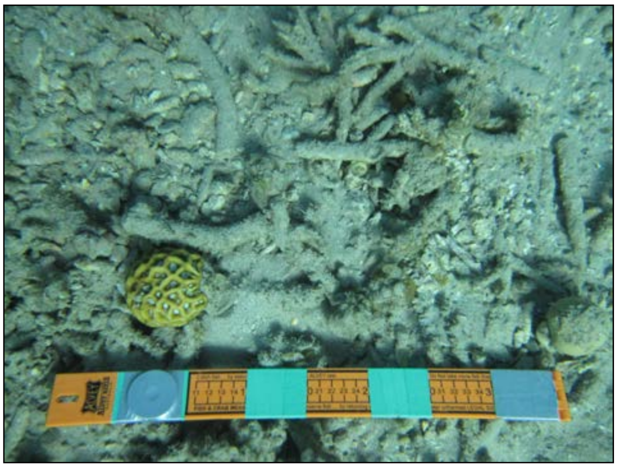


Figure 2.20 Mean percent cover of rubble (± SE) at each site.

Figure 2.21

High cover of rubble at Long Beach.



Sand

The amount of substrate covered with sand varied between sites but was similar between surveys at most sites. There was no sand recorded at the Middle Island sites and cover was consistently low (<10%) at most sites during most surveys. Cover ranged from 0% at several sites to 40% at site FB (Fishermans Beach) during the post-wet (Figure 2.22 and Figure 2.23).

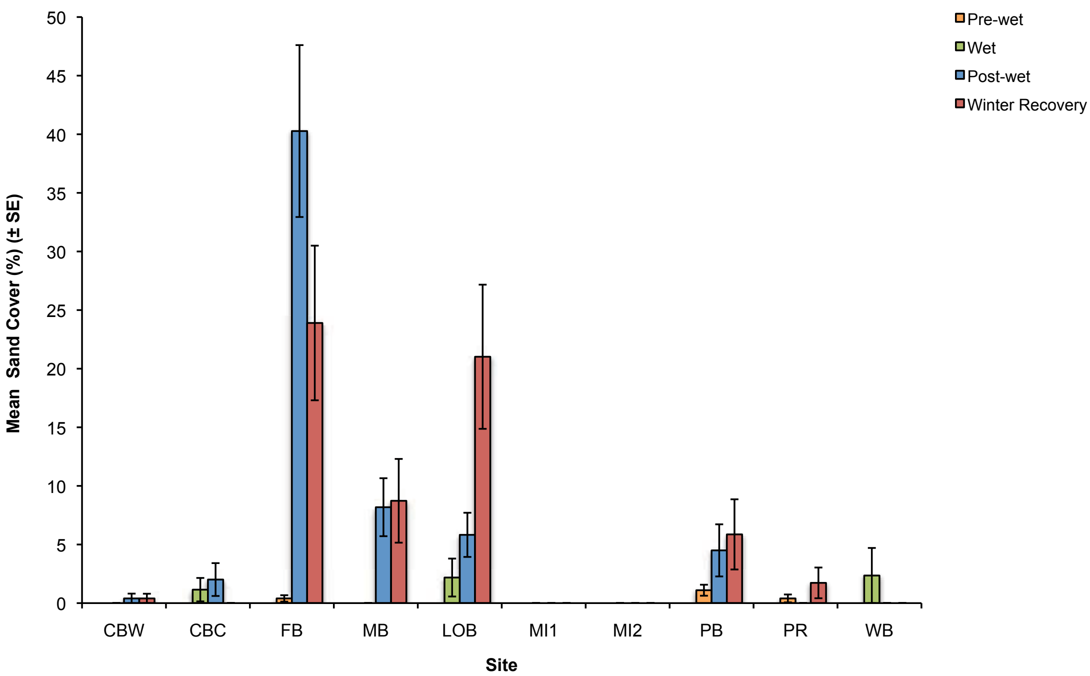


Figure 2.22 Mean percent cover of sand (± SE) at each site.

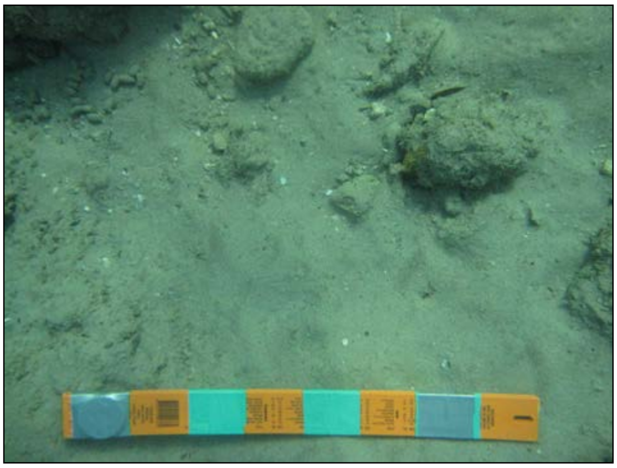


Figure 2.23

High cover of sand at Fishermans Beach.

Fine Sediment

Cover of fine sediment, trapped by turf algae, varied between sites but was similar between surveys at most sites. Cover was consistently high (>42%) at site PB (Putney Beach), and to a lesser extent (>29%) site FB (Fishermans Beach), and consistently low (<11%) at several sites (CBC, MB, LOB, MI2, PR and WB). Fine sediment was not recorded at site MI1 (Middle Island). Cover ranged from 0% at several sites to 72% at site PB (Putney Beach) during the post-wet survey (Figure 2.24).

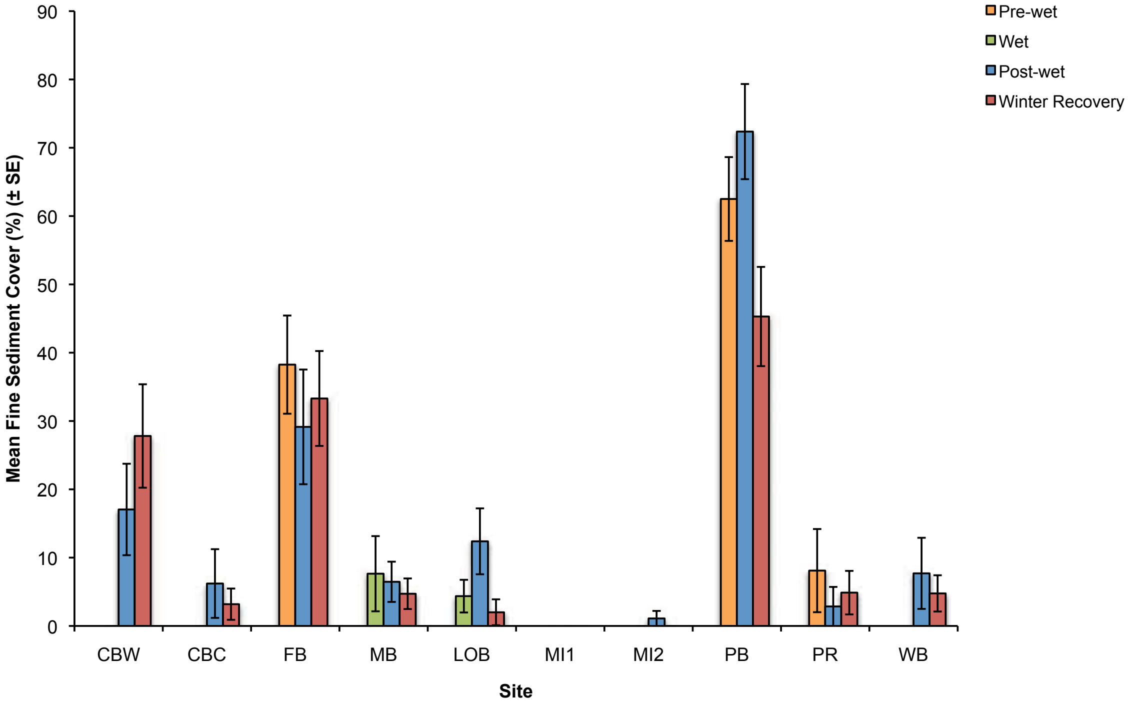


Figure 2.24 Mean percent cover of fine sediment (± SE) at each site.

2.2 Intertidal Rocky Shores

The intertidal rocky shore at Putney and Fishermans beaches supported a diverse invertebrate community, including oysters, barnacles, gastropods, limpets, chitons, anemones and crabs (Table 2.2, Figure 2.25 and Figure 2.26).

Figure 2.25

The rocky shore at Putney Beach.

Figure 2.26

The rocky shore at Fishermans Beach.

Table 2.2 Rocky shore taxa recorded at Putney and Fishermans beaches.

Family *Species*	Common Name	Putney Beach	Fishermans Beach
Actiniidae			
Aulactinia veratra	anemone	√	√
Balanidae			
Austromegabalanus sp.	royal barnacle	√	–
Chitonidae			
Acanthopleura gaimardi	Gaimard's chiton	√	–
Chthamalidae			
Chthamalus antennatus	upper-shore barnacle	√	√
Grapsidae			
Grapsus sp.	grapsid crab	√	–
Littorinidae			
Bembicium nanum	stripe-mouthed periwinkle	√	–
Nodilittorina millegrana	periwinkle	√	–
Nodilittorina pyramidalis	pyramid periwinkle	√	√
Nodilittorina unifasciata	blue periwinkle	√	√
Muricidae			
Morula marginalba	mulberry whelk	√	√
Neritidae			
Nerita polita	polished nerite	√	√
Nerita atramentosa	black nerite	√	√
Ostreidae			
Saccostrea sp.	rock oyster	√	√
Patellidae			
Cellana conciliata	limpet	√	–
Cellana radiata	limpet	√	√
Cellana tramoserica	limpet	√	√
Planaxidae			
Planaxis sulcatus	furrowed clusterwink	√	√

Family *Species*	**Common Name**	**Putney Beach**	**Fishermans Beach**
Siphonariidae			
Siphonaria denticulata	false limpet	√	√
Tetraclitidae			
Tesseropora rosea	rose barnacle	√	√
Trochidae			
Austrocochlea sp.	top snail	√	√

Rock oysters (*Saccotrea* sp.) dominated the upper intertidal zone at both Putney and Fishermans beaches (Figure 2.27). There are several licences for commercial wild harvest of the milky oyster (*Saccostrea amasa*) near the proposed development (as discussed in Appendix G). The licence for Putney Beach, adjacent to the proposed marina development, has been surrendered.

Figure 2.27

Rock oysters (*Saccostrea* sp.) dominate the intertidal zone.

Putney Beach had a more diverse rocky shore community then Fishermans Beach with a total of 20 species compared to 14 species. The Putney Beach community included three species of barnacle, 13 species of gastropod, and one species of chiton, anemone and crab (Figure 2.28 and Figure 2.29). The most common gastropods were furrowed clusterwinks (*Planaxis sulcatus*) and pyramid periwinkles (*Nodilittorina pyramidalis*) (Figure 2.30 and Figure 2.31). These communities are typical of rocky shores in the region, as discussed in Section 3.2.

Figure 2.28

A variety of gastropods (*Nerita* sp., *Austrocochlea* sp. and *Planaxis sulcatus*) at Putney Beach.

Figure 2.29

A grapsid crab (*Grapsus* sp.) at Putney Beach.

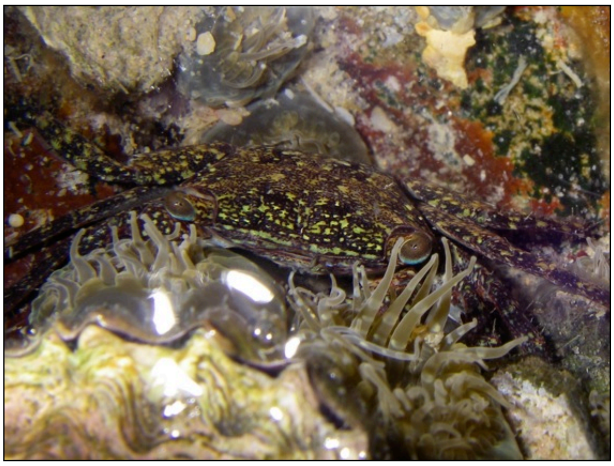


Figure 2.30

Furrowed clusterwinks (*Planaxis sulcatus*) were widespread at Putney and Fishermans beaches.

Figure 2.31

Pyramid periwinkles (*Nodilittorina pyramidalis*) were widespread.

2.3 Benthic Infaunal Invertebrate Communities

Polychaeta (worms) and malacostracan crustaceans (amphipods, isopods and decapods) were the most common and abundant benthic infaunal taxa, recorded at each site in all of the surveys.

Taxonomic Richness

Mean taxonomic richness (mean number of taxa per core, typically families) varied between sites and within some sites. Taxonomic richness was relatively high, but variable between surveys, at site PB3 (Putney Beach), and consistently low (<2 taxa) at sites CB (Clam Bay), LOB (Long Beach) and at the mainland (KB and TB). Taxonomic richness ranged from <1 taxa at site WB (Wreck Beach) in the wet survey and at the mainland sites (KB and TB) during the post-wet survey, to 10 taxa at site PB3 (Putney Beach) during the pre-wet survey (Figure 2.32)[8].

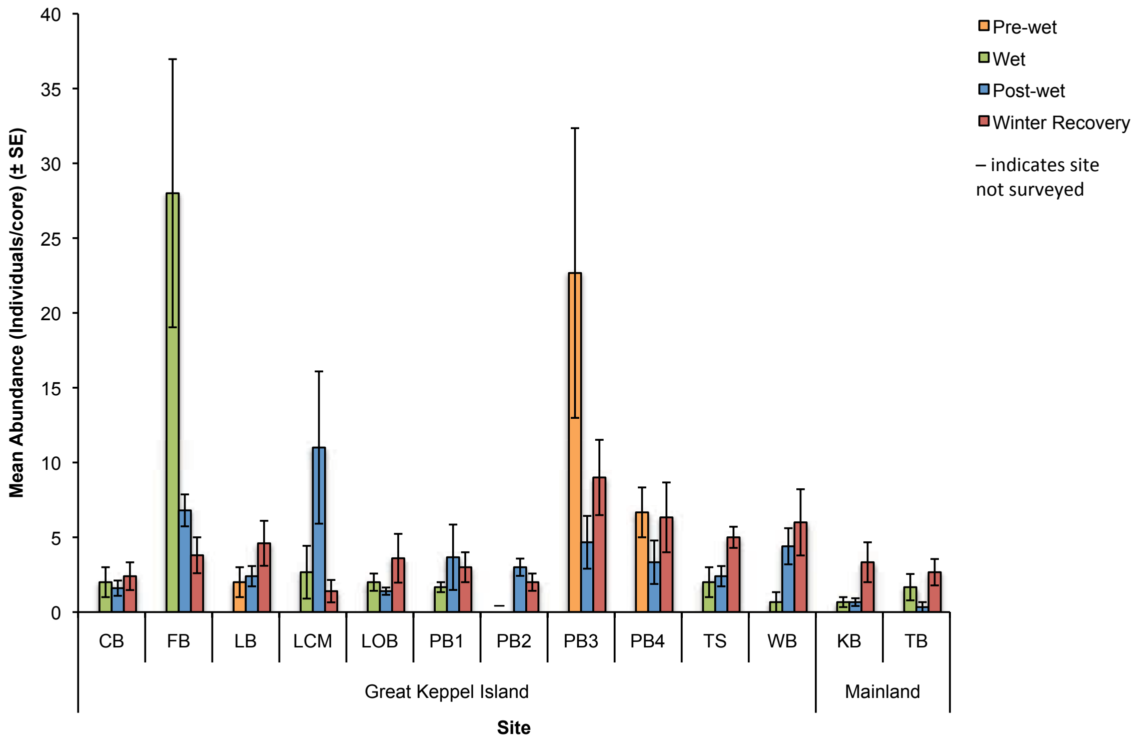


Figure 2.32 Mean taxonomic richness (± SE) at each site.

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8 Invertebrate communities of Fishermans Beach and Putney Beach were surveyed during the pre-wet, post-wet and winter surveys. Invertebrate communities of Clam Bay, Monkey Beach, Long Beach, Middle Island and Wreck Beach were surveyed during the wet survey (as they were not accessible during the pre-wet season due to permit and boat constraints), post-wet and winter surveys. Invertebrate communities of the mainland were surveyed during the wet survey (as they were added to the project area after the pre-wet survey, to consider impacts of the submarine cable crossing), post-wet and winter survey.

Abundance

The mean abundance of invertebrates (i.e. mean number of individuals per core) varied between sites, but was relatively similar between surveys at each site. Abundance was relatively low (<7 individuals) at most sites in most of the surveys. Abundance was highly variable at sites FB (Fisherman Beach) and PB3 (Putney Beach); this may reflect 'boom and bust' cycles often associated with nutrient enrichment, due to sewage input from Putney Creek and moored vessels at Fishermans Beach (as discussed below). Mean abundance ranged from <1 individual at site KB (Kinka Beach) during the wet survey to 28 individuals at site FB (Fishermans Beach) during the pre-wet survey (Figure 2.33).

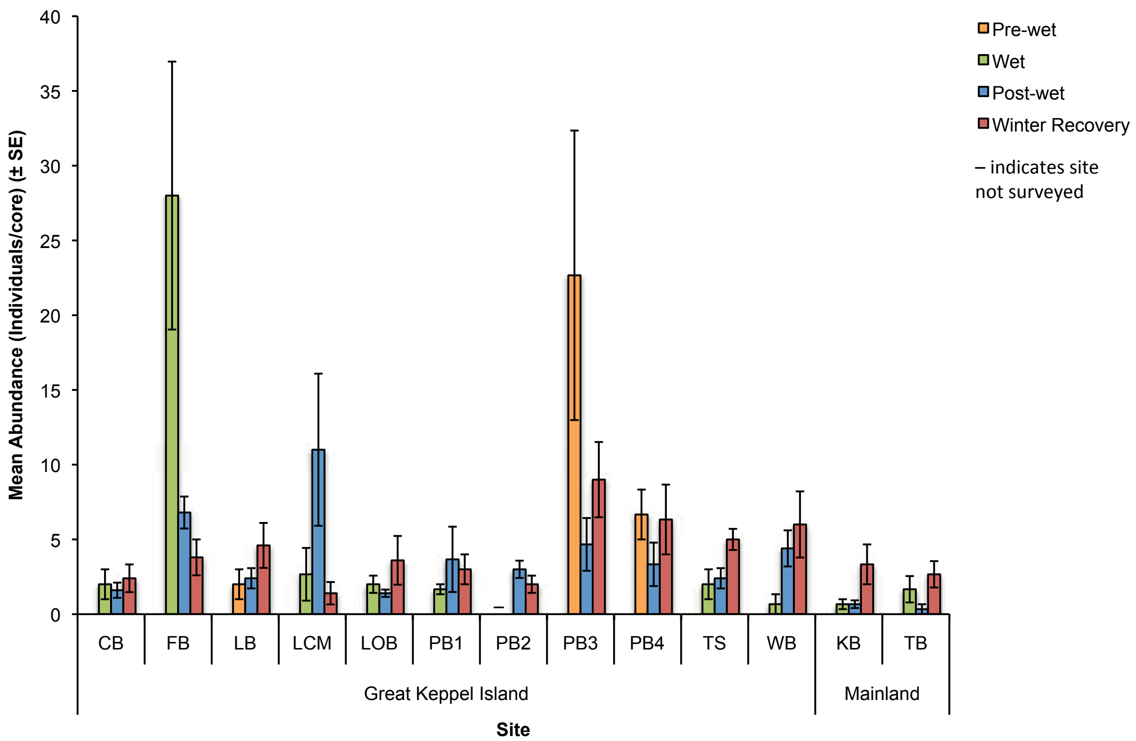


Figure 2.33 Mean abundance (± SE) at each site.

Dominant Taxa

Polychaetes were the most widespread and abundant taxa. The most common polychaete families were Capitellidae, Oenonidae, Sabellidae and Orbinidae. These four families are common in sand to mud substrates and are often associated with seagrass beds (Beesley et al. 2000).

Polychaetes

At sites FB (Fishermans Beach) and PB3 (Putney Beach) the mean abundance of polychaetes was relatively high, but varied between surveys. Mean abundance was relatively low (<5 individuals per core) at most of the remaining sites during most surveys. Mean abundance ranged from 0 individuals per core at sites CB (Clam Bay) and TB (Tanby Beach) during the post-wet survey to 27 individuals per core at site FB (Fishermans Beach) during the pre-wet survey (Figure 2.34).

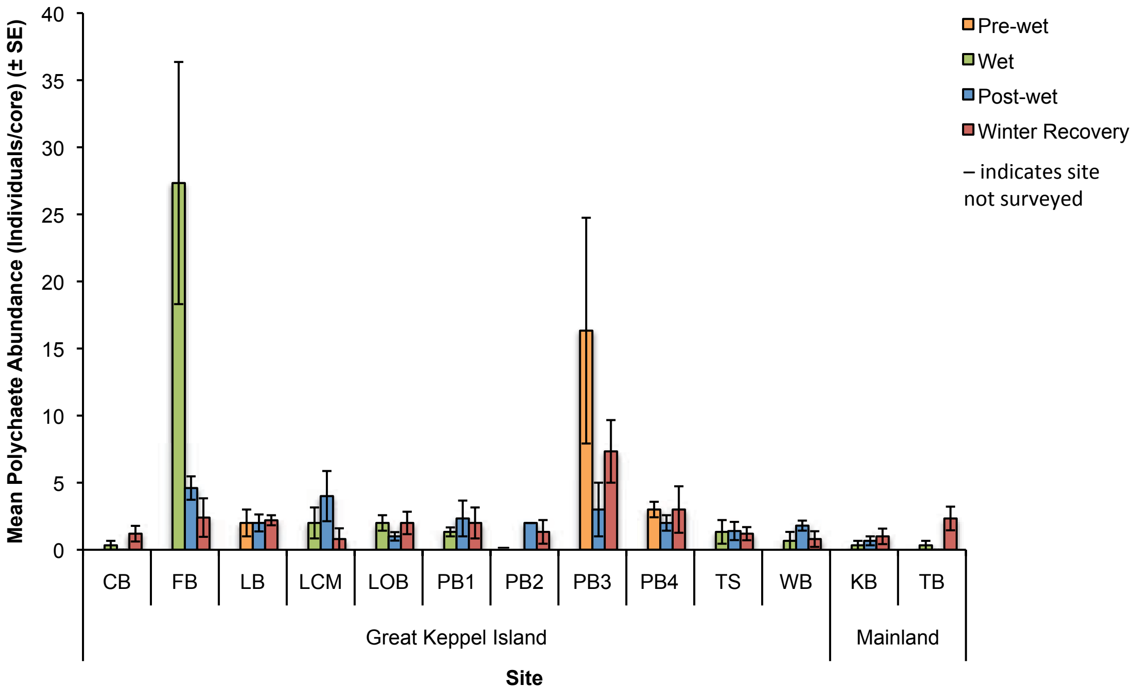


Figure 2.34 Mean abundance of polychaetes (± SE) at each site.

The high abundance of polychaetes at Fishermans and Putney beaches during the wet survey is likely to be related to nutrient enrichment associated with sewage input from Putney Creek and moored vessels at Fishermans Beach (marine water quality is discussed in Appendix C and freshwater water quality is discussed in Appendix G). Capitellids dominated polychaete assemblages during the pre-wet survey, and are indicative of nutrient enrichment (ANZECC & ARMCANZ 2000).

Malacostracan Crustaceans

Malacostracan crustaceans were relatively widespread and abundant, which is common in marine sediment of tropical waters. Gammerid amphipods were the dominant taxa, particularly during the winter survey. The mean abundance of malacostracans was highly variable between sites and within sites. Abundance was relatively high, but variable between surveys and within surveys, at sites PB4 (Putney Beach) and WB (Wreck Bay), and consistently low (<1 individuals per core) at sites FB (Fishermans Beach), LCM (Leeke's Creek Mouth) and PB2 (Putney Beach) (Figure 2.35).

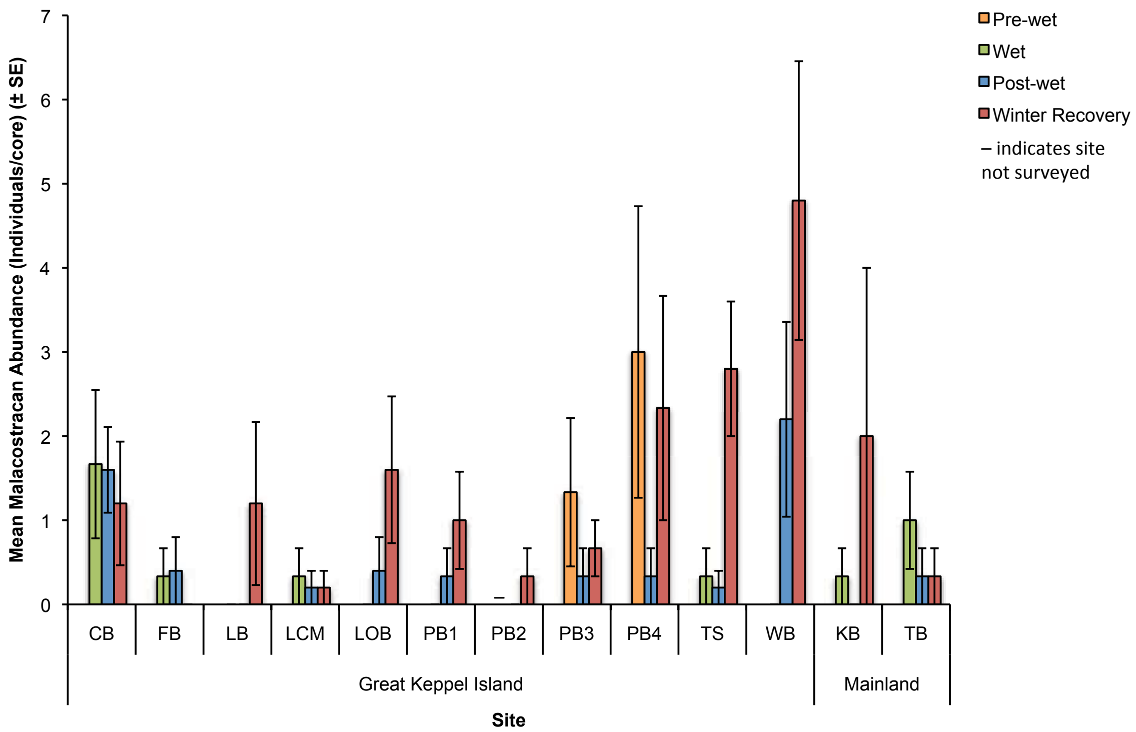


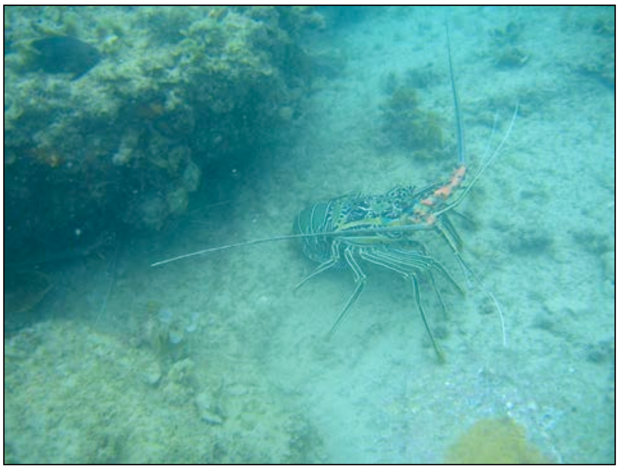
Figure 2.35 Mean abundance of malacostracan crustraceans (± SE) at each site.

2.4 Decapod Macrocrustaceans

The ornate spiny lobster (*Panulirus ornatus*) was recorded at several coral sites, including several individuals at Putney Beach during the pre-wet, post-wet and recovery surveys (Figure 2.36). Ghost crabs (*Ocypode* spp.) were common on the upper beaches while soldier crabs (*Mictyris longicarpus*) were common on lower beaches. Grapsid crabs (*Grapsus* sp.) were common in the rock pools of Putney and Fishermans beaches. Hermit crabs (*Dardanus pedunculatus* and *Cilianarius taeniatus)* were common in a range of habitats.

Figure 2.36

Ornate spiny lobster (*Panulirus ornatus*) at Putney Beach.



Mud crabs (*Scylla serrata*) are likely to occur in association with the mangrove forests of Leeke's Creek. Orange-clawed fiddler crabs (*Uca coarctata*) were common in the mangrove forests. Soldier crabs were particularly abundant in Leeke's Creek on the low tide.

The blue swimmer crab (*Portunus pelagicus*) is likely to inhabit the project area; it is common in shallow, sandy to muddy inshore waters and seagrass meadows of the region (Queensland Museum 2011).

Several species are of fisheries significance, as discussed in Appendix H.

2.5 Fishes

The coral, seagrass and mangrove communities of the project area provide habitat for a variety of elasmobranchs and fin-fishes. Species important to fisheries are discussed in Appendix G.

Elasmobrachs

Elasmobrachs recorded during the surveys included:

- epaulette shark (*Hemiscyllium ocellatum*) at Putney Beach and Passage Rocks (Figure 2.37)
- blue-spotted stingray (*Dasyatis kuhlii*) at Putney Beach and Leeke's Creek (Figure 2.38)
- cowtail stingray (*Taeniura melanospila*) at Putney Beach
- estuarine stingray (*Dasyatis fluviorum*) at Leeke's Creek
- common shovel-nosed ray (*Rhinobatos batillum*) at Fishermans Beach, and
- spotted eagle ray (*Aetobatus narinari*) at Wreck Beach.

Figure 2.37

Epaulette shark (*Hemiscyllium ocellatum*) at Putney Beach.

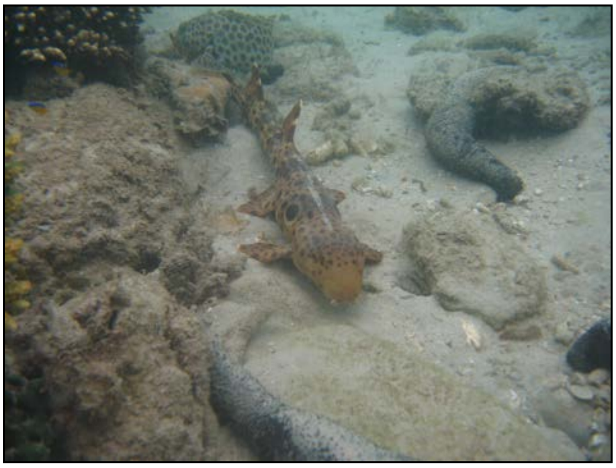


Figure 2.38

Blue-spotted stingray (*Dasyatis kuhlii*) at Putney Beach.

Whilst manta rays (*Manta birostris*) are reported to frequent Putney Beach annually (CCC 2009), they were not recorded during the surveys and are more characteristically associated with areas of upwelling and oceanic island chains (particularly seamounts and offshore pinnacles) (Marshall et al. 2009 and references cited within).

Manta alfredi may occur in the waters of the project area. This species is commonly sighted inshore (within a few kilometres of the mainland) in association with coral and rocky outcrops as well as area of upwelling and oceanic island chains (Marshall et al. 2009 and references cited within). *Manta alfredi* is typically found in waters with abundant plankton as this species feeds primarily on zooplankton. There is no information readily available on the feeding ecology of Australian populations. Populations in the Maldives feed almost exclusively on the downstream side of atolls as water currents create a phytoplankton bloom in the lee of the atoll (which is a food source for zooplankton); manta rays are most commonly observed in areas of relatively low visibility (mean of 12 m) due to abundant plankton (Anderson et al. 2011).

Manta alfredi is reported to have high site fidelity and are known to travel long distances (e.g. approximately 500 km from Lady Elliott Island to Byron Bay) on a seasonal basis (Anderson et al. 2011; Couturier et al. 2011; Deakos et al. 2011).

Coral-associated Communities

Coral reef fin-fish communities were generally dominated by damselfish (Pomacentridae), wrasse (Labridae), sweetlip (Haemulidae) and fusiliers (Caesionidae), together with rabbitfish (*Siganus* spp.), butterflyfish (Chaetodontidae), emperors (Lethrinidae), seaperch (*Lutjanus* spp.), cardinalfish (Apogonidae), drummers (Monodactlidae), angelfish (Pomacanthidae), emperors (*Lethrinus* spp.), goatfish (Mullidae), puffers (Tetradontidae), cod (Serranidae), surgeonfish (Acanthuridae) and parrotfish (Scaridae) (Figure 2.39 to Figure 2.42).

These families are typical of inshore reefs of the Great Barrier Reef. Community composition is generally similar on reefs located a similar distance from the mainland, in terms of all major reef fin-fish families (pers. obs; Russell et al. 1978; Williams 1982; Williams 1983; Williams & Hatcher 1983; Russ 1984; Newman & Williams 1996; Fabricius et al. 2005). The distribution and abundance of reef fin-fish taxa appears to be strongly influenced by physical factors such as wave exposure, sediment loads, water depth and topographical complexity, together with biological factors. The small differences in within-reef community composition appear to be related to wave energy (Williams 1982). Coral reef fin-fish of the region are discussed in Section 3.5.

Figure 2.39

Mixed fish community at Putney Beach.

Figure 2.40

Mixed fish community at Middle Island, dominated by pomacentrids and labrids.

Figure 2.41

Mixed pomacentrids at Fishermans Beach

Figure 2.42

Mixed fish community at Fishermans Beach, including pomacentrids, goldlined rabbitfish (*Siganus lineatus*), Spanish flag (*Lutjanus carponotatus*) and blackeye thicklip (*Hemigymnus melapterus*).

The fin-fish communities associated with the coral of Putney Beach were dominated by:

- goldlined rabbitfish (*Siganus lineatus*)
- sergeant major (*Abudefduf* sp.), Barrier Reef chromis (*Chromis nitida*), *Neopomacentrus* sp., *Chromis* spp. and other pomacentrids
- moon wrasse (*T. lunare*) and other labrids
- blackeye thicklip (*H. melapterus*)
- rockcods (*Epinephelus* spp.)
- yellowfin bream (*Acanthopargus australis*), a species of fisheries importance
- sweetlip (*Lethrinus* spp. and *Plectorhinus* spp.) including species of fisheries importance such as the grass (*Lethrinus laticaudisi)* and brown sweetlip (*Plectorhinus gibbosus*)
- golden-striped butterflyfish (*C. aureofasciatus*)
- cardinalfish (*Apogon* spp.)
- Spanish flag (*L. carponotatus*)
- striped pufferfish (*Arothron manilensis*)
- butter bream (*Monodactylus argenteus),* and
- freckled goatfish (*Upeneus tragula*).

Coral trout (*Plectropomus* spp.) were recorded at Passage Rocks, Middle Island (both coral sites) and Clam Bay during all surveys. Sweetlip (*Plectorhinus* spp.) were particularly abundant at Middle Island (coral site MI1) and Passage Rocks during the winter survey. Fusilers (*Caesio* spp. and *Pterocaesio* spp.) and the Barrier Reef chromis (*C. nitida*) dominated communities at Monkey Beach, Long Beach and Wreck Beach (coral sites) in all of the surveys.

Evans et al (2008) compared fecundity and biomass of *L. carponotatus* in no-take areas of Marine National Park (green) zones and fished areas around Great Keppel Island. The potential fecundity and biomass was greater in the no-take areas than in fished areas. Greater biomass of *L. carponotatus* in no-take areas compared to fished areas was also reported around Great Keppel Island by Williamson et al (2004). The zoning of no-take areas appears to significantly increase the biomass of species targeted by fishing (such as *L. carponotatus* and coral trout) around Great Keppel Island (Williamson et al. 2004; Evans et al. 2008) and other inshore reefs of the Great Barrier Reef (Graham et al. 2003; Evans & Russ 2004; Fabricius et al. 2005; Russ et al. 2008); however there are no reported difference in the densities or size of *L. carponotatus,* or *Plectropomus maculatus,* between no-take and fished areas around Great Keppel Island. Mannering (2008).

The anemone fishes *Heteractis crispa* and *Cryptodendrum adhaesivu* have been recorded in association with coral reef at the mouth of Leeke's Creek, with two other species found at other sites in Keppel Bay (CCC 2010). Anemone fish were not recorded in these surveys (however the reef at Leeke's Creek mouth were not surveyed). Frisch and Hobbs (2009) report that anemones and anemonefishes are currently rare in Keppel Bay, and appear to have been impacted by bleaching and unsustainable collection for the aquarium trade.

Seagrass-associated Communities

Few adult fish were recorded in the seagrass meadows; however several blenny and goby burrows were observed. These species are a food source for commercially and recreationally important fish species. Ray feeding-pits were relatively common in the seagrass meadows, suggesting that the blue-spotted, cowtail and shovelnose rays commonly fed on benthic infaunal invertebrates within the sediment of the meadows.

Seagrass communities typically provide nursery habitat for larval and juvenile fishes from a variety of commercially and recreationally important species, including trevally (*Carangoides* sp.), queenfish (*Scomberoides commersonianus*), dusky flathead (*Platycephalus fuscus*) and flounder (*Pseudorhombus* sp.). The seagrass meadows of the project area are fragmented, comprising small patches of sparse seagrass. Fragmentation of seagrass meadows influences the diversity and abundance of infauna and epifauna in them (Jelbart et al. 2006; Reed & Hovel 2006), with increased fragmentation typically leading to lower abundance and diversity of species within a patch (Connolly & Hindell 2006; Jackson et al. 2006).

The proximity of mangroves also strongly influences fauna assemblages in seagrass communities (e.g. Skilleter et al. 2005; Jelbart et al. 2007), with significantly greater densities of fish species, and juveniles, in seagrass beds close to mangroves compared to beds further away (Jelbart et al. 2007). The abundances of two species of penaeid prawns was also greater in seagrass beds nearer mangroves, regardless of seagrass shoot density Skilleter et al. (2005), that is, the influence of habitat connectivity may be more important than structural complexity.

Seahorse, pipefish and pipehorse species (sygnathids) are listed 'marine' species under the EPBC Act, meaning that they are protected within Commonwealth Marine waters, including the GBRMP. The distribution of these species is often closely associated with seagrass beds. Sygnathids were not recorded during the surveys and are unlikely to be common in the project area given the sparse and patchy distribution of seagrass.

Leatherjackets (species unknown) are reported to frequent the seagrass beds of Putney Beach (CCC 2009). Leatherjackets were not recorded during the surveys, and are unlikely to be currently common in the project area given the sparse and patchy distribution of seagrass.

Mangrove-associated Communities

Fish communities associated with the Leeke's Creek mangrove forest were characterised by mobile, transient species with little direct commercial or recreational value, in particular hardyheads (*Atherinidae* spp.) and silverbiddies (*Gerres subfasciatus*). Estuarine and blue-spotted rays were regularly observed feeding in Leeke's Creek in relatively large numbers (up to ten individuals were observed near the creek mouth with tens of feeding-pits evident).

Fish communities in Putney Creek were highly variable as the creek was dry for much of the year. Mangrove-associated communities would include mobile, transient species such as hardyheads and silverbiddies following large tides, although communities would die-off when pools dry-up.

2.6 Marine Reptiles

Marine Turtles

Marine turtles are relatively widespread in the project area. Three species of marine turtle were recorded during the surveys, the flatback (*Natator depressus*), green (*Chelonia mydas*) and hawksbill (*Eretmochelys imbricata*). The following turtle sightings were recorded in the ecological surveys:

- unidentified turtle swimming near Fishermans Beach during the pre-wet survey
- hawksbill turtle feeding on the reef at Passage Rocks during the pre-wet survey
- unidentified turtle swimming off Wreck Beach during the wet survey
- green turtle feeding on reef at Long Beach during the wet survey
- unidentified turtle swimming in the channel adjacent to Middle Island during the wet survey
- two unidentified turtles swimming in the channel near Passage Rocks during the wet survey

- unidentified turtle swimming near Clam Bay during the wet survey
- unidentified turtle swimming near Fishermans Beach point during the wet survey
- green turtles feeding near Clam Bay during the post-wet survey
- green turtle swimming near Wreck Beach during the post-wet survey
- hawksbill turtle feeding on the reef at Middle Island during the winter survey
- unidentified turtle feeding on reef at Long Beach during the winter survey, and
- unidentified turtle swimming off Bald Rock point during the winter survey.

Other marine turtles are likely to occur in the project area as discussed on Section 3, specifically the loggerhead (*Caretta caretta*) hawksbill (*Eretmochelys imbricata*) and olive ridley (*Lepidochelys olivacea*) turtle.

Nesting Activity

A total of 29 nesting activities were recorded on Leeke's, Putney and Long beaches during the 2010–11 nesting season. Twenty of these were recorded on Leeke's Beach, while six on Long Beach, and three on Putney Beach (Figure 2.43 and Figure 2.44 to Figure 2.46). No turtle nesting was recorded on Fishermans Beach. Predation by monitors was recorded at several nests (Figure 2.47) and some nests were inundated by large tides.

Figure 2.43

Flatback turtle (*Natator depressus*) on Long Beach.

frc environmental AQUATIC ECOLOGISTS deep thinking. science.	Great Keppel Island Revitalisation EIS	
	Figure 2.44 Turtle nesting locations on Leeke's Beach in the 2010-11 nesting season.	
	Microsoft Bing © 2010 Microsoft Corporation	March 2011

Great Keppel Island Revitalisation EIS	
Figure 2.45 Turtle nesting locations on Long Beach in the 2010-11 nesting season.	
Microsoft Bing © 2010 Microsoft Corporation	March 2011

Figure 2.47

Predation of turtle eggs by monitor.

These results are consistent with observation by island resident Lyndie Svendsen[9], who recorded a small number of flatback and green turtles nesting on the beaches of Great Keppel Island in previous years. Of the beaches observed, most nesting activity has been reported from Leeke's Beach, Long Beach, Second Beach and Butterfish Bay. From 2005 to 2009, four turtle nesting activities were reported for Putney Beach.

Flatback turtles appear to prefer nesting beaches adjacent to sand / mud intertidal zones, rarely nesting on beaches fronted by coral. The major eastern Australian breeding aggregation includes nearby Peak Island, approximately 15 km from the project area, Wild Duck and Avoid islands to the north and Curtis Island to the south. Females display a high degree of fidelity to a nesting beach; most return to the same small beach during a nesting season, and in successive nesting seasons (Limpus 1971; Limpus et al. 1981; Limpus et al. 1984; Limpus et al. 1992).

Green turtles prefer nesting beaches adjacent to coral reef, and females also show high fidelity to nesting beaches (Limpus et al. 1992). There is a major eastern Australian breeding aggregation on coral cays of the Capricorn Bunker group, approximately 70 km to the east of the project area. Turtles nest on a variety of beaches, but nesting activity tends to be highest on beaches that have a relatively high dune (to reduce flood impacts) and on sand that is coarse enough to facilitate gas diffusion, but fine enough to support excavation of the egg cavity by hatchlings. Nest site selection also appears to be influenced by factors such as beach morphology (e.g. width, slope and area), vegetative

9 Information received by email dated 12 April 2011. Observations were made at Leeke's, Second, Wreck, Putney, Long, Svendsen's and Fishermans beaches together with Butterfly Bay. Most observations were made by one individual, together with incidental sightings and reports by yachties, ferry staff etc.

cover (with high cover avoided) and human activity (e.g. Butler 1998; McLachlan & Brown 2006; Fuentes et al. 2009; Lawrence & Nelson 2011). The near vertical (eroding) dune of Putney Beach and dense vegetation may reduce the number of turtles nesting at this beach (Figure 2.48).

Figure 2.48

Erosion of Putney Beach associated with flow in Putney Creek, following heavy rainfall during the wet season.

Seasnakes

A seasnake (unidentified) was recorded off Leeke's Beach over sandy substrate. Seasnakes inhabit a range of habitats, including sandy bottom habitats, reef habitats and pelagic habitats (*Pelamis* sp. only) (Stokes 2004). The olive (*Aipysurus laevis*) and stokes (*Astrotia stokesii*) seasnake are relatively abundant at Passage Rocks and Middle Island (Lynch 2000; GBRMPA 2007), and are likely to inhabit the project area.

2.7 Marine Mammals

A small pod (approximately six to eight individuals) of bottlenose dolphin (*Tursiops* sp.) was recorded near Fishermans Beach during the pre-wet survey. The pod consisted of adults and juveniles, and appeared to be feeding.

Other marine mammals may occur in the project area as discussed in Section 3, specifically the Indo–Pacific humpback dolphin (*Sousa chinensis*) and dugong (*Dugong dugon*), and to a lesser extent humpback whale (*Megaptera novaeangliae*) and minke whale (*Balaenoptera acutorostrata)* (with the latter traversing open waters offshore of the project area).

Dugong feed in the waters of Great Keppel Island, with a mother and calf having been reported to frequent Putney Bay (CCC 2009). While it is likely that seagrass meadows of the project area may have been relied upon for food in the past, they are likely to provide a less critical source of food since the 1970-80s, when the meadows substantially decreased in cover and extent (refer Appendix E).

Dugongs can be highly migratory due to their search for suitable seagrass (Marsh et al. 2002) and are known to travel several hundreds of kilometers. Dugongs have evolved to cope with the inherently unpredictable and patchy nature of seagrass meadows by moving to alternative areas known to support seagrass in the past. For example, following a large-scale loss of seagrass in Hervey Bay, associated with two floods and a cyclone in quick succession, individuals appeared to survive by relocating to Moreton Bay 300 km to the south (Sheppard et al. 2006).

3 Regional and Ecological Context

3.1 Coral communities

Of the Region

While the most diverse coral communities are in clear, offshore waters, extensive inshore coral communities are also common in tropical waters such as those of the project area. Coral communities typically include hard corals together with soft corals, sponges, ascidians, gastropods, macroalgae and other invertebrate taxa. Coral reefs are the most diverse marine ecosystem, supporting a wide range of species including fishes, reptiles, echinoderms, polychaetes and crustaceans.

The coastal waters of the project area are described as being within the 'high nutrient coastal strip' bioregion of the Great Barrier Reef. This bioregion is characterised by terrigenous mud, high levels of nutrients from the adjoining land, seagrass in sheltered waters and a wet tropic climate. Within this area, there are scattered coastal fringing reefs that generally develop around the mainland and high continental islands and have high coverage of hard coral, soft coral and macroalgae, but low coral diversity (Kerrigan et al. 2010). The Keppel Bay islands are surrounded by a small, geographically isolated system of fringing reefs, with relatively high coral cover (~67%) compared to the rest of the Great Barrier Reef (~35%) (Jones & Berkelmans 2010; Jones et al. 2011).

Coral communities of this bioregion generally have a high cover of coral and microalgae, a capacity to recover following disturbance (e.g. coral bleaching), a high but often variable spat settlement (recruitment), and low juvenile coral densities (Diaz-Pulido et al. 2009; Johnson et al. 2010). Coral reefs of the region have been repeatedly affected by bleaching with substantial declines in coral coverage observed in 1998, 2002 and 2006[10]; in January 2006, 100% of corals in Keppel Bay were bleached with approximately 40% mortality by May 2006 (GBRMPA 2007; Weeks et al. 2008). However, rapid recovery has also been documented (e.g. Diaz-Pulido et al. 2009; Johnson et al. 2010) and some reefs in southern Keppel Bay (Humpy, Middle, Halfway and Pumpkin islands, and the reef surrounding Passage and Outer rocks) have been described as coral 'refuges' due to high diversity and connectivity to sites with lower diversity and coral cover (Jones et al. 2011). Walker (2011) suggests that currently available data is insufficient to accurately assess the level of connectivity between Passage Rocks and other reefs of the region.

[10] And most likely 2010 -11, although the effect of the recent Fitzroy River flooding on coral reef communities is yet to be confirmed.

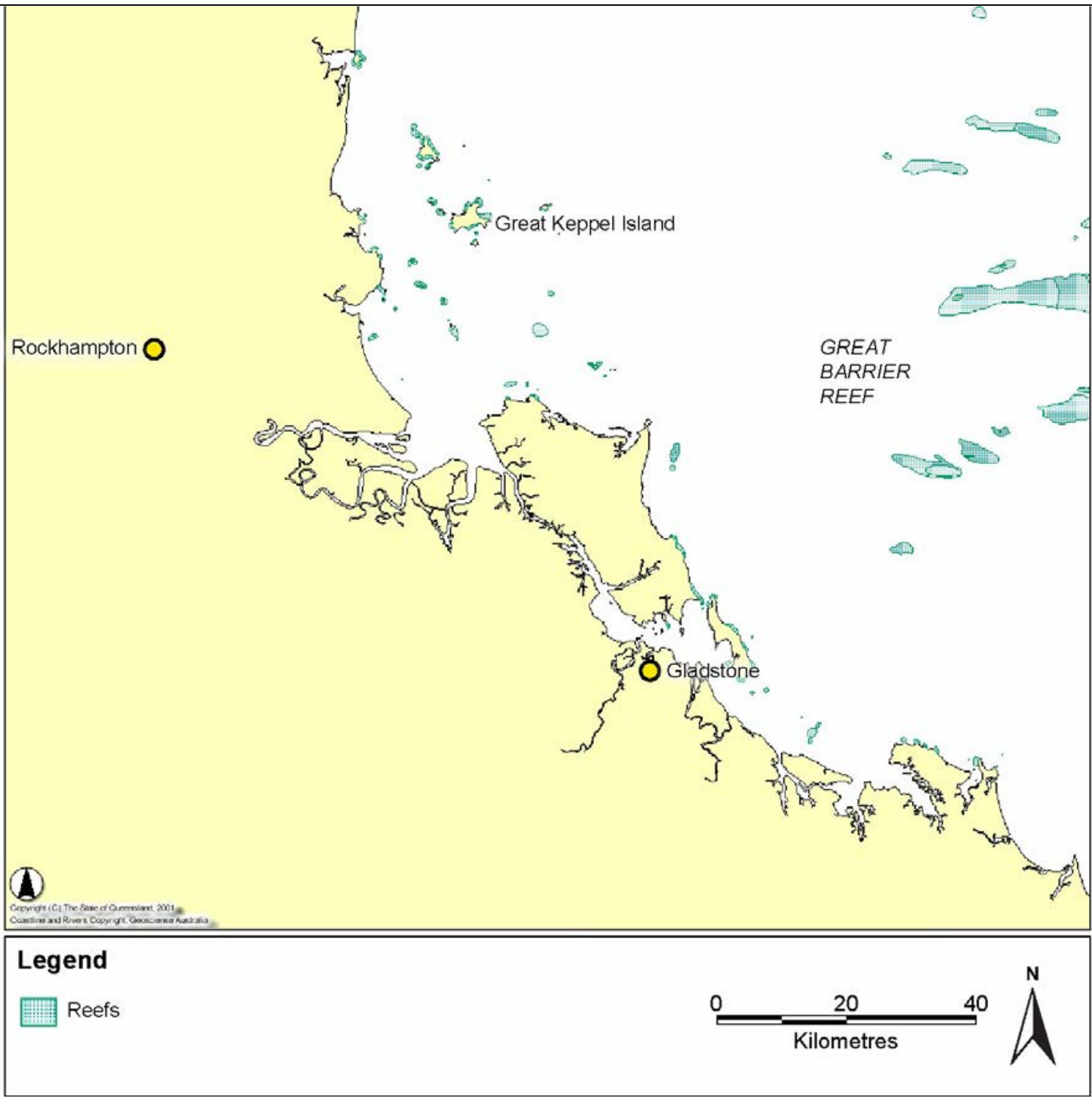


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	Figure 3.1 Coral communities of the region.
	Microsoft Bing © 2010 Microsoft Corporation; DERM 2011 — March 2011

Reefs of Keppel Bay, including those of Middle Island and nearby Half Tide Rocks were surveyed by in April 2007 (GBRMPA 2007). These coral communities were dominated by fast growing *Acropora* species including *A. formasa, A. microphthalma*, and *A. millepora* (GBRMPA 2007). These species are the most susceptible types of coral to thermal stress. However, these reefs have demonstrated resilience to bleaching events and strong recovery following floods (GBRMPA 2007). *Acropora* species are among the fastest growing corals.

In general, leeward reefs are shallow and support high coral cover on well-defined reef flats, crests and steep (although shallow) reef slopes, whereas, windward reefs extend deeper, with higher coral diversity, but without any reef flats (Van Woesik 1991).

After a major flood event in January 1991, large freshwater input from the Fitzroy River resulted in reduced coral cover and increased bleaching. Approximately 85% of coral in the area was dead and overgrown by turf algae, shallow areas were most affected. Mortality was greatest for acroporids and pocilloporids, with survival in shallow habitats apparent for faviids, *Turbinaria* spp., *Porites* spp., *Psammocora* sp. and *Coscinaraea* sp. (Van Woesik 1991).

Susceptibility of Corals

The distribution of coral-associated flora and fauna is determined principally by exposure to wave action, and water quality (in particular turbidity).

Hard coral communities are most widespread in clear, warm waters that are well mixed with relatively low turbidity. Clear water promotes the photosynthetic activity of symbionts (symbiotic algae hosted by most shallow water corals and required for feeding and survival) and water movement provides nutrients (food) and dissolved oxygen, removes wastes, and can discourage predation by herbivores and coralivores (Hubbard 1988).

Diversity in coral communities is often controlled by abiotic (physical) factors, in particular salinity, turbidity, sedimentation and the availability of suitable substrate (Lovell 1989). Biotic (living) factors may also be significant, including competition with soft corals, other sessile invertebrates and macroalgae. Macroalgae is likely to both compete for space (particularly in respect of substrate suitable for recruitment), and to physically inhibit coral growth through abrasion, shading and sediment retention (Johannes et al. 1983; Smith & Simpson 1991).

3.2 Intertidal Rocky Shores

There is limited information available regarding intertidal rocky shores of the region. Communities of the nearby Port Curtis region, approximately 75 km south of the project area, support diverse floral and faunal communities, including gastropods, sponges, ascidians, soft and hard coral and macroalgae. Taxonomic richness is typically greater on the lower portions of rocky shores (URS 2009).

Artificial structures, such as jetties, seawalls and pipes, are also likely to provide hard surfaces for sessile marine communities. The habitat diversity (including rock pools, gullies and ledges) of these environments often supports diversity ecological communities that include fishes, reptiles (such as sea snakes and turtles), echinoderms, polychaetes and crustaceans. These habitat types are of importance to many species that require hard substrate for colonisation.

3.3 Benthic Infaunal Invertebrate Communities

Benthic infaunal invertebrate communities of the region are typically dominated by filter feeders, which can account for more than 50% of the total abundance and nearly 30% of the species richness. Abundant species include, the bivalve, *Carditella torresi,* the ascidian, *Ascidia sydneiensis*, and to a lesser extent the bivalves, *Corbula tunicata*, *Mimachlamys gloriosa*, *Leionuculana superba*, *Mactra abbreviata* and *Placamen tiara*, the polychaete worm, *Eunice vittata*, the caridean shrimp, *Alpheus* sp. and the ascidian, *Ascidiacea* sp. Species richness and abundance are typically lowest in fine muddy substrates of intertidal areas, and highest in coarse sandy sediments. Abundance typically increases with regional rainfall and freshwater inflow (Currie & Small 2005; 2006).

Infaunal invertebrate communities in the Port Curtis region included 129 taxa, and were dominated by polychaetes, molluscs and crustaceans. The highest mean abundance was 37 individuals and the highest mean taxonomic richness was 16 taxa (URS 2009). This is higher than that recorded during this study, which is likely to be related to the finer sediments of the Port Curtis area as finer sediments typically support more diverse and abundant infaunal communities.

3.4 Decapod Macrocrustaceans

There is limited information available regarding macrocrustacean communities of the region. Communities are expected to be typical of other Queensland inshore waters and include (Queensland Museum 2011):

- prawns and shrimps from the genera *Penaeus, Periclimenes, Stenopus* and *Thor*
- mantis shrimps from the genus *Odontodactylus*
- lobsters and crayfish from the genera *Allogalathea, Callianassa*, *Ibacus, Neaxius, Panulirus* and *Thenus*
- hermit crabs from the genera *Cilianarius* and *Dardanus,* and
- crabs from the several genera including *Uca, Mictyris, Trapezia, Charybdis, Portunus, Scylla* and *Ocypode.*

Species of fisheries significance are discussed in Appendix H.

3.5 Fishes

Fish assemblages of Keppel Bay are typical of inshore waters of the Great Barrier Reef; community composition is generally similar on reefs located a similar distance from the mainland, in terms of all major reef fin-fish families (pers. obs; Russell et al. 1978; Williams 1982; Williams 1983; Williams & Hatcher 1983; Russ 1984; Newman & Williams 1996; Fabricius et al. 2005).

Williams (1982) reported substantially fewer fin-fish species on inshore reefs of the central Great Barrier Reef than on mid-shelf or outer-shelf reefs, with particularly low numbers of acanthurids and scarids on inshore reefs. The most dominant species were the pomacentrids *Neopomacentrus* sp., *Pomacentrus popei, Pomacentrus wardi, Acanthochromis polyacanthus*, the lutjanid *Caesio erythrogaster* and the chaetodontid *Chaetodon aureofasciatus*. *Thalassoma lunare*, *Hemigymnus melapterus* and *Lienardiella fasciata* were the most abundant labrids. The only acanthurids regularly recorded on inshore reefs were *Acanthurus dussumieri* and *Acanthurus mata*. *Scarus ghobban* and *Scarus rivulatus* were the most abundant scarids on inshore reefs.

Newman and Williams (1996) reported significantly fewer lutjanids and lethrinids on inshore reefs than mid-shelf or outer-shelf reefs. The genera *Aprion, Lutjanus, Macolor, Symphorichthys, Symphorus, Gnathodentex, Gymnocranius, Lethrinus* and *Monotaxis* were common in the shallower shelf waters. Of the lutjanids, *Lutjanus carponotatus,* *Lutjanus russelli and Lutjanus sebae* were common on inshore reefs*; L. carponotatus* was the only species that was significantly more abundant on inshore reefs than mid-shelf or outer-shelf reefs. Of the 12 species examined, three were recorded on inshore reefs, eight on the mid-shelf reefs and seven on the outer-shelf reefs. All species recorded inshore also occurred on the mid-shelf, but not the outer-shelf.

The rock and reef habitat at nearby Port Curtis is used by a range of adult and juvenile fish species such as yellowfin bream (*Acanthopargus australis*), sweetlip (*Lethrinus* spp.), and estuary cod (*Epinephelus coioide*) (URS 2009). Species of significance to fisheries are discussed in Appendix H.

Anemones and anemonefishes are currently rare in Keppel Bay, and appear to have been impacted by bleaching and the unsustainable collection for the aquarium trade (Frisch & Hobbs 2009).

3.6 Marine Reptiles

Marine Turtles

Five of Australia's six species of marine turtles are likely to occur in the project area. This includes resident populations of flatback (*Natator depressus*) and green (*Chelonia mydas*) turtles, and occasional occurrence of the loggerhead (*Caretta caretta*) hawksbill (*Eretmochelys imbricata*) and olive Ridley (*Lepidochelys olivacea*) turtle. The leatherback (*Dermochelys coriacea*) is unlikely to occur in the project area.
Marine turtles are generally highly migratory, moving between feeding grounds and rookeries, with both males and females undertaking migrations of up to 3000 km. Marine turtles tend to nest on mainland or island beaches (Environment Australia 2003).

All marine turtle species are experiencing serious threats to their survival. The main threats are:

- habitat degradation and destruction, particularly nesting beaches, seagrass meadows, mangrove forests and coral reefs
- entanglement and drowning in fishing gear (e.g. trawler nets) and shark nets and drum lines
- ingestion of plastic bags
- pollution and declining water quality
- disease

- indigenous over-harvesting of both turtles and eggs, and
- predation of eggs by native and introduced animals (Environment Australia 2003; Kirkwood & Hooper 2004; EPA 2006).

The threat posed by trawler nets has been substantially reduced with the implementation of the Fisheries East Coast Trawl Management Plan 1999, which requires trawlers to use approved turtle exclusion devices (TEDs). Fibro-papillomatosis disease is a common disease amongst turtles in some areas, which may be related to high industrial or agricultural runoff (Kirkwood & Hooper 2004). There is limited information on the prevalence of this disease in the project area.

The number of marine turtle strandings (sick, injured or dead individuals) recorded in the region (along the Queensland coast in latitudinal block 23°) from 1999 to 2004 is presented in Table 3.1. Each year, more green turtle strandings were reported than for any other species (QPWS 1999; 2000; 2001; 2003; 2004a). The major causes of marine turtles strandings along the Queensland coast from 1994 to 2004 were:

- the Queensland coast shark safety program
- dredging
- ingestion of synthetic material
- hunting
- fisheries bycatch or entanglement in fishing gear
- boat strike, propeller damage or fractures
- depredation (e.g. shark attack), and
- disease not directly linked to anthropogenic sources.

Table 3.1 Number of marine turtle strandings in the region from 1999 to 2004

Species	Common Name	2004	2003	2002	2001	2000	1999	1998
Caretta caretta	loggerhead turtle	0	4	4	2	2	1	2
Chelonia mydas	green turtle	43	57	34	20	25	27	14
Eretmochelys imbricata	hawksbill turtle	7	3	2	0	7	1	2
Natator depressus	flatback turtle	2	2	2	1	0	1	0
Lepidochelys olivacea	olive ridley turtle	1	0	0	0	0	0	0
Unidentified turtle	–	0	5	4	1	2	1	0

Flatback Turtle

The flatback turtle (*Natator depressus*) is listed under the 'vulnerable', 'migratory' and 'marine' schedule of the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) and under the 'vulnerable' schedule of the Nature Conservation (Wildlife) Regulation 2006 (NCWR). Internationally, it is listed under the Convention on Migratory Species (CMS) and the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) and as 'data deficient' on the International Union for Conservation of Nature (IUCN) Red List.

The flatback turtle tends to forage in shallow continental shelf waters with soft substrates, feeding on a variety of soft-bodied animals, including soft corals, sea pens, sea cucumbers and jellyfish (Limpus 2007). Catch records from trawlers (as bycatch) indicate that the flatback turtle also feeds in turbid, shallow (depth of 10 m to 40 m) inshore waters (Robins 1995).

Unlike other turtles, the flatback lacks an oceanic phase and remains in the surface waters of the continental shelf throughout its life. Little is known about their foraging habits and habitat, although juvenile and adult turtles seem to occupy similar habitats and both forage on soft-bodied (mostly benthic) organisms (Limpus et al. 1994).

In eastern Queensland, flatback turtles nest between Bundaberg in the south to the Torres Strait in the north. The main nesting sites in the southern Great Barrier Reef are:

- Curtis Island
- Peak Island

- Facing Island
- Hummock Hill Island, and
- Wild Duck islands (Limpus 1971; Limpus et al. 1983).

Peak Island beaches are one of the most important nesting areas on Australia's east coast. The beaches of Curtis, Facing and Hummock Hill islands are key nesting areas for the flatback turtle and are identified nationally as medium density rookeries (Limpus et al. 2006). There is minor nesting at Mon Repos and in the Mackay Region, and scattered aperiodic nesting along the mainland and on inshore islands between Townsville and the Torres Strait (Limpus et al. 1994).

Nesting activity is greatest between late November and early December ceasing sometime in late January. Hatchlings typically emerge from nests from early December to late March, with peak hatching in February (Limpus 2007).

The flatback turtle is likely to be relatively common in the project area. It is likely to use the area for foraging, given the dominant soft-sediment habitat, and also for nesting (or traversing during the nesting season) as it is close to several rookeries (Limpus 2008b).

Green Turtle

The green turtle (*Chelonia mydas*) is listed under the 'vulnerable', 'marine' and 'migratory' schedules of the EPBC Act and under the 'vulnerable' schedule of the NCWR. Internationally, it is listed under the CMS and the CITES and as 'endangered' on the IUCN Red List.

The green turtle feeds extensively on seagrass, particularly *Halophila ovalis*, *Halophila spinulosa* and *Halodule uninervis,* and is commonly found in association with seagrass meadows. It also feeds on algae and propagules of the grey mangrove (*Avicennia marina*) and algae (GBRMPA 2007). The long life-span of green turtles (35 to 50 years to sexual maturity) and fidelity to feeding grounds means that green turtles rely on the seagrass meadows (Couper 1998), and consequently their survival can be threatened if seagrass meadows are diminished.
Regionally, the southern Great Barrier Reef provides key nesting and inter-nesting areas for the green turtle. Including:

- Northwest Island
- Wreck Island
- Hoskyn Island

- Tryon Island
- Heron Island
- Lady Musgrave Island
- Masthead Island
- Erskine Island
- Fairfax Island
- North Reef Island, and
- Wilson Island (Limpus et al. 2006).

Green turtles mate in October, with eggs laid between October and March. Green and loggerhead turtles migrate to breed, but tend to maintain small home range feeding areas (within approximately 10 to 15 km of coastline). Turtle movements within foraging grounds are likely to be related to food availability and environmental factors such as the tide cycle (as they can only feed in intertidal areas when the water depth is between 0.5 and 1 m) (Bell 2003).

The green turtle is likely to be relatively common in the project area. It may use the area for feeding (although given the patchy and spare nature of the meadows this species is unlikely to reply on those meadows for feeding) and also nesting (or traversing during the nesting season) as it is close to several rookeries.

Loggerhead Turtle

The loggerhead turtle (*Caretta caretta*) is listed under the 'endangered', 'marine' and 'migratory' schedules of the EPBC Act and under the 'endangered' schedule of the NCWR. Internationally, it is listed under the CMS and the CITES and as 'endangered' on the IUCN Red List.

The loggerhead turtle has a diverse diet including bivalves, gastropods, molluscs, crabs and jellyfish from a wide range of intertidal and subtidal habitats, including coral and rocky reefs, seagrass meadows, and unvegetated sand or mud areas (Limpus 2008b). As is the case with the green turtle, the loggerhead turtle tends to maintain small home ranges within their foraging grounds (within approximately 10 to 15 km of coastline). Loggerhead turtles can be found in the waters of coral and rocky reefs, seagrass beds and muddy bays throughout eastern, northern and western Australia (Limpus et al. 1992; Prince 1994; Limpus 1995).

The east coast population of loggerhead turtles has been sharply declined, with an estimated loss of 50 to 80% of its annual nesting population from the mid-1970s to 1990. Furthermore, continued loss of a few hundred individuals annually may threaten the survival of the species on the east coast (Limpus & Reimer 1994).

Three major nesting areas in Queensland include:

- the Capricorn Bunker Island Groups, especially Wreck, Tryon and Erskine islands
- Mon Repos and adjacent beaches of the Woongarra Coast and Wreck Rock Beach, together with
- the islands of the Swain Reefs, especially Pryce Island and Frigate, Bylund, Thomas and Bacchi cays.

While nesting is concentrated in southern Queensland on the east coast, and from Shark Bay to the North West Cape on the west coast, foraging areas are more widely distributed (Limpus 2008a).

The loggerhead turtle may feed in, or traverse, the project area.

Hawksbill Turtle

The hawksbill (*Eretmochelys imbricata*) turtle is listed under the ‘vulnerable’, ‘migratory’ and ‘marine’ schedules of the EPBC Act and under the ‘vulnerable’ schedule of the NCWR. Internationally, it is listed under the CMS and the CITES and as ‘critically endangered’ by the IUCN Red List.

Hawksbills breed in the northern Great Barrier Reef and the Torres Strait and are heavily reliant on reef and rocky habitats, where it forages mainly on sponges but also seagrass, algae, squid, gastropods and jellyfish.

The project area is highly unlikely to support nesting populations although some hawksbill turtles may feed over the reef and rocky habitat of the area.

Olive Ridley Turtle

The olive Ridley (*Lepidochelys olivacea*) is listed under the ‘endangered’, ‘migratory’ and ‘marine’ schedules of the EPBC Act and under the ‘endangered’ schedule of the NCWR. Internationally, it is listed under the CMS and the CITES and as ‘vulnerable’ under the IUCN Red List.

The olive Ridley appears to forage in benthic and pelagic habitats (Musick & Limpus 1997), for mostly gastropods and bivalves (Conway 1994). It is most commonly found in waters with a depth of 11 to 40 m (Robins 1995) but has also been reported in water more than 100 m deep (Hughes 1974). No large rookeries of olive Ridley turtle have been recorded in Australia (DERM 2011a).

The olive Ridley turtle is highly unlikely to nest in the project area but may feed in, or traverse, the project area.

Seasnakes

Seasnake are listed under the 'marine' schedule of the EPBC Act, and are consequently protected within Commonwealth Marine waters such as the GBRMP. Seasnakes inhabit a range of habitats, including sandy bottom habitats, reef habitats and pelagic habitats (*Pelamis* sp. only) (Stokes 2004). Seasnakes are likely to inhabit the project area; the olive (*Aipysurus laevis*) and stokes (*Astrotia stokesii*) seasnake are relatively abundant at Passage Rocks and Middle Island (Lynch 2000; GBRMPA 2007).

Sea snakes (family Hydrophiidae) are predatory marine reptiles that inhabit shallow, tropical waters over reef, inter-reef or sandy habitats throughout the Indo Pacific region. The highest diversity occurs in northern Australia and southeast Asia. There are approximately 54 species within approximately 13 genera, and each genus is represented by both widespread and endemic species. The two largest genera, *Aipysurus* and *Hydrophis*, account for more than half of all species. Six of the seven *Aipysurus* species are restricted to Australasian waters. By contrast, species diversity of the genus *Hydrophis* is highest in southeast Asia, with up to eight species reported from Australian waters, and five of these appearing to be Australasian endemics (Lukoschek 2008 and references cited within).

Basic biological, distributional, and ecological information is limited for most seasnakes (Lukoschek 2008); the olive seasnake is one of the most studies species. The olive seasnake typically occurs at discrete reefs, with habitat preference related to reef location, exposure and area; distribution did not appear to be related to the protection status of reefs (GBRMP zoning). Factors driving spatial and temporal changes are poorly understood (Lukoschek 2008 and references cited within). Studies of the olive seasnake in the Keppel Island region found that this species maintains small home ranges over short time periods, and that females have larger home ranges than males (Burns & Heatwole 1998; Lynch 2000). Males also appear to move off reefs in the summer, returning to the same or a nearby reef to mate in winter (Lynch 2000). Despite the ability of the olive seasnake to expand into new marine habitats, local populations appear to be relatively isolated and, if subject to extinction, are unlikely to re- establish by dispersal (Lukoschek 2008 and references cited within).

The conservation status of seasnakes is poorly known. Recent reports suggest declining abundances and loss of endemic species on protected Australian reefs. Threatening processes for reef-associated species, such the olive seasnake, are unclear but appear to include habitat degradation and loss and fisheries bycatch (Lukoschek 2008 and references cited within).

3.7 Marine Mammals

Several cetaceans (whales, dolphins and porpoises) are listed under the 'cetaceans' schedule of the EPBC Act. Several species are also listed as under the 'threatened' schedule of the EPBC Act and NCWR, and in the IUCN Red List. Species likely to use habitats in the project area are discussed below.

The number of marine mammal strandings in the region (latitudinal block 23°of the Queensland coast) from 1999 to 2010 is presented in Table 3.2. The major causes of marine mammal strandings along the Queensland coast from 1999 to 2006 were:

- the Queensland coast shark safety program
- hunting
- fisheries bycatch or entanglement in fishing gear
- boat strike, propeller damage or fractures, and
- disease not directly linked to anthropogenic sources.

The dugong (*Dugong dugon*) was the most commonly stranded marine mammal with up to 10 individuals stranded per year. Commercial fishing and indigenous hunting are currently the major causes of dugong strandings. 'Go slow' areas appear to have reduced incident of boat strike and Dugong Protection Areas (DPAs) appear to have reduced the incident of entanglement in fishing gear (QPWS 2004b; 2007).

The humpback whale (*Megaptera novaeangliae*) was the most common whale to strand and the Indo-Pacific humpback dolphin (*Sousa chinensis*) was the most common dolphin to strand, although strandings were uncommon (<3 per year with no strandings for most species in most years).

Whales

Humpback Whale

The humpback whale is listed under the 'vulnerable', 'migratory' and 'cetacean' schedules of the EPBC Act, and under the 'vulnerable' schedule of the NCWR. Internationally, it is listed under the CITES, and as 'least concern' on the IUCN Red List.

Humpback whales make an annual migration from Antarctica to Australian coastal waters. During migration, pods of mothers, calves and young whales shelter from predators and rough seas in the warm, protected waters of bays before they make the long journey to Antarctic feeding grounds (Vang 2002). Humpbacks are known to feed while migrating (DOE 1997). The greatest prevalence of humpbacks in Australian coastal waters is from August to October (Vang 2002).

Sightings of humpbacks are most commonly reported within relatively open water. During migration, humpback whales have calving, migration and resting areas along the east coast of Australia.

While the project area is not recorded as an important area for humpback whales (DSEWPC 2011), they may occur in open waters offshore of the project area during their annual migration. Their occurrence may increase over the life of the project as there is an increasing rate of humpback whales migrating along the east of Australia (Noad et al. 2008). The east coast humpback whale population is recovery, from whaling activities, at a rate of approximately 10 to 11% per year, (Commonwealth of Australia 2012).

Table 3.2 Number of marine mammal strandings in the region from 1996 to 2010.

Species	Common Name	2010	2009	2008	2007	2006	2005	2004	2003	2002	2001	2000	1999	1998	1997	1996
Whales																
Megaptera novaeangliae	humpback whale	–	–	–	1	0	1	1	0	0	1	0	0	–	–	–
Balaenoptera musculus brevicauda	pygmy blue whale	–	–	–	0	0	0	0	1	0	0	0	0	–	–	–
Unidentified whale		–	–	–	0	0	0	0	0	0	0	0	1	–	–	–
Globicephala macrorhynchu	short-finned pilot whale	–	–	–	0	0	0	0	0	1	0	0	0	–	–	–
Ziphius cavirostris	Cuvier's beaked whale	–	–	–	0	0	0	0	0	1	0	0	0	–	–	–
Mesoplodon layardi	strap-toothed whale	–	–	–	0	0	0	1	0	0	0	0	0	–	–	–
Peponocephala electra	melon-leaded whale	–	–	–	0	0	0	0	0	0	0	0	1	–	–	–
Pseudorca crassidens	false killer whale	–	–	–	0	2	0	0	0	0	0	0	0	–	–	–

Species	Common Name	2010	2009	2008	2007	2006	2005	2004	2003	2002	2001	2000	1999	1998	1997	1996
Dolphins																
Tursiops sp.	-	–	–	–	0	0	0	1	0	0	0	1	0	–	–	–
Tursiops truncates	bottlenose dolphin	–	–	–	2	0	1	0	0	0	0	0	0	–	–	–
Delphinus delphis	short-beaked common dolphin	–	–	–	0	0	0	0	0	0	0	0	1	–	–	–
Orcaella heinsohni	snubfin dolphin	–	–	–	1	0	1	0	0	0	0	0	0	–	–	–
Orcaella brevirostris	Irrawaddy dolphin	–	–	–	0	0	0	0	0	0	0	0	1	–	–	–
Sousa chinensis	Indo-Pacific humpback dolphin	–	–	–	1	0	3	2	1	2	1	1	0	–	–	–
Dolphin unidentified	-	–	–	–	0	0	0	0	0	1	1	0	0	–	–	–
Dugong																
Dugong dugon	Dugong	1	1	1	2	2	2	3	4	4	10	3	2	5	1	3

– indicates data not available.

Minke Whale

The minke whale (*Balaenoptera acutorostrata*) is listed under the 'cetacean' schedule of the EPBC Act.

This species undertakes extensive migrations between cold water feeding grounds and warmer water breeding grounds. Migration paths are presumably widespread (approximately 12 to 65°S), although they are less predictable than most other Balaenopterids, such as the humpback whale, and the exact location of breeding grounds is not known. Minke whales feed predominantly on *Euphausia superba* (Antarctic krill) and smaller krill (Bannister et al. 1996).

The project area is not recorded as an important area for minke whales (DSEWPC 2011) and they are unlikely to feed in the area, however they may traverse open waters offshore of the project area during their annual migration .

Bryde's Whale

Bryde's whale (*Balaenoptera edeni*) is listed under the 'migratory' and 'cetacean' schedule of the EPBC Act

Bryde's whales occur in both temperate and tropical waters, oceanic and inshore, bounded by latitudes 40° N and 40° S (Bannister et al. 1996), mostly swimming alone or in pairs. They are considered to be a fairly opportunistic feeders, readily consuming whatever shoaling prey is available (DSEWPC 2011). Future expansion of high-seas pelagic fisheries, particularly those targeting schooling pelagic fishes, may result in increased interactions with Bryde's whales, including incidental catches and injury (DSEWPC 2011).

The project area is unlikely to provide important habitat for Bryde's whales (DSEWPC 2011), however they may traverse open waters in the vicinity of the project.

Dolphins

Indo-Pacific Humpback Dolphin

The Indo-Pacific humpback dolphin (*Sousa chinensis*) is listed under the 'cetacean' and 'migratory' schedules of the EPBC Act. Internationally, it is listed under the CMS and the CITES and as 'data deficient' on the IUCN Red List.

The Indo-Pacific humpback dolphin is an opportunist-generalist feeder. It consumes a wide variety of coastal and estuarine fishes, but also reef, littoral and demersal fishes, and some cephalopods and crustaceans. The Indo-Pacific humpback dolphin generally eats fish associated with mangrove habitats and is consequently affected by disturbances to these habitats (Parra 2005).

In Australia, the Indo-Pacific humpback dolphin is known to occur along the northern coastline from the Exmouth Gulf on the west coast to the Queensland border on the east coast. Distribution appears to be continuous along the east coast (Corkeron et al. 1997).

The Indo-Pacific humpback dolphin usually inhabits shallow coastal waters in association with rivers or creeks, estuaries, enclosed bays and coastal lagoons (Hale et al. 1998; Parra 2006). It mostly occurs in protected shallow waters (less than 15 m deep), which are close to the coast (within 10 km of the coast) and river and creek mouths (within 20 km of a river or creek) (Parra 2006). The habitat use of Indo-Pacific humpback dolphin in Cleveland Bay (Townsville) appears to include significant overlap for individuals, but slightly different to that of the Australian snubfin dolphin as the latter preferred slightly shallower waters of the bay (Parra 2006).

Population levels in Queensland are likely to be in the order of thousands (Parra et al. 2002). Indo-Pacific humpback dolphins seem to stay within a large home range and females in particular are site-specific. Recent surveys recorded Indo-Pacific humpback dolphins as the most common coastal dolphin species in the region (from Curtis Island to south of Rodd’s Bay).

The Indo-Pacific humpback dolphin is likely to occur in the project area.

Bottlenose Dolphin

Bottlenose dolphins are listed under the ‘cetacean’ schedule of the EPBC Act. Bottlenose dolphins have been recently re-evaluated based on genetic information. *Tursiops truncatus*, previously the taxon of all bottlenose dolphins but now only the inshore bottlenose dolphin, is currently considered the poorly known species in Australian waters. *Tursiops aduncus*, the current taxon of the Indian Ocean bottlenose dolphin, occurs widely around Australia in large groups (Hale et al. 2000 in Ross 2006).

The Indo-Pacific bottlenose dolphin inhabits warm, shallow inshore waters north of about Port Macquarie in New South Wales, and it is found slightly further offshore where sympatric with the Indo-Pacific humpbacked dolphin (Bannister et al. 1996). This species is highly visible and relatively common in coastal, estuarine, pelagic and oceanic waters between about 65°N and 55°S. It frequents a large number of bays in considerable numbers (Ross 2006). This species is generally considered an opportunistic feeder on items such as fish, cephalopods and crustaceans (DOE 1997) and often feeds in association with trawlers (Bannister et al. 1996).

The bottlenose dolphin inhabits cooler, deeper offshore waters than the Indo-Pacific bottlenose south of about Hervey Bay (Bannister et al. 1996). No information is available on their biology in Australian waters but studies in South Africa suggest they feed on squid and fish from deep, cool waters (Ross 1984 in Ross 2006).

The bottlenose dolphin is likely to occur in the project area.

Australian Snubfin Dolphin and Irrawaddy Dolphin

The Australian snubfin dolphin (*Orcaella heinsohni*) is listed under the 'cetacean' and 'migratory' schedules of the EPBC Act and under the 'rare' schedule of the NCWR. Internationally, it is listed under Appendix II of the CMS and Appendix I of the CITES (as *O. brevirostris*) and as 'near threatened (as *O. brevirostris*) on the IUCN Red List (IUCN 2011). The Australian snubfin dolphin is Australia's only endemic dolphin and was described as a separate species from the Irrawaddy dolphin (*Orcaella brevirostris*) in 2005 (Beasley et al. 2005).

The Australian snubfin dolphin is an opportunistic-generalist feeder, taking food from the bottom and water column within coastal and estuarine waters. Its diet consists primarily of fish, but includes cephalopods (squid and octopus) and crustaceans (prawns and crabs). Based on the stomach contents of 14 Australia snubfin dolphin, collected from stranded and by-caught animals between 1970 and 2008, the most important prey in numerical terms was cardinal fishes (*Apogon* sp.), followed by cuttlefishes (*Sepia* sp.), squid (*Uroteuthis* sp. and *Photololigo* sp.) and toothpony fishes (*Gazza* sp.) (Parra & Jedensjö 2009).

The snubfin appears to be the rarest dolphin in Queensland (Parra et al. 2002). Little is known about the ecology and population status of this species throughout its range and this species is considered a high priority research species (Parra et al. 2006; Ross 2006). Coastal, estuarine and riverine areas are important for *Orcaella* in other regions however only marine populations are evident in Australia. They appear to inhabit shallow waters <15 m deep within 10 km of the coast and 20 km of a river mouth. Their association with near-shore and estuarine tropical waters is likely related to the productivity of these waters and their diet consisting of a wide variety of coastal, estuarine and near-shore fishes (Parra et al. 2006).

Major threats to the snubfin include entanglement and drowning in nets and over-fishing of prey species. When sympatric with the Indo-Pacific humpbacked, the snubfin tends to occur closer to the river mouth and is therefore probably more susceptible to drowning associated with gill-nets set across rivers to catch barramundi and other species (Parra et al. 2006). Habitat destruction and degradation, pollution and harassment also have the potential to impact this little known species (Bannister et al. 1996; Ross 2006).

The project area is unlikely to provide important habitat for the Australian snubfin dolphin, however they occur in the nearby waters of the Fitzroy River mouth.

Common Dolphin

The common dolphin (*Delphinus delphis*) is listed under the ‘cetacean’ schedule of the EPBC Act.

A very gregarious species observed in Australian waters in large groups. This species is not known to be migratory (Bannister et al. 1996) although it is highly mobile and capable of moving long distances (Ross 2006). The common dolphin is an opportunistic feeder that may move inshore or offshore following food (Ross 2006). It is known to feed on mesopelagic fish and cephalopods (Bannister et al. 1996) to a depth of 280 m but also at the surface and in association with tuna (Ross 2006).
The common dolphin, together with the bottlenose, are also subject to being kept in oceanariums and deliberately killed for bait. Locally this species may be threatened by bioaccumulation of toxins and entanglement associated with netting activities (Bannister et al. 1996; Ross 2006).

The common dolphin may occur in the project area.

Risso’s Dolphin

The Risso’s dolphin (*Grampus griseus*) is listed under the ‘cetacean’ schedule of the EPBC Act.

Risso’s dolphin is considered to be pelagic and oceanic species to latitudes of ~55° (Ross 2006), although inhabits both inshore and offshore waters and most frequently seen over the continental slope. Offshore waters of Fraser Island have the only known ‘resident’ population in Australia (Bannister et al. 1996). The Risso’s dolphin feeds in pelagic waters primarily on squid, some octopus and possibly fish (Bannister et al. 1996).

The project area is unlikely to provide important habitat for the Risso's dolphin.

Dugong

The dugong (*Dugong dugon*) is listed under the 'marine' and 'migratory' schedule of the EPBC Act and under the 'vulnerable' schedule of the NCWR. Internationally, it is listed under the CMS and the CITES and as 'vulnerable' on the IUCN Red List.

Dugongs feed almost exclusively on seagrass, particularly *H. uninervis, H. ovalis* and *H. spinulosa*, and principally inhabit seagrass meadows (Preen 1992; Preen et al. 1995; Lanyon & Morris 1997). Their dependence on seagrass for food generally limits them to waters within 20 km of the coast, although individuals have been sighted further from the coast during aerial surveys (e.g. Marsh & Lawler 2002) and they have been observed feeding in deep-water (water depth of more than 20 m) seagrass (Lee Long et al. 1997).

Dugongs prefer shallow and protected areas with seagrass meadows, however they can be highly migratory due to their search for suitable seagrass or warmer waters (Marsh et al. 2002) and are known to travel several hundred of kilometers. Dugongs have evolved to cope with the inherently unpredictable and patchy nature of seagrass meadows by moving to alternative areas known to support seagrass in the past. For example, following a large-scale loss of seagrass in Hervey Bay, associated with two floods and a cyclone in quick succession, some individuals appeared to survive by relocating to Moreton Bay 300 km to the south (Sheppard et al. 2006). As dugong are long-lived animals, with a low reproduction rate and long generation time, the population takes a long time to rebuild after disaster (Marsh 1989).

A significant proportion of the world's dugongs are found in northern Australian waters from Shark Bay on the west coast to Moreton Bay on the east coast (Marsh & Lefebvre 1994). Aerial surveys indicate that dugongs are the most abundant marine mammal in the inshore waters of northern Australia with an estimated population of about 85 000 individuals (although some suitable habitat has not been surveyed so this could be an under-estimate) (Bryden et al. 1998; Marsh et al. 1999). The dugong population of the Great Barrier Reef Marine Park is estimated at 14 000 individuals (Dobbs et al. 2008). Aerial surveys of dugongs have been undertaken along the Queensland coast since the 1980s and regional population size estimates have fluctuated, which may be related to movements between regions (Sheppard et al. 2006).

Sixteen Dugong Protection Areas have been declared under the Queensland *Nature Conservation Act 1992* (NC Act), as have Special Management Areas under the Great Barrier Reef Marine Park Regulations 1983 and the Great Barrier Reef Marine Park

Zoning Plan 2003 (refer to Appendix B for legislation details). There are two main objectives for these areas:

- to reduce the mortality of dugongs from all human-related causes in order to assist population recovery and to potentially allow for future sustainable traditional use.
- to protect the quality and extent of habitat for dugongs, including feeding, calving and mating areas and migratory pathways.

Dugong Protection Area A represents significant dugong habitat. Dugong Protection Area B also represents important habitat but is considered to be less significant. The Rodds Bay / Port Curtis area is located approximately 30 km south of the project area and is designated a Dugong Protection Area B. The project is unlikely to affect Dugong Protection Areas.

While there is little scientific data on dugong within the project area, dugong may occur in the project area on occasion.

Water Mouse

The water mouse (*Xeromys myoides*) is listed under the 'vulnerable' schedule of the EPBC Act and NCWR. Internationally, it is listed as 'vulnerable' on the IUCN Red List.

The water mouse depends on mangrove communities, and a range of other wetland communities, for survival. Wetland communities are widely threatened by development and the main cause of species decline is loss of mangroves. This species is also threatened by predation from dingoes, foxes and feral pigs (Kirkwood & Hooper 2004), together with loss of habitat associated with sea level rise (Kirkwood & Hooper 2004).

The water mouse is nocturnal, and nests and feeds in the supralittoral and intertidal zones of tidal wetlands. Their foraging activities are constrained both by their nocturnal nature and the tide; they can only forage for their invertebrate prey items (such as molluscs, crabs and worms that are especially abundant in mangrove forests) during a low tide. In daylight hours, or when it cannot forage, the water mouse will retreat to its nest. Nests may be built anywhere from the reed / sedge zone to the mangrove zone, and they may be free-standing mounded soil structures, structures incorporated into 'islands' of existing vegetation, tree hollows, or spoil heaps of human origin. Nests are extremely difficult to detect, as the simple burrow entrance can look like a crab hole (Van Dyke & Janetzki 2004).

The water mouse may occur in the mangroves forest of Leeke's Creek.

3.8 Exotic Marine Fauna

No introduced marine species have been reported outside of designated ports in the Great Barrier Reef (GBRMPA 2011c). Although nine introduced marine species have been recorded in the Port Curtis region, including:

- bryozoans (*Amathia distans*, *Bugula neritina*, *Cryptosula pallasiana*, and *Watersporia subtoraquata*)
- ascidians (*Botrylloides leachi* and *Styela plicata*)
- isopod crustaceans (*Paracerceis sculpta*)
- hydrozoans (*Obelia longissima*), and
- dinoflagellates (*Alexandrium* sp.) (Lewis et al. 2001).

4 Potential Impacts

The potential impacts of the proposed development on marine fauna (not unique to marine fauna) are discussed in Appendix C (Marine Water Quality) and E (Marine Flora).

4.1 Marina Operation

Potential impacts associated with marina operation and associated infrastructure are likely to be primarily linked to human activity, e.g. marine pests, increased boat traffic, refuelling operations, antifoul leaching and increased litter, together with stormwater run-off (which will be mitigated using retention basins). Marine pests, refuelling operations, antifoul leaching, increased litter and stormwater run-off are discussed in Appendix C (Marine Water Quality) and E (Marine Flora).

The direct impact of increased boat traffic and boat strike is discussed below.

Boat Strike

During 1999 and 2000, boat strike was the primary cause of human-associated mortality of marine turtles in Queensland, accounting for up to 60% of deaths. Green turtles are especially at risk because of their habit of basking at the surface of the water (GBRMPA 2005).

During 2001 and 2002, boat strike was also a major concern for dugongs (QPWS 2004b). Dugongs may be seriously injured when struck by high-sped boat hulls, including fractures and internal injuries. Propeller cuts can lacerate organs killing the animal outright, or lead to serious infection or disability that may lead to death (GBRMPA 2005).

More recent data suggests that ‘go slow’ zones are reducing the incident of boat strike in areas with relatively high boat traffic and relatively large marine turtle and dugong populations, i.e. the Great Sandy Straits and Moreton Bay (QPWS 2004b; 2007).

An increased number of high-speed boats in the project area would increase the risk of boat strike in areas frequented by turtles and dugongs. In the project area, dugongs and marine turtles are relatively uncommon and segarass meadows are relatively sparse and patchy, compared to regions such as the Great Sandy Straits and Moreton Bay; hence boat strike is considered manageable where 'go slow' zones are introduced over shallow water likely to have increased high-speed boat traffic.

The risk of boat strike associated with wildlife tours is considered manageable where a Resort Tours Management Plan as part of the Environmental Management Plan (EMP) is developed and adhered to, with all activities undertaken in accordance with current best practice including GBRMPA's *Best Environmental Practices* for dugong watching (GBRMPA 2011a).

4.2 Resort Activities and Reef Visitation

There is a risk of physical destruction and / or depletion of ecosystems in association with resort activities and reef visitation. The risk is considered manageable where a management plan is developed as part of the EMP, with all activities undertaken in accordance with current best practice, including *GBRMPA's The Tourism Operator's Handbook for the Great Barrier Reef* (GBRMPA 2012b) and reefED's *Best Environmental Practices* (GBRMPA 2012a).

There are currently a range of tourism activities in the Keppel Bay region, including sailing, charter fishing, bareboat hire, snorkelling and scuba diving (GBRMPA 2011b). Cumulative impacts will be minimised where all operators adhere to their respective EMPs, under collaborative GBRMPA management.

Damage associated with anchoring will be minimised where moorings are installed and anchoring is in accordance with GBRMPA protocols. No Anchoring Areas were installed at Big Peninsula and Monkey Beach Reef on Great Keppel Island, and at Barren and Humpy islands, in November 2008. There are currently a small number of permitted private moorings in the Keppel Bay region, and GBRMPA encourages mooring owners to develop agreements to allow other operators to use the mooring (GBRMPA 2011b).

All fishing activities will adhere to GBRMPA and fisheries guidelines. There is a Public Appreciation Areas adjacent to the western coastline of Great Keppel Island: spearfishing and harvest fisheries are prohibited in this area. Spearfishing is also prohibited along the western shoreline of Great Keppel Island (and North Keppel Island) under Queensland fisheries legislation (GBRMPA 2011b).

Potential impacts will be minimised where the management plan includees:

- Boating
  - 'go slow' areas and staying alert for dugong and marine turtles in shallow waters, particularly over seagrass meadows
  - be particularly alert for marine turtles during the mating season (typically September and October), and do not disturb
  - be particularly alert for whales and their calves during the migration season (typically June to October), and do not disturb; noting that there is an increasing rate of humpback whales migrating along the east of Australia
  - adhere to any boating restrictions
  - be particularly alert when approaching shorelines, beaches and reef edges; proceed slowly and choose carefully where to come ashore or anchor
  - take care when transferring fuel to minimise the risk of spillages; re-fuel onshore or at the marina
- Anchoring
  - mooring are installed where possible
  - when anchoring
    - carry enough chain and line for the depth of anchoring
    - check the area before anchoring for coral or other sensitive ecological communities; anchor in sand or mud away from corals
    - use the appropriate type of anchor for the sediment
    - motor in the direction of the anchor when retrieving
- Diving and snorkeling
  - All snorkeling and diving tours to be adequately supervised
  - all beginners to practise buoyancy control away from coral or other wildlife
  - secure dragging diving equipment such as spare regulators and gauges
  - do not stand on coral or touch coral with your fins
  - observe but do not touch coral or other wildlife (noting they may be dangerous); take extra care when taking photographs underwater
  - if you pick up something, living or dead, always return it to the same position
  - do not block, chase, ride or grab wildlife

- Reef walking
    - avoid stepping on coral or other wildlife
    - develop marked trails for guests and supervise reef walks
    - if there is no marked trail, use obvious routes and / or follow sand channels
    - use a pole or a stick for balance
    - observe but do not touch coral or other wildlife (noting they may be dangerous)
    - if you pick up something, living or dead, always return it to the same position
- Turtle nesting
    - do not approach closely or shine lights on turtles leaving the water or moving up the beach
    - do not shine lights directly on the turtle during nest-digging or egg-laying
    - do not touch the turtles, hatchlings or eggs
    - avoid loud noise and sudden movements
    - do not light campfires on turtle nesting beaches
    - report sick, injured or dead turtles to the Marine Animals Hotline (1300 360 898)
- Marine wildlife watching
    - adhere to all 'boating' guidelines (above)
    - reduce your vessel speed to minimise the risk of collision in areas where marine turtles, dugongs, whales and dolphins are sighted; stay at least 100 m from whales
    - be quiet when you are around a marine turtles, dugongs, whales or dolphins
    - If there is a sudden change in marine turtle, dugong, whale or dolphin behavior move away immediately
    - do not chase or block passage
    - report sick, injured or stranded wildlife to the Marine Animal Hotline (1300 360 898)

- Fish feeding
  - use no more than one kilogram of raw marine products or fish pellets
  - throw the fish food onto the water; do not feed directly by hand
  - avoid fish feeding in areas where fishing or other in-water activities are also taking place
  - swimmers and snorkellers should not be in the water at the time of fish feeding
- Fishing
  - adhere to fisheries regulations, e.g. closed areas and GBRMPA zoning, bag limits and no take species
  - take only what you need
  - return all undersized or unwanted fish to the water carefully and quickly
  - if you intend keeping a fish, remove it from the hook or net quickly and humanely
  - avoid fishing where fish feeding or other in-water resort activities are taking place
  - avoid fishing in fish spawning areas
  - do not discard fishing line or any other foreign material as it can kill wildlife
  - report tagged fish to the Suntag hotline (1800 077 001), and
  - report 'fish kills' to the Marine Animals Hotline (1300 360 898).

5 Measures to Avoid, Minimise and Mitigate Impacts

5.1 Risk Assessment

A risk assessment of potential impacts has been undertaken in accordance with a standard risk assessment matrix (Table 5.1), as presented in Table 5.2. Mitigation measures associated with potential indirect impacts are discussed in Appendix C (Marine Water Quality) and Appendix E (Marine Flora), those associated with direct impacts are discussed below.

Table 5.1 Risk assessment matrix.

Probability	**Consequence**				
	Catastrophic Irreversible Permanent (5)	Major Long-term (4)	Moderate Medium-term (3)	Minor Short-term Manageable (2)	Insignificant Manageable (1)
Almost Certain (5)	(25) Extreme	(20) Extreme	(15) High	(10) Medium	(5) Medium
Likely (4)	(20) Extreme	(16) High	(10) Medium	(8) Medium	(4) Low
Possible (3)	(15) High	(12) High	(9) Medium	(6) Medium	(3) Low
Unlikely (2)	(10) Medium	(8) Medium	(6) Medium	(4) Low	(2) Low
Rare (1)	(5) Medium	(4) Low	(3) Low	(2) Low	(1) Low

Table 5.2 Summary of potential impacts on marine flora.

Design	Construction	Operation	Potential Impact	Mitigation Measure	Monitoring	Significance of Impact (Unmitigated)	Significance of Residual (Mitigated Impact)
●	●	●	boat strike	• 'go slow' zones • Resort Tours Management Plan as part of the EMP • report of any boat strikes or standings to management and relevant agency	• undertaken by agencies	Marine turtles (15) High Dugongs (15) High Dolphins (5) Medium Whales (5) Medium	Marine turtles (10) Medium Dugongs (10) Medium Dolphins (5) Medium Whales (5) Medium
●		●	damage or depletion associated with resort tours	• Resort Tours Management Plan as part of the EMP	• an annual (pre-wet) coral monitoring program would provide the opportunity to assess the severity of predicted impacts and inform management of potential issues, including operational EMPs and remediation	Mangroves (4) Low Seagrass (4) Low Coral reef (10) Medium Mobile biota (6) Medium Listed species (8) Medium	Mangroves (2) Low Seagrass (2) Low Coral reef (9) Medium Mobile biota (4) Low Listed species (6) Medium

5.2 Mitigation Measures

Current 'best practice' assessment offer significant opportunities to minimise the impacts associated with the operation of the proposed development.

Development and adherence to a Resort Tours Management Plan as part of the EMP offers significant opportunity to mitigate impacts associated with boat strike and resort tours, including:

- 'go slow' areas and staying alert for dugong and marine turtles in shallow waters, particularly over seagrass meadows
- be particularly alert for marine turtles during the mating season (typically September and October), and do not disturb
- be particularly alert for whales and their calves during the migration season (typically June to October), and do not disturb; noting that there is an increasing rate of humpback whales migrating along the east of Australia
- adhere to any boating restrictions
- be particularly alert when approaching shorelines, beaches and reef edges; proceed slowly and choose carefully where to come ashore or anchor
- take care when transferring fuel to minimise the risk of spillages; re-fuel onshore or at the marina
- carry enough chain and line for the depth of anchoring
- check the area before anchoring for coral or other sensitive ecological communities; anchor in sand or mud away from corals
- use the appropriate type of anchor for the sediment
- motor in the direction of the anchor when retrieving anhors
- all resort tours to be adequately supervised
- all beginner snorkelers and divers to practise buoyancy control away from coral or other wildlife
- avoid stepping on coral or other wildlife
- observe but do not touch coral or other wildlife (noting they may be dangerous); if you pick up something, living or dead, always return it to the same position
- do not block, chase, ride or grab wildlife
- develop marked trails for guests and supervise reef walks; if there is no marked trail, use obvious routes and / or follow sand channels

- do not approach closely or shine lights on turtles leaving the water or moving up the beach
- do not shine lights directly on the turtle during nest-digging or egg-laying
- reduce your vessel speed to minimise the risk of collision in areas where marine turtles, dugongs, whales and dolphins are sighted; stay at least 100 m from whales
- adhere to fisheries regulations, e.g. bag limits and no take species
- report incidents to the Marine Animals Hotline (1300 360 898)

5.3 Monitoring Requirements

Undertaking an annual (pre-wet) coral monitoring program will provide the opportunity to assess the accuracy of predicted impacts and inform management (and construction and operation Environmental Management Plans (EMPs), of potential issues and the need for responsive action. Regular monitoring will provide increased opportunity to identify the source of impacts and as required, distinguish them from the *perceived* source of impact.

Monitoring will focus of the distribution and health of communities in the vicinity of the development footprint and in areas where resort tours and associated boating are likely to impact on corals. Likely indicators of coral condition include evidence of physical damage (e.g. anchoring or diving), community description, condition (health), coral bleaching, disease, macroalgal and sediment loads and pest species (e.g. crown of thorns starfish and introduced marine pests).

6 Summary and Conclusions

6.1 Existing Environment

Coral Communities

Coral cover was consistently high (>41%) at one Middle Island site and consistently low (<16%) at the site near the observatory at Middle Island. Cover was moderately high (>31%) at Passage Rocks.

Communities were dominated by branching growth forms from the family Acroporidea (mostly *Acropora* spp. and *Montipora* spp.) and massive growth forms from the families Faviidae (mostly *Favia* spp., *Favites* spp., *Gonisterea* spp. and *Platygyra* spp.) and Poritidae (mostly *Porites* spp.), together with some plate / foliose, soft, mushroom and encrusting growth forms. The corals of Putney Beach were dominated by *Turbinaria* sp. and the soft coral *Sarcophyton* sp..

Severely bleached corals were most abundant at Clam Bay during the wet season survey (up to 17% cover). Coral disease was not observed.

Coral-associated epifauna (e.g. ascidians, barnacles, bivalves, echinoderms, polychaetes and zoanthids) were not abundant, covering <10% of the substrate at any one site.

Turf algae dominated the macroalgal communities, and typically grew on dead branching corals. There was low (typically <10%) cover of crustose coralline algae and larger growth forms from the genera *Lobophora*, *Padina* and *Halimeda* at most sites during most surveys.

Cover of sediment (rubble, sand and fine sediment) varied between sites and within most sites. Cover was consistently high (>47%) at Fishermans Beach and Putney Beach, and consistently low (<3%) at Middle Island sites and to a lesser extent (<13%) at Passage Rocks and Wreck Bay.

Coral communities of the project area were consistent with those reported by other studies of the area, and typical of the region.

Intertidal Rocky Shore

The intertidal rocky shore at Putney and Fishermans beaches supported a diverse invertebrate community, including oysters, barnacles, gastropods, limpets, chitons, anemones and crabs. Rock oysters (*Saccotrea* sp.) dominated the upper intertidal zone at both Putney and Fishermans beaches.

Benthic Infaunal Invertebrate Communities

Polychaeta (worms) and malacostracan crustaceans (amphipods, isopods and decapods) were the most common and abundant benthic infaunal taxa, recorded at all sites during all of the surveys. Taxonomic richness was relatively high but variable between surveys at Putney Beach, and consistently low (<2 taxa) at Clam Bay, Long Beach and the mainland sites. Abundance was relatively low (<7 individuals) at most sites during most surveys. Abundance was highly variable at Fishermans Beach and Putney Beach; this may reflect 'boom and bust' cycles often associated with nutrient enrichment, due to sewage input from Putney Creek and moored vessels at Fishermans Beach.

Decapod Macrocrustaceans

A range of macrocrustaceans were recorded in, or are likely to inhabit, the project area including the ornate spiny lobster and crabs such as the mud, blue swimmer, orange-clawed fiddler, ghost, soldier, grapsid and hermit crabs.

Fishes

The coral, seagrass and mangrove communities of the project area provide habitat for a variety of fish.

Elasmobrachs were recorded during the surveys included the epaulette shark, blue-spotted stingray, cowtail stingray, estuarine stingray, common shovel-nosed ray, and spotted eagle ray.

Coral-associated fin-fish communities were generally dominated by damselfish (Pomacentridae), wrasse (Labridae), sweetlip (Haemulidae) and fusiliers (Caesionidae), together with rabbitfish (*Siganus* spp.), butterflyfish (Chaetodontidae), emperors (Lethrinidae), seaperch (*Lutjanus* spp.), cardinalfish (Apogonidae), drummers (Monodactlidae), fusiliers (Caesionidae), angelfish (Pomacanthidae), emperors (*Lethrinus* spp.), goatfish (Mullidae), puffers (Tetradontidae), cod (Serranidae), surgeonfish (Acanthuridae) and parrotfish (Scaridae).

Few adult fish were recorded in the seagrass meadows; several blenny and goby burrows were observed. These species are a food source for commercially and recreationally important fish species. Ray feeding-pits were relatively common in the seagrass meadows, suggesting that the blue-spotted, cowtail and shovelnose rays commonly fed on benthic infaunal invertebrates within the sediment of the meadows.

Fish communities associated with the Leeke's Creek mangrove forest were characterised by mobile, transient species with little direct commercial or recreational value, in particular hardyheads and silverbiddies. Estuarine and blue-spotted rays were regularly observed feeding in Leeke's Creek in relatively large numbers (up to ten individuals observed near the creek mouth with tens of feeding-pits evident).

Marine Reptiles

Marine turtles are relatively widespread in the project area. Three species of marine turtle were recorded during the surveys, the flatback (*Natator depressus*), green (*Chelonia mydas*) and hawksbill (*Eretmochelys imbricata*).

A total of 29 nesting activities were recorded on Leeke's, Putney and Long beaches during the 2010–11 nesting season. Twenty of these activities were recorded on Leeke's Beach, while six were recorded on Long Beach and three were recorded on Putney Beach. These results are consistent with observation by island resident Lyndie Svendsen, which recorded a small number of flatback and green (*Chelonia mydas*) turtles nest on the beaches of Great Keppel Island. Of the beaches observed, most nesting activity has been reported from Leeke's Beach, Long Beach, Second Beach and Butterfish Bay. Over the period 2005 to 2009, four turtle nesting activities were reported for Putney Beach.

A seasnake (unidentified) was recorded off Leeke's Beach over sandy substrate. Seasnakes, including the olive (*Aipysurus laevis*) and stokes (*Astrotia stokesii*), are likely to inhabit the project area.

Marine Mammals

A small (approximately six to eight individuals) pod of bottlenose dolphins (*Tursiops* sp.) was recorded near Fishermans Beach during the pre-wet survey. The pod consisted of adults and juveniles that appeared to be feeding.

Regional and Ecological Context

Coral Communities

The coastal waters of the project area are described as being within the 'high nutrient coastal strip' bioregion of the Great Barrier Reef. This bioregion is characterised by terrigenous mud, high levels of nutrients from the adjoining land, seagrass in sheltered waters and a wet tropic climate. Within this area, there are scattered coastal fringing reefs that generally develop around the mainland and high continental islands and have high coverage of hard coral, soft coral and macroalgae, but low coral diversity.

Coral communities of this bioregion generally have a high cover of coral and microalgae, a clear capacity to recover following disturbance (e.g. coral bleaching), a high but often variable spat settlement (recruitment), and low juvenile coral densities. Coral reefs of the region have been repeatedly affected by bleaching with substantial declines in coral coverage observed in 1998, 2002 and 2006[11]; in January 2006, 100% of corals in Keppel Bay were bleached with approximately 40% mortality by May 2006. However, rapid recovery has also been documented and some reefs in southern Keppel Bay (Humpy, Middle, Halfway and Pumpkin islands, and the reef surrounding Passage and Outer rocks) may be coral 'refuges' due to high diversity and connectivity to sites with lower diversity and coral cover.

After a major flood event in January 1991, large freshwater input from the Fitzroy River resulted in reduced coral cover and increased bleaching. Approximately 85% of coral in the area died and was overgrown by turf algae, shallow areas were most affected. Mortality was greatest for acroporids and pocilloporids, with survival in shallow habitats apparent for faviids, *Turbinaria* spp., *Porites* spp., *Psammocora* sp. and *Coscinaraea* sp..

The distribution of coral-associated flora and fauna is determined principally by exposure to wave action, and water quality (in particular turbidity).

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[11] And most likely 2010-11, although the effect of the recent Fitzroy River flooding on coral reef communities is yet to be confirmed.

Intertidal Rocky Shores

There is limited information available regarding intertidal rocky shores of the region. Communities of the nearby Port Curtis region, approximately 75 km south of the project area, support diverse floral and faunal communities, including gastropods, sponges, ascidians, soft and hard coral and macroalgae. Artificial structures, such as jetties, seawalls and pipes, are also likely to provide hard surfaces for sessile marine communities. The habitat diversity of these rocky environments often supports diversity ecological communities that include fishes, reptiles (such as sea snakes and turtles), echinoderms, polychaetes and crustaceans. These habitat types are of importance to many species that require hard substrate for colonisation.

Benthic Infaunal Invertebrate Communities

Benthic infaunal invertebrate communities of the region are typically dominated by filter feeders. Species richness and abundance are typically lowest in fine muddy substrates of intertidal areas, and highest in coarse sandy sediments. Abundance typically increases with regional rainfall and freshwater inflow. Infaunal invertebrate communities in the Port Curtis region included 129 taxa, and were dominated by polychaetes, molluscs and crustaceans. The highest mean abundance was 37 individuals and the highest mean taxonomic richness was 16 taxa. This is higher than that recorded during this study, which is likely to be related to the finer sediments of the Port Curtis area (as finer sediments typically support more diverse and abundant infaunal communities).

Decapod Crustaceans

There is limited information available regarding macrocrustacean communities of the region. Communities are expected to be typical of other Queensland reefs and include prawns and shrimps (from the genera *Penaeus, Periclimenes, Stenopus* and *Thor*), mantis shrimps (from the genus *Odontodactylus*), lobsters and crayfish (from the genera *Allogalathea, Callianassa*, *Ibacus, Neaxius, Panulirus* and *Thenus*), hermit crabs (from the genera *Cilianarius* and *Dardanus),* and crabs (from the several genera including *Uca, Mictyris, Trapezia, Charybdis, Portunus, Scylla* and *Ocypode*).

Fishes

There is limited information available regarding fish communities of the region. Fish assemblages of Keppel Bay are typical of inshore waters. The rock and reef habitat at nearby Port Curtis is used by a range of adult and juvenile fish species such as yellowfin bream (*Acanthopargus australis*), sweetlip (*Lethrinus* spp.), and estuary cod (*Epinephelus coioide*).

Marine Reptiles

Five of Australia's six species of marine turtles are likely to occur in the project area. This includes resident populations of flatback (*Natator depressus*) and green (*Chelonia mydas*) turtles, and occasional occurrence of the loggerhead (*Caretta caretta*) hawksbill (*Eretmochelys imbricata*) and olive Ridley (*Lepidochelys olivacea*) turtle. Marine turtles are protected under the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) and Queensland Nature Conservation (Wildlife) Regulation 2006 (NCWR).

Seasnake are listed under the 'marine' schedule of the EPBC Act, and are consequently protected within Commonwealth Marine waters such as the GBRMP. Seasnakes inhabit a range of habitats, including sandy bottom habitats, reef habitats and pelagic habitats (*Pelamis* sp. only). Seasnakes are likely to inhabit the project area; the olive (*Aipysurus laevis*) and stokes (*Astrotia stokesii*) seasnake are relatively abundant at Passage Rocks and Middle Island.

Marine Mammals

Several cetaceans (whales, dolphins and porpoises) are listed under the 'cetaceans' schedule of the EPBC Act. Several species are also listed as under the 'threatened' schedule of the EPBC Act and NCWR, and in the IUCN Red List. Species likely to use habitats in the project area include the Indo-Pacific humpback dolphin (*Sousa chinensis*), bottlenose dolphin (*Tursiops* spp.), common dolphin (*Delphinus delphis*), dugong (*Dugong dugon*) and water mouse (*Xeromys myoides*). Several other species may occur in nearby waters, including the humpback whale (*Megaptera novaeangliae*), minke whale (*Balaenoptera acutorostrata*), Bryde's whale (*Balaenoptera edeni*), Australian snubfin dolphin (*Orcaella heinsohni*) and Risso's dolphin (*Grampus griseus*).

Exotic Marine Fauna

No introduced marine species have been reported outside of designated ports in the Great Barrier Reef. Although nine introduced marine species have been recorded in the Port Curtis region, including bryozoans (*Amathia distans*, *Bugula neritina*, *Cryptosula* pallasiana, and Watersporia subtoraquata), ascidians (Botrylloides leachi and Styela plicata), isopod crustaceans (Paracerceis sculpta), hydrozoans (Obelia longissima), and dinoflagellates (Alexandrium sp.) (Lewis et al. 2001). However, none of these are classified as marine pest species and are unlikely to have a significant impact on native marine assemblages.

6.2 Potential Impacts

Cumulative impacts of the proposed development on marine fauna, including nearby tourism developments, climate change and ecosystem functioning, are discussed in Appendix C (Marine Water Quality).

6.3 Mitigation Measures

Mitigation measures associated with the potential impacts of the proposed development on marine fauna are discussed in Appendix C and E.

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Appendix G Freshwater Communities

Contents

Tables

Figures

1 Methods

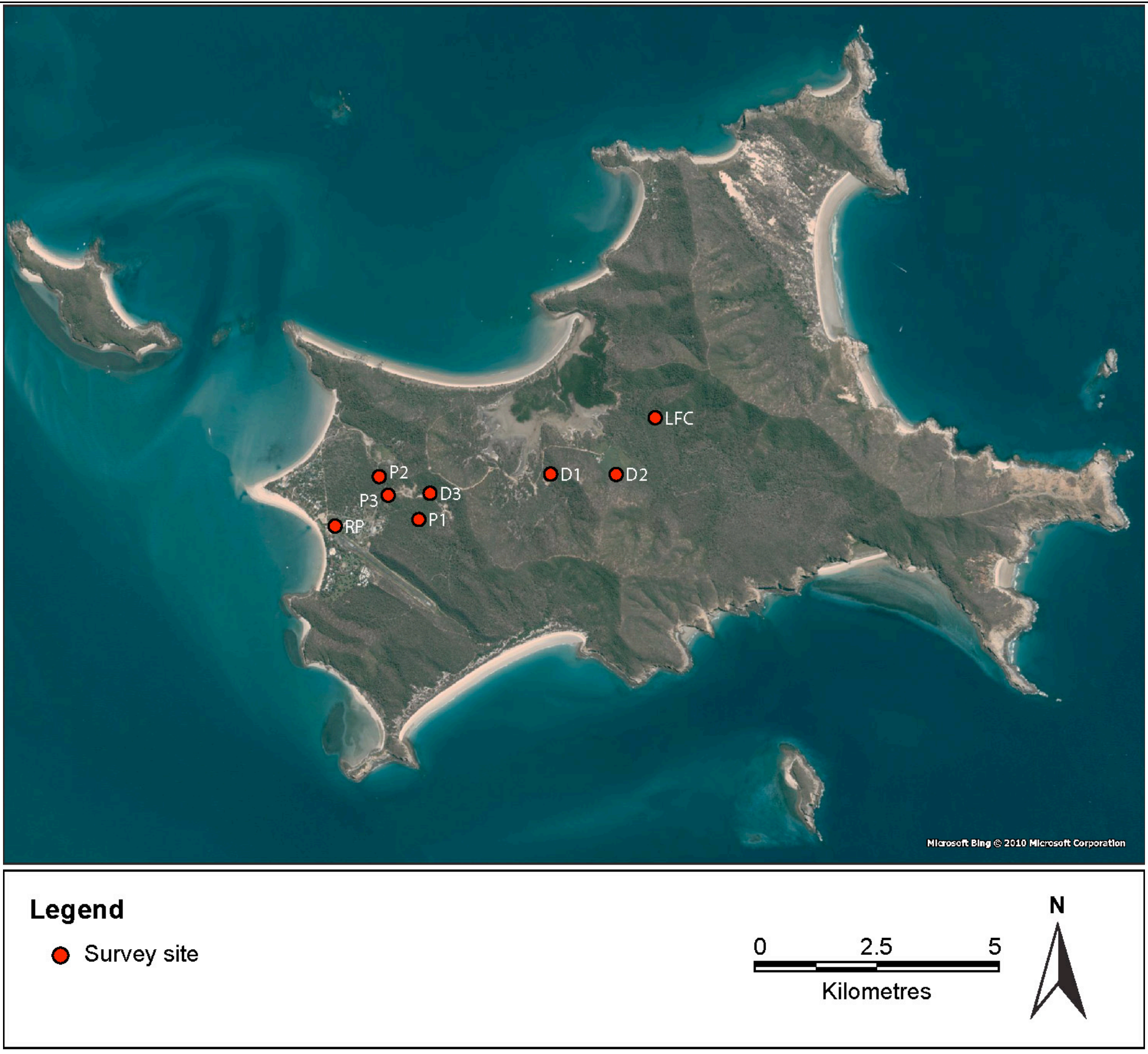
1.1 Sites Surveyed

Eight freshwater sites on Great Keppel Island were surveyed in the post-wet season (on 2 April 2011, 3 May 2011 and on 18 June 2011) (Figure 1.1):

- Large Dam (D1)
- Homestead Dam (D2)
- Resort Dam (D3)
- Putney Creek (P1, P2 and P3)
- Leeke's Creek (LFC), and
- Resort Creek (RP).

Freshwater surveys included assessment of:

- aquatic habitat
- water quality
- sediment quality
- aquatic flora, and
- aquatic fauna (macroinvertebrates, fish and turtles).



frc environmental AQUATIC ECOLOGISTS deep thinking. science.	Great Keppel Island Revitalisation EIS	
	Figure 1.1 Freshwater sites.	
	(Microsoft Bing © 2010)	June 2011

1.2 Aquatic Habitat

Based on the Australian River Assessment System (AUSRIVAS) protocol described in the *Queensland AUSRIVAS Sampling and Processing Manual* (DNRM 2001), the in-stream habitat condition at each site was assessed based on the following parameters:

- habitat bioassessment scores
  - bottom substrate / available cover
  - embeddedness
  - velocity / depth
  - channel alteration
  - bottom scouring and deposition
  - pool / riffle, run / bend ratio
  - bank stability, and
  - bank vegetative stability and streamside cover
- reach environs (land immediately adjacent to the riparian zone)
- bank erosion
- substrate composition (silt / clay, sand, pebble, cobble, boulder)
- channel diversity (pool / riffle / run), and
- in-stream habitat (in-stream vegetation and substrate characteristics).

Habitat Bioassessment Scores

The habitat bioassessment score datasheets (DNRM 2001) were used to numerically score nine criteria, which were then allocated to one of four categories (excellent, good, moderate and poor). The sum of the numerical rating from each category produced an overall habitat assessment score (Table 1.1):

- Excellent >110,
- Good 75–110,
- Moderate 39–74, and
- Poor ≤38.

Table 1.1 Habitat bioassessment scores used to derive overall condition categories.

Habitat Category	Category Score Range			
	Excellent	Good	Moderate	Poor
Bottom substrate / available cover	16–20	11–15	6–10	0–5
Embeddedness	16–20	11–15	6–10	0–5
Velocity / depth category	16–20	11–15	6–10	0–5
Channel alteration	12–15	8–11	4–7	0–3
Bottom scouring & deposition	12–15	8–11	4–7	0–3
Pool / riffle, run / bend ratio	12–15	8–11	4–7	0–3
Bank stability	9–10	6–8	3–5	0–2
Bank vegetative stability	9–10	6–8	3–5	0–2
Streamside cover	9–10	6–8	3–5	0–2
Total (Habitat Bioassessment Score for the Site)	**111–135**	**75–110**	**39–74**	**0–38**

1.3 Water Quality

In situ Snapshot

Physical water quality measurements were collected *in situ* at each site. A Hydrolab Quanta water quality meter was used to measure:

- pH
- electrical conductivity
- dissolved oxygen
- water temperature, and
- turbidity.

Laboratory Analyses

Water samples were collected from each site, in accordance with the *Monitoring and Sampling Manual 2009* (DERM 2010b). Two water samples were collected at sites D1 (large dam) and D3 (resort dam) to estimate within-site variation.

Samples were held under the appropriate holding conditions, before being forwarded to Advanced Analytical (a NATA-accredited laboratory) for analysis of the concentration of:

- total suspended solids
- nutrients (ammonia as N, total nitrogen, total Kjeldahl nitrogen, nitrate as N, nitrite as N, total phosphorus and total phosphate)
- $CaCO_3$ (water hardness)
- total metals and metalloids (arsenic, cadmium, chromium, copper, lead, mercury, nickel and zinc)
- aromatic hydrocarbons (benzene, ethylbenzene, toluene, total BTEX, m+p-xylene and o-xylene)
- total petroleum hydrocarbons (C6–9, C10–14, C15–C28 and C29–C36), and
- organochlorine pesticides (aldrin, alpha-BHC, beta-BHC, gamma-BHC, delta-BHC, cis-Chloradane, trans-Chloradane, p,p'-DDE, p,p'-DDT, dieldrin, alpha-endosulfan, beta-endosulfan, endosulfan sulphate, endrin, endrin aldehyde, endrin ketone, heptachlor, heptachlor epoxide, hexachlorobenzene, methoxychlor, and mirex).

Data Analysis

Results were compared with the Queensland Water Quality Guidelines (QWQG) low and high trigger values for lowland streams in the Central Coast region (DERM 2009) where available (Table 1.2). Concentrations of metals and metalloids, aromatic and petroleum hydrocarbons and organochlorine pesticides were compared with the ANZECC & ARMCANZ (2000) trigger values for toxicants in slightly to moderately disturbed systems (Table 1.3). Concentrations were compared to the 95% level of protection ANZECC & ARMCANZ trigger value given the level of disturbance (slight to moderate) at most sites, including historical livestock grazing, landfill / rubbish dumps, seepage from septic tanks, and the potential for hydrocarbon and / or oil to enter waterways from access tracks. The 99% level of protection trigger value was used for mercury and several organochloride pesticides due to the potential for bioaccumulation, as recommended in the ANZECC & ARMCANZ (2000) guidelines.

Table 1.2 Queensland Water Quality Guideline values for lowland streams in Central Coast Queensland.

Parameter	Units	QWQG Value for Lowland Streams
Temperature	ºC	–
Turbidity	NTU [a]	50
pH	pH units	6.5–8.0
Electrical conductivity [b]	µS/cm	340
Dissolved oxygen	% saturation	85–110
Total nitrogen	µg/L	500
Total phosphorous	µg/L	50

[a] Nephelometric Turbidity Units
[b] preliminary guideline value for the Fitzroy central salinity zone

Table 1.3 ANZECC & ARMCANZ trigger values for potential contaminants in freshwater systems at different levels of protection.

	Level of Protection (% species)			
	99%	95%	90%	80%
Metals and Metalloids				
Arsenic (As III)	1.0	24.0	94.0	360.0
Arsenic (As V)	0.8	13.0	42.0	140.0
Cadmium	0.06	0.2	0.4	0.8
Chromium (Cr III)	ID	ID	ID	ID
Chromium (Cr VI)	0.01	1.0	6.0	40.0
Copper	1.0	1.4	1.8	2.5
Lead	1.0	3.4	5.6	9.4
Mercury (Inorganic)	0.06	0.6	1.9	5.4
Nickel	8.0	11.0	13.0	17.0
Zinc	2.4	8.0	15.0	31.0
Aromatic Hydrocarbons				
Benzene	600	950	1300	2000
Ethylbenzene	ID	ID	ID	ID
Toluene	ID	ID	ID	ID
m+*p*-xylene	ID	ID	ID	ID
o-xylene	200	350	470	640
Petroleum Hydrocarbons				
C6-9	ID	ID	ID	ID
C10-14	ID	ID	ID	ID
C15-28	ID	ID	ID	ID
C29-36	ID	ID	ID	ID
Organochlorine Pesticides				
Aldrin	ID	ID	ID	ID
alpha-BHC	–	–	–	–
beta-BHC	–	–	–	–
gamma-BHC	–	–	–	–

	Level of Protection (% species)			
	99%	95%	90%	80%
delta-BHC	–	–	–	–
Chlordane	0.03	0.08	0.14	0.27
DDE	ID	ID	ID	ID
DDT	0.006	0.01	0.02	0.04
Dieldrin	ID	ID	ID	ID
alpha-endosulfan	ID	ID	ID	ID
beta-endosulfan	ID	ID	ID	ID
Endosulfan	0.03	0.2	0.6	1.8
Endrin	0.01	0.02	0.04	0.06
Endrin aldehyde	–	–	–	–
Endrin ketone	–	–	–	–
Heptachlor	0.01	0.09	0.25	0.7
Heptachlor epoxide	–	–	–	–
Hexachlorobenzene	–	–	–	–
Methoxychlor	ID	ID	ID	ID
Mirex	ID	ID	ID	ID

Note ANZECC & ARMCANZ guidelines do not specify whether these trigger values apply to dissolved and / or total metal concentrations; shaded cells indicated level of protection that applies to slightly to moderately disturbed systems, as used in this study

ID insufficient data

– not available in ANZECC & ARMCANZ guidelines

The toxicity trigger values for cadmium, chromium, copper, lead, nickel and zinc, were modified for water hardness as outlined in ANZECC & ARMCANZ (2000), resulting in site-specific trigger values (determined by the metal specific algorithms in Table 1.4). Results for these metals were compared to site-specific trigger values, and therefore graphed without trigger values. Water hardness was soft at five sites. Water hardness was moderate at two sites, D3 (Resort Dam) and LFC (Leeke's Freshwater Creek) and extremely hard at site RP (Resort Creek), hence values were compared to modified trigger values at these sites (Table 1.5).

Any results less than the laboratory detection limits were entered as half the laboratory detection limit, for analytical purposes (DEWHA 2009).

Table 1.4 ANZECC & ARMCANZ algorithm to apply to trigger values for metal concentrations in freshwater of varying water hardness.

Metal	Algorithm
Cadmium	$HMTV = TV (H/30)^{0.89}$
Chromium	$HMTV = TV (H/30)^{0.82}$
Copper	$HMTV = TV (H/30)^{0.85}$
Lead	$HMTV = TV (H/30)^{1.27}$
Nickel	$HMTV = TV (H/30)^{0.85}$
Zinc	$HMTV = TV (H/30)^{0.85}$

Table 1.5 Site specific ANZECC & ARMCANZ trigger values for metals modified for water hardness in freshwater systems at 95% protection.

Site	Hardness (mg/L of $CaCO_3$)	Cadmium (µg/L)	Chromium (µg/L)	Copper (µg/L)	Lead (µg/L)	Nickel (µg/L)	Zinc (µg/L)
RP	90	7.4	6.3	6.5	16.8	6.5	6.5
D3	93	7.2	6.1	6.3	16.1	6.4	6.4
LFC	275	71.8	55.2	59.2	445.2	59.2	59.2

1.4 Sediment Quality

Sediment samples were collected from the wet channel bed at each site and from accreting banks, where possible.

Laboratory Analyses

Sediment samples were analysed by Advanced Analytical (a NATA-accredited laboratory) for particle size distribution, moisture content and the concentration of:

- nutrients (ammonia as N, total nitrogen, total Kjeldahl nitrogen, nitrate as N, nitrite as N, orthophosphate as P and total phosphate)
- organochlorine pesticides (aldrin, alpha-BHC, beta-BHC, gamma-BHC, delta-BHC, cis-Chloradane, trans-Chloradane, p,p'-DDE, p,p'-DDT, dieldrin, alpha-endosulfan, beta-endosulfan, endosulfan sulphate, endrin, endrin aldehyde, endrin ketone, heptachlor, heptachlor epoxide, hexachlorobenzene, methoxychlor, and mirex), and
- metals and metalloids (arsenic, cadmium, chromium, copper, lead, mercury, nickel and zinc).

Data Analysis

Data from each site was compared to:

- laboratory detection limits, and
- ANZECC & ARMCANZ (2000) trigger values for sediment (Interim Sediment Quality Guideline (ISQG) low trigger value) (Table 1.6).

Concentrations were compared to the ISQG-low trigger value (most protective) given the slight to moderate disturbance at most sites, rather then the ISQG-high trigger value, which is more appropriate for heavily disturbed sites.

Any results less than the laboratory detection limits were entered as half the laboratory detection limits, for analytical purposes (DEWHA 2009).

Table 1.6 ANZECC & ARMCANZ sediment trigger values for all parameters analysed.

Parameter	ISQG-low trigger value (mg/kg dry wt)
Nutrients	
Total nitrogen	–
Total phosphorous	–
Metals and Metalloids	
Arsenic (As III & V)	20
Cadmium	1.5
Chromium (Cr III & VI)	80
Copper	65
Lead	50
Mercury	0.15
Nickel	21
Zinc	200
Organochlorine Pesticides	
Aldrin	–
alpha-BHC	–
beta-BHC	–
gamma-BHC (Lindane)	0.32
delta-BHC	–
Chlordane	0.5
DDD	2
DDE	2.2
DDT	1.6
Dieldrin	0.02
alpha-endosulfan	–
beta-endosulfan	–
Endosulfan	–
Endrin	0.02
Endrin aldehyde	–
Endrin ketone	–
Heptachlor	–

Parameter	ISQG-low trigger value (mg/kg dry wt)
Heptachlor epoxide	–
Hexachlorobenzene	–
Methoxychlor	–
Oxychlordane	–

ISQG-Low trigger value Interim Sediment Quality Guidelines (highest level of protection)
– not available in guidelines

1.5 Aquatic Flora

The aquatic flora (macrophyte) community at each site was assessed along a 100 m reach within the stream. Plants were identified, and the following recorded:

- taxonomic richness
- whether the plant was native or exotic to Australia
- growth form of each species (submerged, floating (free-floating or rooted) and emergent)
- total percent cover (% of substrate (bed / bank) covered by each species), and
- mean percent cover (% of substrate (bed / bank) covered by vegetation).

Macrophyte species were identified in the field, where practical. Representative specimens were collected for identification in the laboratory (or by the Queensland Herbarium, if required). The *Census of Queensland Flora 2007* (Queensland Herbarium 2007) was used to classify macrophytes as native or exotic. Total percent cover of listed species, under the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999* or Queensland *Nature Conservation Act 1992* was determined for each site.

Macrophytes with a submerged growth form, predominantly grow beneath the surface of the water, although flowers may project above the water surface and some leaves may float on the water surface (e.g. Sainty & Jacobs 2003).

Macrophytes with a floating growth form, can be either free-floating or rooted (Sainty & Jacobs 2003). Free-floating species are usually not attached to the substrate, whereas rooted species are attached to the substrate and normally have at least the mature leaves floating on the water surface (Sainty & Jacobs 2003).

Macrophytes with an emergent growth form, are rooted in the substrate and the stems, flowers and most of the mature leaves project above the water surface (Sainty & Jacobs 2003).

Total percent cover of each species was assessed visually.

1.6 Aquatic Macroinvertebrate Communities

Sample Collection

AUSRIVAS Samples

At each site, one sample from the bed habitat and one sample from the edge habitat (where available [1]) were collected, to enable comparison to AUSRIVAS data sets of the region. This sampling was based on the methods in the Queensland AUSRIVAS sampling manual, and is designed to provide a broad description of macroinvertebrate communities, rather than a quantitative assessment (DNRM 2001). A standard triangular-framed, macroinvertebrate sampling net with 250 µm mesh was used to collect the samples. In this method a 10 m long section of streambed or edge habitat is disturbed, and a sample collected by sweeping the net through the disturbed area.

Quantitative Samples

Five macroinvertebrate samples were collected from bed and edge habitat at most sites [2] (D1, D2, D3, LFC and RP). There was no riffle habitat in the project area. Sediment was disturbed within a 30 x 30 cm area for five seconds, and each sample was collected by sweeping a standard triangular-framed, macroinvertebrate sampling net, with 250 µm mesh, through the disturbed area five times. This quantitative sampling enabled a more rigorous analysis of the variability within and between sites.

[1] Only bed habitat was available at Putney Creek sites (PI, P2 and P3) due to the small size of the pool. The pool was less than 10 m long (the standard length collected within the AUSRIVAS method) at sites P1 and P3 hence this data should be interpreted with caution.

[2] Quantitative samples were not collected at Putney Creek sites (P1, P2 and P3) as these sites would be lost to the development and not included in future monitoring programs.

Macrocrustacean Samples

Macrocrustaceans (e.g. shrimps, yabbies and crabs) were caught during fish surveys, using a combination of baited traps and netting (Table 1.7).

Table 1.7 Baited trap effort at each site.

Site	Method	Date	Time In	Time Out	Effort (hr)
RP	Small bait traps (5)	2/4/11	9:50	11:30	1.7
P1	Small bait traps (5)	–	–	–	Too shallow
P2	Small bait traps (5)	–	–	–	Too shallow
P3	Small bait traps (5)	–	–	–	Too shallow
D1	Small bait traps (5)	2/4/11	13:50	16:10	2.2
D2	Small bait traps (5)	3/5/11	8:30	10:30	2.0
D3	Small bait traps (5)	3/5/44	10:15	12:30	2.2
LFC	Small bait traps (5)	–	–	–	Too shallow

Sample Processing

All samples were frozen and returned to the frc environmental biological laboratory, where they were sorted, counted and identified to the lowest practical taxonomic level (in most instances family), to comply with AUSRIVAS standards and those described by Chessman (2003).

Data Analysis

The following indicators were determined at each site:

- taxonomic richness
- abundance
- PET richness
- dominant taxa
- community composition, and
- SIGNAL 2 / family bi-plots.

The results for total taxonomic richness, PET scores and SIGNAL 2 scores were compared to the biological guidelines outlined in the QWQG for slightly to moderately disturbed streams in the central Queensland region (Table 1.8) (DERM 2009).

Table 1.8 Queensland Water Quality Guidelines biological values for central Queensland.

Indicator	Habitat	Biological Value
Taxonomic richness	Composite [a]	12–21
	Edge	23–33
PET richness	Composite [a]	2–5
	Edge	2–5
SIGNAL 2 score	Composite [a]	3.33–3.85
	Edge	3.31–4.20

[a] comprises all bed habitat within the site, including sandy pool, rocky pool, riffle, run and cascade

Calculation of Indices

Taxonomic richness, PET richness and SIGNAL 2 scores were calculated for each habitat at each site, based on the results from all five replicates combined (to more closely approximate the methods used by DERM to calculate the biological guidelines, which are based on AUSRIVAS sampling methods, i.e. a 10 m sweep of each habitat at each site). These indices were used to indicate the current ecological health of surveyed waterways.

Mean taxonomic richness and abundance (the number of macroinvertebrates per samples) was also calculated for each habitat at each site, to enable a more detailed comparison between sites.

Taxonomic Richness

Taxonomic richness is the number of taxa (in this assessment, families). Taxonomic richness is a basic, unambiguous and effective diversity measure. It is however, affected by arbitrary choice of sample size. Where all samples are of equal size, taxonomic richness is a useful tool when used in conjunction with other indices. Richness does not take into account the relative abundance of each taxon, so rare and common taxa are considered equally.

Abundance

Abundance is the total number of macroinvertebrates.

PET Richness

While some groups of macroinvertebrates are tolerant to pollution and environmental degradation, others are sensitive to these stressors (Chessman 2003). Plecoptera (stoneflies), Ephemeroptera (mayflies), and Trichoptera (caddisflies) are referred to as PET taxa, and they are particularly sensitive to disturbance. There are typically more PET families within sites of good habitat and water quality than in degraded sites. PET taxa are often the first to disappear when water quality or environmental degradation occurs (EHMP 2007). The lower the PET score, the greater the inferred degradation.

SIGNAL 2 Scores

SIGNAL (**S**tream **I**nvertebrate **G**rade **N**umber — **A**verage **L**evel) scores are also based on the sensitivity of each macroinvertebrate family to pollution or habitat degradation. The SIGNAL system has been under continual development for over 10 years, with the current version known as SIGNAL 2. Each macroinvertebrate family has been assigned a grade number between 1 and 10 based on their sensitivity to various pollutants. A low number means that the macroinvertebrate is tolerant of a range of environmental conditions, including common forms of water pollution (e.g. suspended sediments and nutrient enrichment).

SIGNAL 2 scores are weighted for abundance. The scores take the relative abundance of tolerant or sensitive taxa into account (instead of only the presence / absence of these taxa). The overall SIGNAL 2 score for a site is based on:

- the total of the SIGNAL grade
- multiplied by the weight factor for each taxa, and
- divided by the total of the weight factors for each taxa.

SIGNAL 2 scores are interpreted in conjunction with the number of families found in the sample. This is achieved using a SIGNAL 2 / Family bi-plot (Chessman 2003). The plots are divided into quadrants, with each quadrant indicative of particular conditions (Figure 1.2).

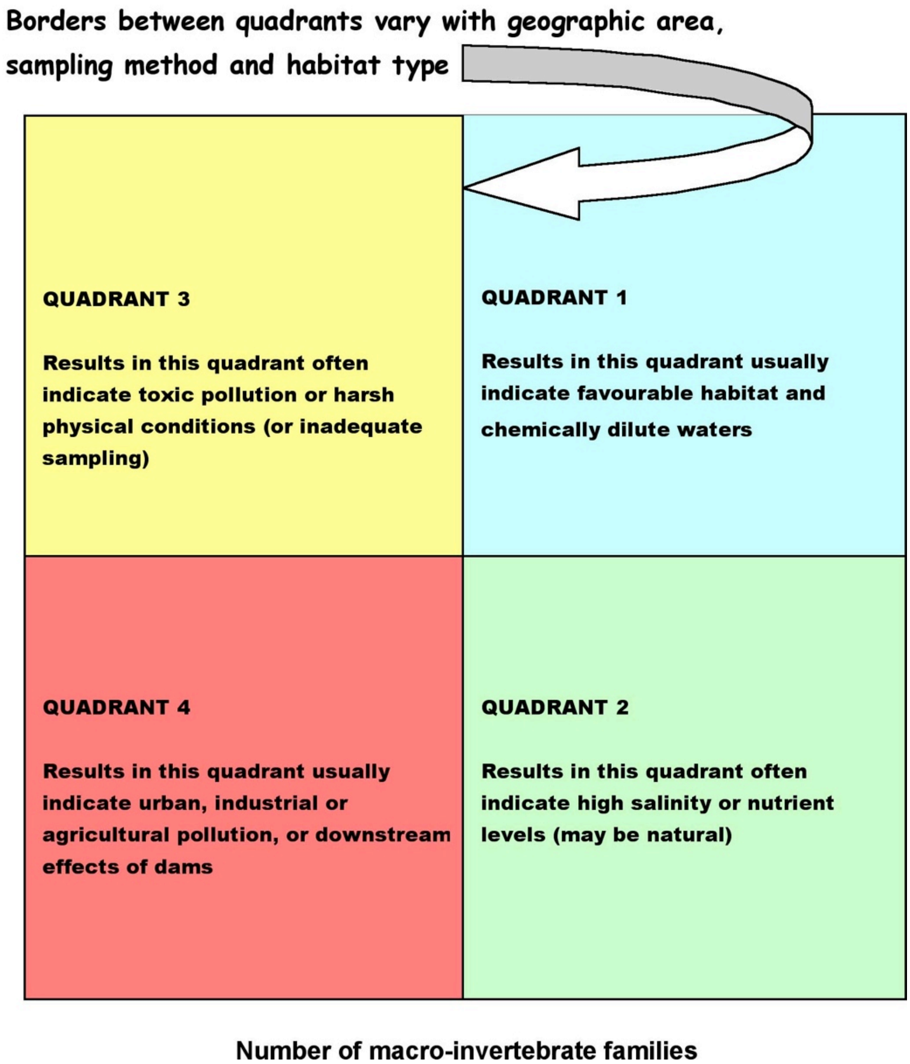


Figure 1.2 Quadrant diagram for SIGNAL 2 / Family Bi-plot.

Regional Context

At each site, total taxonomic richness, PET richness and SIGNAL 2 scores / family bi-plot for the AUSRIVAS samples were compared to data collected from waterways in the region by the Department of Environment and Resource Management (DERM). DERM data were collected from the nearest mainland sites, as data for island sites were not available: Coorooman Creek at Coorooman Creek Road (site 1290009) and Moores Creek at First Turkey (site 1300001) in 1998. Regional comparisons were made with caution as freshwater streams on islands are likely to be different to those on the mainland; in addition, several of the sites in this study were off-stream dams.

1.7 Freshwater Fish Communities

Fish communities were surveyed using baited traps (Table 1.7). Set traps included five small (2 mm mesh size) baited traps, which were set at each site, where water levels allowed, for approximately two hours.

The life-history stage, abundance and the apparent health of every fish caught were recorded. Specimens that were unable to be identified in the field were euthanised and returned to the laboratory for identification.

The sampling of fishes was conducted under General Fisheries Permit No. 140240 and Animal Ethics Approval No. CA 2009/03/343 issued to frc environmental.

Data Analysis

Fish communities at each site were assessed for the:

- taxonomic richness (total number of species caught at a site)
- total abundance (total number of individuals caught at a site)
- abundance of exotic species, and
- abundance of species listed under the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999* or Queensland *Nature Conservation Act 1992.*

1.8 Freshwater Turtle Communities

Observations of freshwater turtle communities were made; traps were not set as sites that had low water levels and / or lacked suitable habitat. Turtle communities were described through literature review and database searches, specifically: the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999 (*EPBC Act) *Protected Matters Search Tool* (DSEWPC 2011); and the Queensland *Wildlife Online* with a search area of approximately 25 km around the development (DERM 2011a).

1.9 Regional Context

Freshwater communities of the project area and region were described through literature review and database searches, specifically: the EPBC Act *Protected Matters Search Tool* (DSEWPC 2011); and the *Queensland WildNet database* (DERM 2011b) for a search area that included a 10 km buffer around the project as well as within the wider project area (from Shoalwater Bay to Curtis Island). Where available, information was also sourced from researchers, government agencies, and consultancies to provide a description of floral and faunal communities, including ecologically significant species, in the vicinity of the proposed development and of the region.

2 Existing Environment

2.1 Aquatic Habitat

Most sites had a moderate habitat bioassessment score; sites D1 (Large Dam), LFC (Leeke's Creek) and P2 (downstream of Putney Creek) had a good score (Figure 2.1).

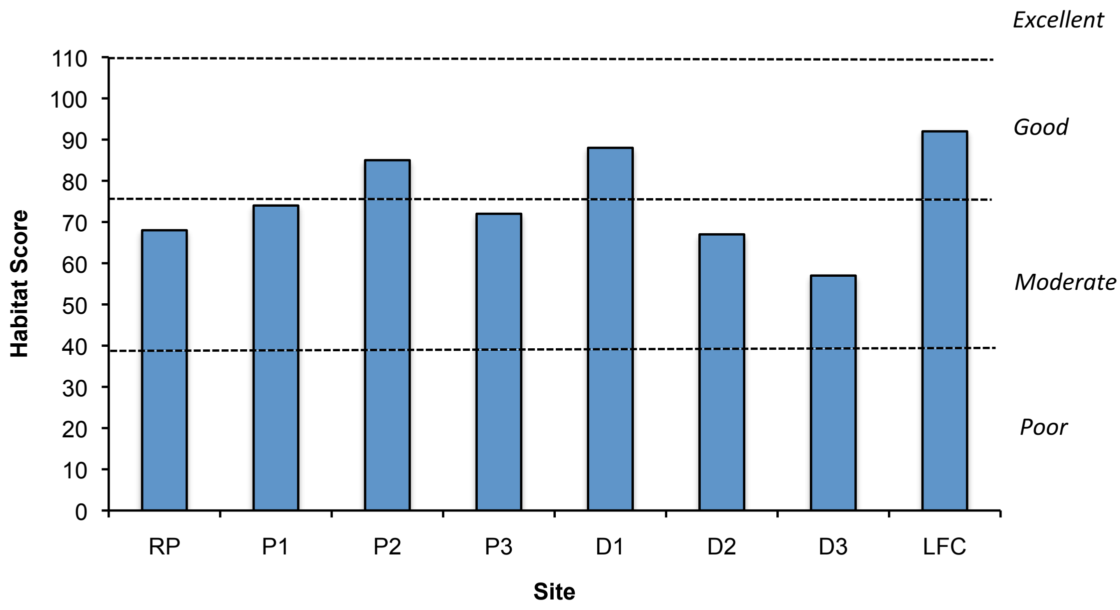


Figure 2.1 Habitat bioassessment scores at each site, and the DNRM thresholds for poor, moderate and good habitats.

The relatively low scores at sites D2 (Homestead Dam), D3 (Resort Dam) and RP (Resort Creek), were due to limited in-stream habitat and lack of water flow as the dams were located off-stream (i.e. dug into the ground). Dense algal cover reduced habitat diversity at sites D3 (Resort Dam) and RP (Resort Creek) (Figure 2.2 and Figure 2.3); this is likely to be related to light levels in the water column and nutrients (as discussed below).

Site LFC (Leeke's Creek) had the highest score due to low embeddedness (sediment dominated by larger particle sizes such as sand and gravel), limited channel alteration (i.e. natural channel) and relatively high water flow.

Figure 2.2

Dense algal cover at site D3 (Resort Dam).

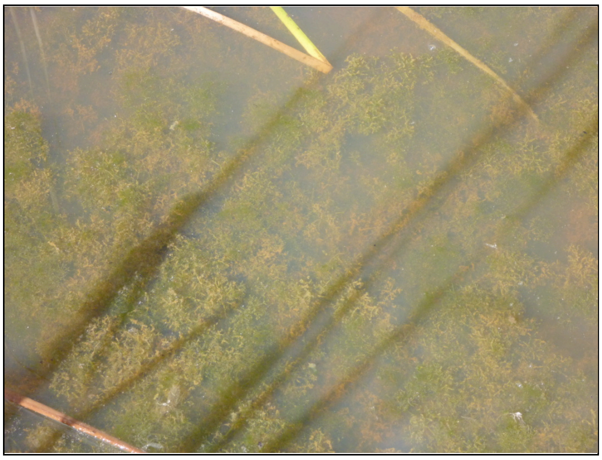


Figure 2.3

Algal cover at site RP (Resort Creek).

A description of each site in provided in Table 2.1.

Table 2.1 Description of each survey site.

Reach	Description	Photograph
Site D1 Large Dam.	This site comprised a wide and deep off-stream dam. Both banks were relatively low (1.5 to 2.5 m) with high stability. The riparian zone extended 10 m on each bank and was dominated by Eucalypt and Acacia trees. In-stream habitat included woody debris and detritus. The substrate included sand and silt / clay. Overall disturbance was moderate due to weeds, historical use of the area for livestock grazing and water extraction.	 View at site D1
Site D2 Homestead Dam.	This site comprised a deep off-stream dam in the centre of the island, near the old homestead. Both the left and right banks were steep and moderately high (2 to 3.5 m) with high stability. The riparian zone extended 25 to 30 m on each bank and was dominated by grass together with a few Eucalypt and Acacia trees. Limited in-stream habitat included exposed roots from bank vegetation. The substrate included sand and silt / clay with some gravel. Overall disturbance was high due to weeds and the historical use of the area for livestock grazing.	 View at site D2
Site D3 Resort Dam.	This site comprised an off-stream dam behind the resort, near the main landfill site. Both the left and right banks were steep and relatively high (1.5 to 5 m) with moderate stability. The riparian zone extended 3 to 10 m on each bank and was dominated by Eucalypt, Casuarina and Acacia trees. Limited in-stream habitat included some small woody debris and detritus; habitat was dominated by macroalgae. The substrate included gravel, sand and silt / clay. Overall disturbance was high due to weeds and the proximity to an access track, resort and main landfill site.	 View at site D3

Reach	Description	Photograph
Site LFC Leeke's Creek.	This site comprised a narrow stream. Both banks were relatively steep and low (<2 m) with moderate stability. The riparian zone extended 15 m on each bank and dominated by grass together with Eucalypt, Melaleuca and Acacia trees. In-stream habitat was dominated by overhanging vegetation with some woody debris and detritus. The substrate included sand and silt / clay, with some gravel. Overall disturbance was moderate due to weeds and the historical use of the area for livestock grazing.	 View upstream at site LFC
Site P1 Putney Creek ~1 km upstream of the creek mouth.	This site comprised a narrow, dry ephemeral channel with a small pool. Both the left and right banks were relatively low (1.5 m) with high stability. The riparian zone extended 2 m on each bank, and included dense grass and Eucalypt trees. In-stream habitat was dominated by small woody debris and overhanging vegetation. The substrate included sand and silt / clay. Overall disturbance was low and limited to weeds.	 View upstream at site P1
Site P2 Putney Creek ~0.5 km upstream of the creek mouth.	This site comprised a wide, meandering ephemeral channel with several pools. Both the left and right banks were relatively low (1 to 3.5 m) with high stability. The riparian zone extended 10 m on each bank and was dominated by grass, shrubs and Eucalypt trees. In-stream habitat included overhanging vegetation, abundant detritus and limited woody debris. The substrate included sand and silt / clay. Overall disturbance was low to moderate, due to weeds and proximity to an access track.	 View downstream at site P2

Reach	Description	Photograph
Site P3 Putney Creek ~ 0.75 km upstream of the creek mouth.	This site comprised a wide ephemeral channel with a small pool. Both the left and right banks were relatively low (<2 m) with high stability. The riparian zone extended 5 to 10 m on each bank was and dominated by grass together with Eucalypt and Melaleuca trees. In-stream habitat was dominated by small woody debris, together with limited vegetation and detritus. The substrate included sand and silt / clay. Overall disturbance was low due to weeds and proximity to an access track.	 View downstream at site P3
Site RP Resort Creek.	This site comprised a wide ephemeral channel that flows into Putney Creek following heavy rain. The pool is fed by groundwater. Both the left and right banks were relatively low (1 to 3.5 m) with high stability. The riparian zone extended 10 to 15 m on each bank and was dominated by grass and Eucalypt and Melaleuca trees. In-stream habitat was dominated by vegetation (mostly macroalgae) and some detritus. The substrate included gravel, sand and silt / clay. Overall disturbance was high due to weeds, inflow / outtake of aquifer and litter.	 View at site RP

2.2 Water Quality

Temperature

There is no Queensland Water Quality Guideline (QWQG) trigger value for water temperature. Temperature varied between sites, ranging from 14.9 °C to 24.0 °C (Figure 2.4). Water temperature at any given site is likely to reflect a number of factors including the season (sites P1 to P3 were surveyed in cooler months), time of day, size of the water body, prevailing weather conditions, flow, and riparian cover.

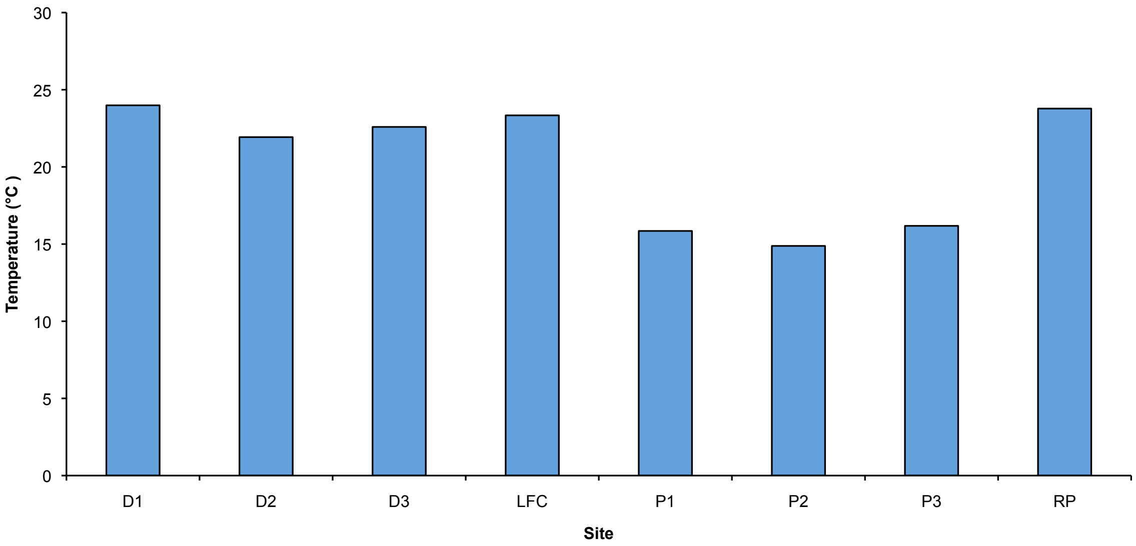


Figure 2.4 Water temperature at each site.

Turbidity

Turbidity was below the QWQG upper trigger value (50 NTU) at all sites. Turbidity was highest at site LFC (Leeke's Creek) and lowest at site RP (Resort Creek) (Figure 2.5). High turbidity at site LFC is likely to be related to this site being located on a natural channel and subject to relatively high flow. Low turbidity at site RP may be because it is fed by groundwater, which is typically very clear.

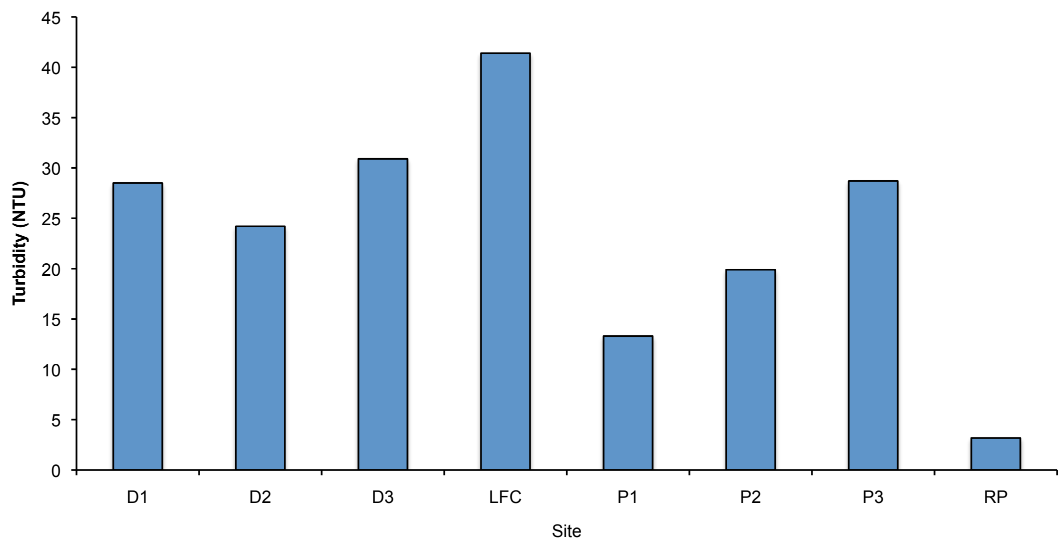


Figure 2.5 Turbidity at each site.

pH

The pH was within the QWQG trigger value range at most sites; it was below the range at sites D2 (Homestead Dam) and LFC (Leeke's Creek) (Figure 2.6). The reason for this is not clear; it may be related to local geology.

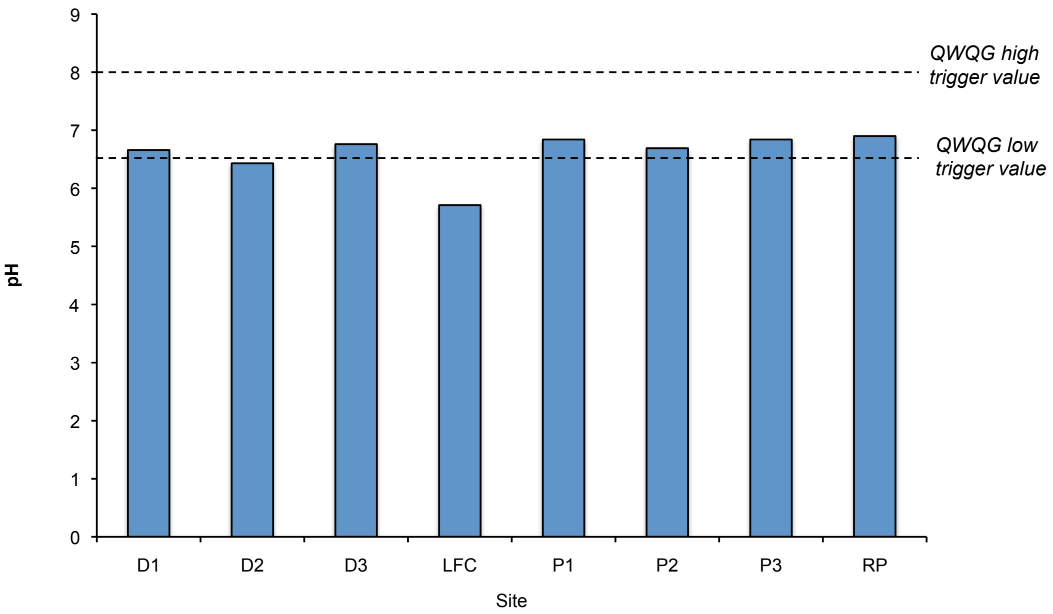


Figure 2.6 The pH at each site, and the QWQG trigger value range.

Electrical Conductivity

Electrical conductivity was above the QWQG upper trigger value at most sites; the dams (D1 to D3) were below the trigger value (Figure 2.7). High electrical conductivity is likely to be related to evaporation at most sites (LFC, P1 to P3 and RP) and groundwater infiltration at site RP (Resort Creek) as groundwater on Great Keppel Island has high salt content due to saltwater intrusion of the aquifer (Opus International Consultants (Australia) Pty Ltd 2011c).

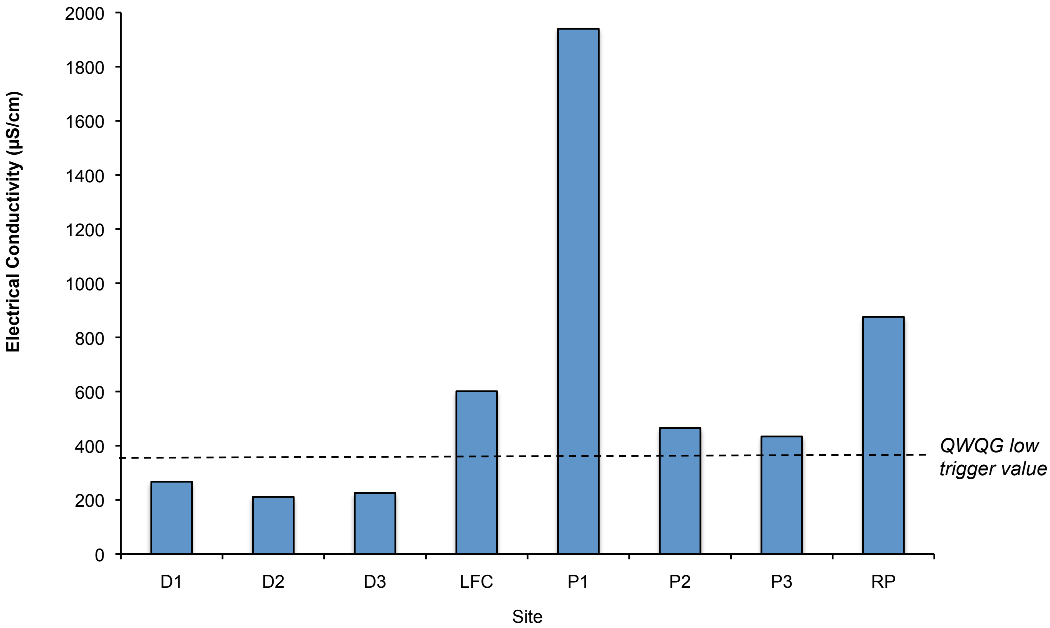


Figure 2.7 Electrical conductivity at each site, and the QWQG trigger value.

Dissolved Oxygen

The percent saturation of dissolved oxygen was below the QWQG lower trigger value at all of the sites (Figure 2.8). Variable dissolved oxygen concentrations are likely to reflect:

- the time of day measurements were taken (plants photosynthesise during the day, producing oxygen)
- the photosynthetic rates of macroalgae and macrophytes (which are affected by light availability and temperature)
- the rate of oxygen uptake by micro-organisms in the waterway associated with decomposing organic matter, and
- the amount of surface mixing at a site (caused by wind and bird activity).

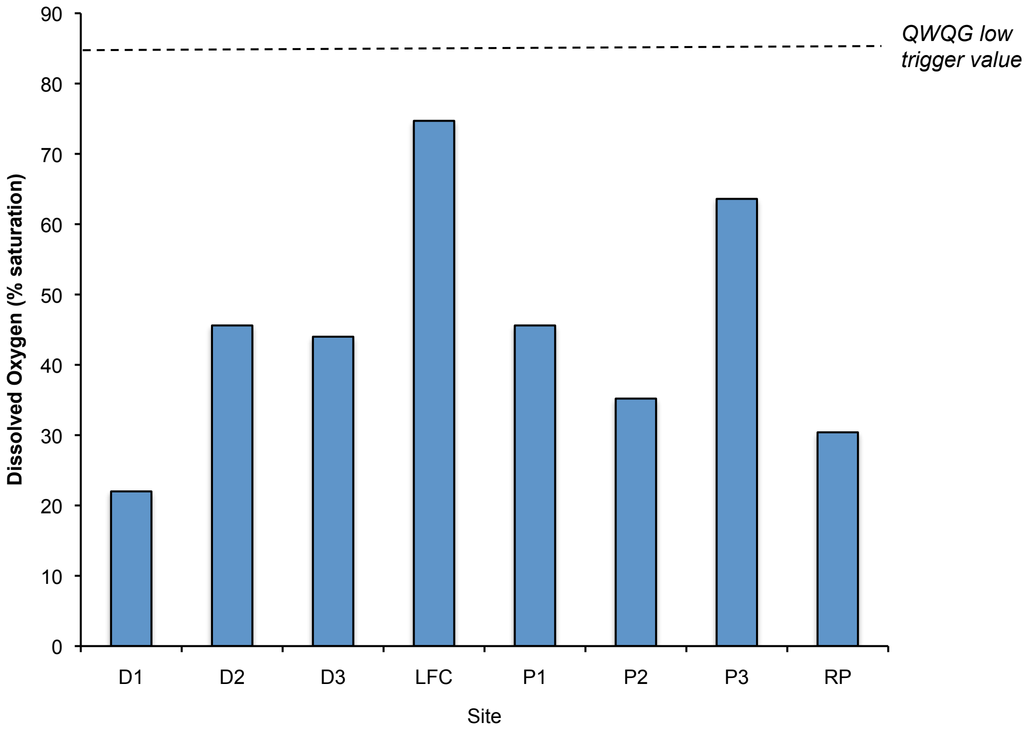


Figure 2.8 Dissolved oxygen at each site and the QWQG trigger value.

Total Suspended Solids

There is no ANZECC & ARMCANZ trigger value for total suspended solids. The concentration of total suspended solids was highest at sites LFC (Leeke's Creek), P2 (downstream Putney Creek) and P3 (mid Putney Creek) and relatively low at sites D3 (Resort Dam) and site RP (Resort Creek) (Figure 2.9). High-suspended solid concentrations are likely to be related to these sites being located on a natural channel and subject to relatively high flow. The low concentration at site RP may be because it is fed by groundwater, while relatively low suspended solid concentrations at the dams and site P1 (upstream Putney Creek) are likely to be related to low to no water flow at these sites.

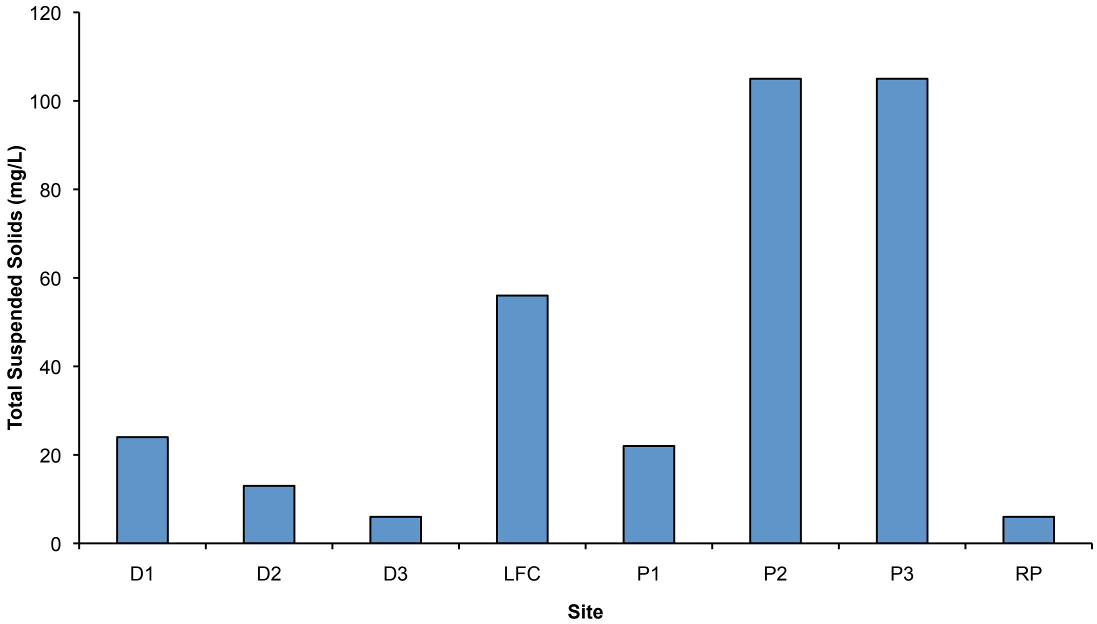


Figure 2.9 Concentration of total suspended solids at each site.

Nutrients

Nitrogen

The concentration of total nitrogen was above the QWQG lower trigger value at all of the sites (Figure 2.10). This is likely to be due to seepage from septic tanks and possibly landfill.

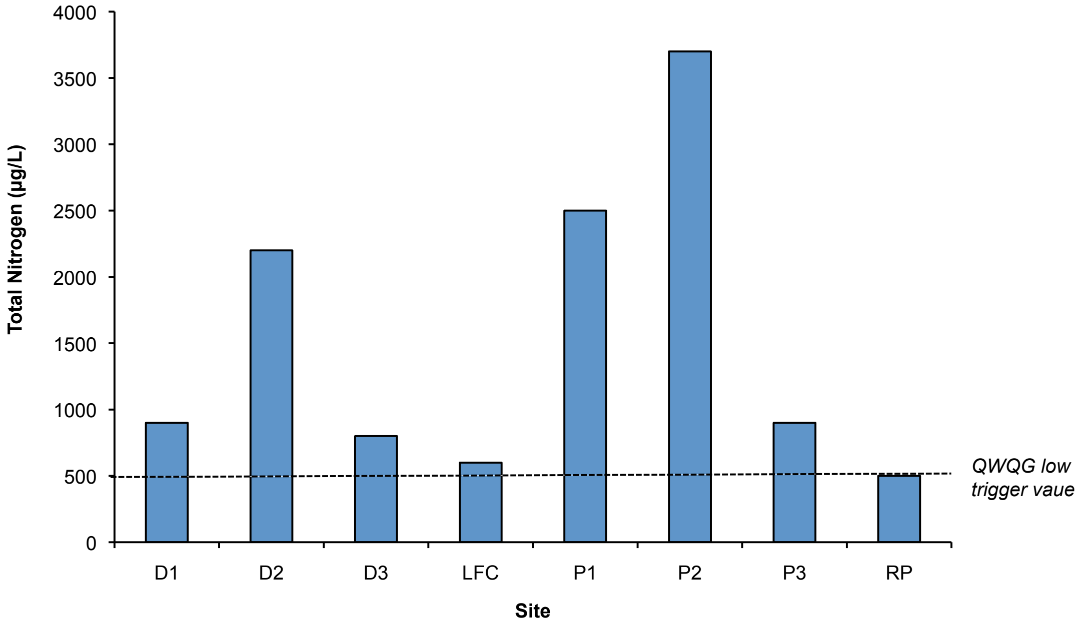


Figure 2.10 Concentration of total nitrogen at each site, and the QWQG trigger value.

Phosphorous

The concentration of total phosphorous was above the QWQG lower trigger value at all of the sites, except site D3 (Resort Dam) (Figure 2.11). This is likely to be due to seepage from septic tanks and possibly landfill.

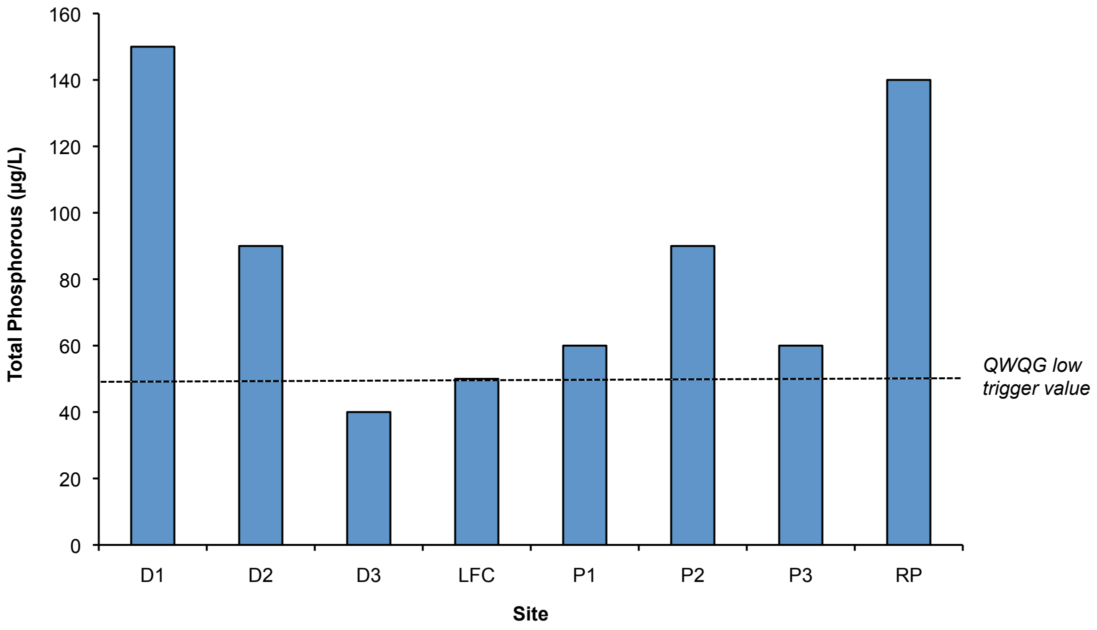


Figure 2.11 Concentration of total phosphorus at each site, and the QWQG trigger value.

Water Hardness

Water hardness was soft at most sites. Water hardness was moderate at sites D3 (Resort Dam) and LFC (Leeke's Creek), and extremely hard at site RP (Resort Creek) (Figure 2.12), likely due to saline groundwater infiltration. Trigger values for metals and metalloids were modified accordingly.

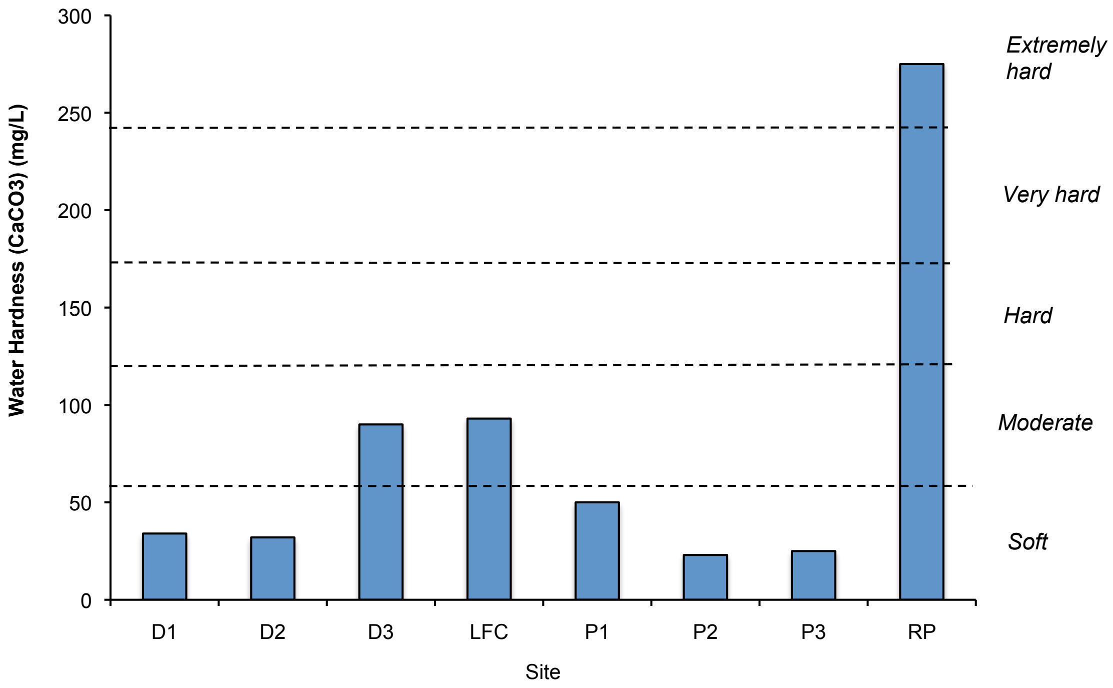


Figure 2.12 Water hardness at each site, and the ANZECC & ARMCANZ value ranges for hardness.

Metals and Metalloids

Concentrations of total arsenic, cadmium[3], mercury and nickel were below laboratory detection limits and / or the relevant ANZECC & ARMCANZ trigger values at all sites.

Chromium

The concentration of total chromium was below the laboratory detection limit (<2 µg/L) at most sites. The concentration was above the ANZECC & ARMCANZ 95% trigger value (site-specific, adjusted for hardness where applicable) at site P1 (upstream of Putney Creek) [4] (Figure 2.13). This is likely to be related to seepage from landfill and / or local geology.

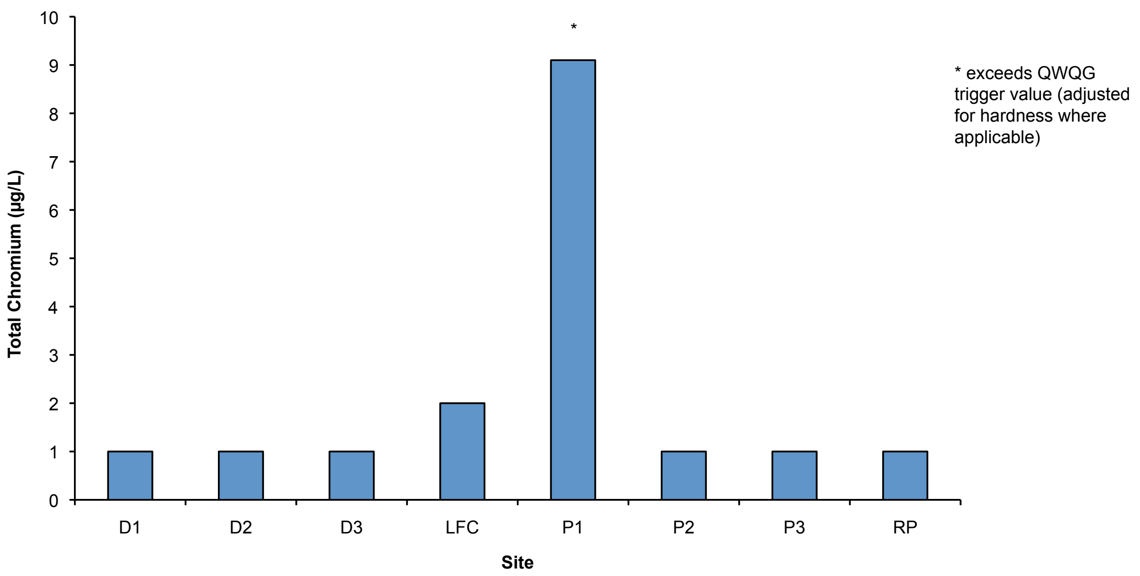


Figure 2.13 Concentration of total chromium at each site.

[3] It is not possible to determine if the concentration was above the 95% trigger value because the laboratory detection limit (0.7 µg/L) was higher than the 95% level of protection trigger value (0.2 µg/L).

[4] It is not possible to determine if the concentration was above the 95% trigger value at sites D1 to D3, P2, P3 and RP because the laboratory detection limit (2 µg/L) was higher than the 95% level of protection trigger value (1 µg/L).

Copper

The concentration of total copper was above the modified ANZECC & ARMCANZ 95% trigger value (site-specific, adjusted for hardness where applicable) at sites D1 (Large Dam), D2 (Homestead Dam) and in Putney Creek (P1 to P3) (Figure 2.14). This is likely to be related to seepage from landfill and / or local geology.

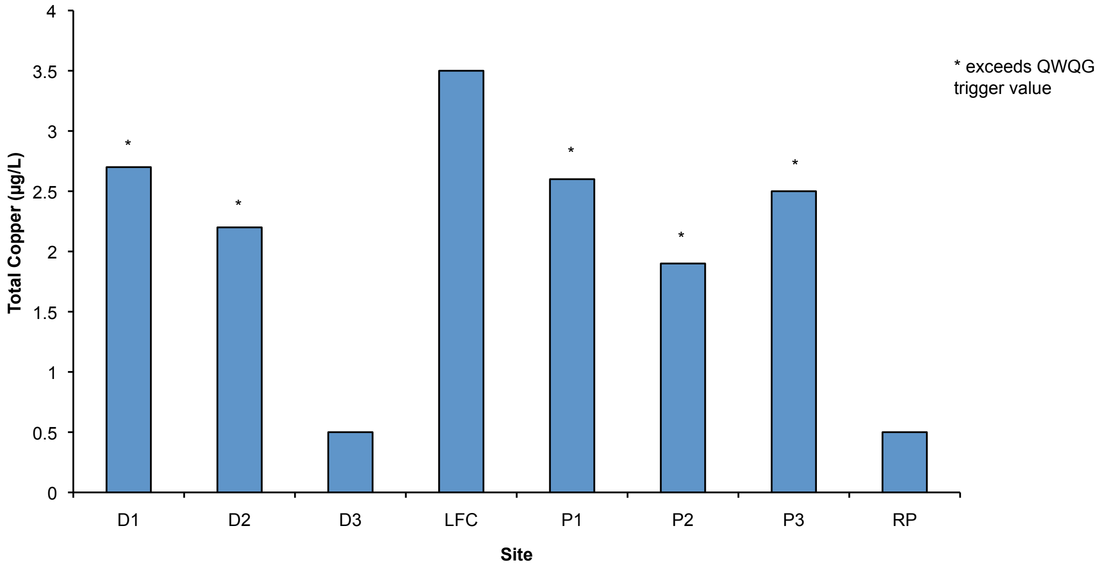


Figure 2.14 Concentration of total copper at each site.

Lead

The concentration of total lead was below the modified ANZECC & ARMCANZ 95% trigger value and / or laboratory detection limit (both 1 µg/L) at most sites. The concentration was above the trigger value at sites D3 (Resort Dam) and LCF (Leeke's Creek) where it was 1.4 and 2.2 µg/L respectively. This is likely to be related to seepage from landfill (of lead-based products such as leaded petrol, lead-based paint or batteries) and / or local geology.

Zinc

The concentration of total zinc was above the ANZECC & ARMCANZ 95% trigger value (site-specific, adjusted for hardness where applicable) at most sites; it was below the trigger value at sites D2 (Homestead Dam), D3 (Resort Dam) and LFC (Leeke's Creek) (Figure 2.15). This is likely to be related to seepage from landfill and / or local geology.

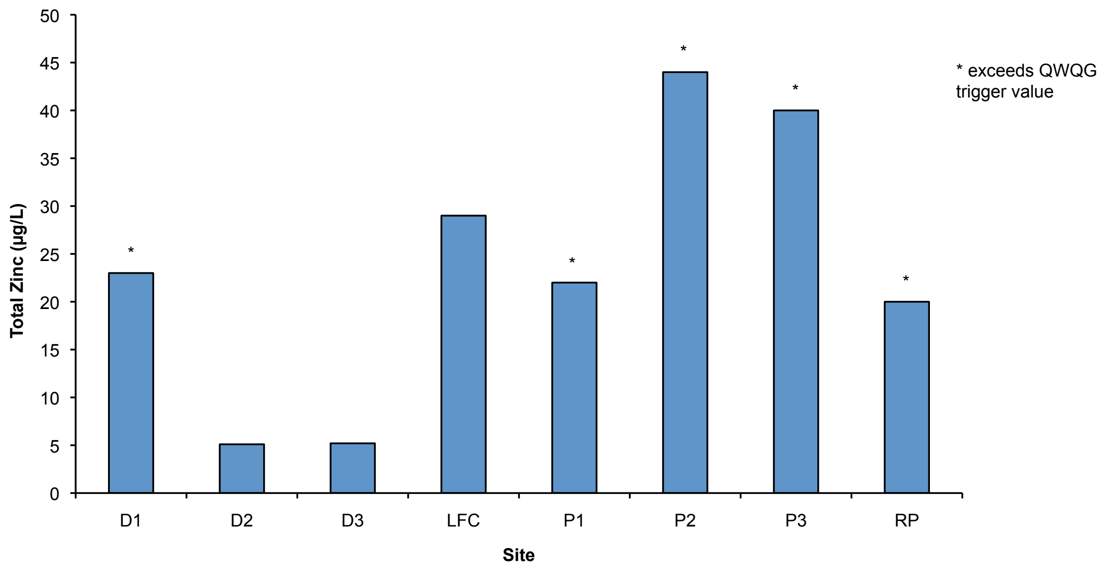


Figure 2.15 Concentration of total zinc at each site.

Total Petroleum and Aromatic Hydrocarbons

The concentration of most petroleum hydrocarbon fractions and all aromatic hydrocarbons was below laboratory detection limits and / or ANZECC & ARMCANZ 95% trigger values where available.

Total Petroleum Hydrocarbons

There are no ANZECC & ARMCANZ guidelines for total petroleum hydrocarbons.

The concentration of total petroleum hydrocarbons of the C15 to C28 fraction was relatively high at site D1 (Large Dam) (Figure 2.16). This site may have been exposed to diesel, as the C15 to C28 fraction is indicative of diesel.

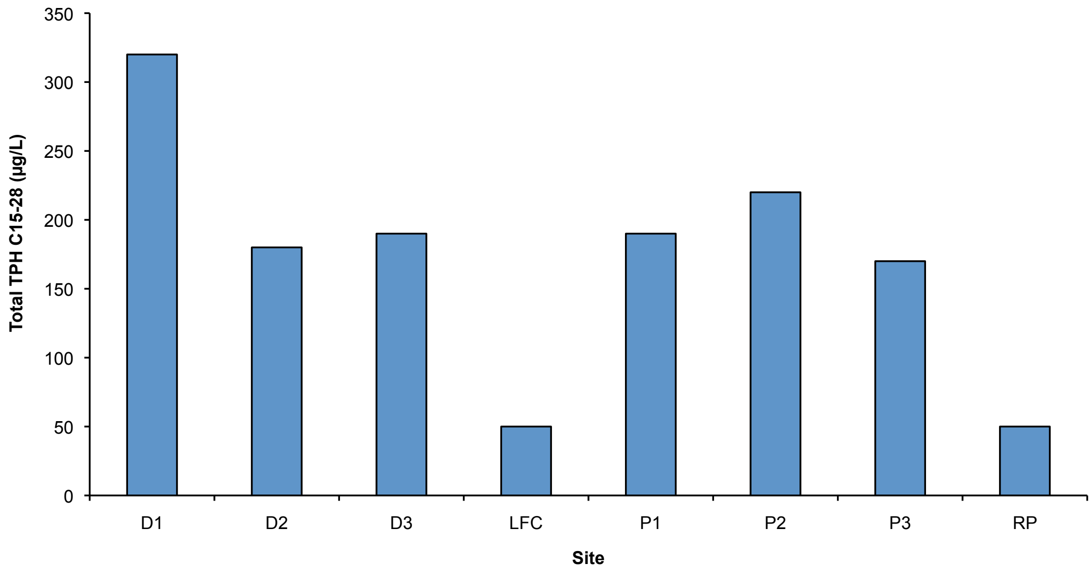


Figure 2.16 Concentration of total petroleum hydrocarbons C15 to C28 at each site.

The concentration of total petroleum hydrocarbons of the C29 to C36 fraction was relatively high at sites D1 (Large Dam), D2 (Homestead Dam) and P2 (downstream Putney Creek) (Figure 2.17). These sites may have been exposed to oil, as this fraction is indicative of mineral-based oils and lubricants.

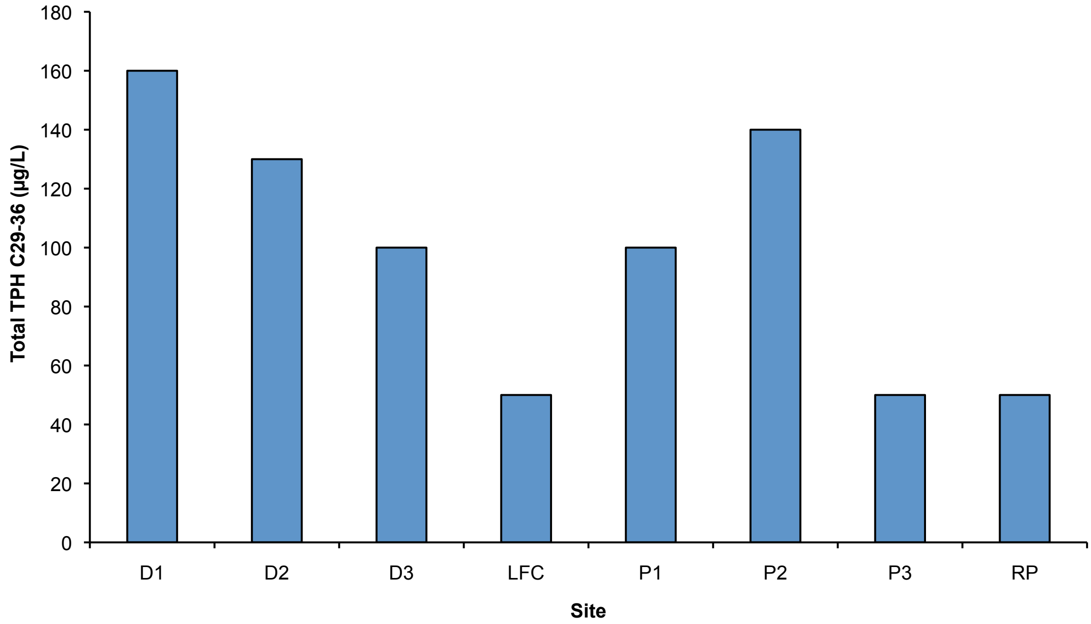


Figure 2.17 Concentration of total petroleum hydrocarbons C29 to C36 at each site.

Organochlorine Pesticides

The concentration of all organochlorine pesticides was below laboratory detection limits and / or the relevant ANZECC & ARMCANZ trigger values where available.

2.3 Sediment Quality

Particle Size Distribution

Sediment samples were dominated by silt / clay at sites D1 (Large Dam), D2 (Homestead Dam), P2 (downstream Putney Creek) and P3 (mid Putney Creek), and sand at sites LFC (Leeke's Creek), P1 (upstream Putney Creek) and RP (resort Creek). Site D3 (Resort Dam) samples contained silt / clay, sand and gravel (Figure 2.18). A higher percentage of silt / clay can facilitate an increase in suspended solids and turbidity; the total suspended solid concentration was substantially higher than sites P2 and P3, and turbidity was relatively high at most sites dominated by silt / clay (P3 and the dams). .

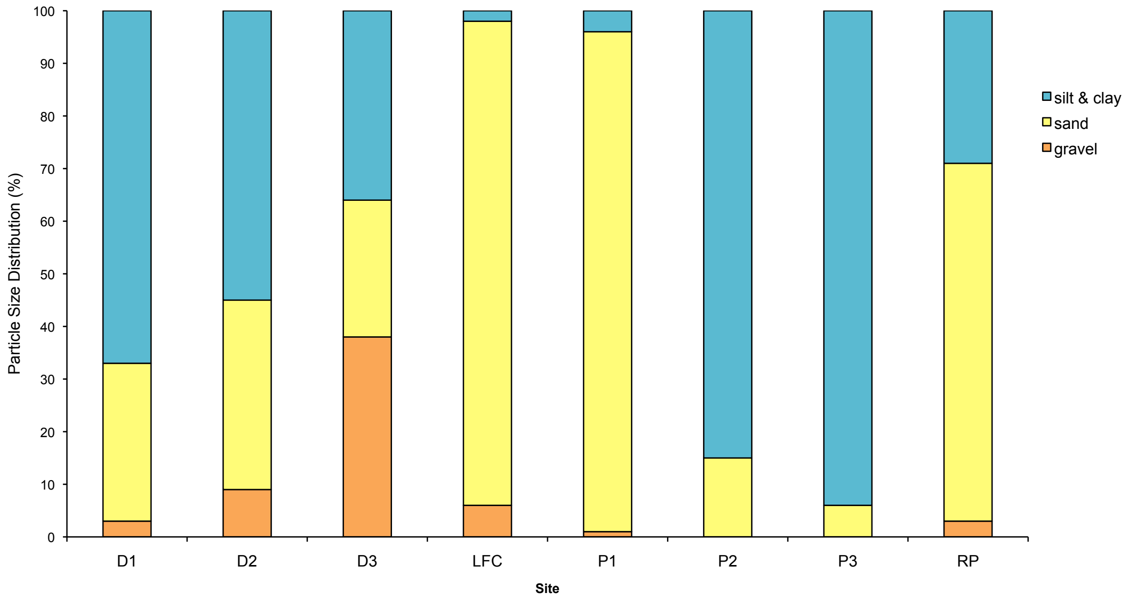


Figure 2.18 Percent distribution of particle size in sediment at each site.

Nutrients

Nitrogen

There is no ISQG trigger value for the concentration of total nitrogen in sediment. The concentration of total nitrogen was highest at sites P2 (downstream Putney Creek), P3 (mid Putney Creek) and RP (Resort Creek) (Figure 2.19). This is likely to be due to seepage from septic tanks and possibly landfill.

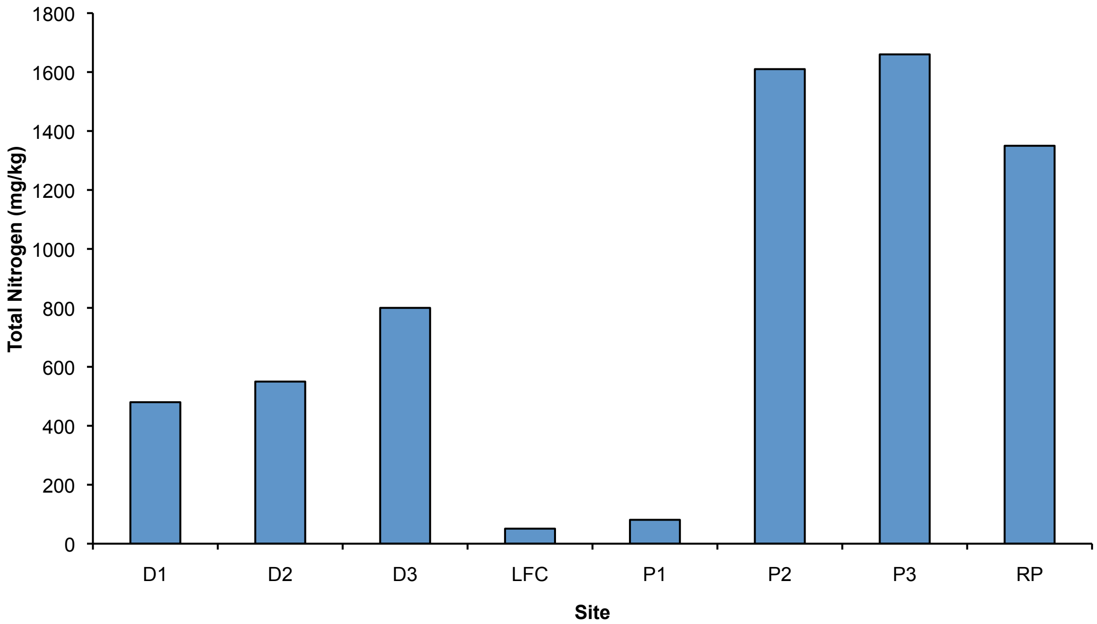


Figure 2.19 Concentration of total nitrogen in the whole fraction of sediment at each site.

Phosphorus

There is no ISQG trigger value for the concentration of total phosphorus in sediment. The concentration of total phosphorus was highest at sites P3 (mid Putney Creek) and RP (Resort Creek) (Figure 2.19). This is likely to be due to seepage from septic tanks and possibly landfill.

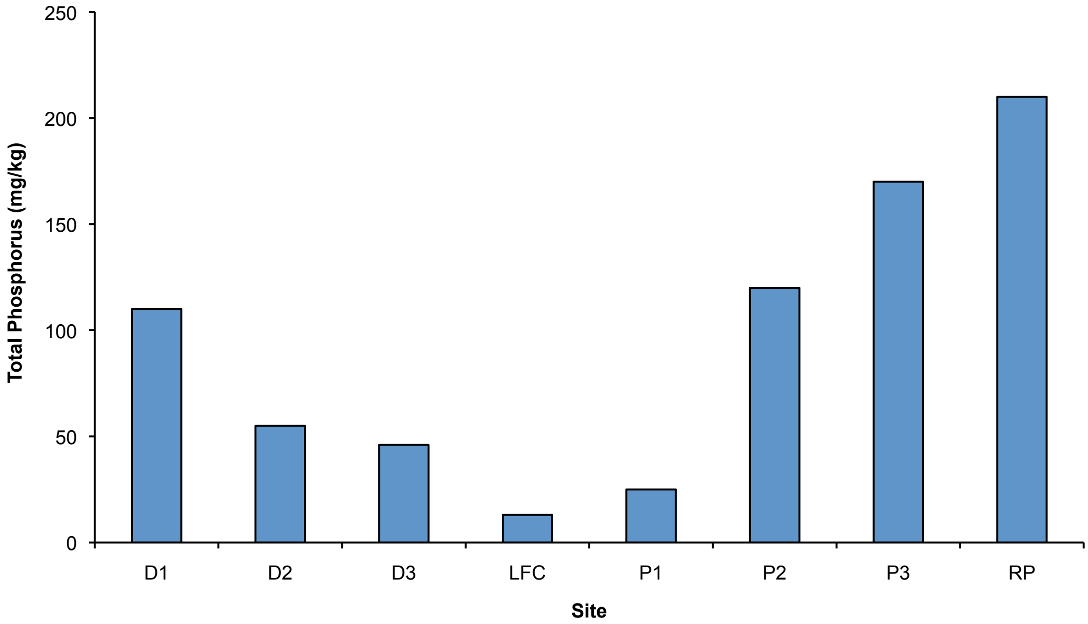


Figure 2.20 Concentration of total phosphorus in the whole fraction of sediment at each site.

Metals and Metalloids

The concentration of arsenic, cadmium, chromium, copper, lead, mercury, nickel and zinc in the whole fraction of the sediment was below the ISQG-low trigger value at all sites.

Arsenic

The concentration of arsenic was below the trigger value at all sites but relatively high at sites D2 (Homestead Dam), D3 (Resort Dam), P2 (downstream Putney Creek) and P3 (mid Putney Creek) (Figure 2.21). This is likely to be related to livestock grazing activities (livestock dips for parasites often contain arsenic), and / or seepage from landfill and local geology.

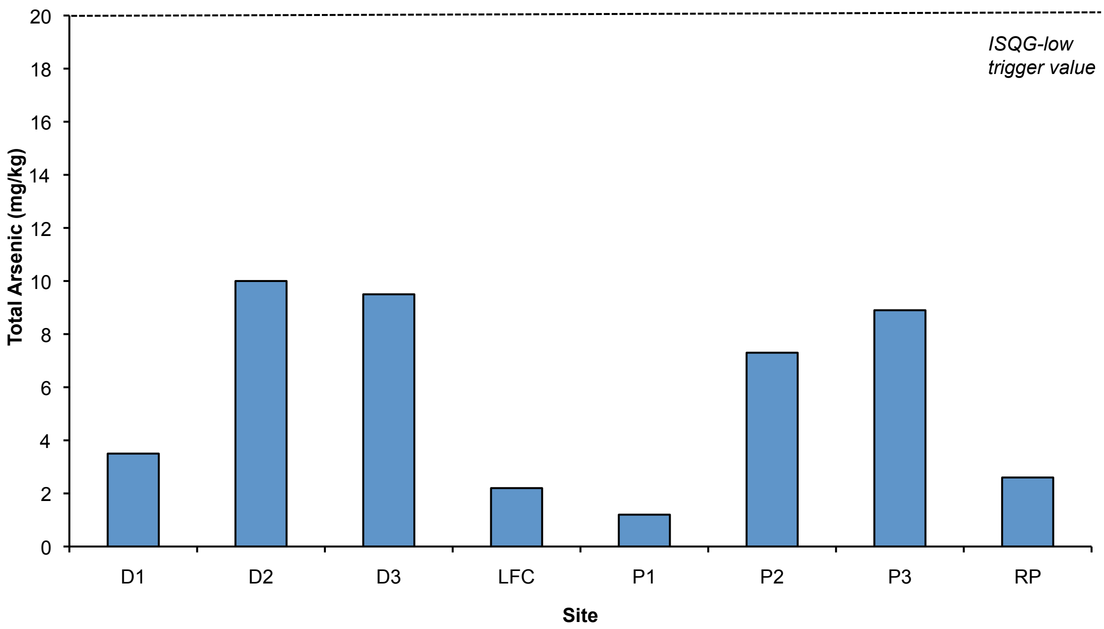


Figure 2.21 Concentration of total arsenic in the whole fraction of sediment at each site.

Cadmium

The concentration of cadmium was below the trigger value at all sites and laboratory detection limit (0.1 mg/kg) at all sites, except site RP (Resort Creek) where it was 0.11 mg/kg. This is likely to be related to seepage from landfill and / or local geology.

Chromium

The concentration of chromium was below the trigger value at all sites but relatively high at site P3 (mid Putney Creek), and to a lesser extent at the dam sites (D1 to D3) and sites P2 (downstream Putney Creek) and RP (Resort Creek) (Figure 2.22). This is likely to be related to seepage from landfill and / or local geology.

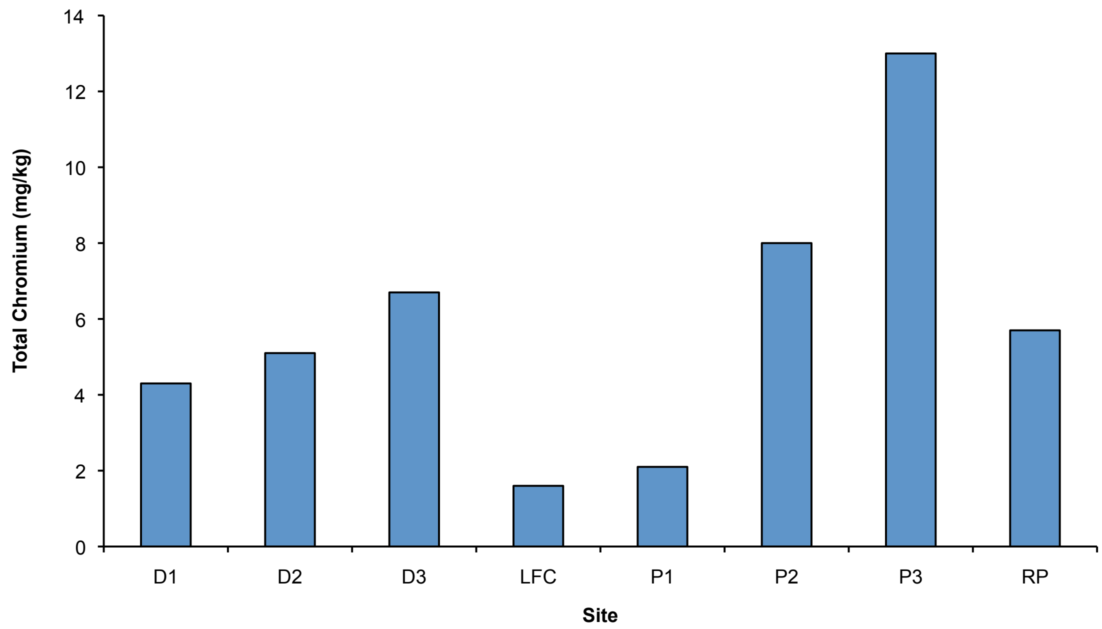


Figure 2.22 Concentration of total chromium in the whole fraction of sediment at each site.

Copper

The concentration of copper was below the trigger value at all sites but relatively high at site P3 (mid Putney Creek), and to a lesser extent at the dam sites (D1 to D3) and sites P2 (downstream Putney Creek) and RP (Resort Creek) (Figure 2.23). This is likely to be related to seepage from landfill and / or local geology.

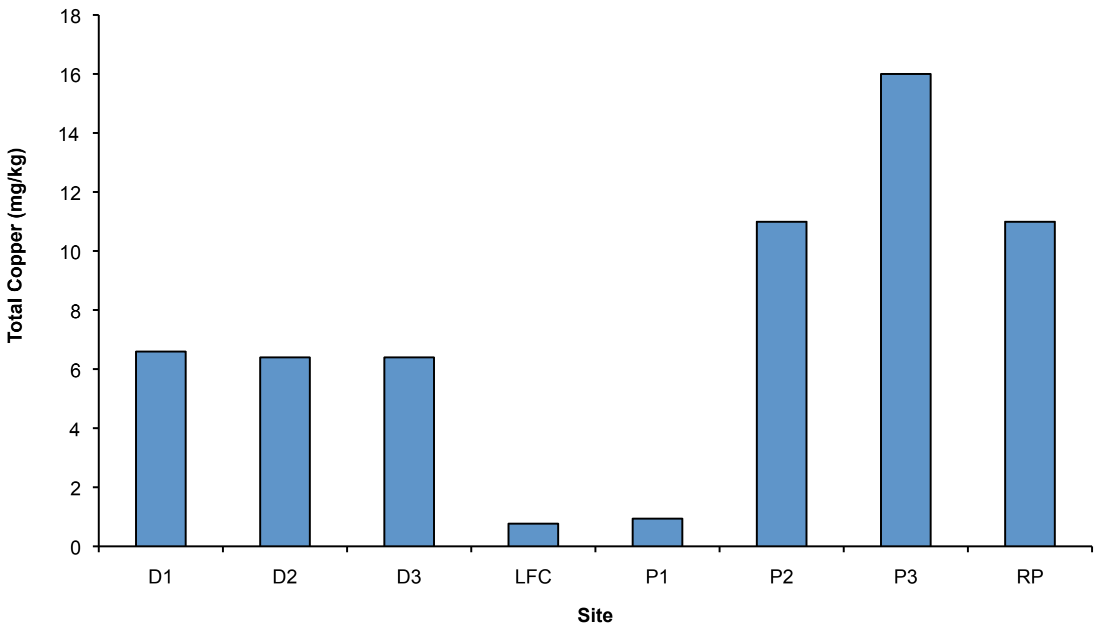


Figure 2.23 Concentration of total copper in the whole fraction of sediment at each site.

Lead

The concentration of lead was below the trigger value at all sites but relatively high at site P3 (mid Putney Creek), and to a lesser extent at the dam sites (D1 to D3) and sites P2 (downstream Putney Creek) and RP (Resort Creek) (Figure 2.24). This is likely to be related to seepage from landfill and / or local geology.

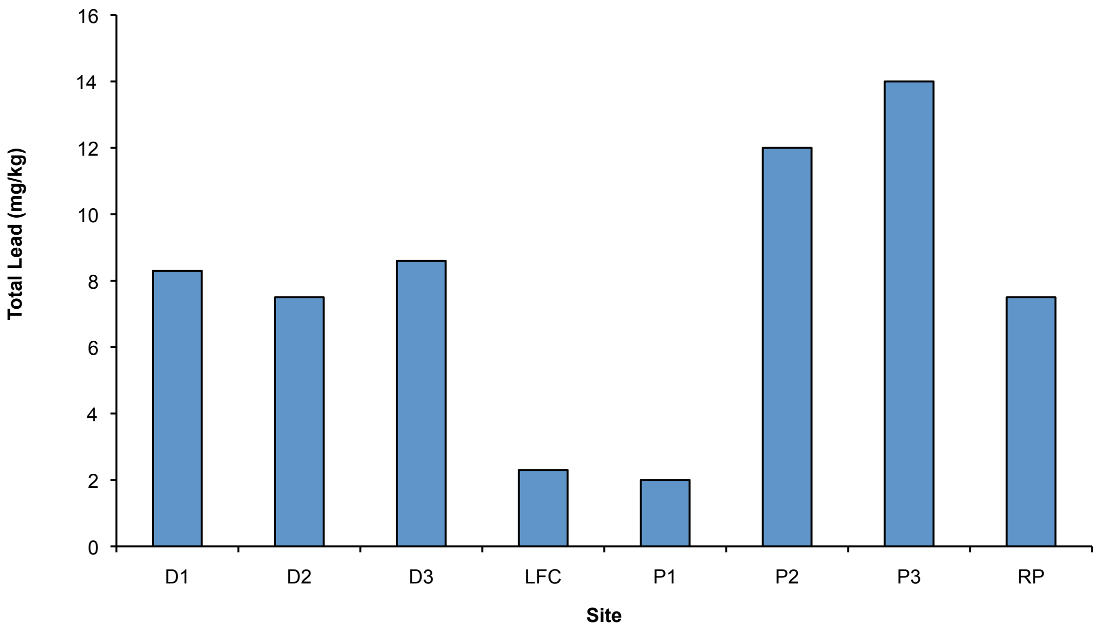


Figure 2.24 Concentration of total lead in the whole fraction of sediment at each site.

Mercury

The concentration of mercury was below the trigger value at all sites but relatively high at sites D1 (Large Dam), P2 (downstream Putney Creek) and P3 (mid Putney Creek) (Figure 2.25). This is likely to be related to seepage from landfill and / or local geology.

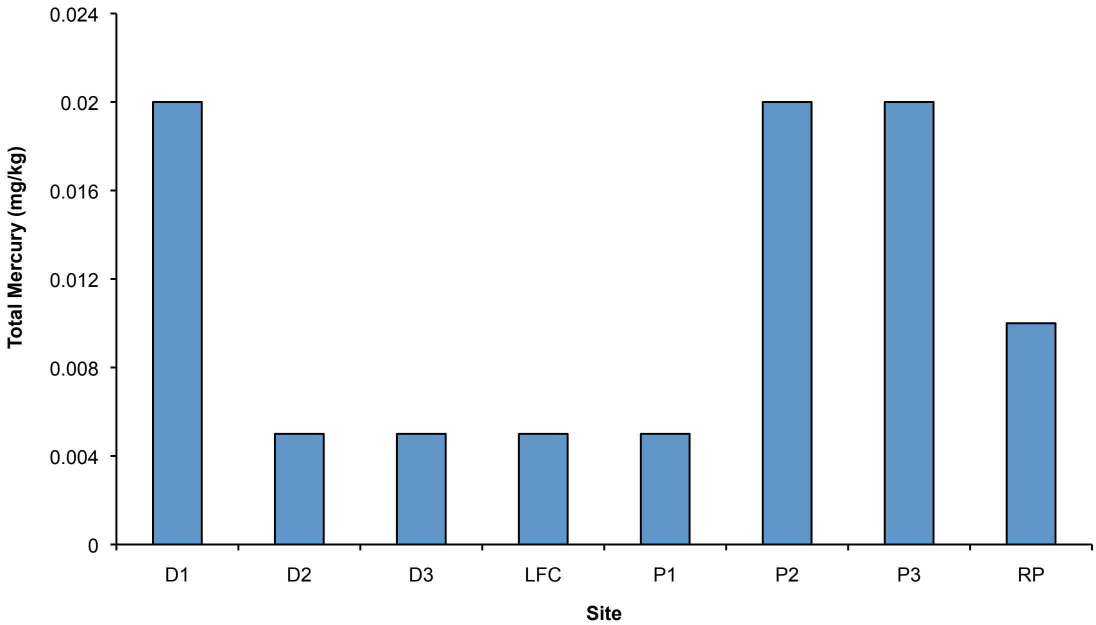


Figure 2.25 Concentration of total mercury in the whole fraction of sediment at each site.

Nickel

The concentration of nickel was below the trigger value at all sites but relatively high at site P3 (mid Putney Creek), and to a lesser extent at the dam sites (D1 to D3) and sites P2 (downstream Putney Creek) and RP (Resort Creek) (Figure 2.26). This is likely to be related to seepage from landfill and / or local geology.

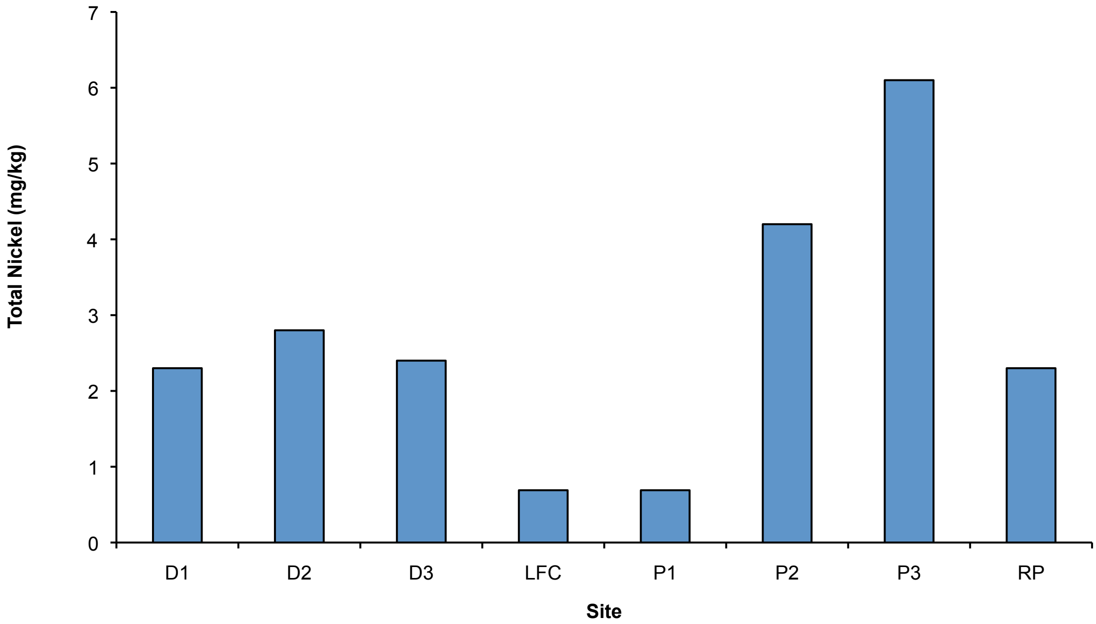


Figure 2.26 Concentration of total nickel in the whole fraction of sediment at each site.

Zinc

The concentration of zinc was below the trigger value at all sites but relatively high at site RP (Resort Creek), and to a lesser extent site P2 (downstream Putney Creek) and site P3 (mid Putney Creek) (Figure 2.27). This is likely to be related to seepage from landfill and / or local geology.

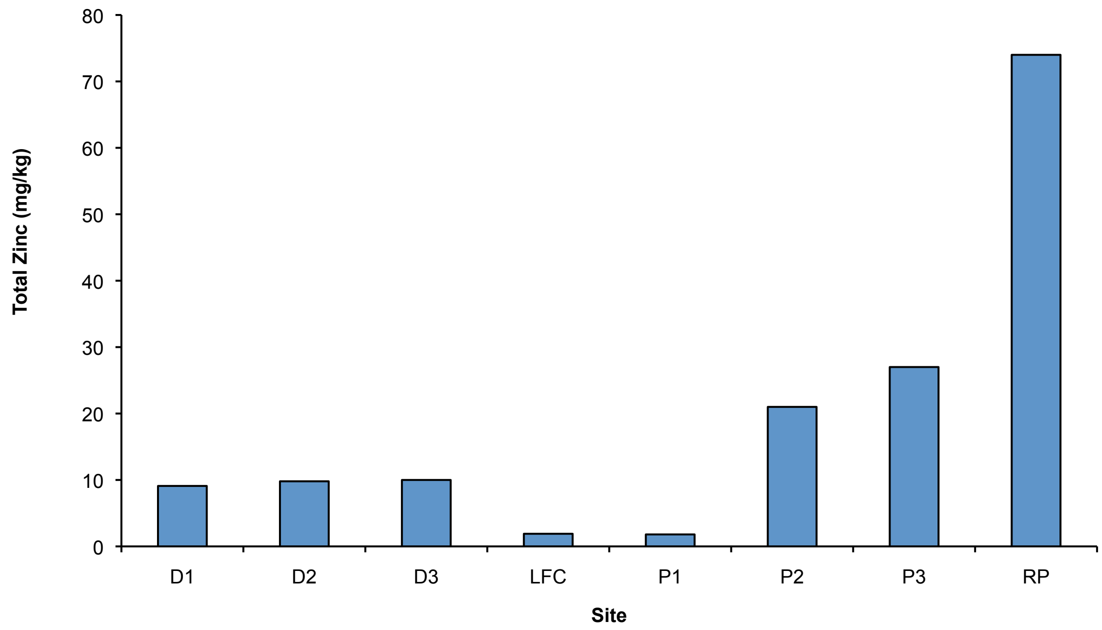


Figure 2.27 Concentration of total zinc in the whole fraction of sediment at each site.

Organochloride Pesticides

The concentration of all organochlorine pesticides was below the laboratory detection limit at all sites.

2.4 Aquatic Flora

Taxonomic Richness

There were between one and six aquatic floral (macrophyte) species at each site. Taxonomic richness (the number of species at a site) was highest at site LFC (Leeke's Creek) and lowest at sites D3 (Resort Dam) and P3 (mid Putney Creek) (Figure 2.28).

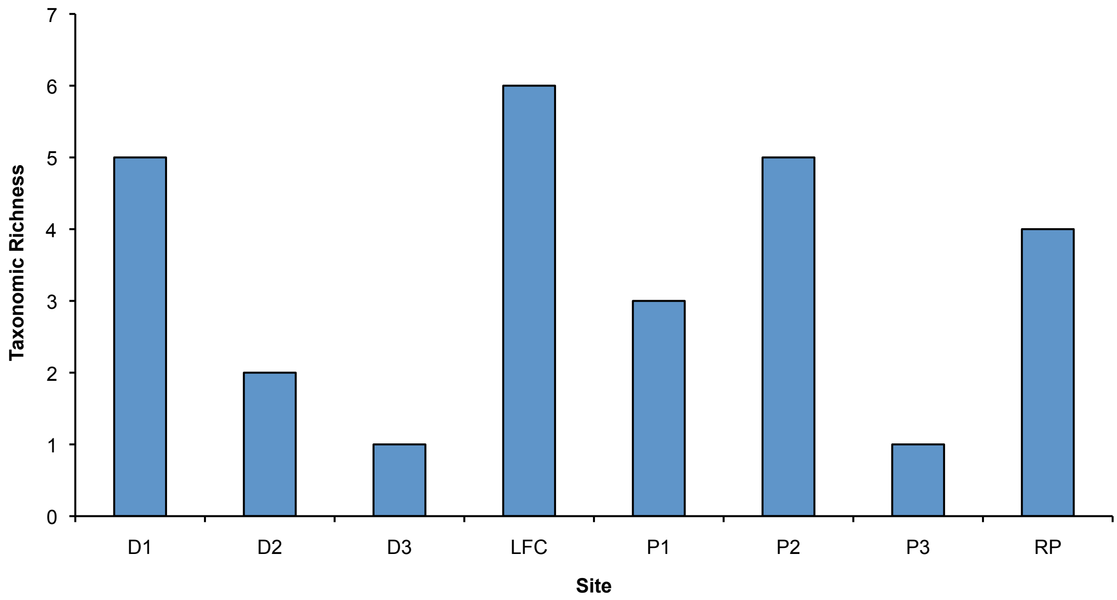


Figure 2.28 Taxonomic richness at each site.

Native macrophytes with an emergent growth form dominated communities of the project area. One submerged macrophyte was observed during the survey; *Chara vulgaris* at site RP (Resort Creek).

The limited number of submerged macrophytes suggests that water levels fluctuate considerably at the on-stream sites (Wager & Unmack 2000), and is likely to be related to the lack of connectivity at the off-stream (dam) sites. Submerged macrophytes cannot survive dry periods; emergent forms are most tolerant to dry conditions. There is no evidence that submerged or floating macrophytes are common in the project area.

No single species was widespread; communities were characterised by a range of species with low cover (Table 2.2).

Table 2.2 Total percent cover of macrophyte species at each site.

Scientific Name	Site							
	RP	P1	P2	P3	D1	D2	D3	LFC
Acrostichum speciosum	–	–	–	–	–	–	–	2.0
Arundinella nepalensis	–	–	–	–	20.0	–	–	–
Carex fascicularis	–	–	–	35.5	–	–	–	–
Chara vulgaris	30.0	–	–	–	–	–	–	–
Chloris virgata [a]	–	–	–	–	–	2.0	–	–
Cyperus betchei	3.0	–	–	–	–	–	–	–
Cyperus bifax	–	–	–	–	2.0	–	–	–
Cyperus difformis	–	–	–	–	2.0	–	–	–
Cyperus haspan subsp. *haspan*	–	–	0.9	–	5.0	–	–	–
Cyperus polystachyos	5.0	–	–	–	–	–	–	–
Cyperus procerus	1.0	–	–	–	–	–	–	–
Cyperus trinervis	–	–	–	–	–	–	–	3.0
Cyperus sp.	–	0.2	–	–	–	–	–	–
Digitaria brownii	–	–	–	–	–	–	–	15.0
Eleocharis equisetina	–	–	–	–	–	–	–	2.0
Eleocharis geniculata	–	–	–	–	–	–	–	3.0
Fimbristylis sp.	–	0.1	–	–	–	–	–	–
Gahnia aspera	–	–	–	–	5.0	–	–	–

Scientific Name	Site							
	RP	P1	P2	P3	D1	D2	D3	LFC
Hygrophila costata [a]	–	–	–	–	–	2.0	–	–
Juncus usitatus	–	–	2.2	–	–	–	–	–
Panicum sp. [b]	–	–	0.5	–	–	–	–	–
Philydrum lanuginosum	–	–	–	–	–	–	19.0	–
Stachytarpheta jamaicensis [a]	–	–	–	–	–	–	–	5.0
Triglochin procerum	–	–	7.2	–	–	–	–	–

[a] naturalised species

[b] may be an exotic species of this genus

Cover

Macrophyte cover (as a percentage of the substrate) was greatest at site RP (Resort Creek), but also relatively high at sites D1 (large Dam), LFC (Leeke's Creek) and P3 (mid Putney Creek), and lowest at site D2 (Homestead Dam) (Figure 2.29). The low cover at site D2 (Homestead Dam) is likely to be related to clearing for livestock grazing.

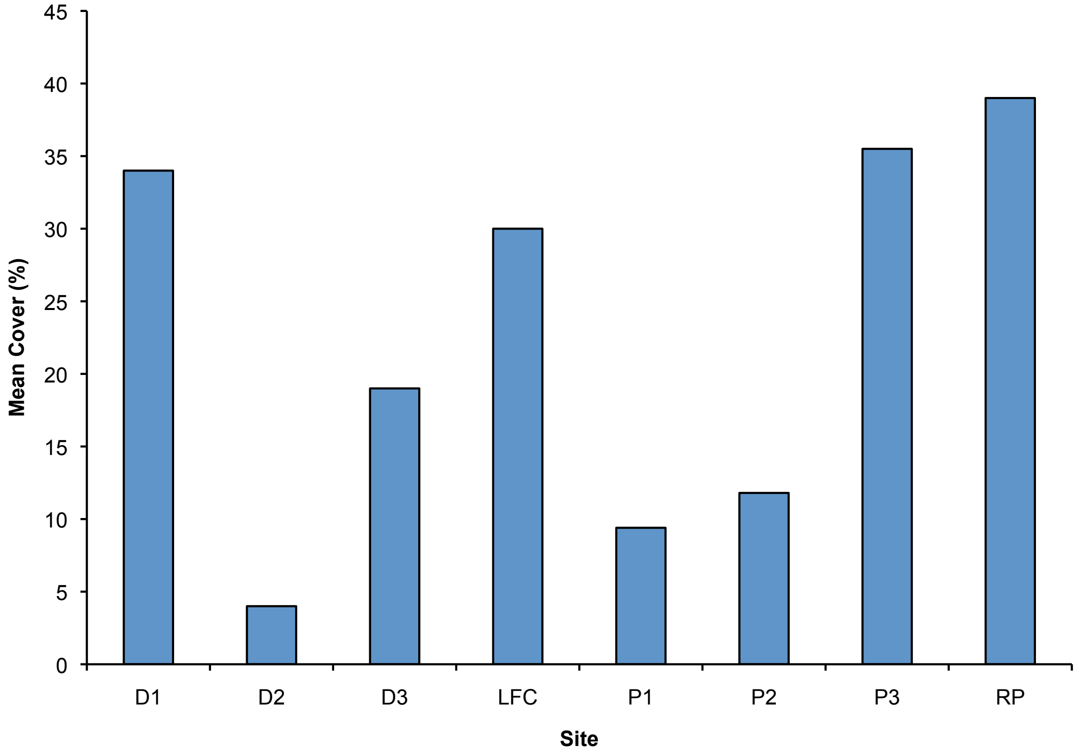


Figure 2.29 Percent cover of macrophytes at each site.

Macroalgae

Macroalgae was very abundant at site D3 (Resort Dam) and RP (Resort Creek). This is likely to be due to related to relatively clear, shallow water (the total suspended solid concentration was particularly low at this site) and low canopy cover (i.e. little shading), which enable light to penetrate the water column and facilitate photosynthesis, and nutrient inputs.

Exotic Species

Three naturalised species (*Chloris virgata, Hygrophila costata,* and *Stachytarpheta jamaicensis*) were recorded and one potentially exotic species (*Panicum* sp.*)* was recorded. These species were uncommon and sparse, with each species covering <5% of one site.

Species of Conservation Significance

No macrophytes listed under the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999* or Queensland *Nature Conservation Act 1992* were recorded during the survey, or are likely to occur in the Project area.

2.5 Aquatic Macroinvertebrate Communities

Community Composition

Diving beetles (family Dytiscidae), midge larvae (subfamilies Chironomidae and Tanypodinae), water boatmen (family Corixidae), backswimmers (family Notonectidae), damselflies (family Coenagrionidae), dragonflies (family Libellulidae) and mayflies (family Baetidae) were the most common and abundant taxa sampled. Typically, these families are tolerant of a wide range of environmental conditions and are often found in moderately disturbed ecosystems (Chessman 2003).

AUSRIVAS Samples

Total Taxonomic Richness

Total taxonomic richness in the AUSRIVAS samples was below the QWQG value at most sites; it was above guidelines at sites P1 (upstream Putney Creek), RP (Resort Creek) in bed habitat, and DERM site 120009 in both habitats. Taxonomic richness was relatively low at site LFC (Leeke's Creek) in both habitats. In bed habitat taxonomic richness was lowest at sites D1 (Large Dam) and LFC (Leeke's Creek) and highest at site RP (Resort Creek). In edge habitat it was lowest at site LFC (Leeke's Creek) and highest at sites RP (Resort Creek) and D3 (Resort Dam). Total taxonomic richness for bed habitat was equal to or slightly below the DERM mainland site. Total taxonomic richness for edge habitat was considerably lower than DERM mainland sites (Figure 2.30).

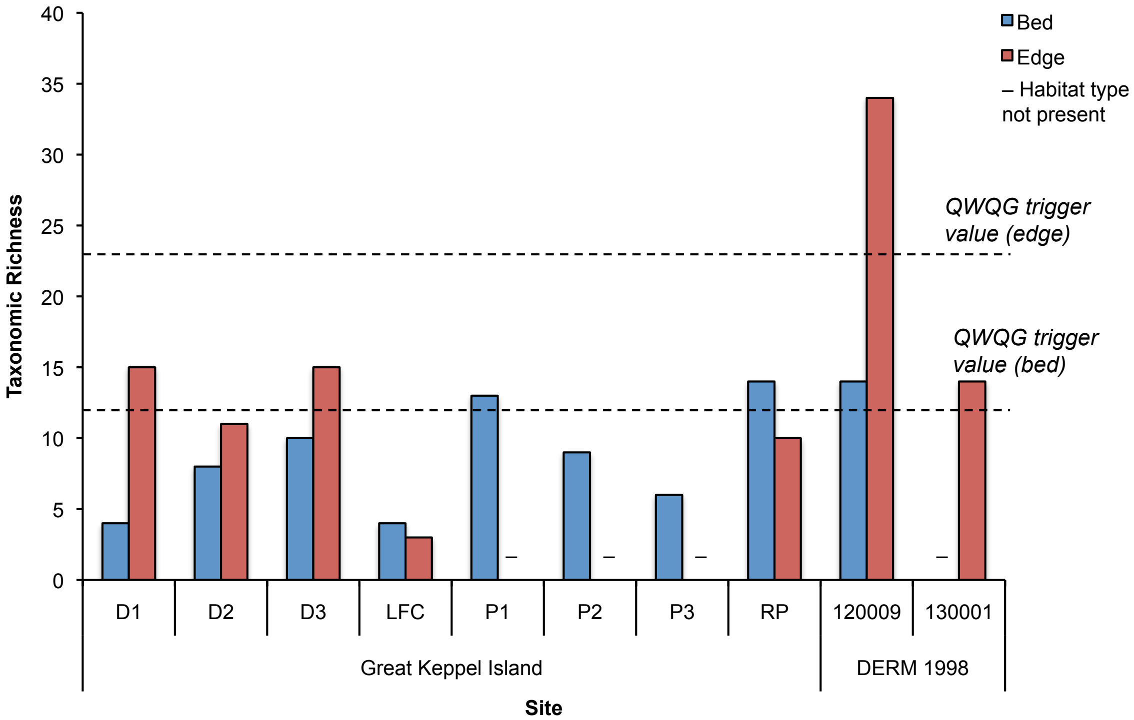


Figure 2.30 Total taxonomic richness in bed and edge habitats at each site, and sites sampled by DERM in 1998.

PET Richness

PET richness in the AUSRIVAS samples was below the QWQG value at most sites; it was equal to or above the guideline at sites D3 (Resort Dam) in edge habitat, P2 (downstream Putney Creek) in bed habitat and DERM site 120009 in both habitats. In bed habitat there were no PET taxa at several sites (D1, D2, LFC and P3). In edge habitat there were no PET taxa at sites D2 (Homestead Dam) and LFC (Leeke's Creek). PET richness for both habitats was generally similar to DERM mainland sites (Figure 2.31). Low abundance of PET taxa may indicate poor water and / or habitat quality, however, several sites were ephemeral and PET taxa are rare in these environments.

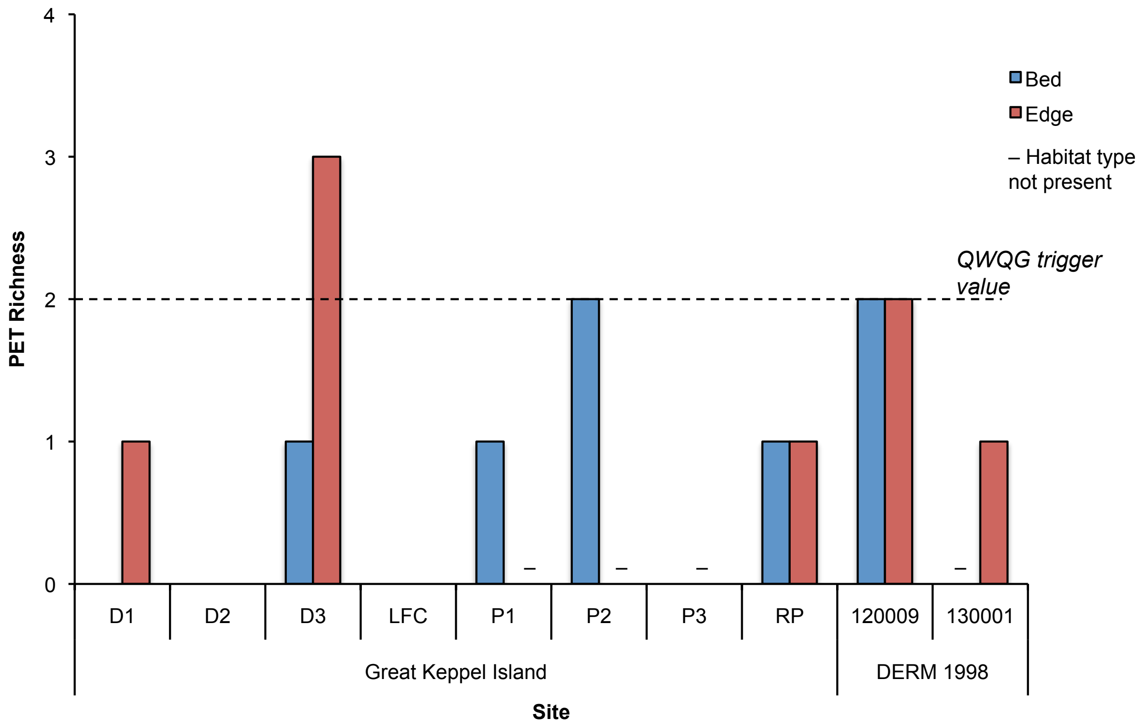


Figure 2.31 PET richness in bed and edge habitat at each site, and at sites sampled by DERM in 1998.

SIGNAL 2 / Family Bi-plot

Most communities were within Quadrant 4 (bottom left). Bed habitats at sites P1 (upstream Putney Creek) and RP (resort Creek) and both habitats at DERM site 120009 (Coorooman Creek) were within Quadrat 2 (bottom right) (Figure 2.32). Sites in Quadrant 4 are indicative of urban, industrial or agricultural pollution, whereas sites in Quadrant 2 typically have better water quality but are indicative of high salinity or nutrient concentrations (which may be natural) (Figure 1.2).

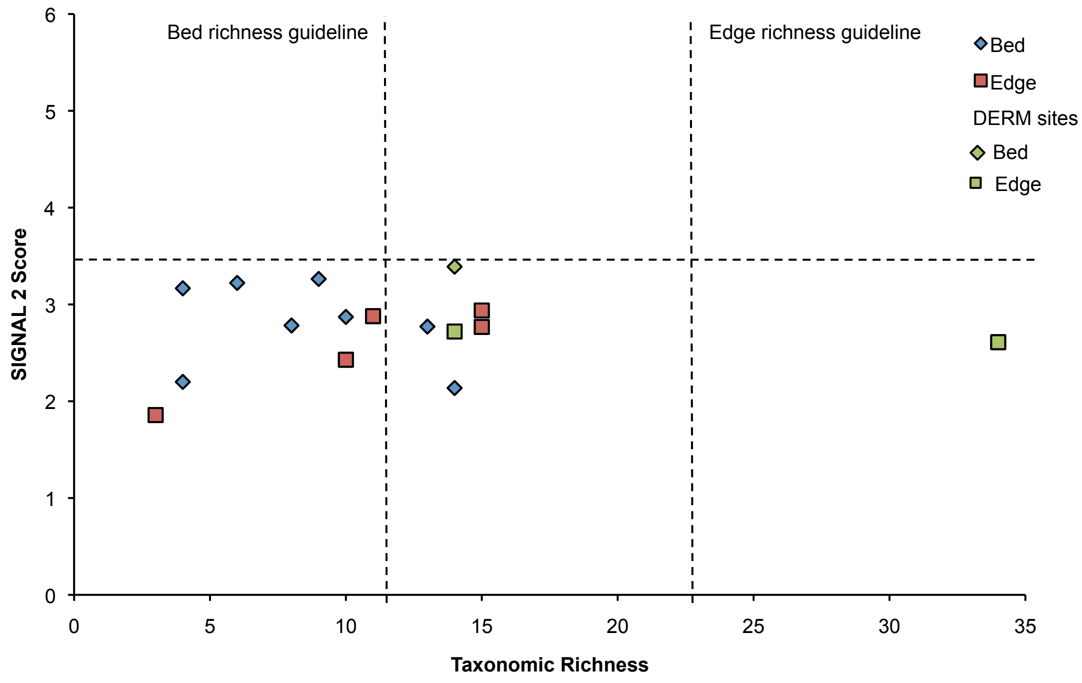


Figure 2.32 SIGNAL 2 / family bi-plot for bed and edge habitat at each site, and at sites sampled by DERM in 1998.

Quantitative Samples

Total Taxonomic Richness

Total taxonomic richness (the total number of taxa in the five samples from each site) was lowest at site LFC (Leeke's Creek) in both habitats, and relatively high at site RP (Resort Creek) in both habitats [5] (Figure 2.33).

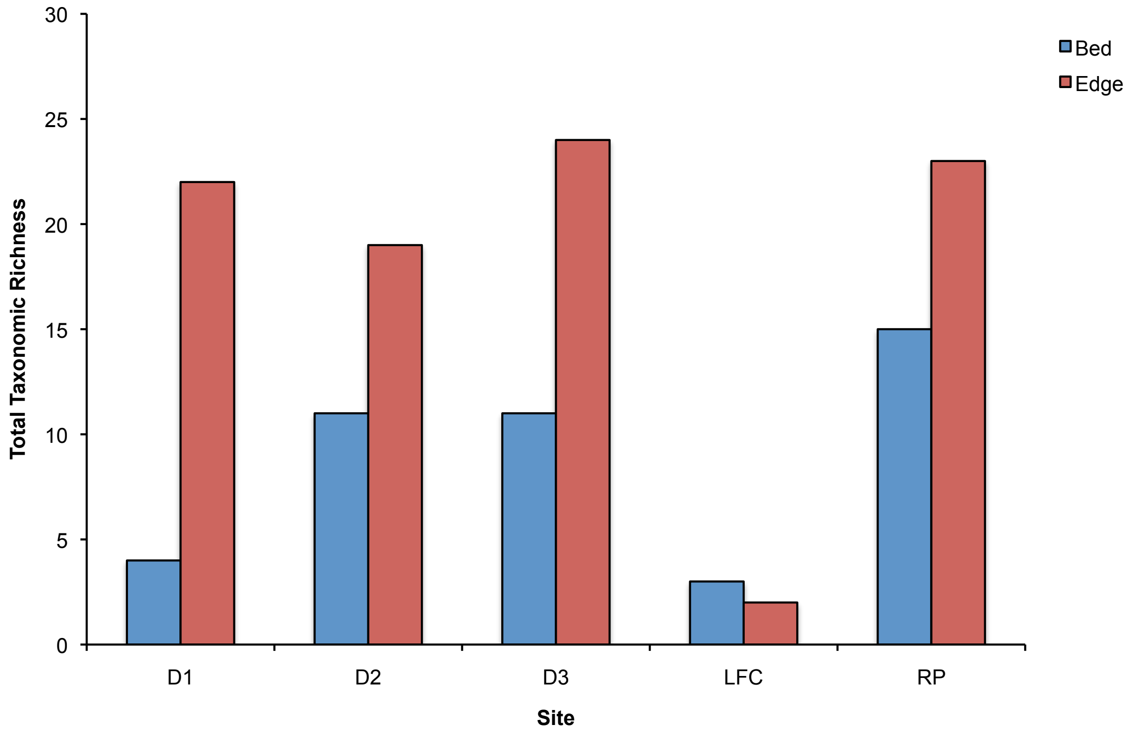


Figure 2.33 Total taxonomic richness in bed and edge habitat at each site.

[5] Quantitative samples were not collected at Putney Creek sites (P1, P2 and P3) as these sites would be lost to the development and not included in future monitoring programs.

Mean Taxonomic Richness

Mean taxonomic richness (the average number of taxa in the five samples from each site) was lowest at site LFC (Leeke's Creek) in both habitats and relatively high at site RP (Resort Creek) in both habitats (Figure 2.34).

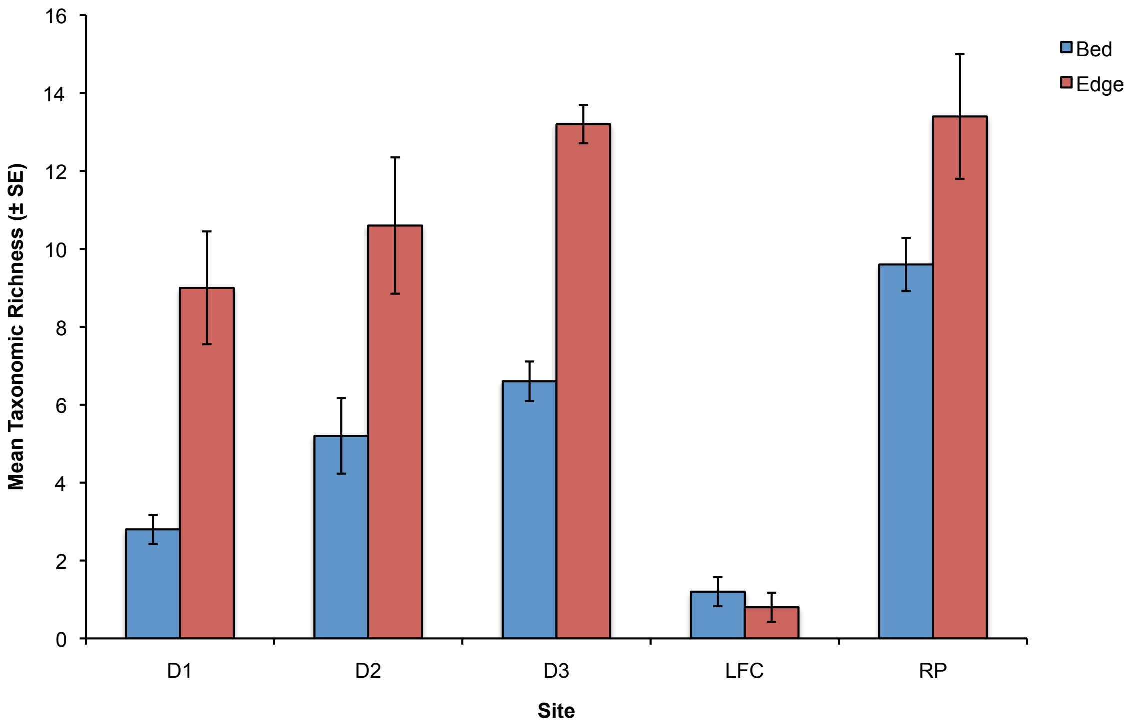


Figure 2.34 Mean taxonomic richness (± SE) in bed and edge habitat at each site.

Mean Abundance

Mean abundance (i.e. the average number of individuals of the five samples from each site) was lowest at sites LFC (Leeke's Creek) in both habitats and relatively high at site RP (Resort Creek) in both habitats (Figure 2.35).

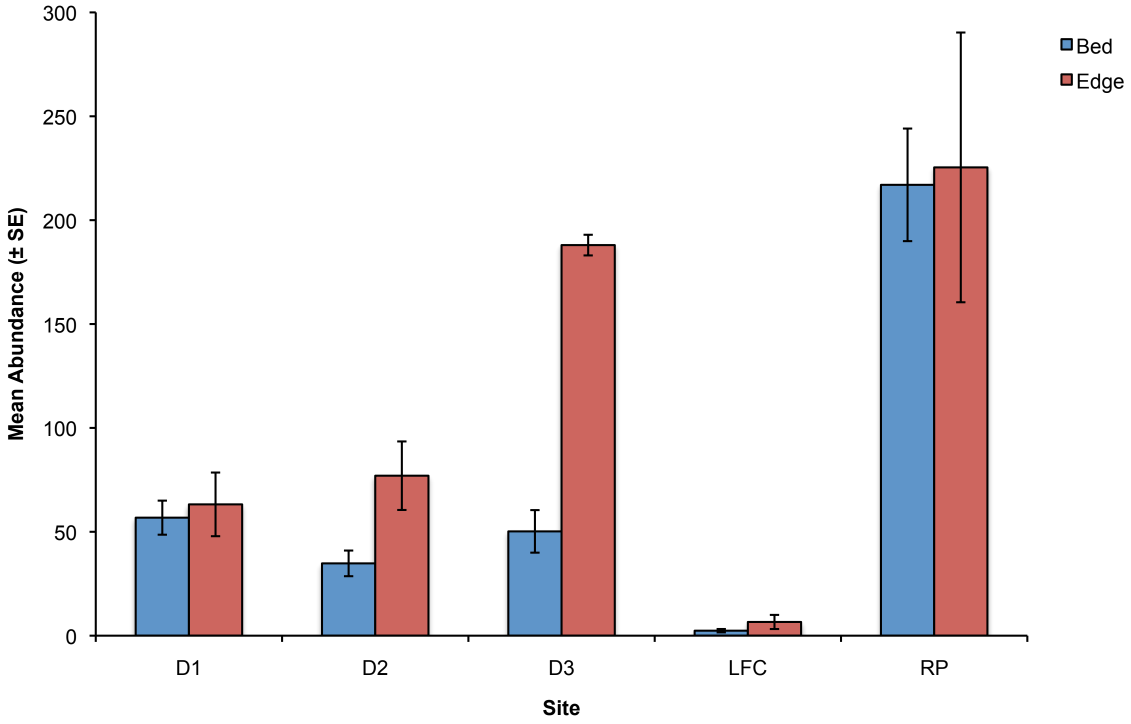


Figure 2.35 Mean abundance (± SE) in bed and edge habitat at each site.

Macrocrustaceans

Macrocrustaceans were not caught during the surveys (in baited traps or in macroinvertebrate samples). This is indicative of unstable (ephemeral) waters.

2.6 Freshwater Fish Communities

Only one freshwater fish (one specimen), Midgley's carp gudgeon (*Hypseleotris* sp.) was caught at site P2 (downstream Putney Creek) (Figure 2.36). The extremely low number of fish is likely to be because the majority of sites are ephemeral streams (that are dry for most of the year) or off-stream dams.

Although only one fish was captured during the surveys, the waterways of the project area are likely to support a depauperate community of freshwater fishes. A discussion of freshwater fishes in the region is presented in Section 3.

Figure 2.36

Hypseleotris sp. caught at site P2 (downstream Putney Creek).

2.7 Freshwater Turtle Communities

Freshwater turtles were not observed during the surveys, however it is possible that there may be turtles in the project area. A discussion of the ecology of freshwater turtles in the region is presented in Section 3.

3 Regional and Ecological Context

Information is not readily available for freshwater streams on continental islands of the region. Most regional data has been obtained from the streams on the mainland near Rockhampton. Comparisons should be made with caution, as freshwater streams on islands are likely to be different to those on the mainland; in addition, several of the sites in this study were off-stream dams.

3.1 Aquatic Habitat

Information is not readily available regarding sediment quality of freshwater streams on continental islands or in the lower Fitzroy Basin.

3.2 Water Quality

The Fitzroy Basin has a large number of mines and high levels of agriculture; so waterways tend to have high turbidity, and high concentrations of suspended solids and nutrients. A recent survey by Australian Pacific (in 2009) reported electrical conductivity above trigger value and dissolved oxygen concentrations and turbidity levels within trigger value ranges (APLNG 2010).

3.3 Sediment Quality

Information is not readily available regarding sediment quality of freshwater streams on continental islands or in the lower Fitzroy Basin.

3.4 Aquatic Flora

Information is not readily available regarding aquatic flora of freshwater streams on continental islands or in the lower Fitzroy Basin.

3.5 Aquatic Macroinvertebrate Communities

Nearby DERM monitoring sites on the mainland include sites 120009 (Coorooman Creek) and 130001 (Moores Creek), which are located approximately 25 km and 50 km south-west of the project area, respectively.

Taxonomic richness at site 120009 was above the lower QWQG values, while site 130001 was slightly below the lower QWQG values. PET richness at site 120009 was above the lower QWQG value in both habitats, however it was below the lower QWQG value at site 130001.

Most communities were within Quadrant 4 of the SIGNAL 2 / family bi-plot, which is indicative of urban, industrial or agricultural pollution. Bed communities at site 120009 were within Quadrat 2, which is indicative of better water quality than Quadrant 2 but is indicative of high salinity or nutrient levels which may be natural).

3.6 Freshwater Fish Communities

Freshwater fish were rare during the surveys, which is likely to be due to the lack of on-stream permanent waterholes. The project area is likely to support a depauperate community of freshwater fishes common to the Fitzroy Basin.

3.7 Freshwater Turtle Communities

Freshwater turtles were not observed during the surveys, however there may low numbers of turtles in the project area.

Six species have been recorded in the Fitzroy Basin (from Limpus et al. 2007):

- Krefft’s river turtle (*Emydura macquarii krefftii*)
- Fitzroy River turtle (*Rheodytes leukops*)
- white-throated snapping turtle (*Elseya albagula*)
- broad-shelled river turtle (*Chelodina expansa*)
- snake-necked turtle (*C. longicollis*), and
- saw-shelled turtle (*Wollumbinia latisternum*).

The island may provide marginal habitat for the Krefft’s, saw-shelled, broad-shelled and snake-necked turtle.

4 Potential Impacts

This section describes the potential impact on freshwater surface water quality, and sediment quality (as they are closely associated). Some impacts may be permanent while others will be temporary and reversible.

4.1 Description of Project

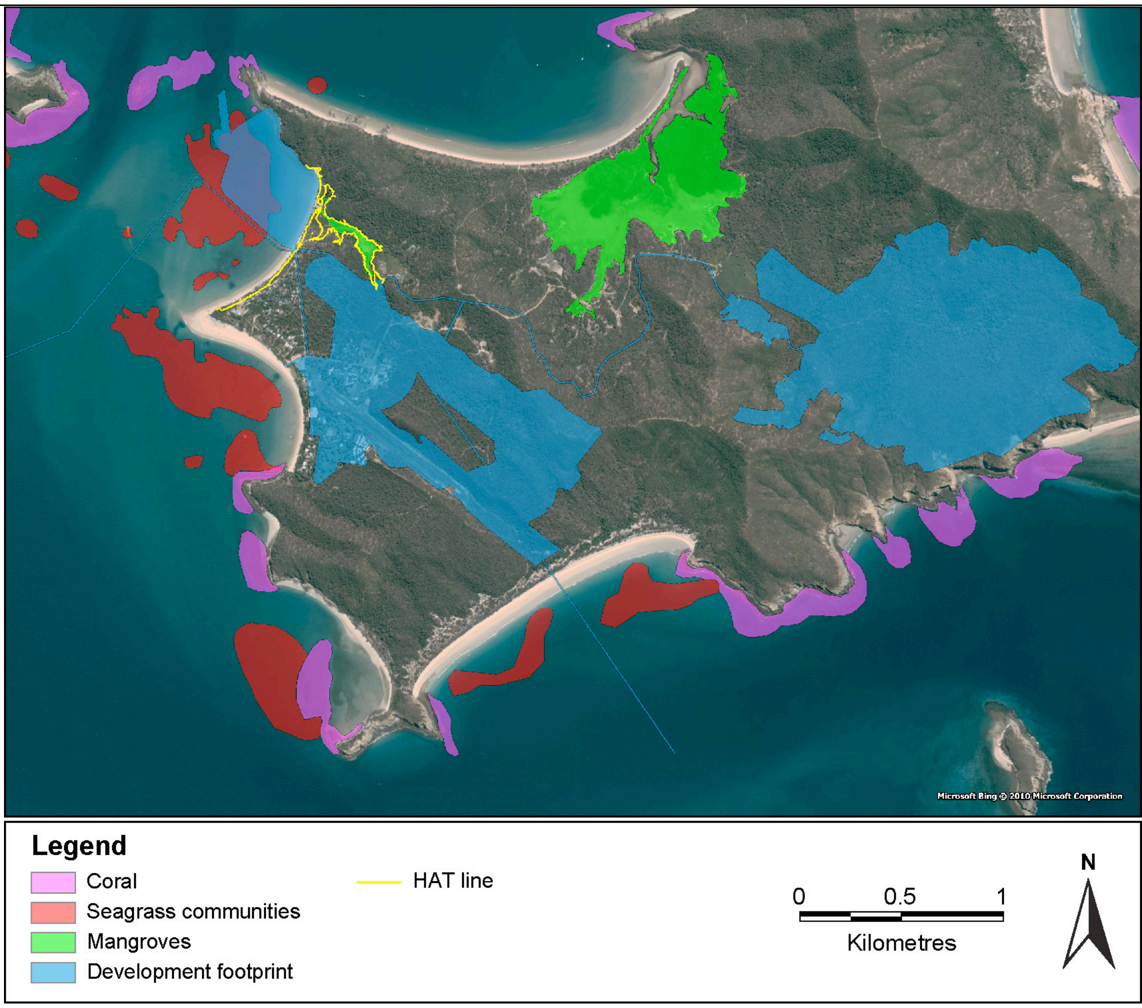
The revised proposal for the Great Keppel Island Resort Revitalisation Plan 2010 includes the following components that have the potential to impact on (freshwater) surface water quality, sediment quality and freshwater ecosystems:

- development of an 18-hole golf course, integrated with essential habitats and ecological corridors, and located on previously disturbed grazing lands
- replacement of the existing airstrip runway
- development of associated service facilities and utilities (e.g. electricity / communications / wastewater / potable water infrastructure corridor, access tracks, waste collection area, fire-fighting and emergency services hub, fuel storage, solar panels and wastewater treatment plant), and
- establishment of a Water Management Plan to mitigate effects of stormwater run-off and golf course run-off into the Great Barrier Reef Marine Park (GBRMP).

Construction and operation activities associated with the following components of the development have the potential to impact on surface water quality, sediment quality and freshwater ecosystems:

- golf course
- airstrip
- service facilities and utilities, particularly the transport and infrastructure corridor, and
- stormwater management.

Figure 4.1 show ecological communities and the proposed development on Great Keppel Island.



frc environmental AQUATIC ECOLOGISTS deep thinking. science.	Great Keppel Island Revitalisation EIS	
	Figure 4.1 Ecological communities and the proposed development on Great Keppel Island.	
	Microsoft Bing © 2010 Microsoft Corporation	August 2011

Golf Course

Fertilisers applied to the golf course have the potential to reach freshwater ecosystems through run-off into creeks and leaching through groundwater. Golf course design and operation ensures that no nutrients enter freshwater environments. Stormwater will be captured in lakes (water features) for treatment prior to being used as turf irrigation, with the lakes lined to prevent groundwater leachate. Furthermore fertiliser application levels will ensure no nutrient leachate through the sand to the groundwater ((T Burt [Opus International Consultants] pers. comm., 27 July 2011; Opus International Consultants (Australia) Pty Ltd 2011b; a).

Capture of stormwater run-off on the golf course, for retention and treatment, is likely to reduce environmental flows in downstream freshwater and estuarine (i.e. mangrove forests) ecosystems. Reduced environmental flows have the potential to negatively affect water quality, sediment quality, flora and fauna.

Airstrip

The development footprint of the proposed airstrip runway includes the upper reaches of Putney Creek. This is unlikely to have a significant impact compared to the current condition, as the upper reaches of Putney Creek are currently not connected to the lower reaches.

Service Facilities and Utilities

The transport and services (e.g. electricity, communications, wastewater and potable water) corridor extends from the marina at Puntey Beach to the golf course and accommodation precincts, crossing Putney and Leeke's creeks. Creek crossings have the potential to introduce contaminants in the waterway, damage habitat for aquatic fauna and interfere for fish passage.

4.2 Golf Course

Golf course construction activities have the potential to result in:

- spills of hydrocarbons and other potential contaminants
- increase suspended sediment levels (turbidity) and sediment deposition due to vegetation clearing and earthworks
- altered passage of aquatic fauna
- litter and waste, and
- associated ecosystem functioning.

Golf course operation activities have the potential to result in:

- spills of hydrocarbons and other potential contaminants (particularly nutrients from fertilisers)
- loss of catchment area
- changes to flow regimes
- litter and waste, and
- water quality issues within water features.

Hydrocarbon Contamination

Various vehicles and equipment will be used in the construction and operation phases. During operation the major of vehicles will be electric or solar powered and therefore the risk of hydrocarbon spills is very low. Construction vehicles and plant will be diesel- or petrol-operated, hence the rick is higher during construction. Construction and operation vehicles may use substances such as hydraulic fluid and lubricating fluids, which each pose a potential threat to water and sediment quality if spilt. Fuels and oils will be stored and managed in accordance with AS1940 (Storage and Handling of Flammable and Combustible Liquids – encompassing spill containment and response protocols).

Spilt diesel and petrol are both likely to form a layer on the surface of the water. The volatility of both diesel and petrol contributes to substantial evaporative loss, while neither product is likely to form water-in-oil emulsions due to their low viscosity. Lubricating oils, of the kind used in diesel engines and gearing, are of a relatively similar density to diesel oils. As such, lubricants would be expected to behave in a similar fashion to diesel oil, and form a surface layer. Lubricants are much less volatile, however, and thus would not evaporate as rapidly. Once incorporated into the sediment, the degradation of oils is significantly slowed, and hydrocarbons may persist in sediments for some time (Boehm et al. 1987 and Struck et al. 1993, both cited in Nicodem et al. 1997).

Spilt fuel is most likely to enter the creeks via an accidental spill on tracks near creek crossings; or when there are construction activities adjacent to waterways. A significant fuel spill to a watercourse (in the order of tens or hundreds of litres) is likely to have a locally significant impact on water quality, with the quantity spilt and the volume of water in the creeks being the most significant factors influencing the length of stream impacted.

Implementation of best practice fuel management will effectively address this risk. Additionally, the risk to aquatic flora and fauna in the project area and downstream waters is reduced as the creeks are dry or isolated pools for much of the year, and therefore many spills could be effectively cleaned up before they can disperse downstream. There is evidence of current hydrocarbon contamination in the project area.

Vegetation Clearing and Earthworks

Vegetation clearing and earthworks will be required in association with construction of several components of the development. There is a high potential for soil erosion and sedimentation following vegetation clearing and earthworks due to the intense seasonal rainfall and soil characteristics present on-site. This could lead to impacts on water and sediment quality via increased turbidity and nutrient and contaminant levels in these waterways.

It is expected that un-contained and un-treated run-off from vegetation clearing and earth works pose a moderate risk to water quality through increases in suspended fine sediment loads and associated nutrients and contaminants during rainfall events. However, where the run-off from disturbed areas is effectively managed by the retention basins and water storages and construction takes place during the dry season, the impact is likely to be negligible.

Increased Turbidity

Increased turbidity may negatively impact fish and macroinvertebrates, as highly turbid water reduces respiratory and feeding efficiency (Karr & Schlosser 1978: cited in Russell & Hales 1993). Increased turbidity may also adversely affect submerged macrophytes as light penetration (required for photosynthesis) is reduced. Reduced light penetration can also lead to a reduction in temperature throughout the water column (DNR 1998).

Turbidity in the project area is variable, ranging from low at some sites to very high at others. Based on the published tolerances of the species captured, the faunal communities of the study area are capable of living in turbid waters. Submerged macrophytes requires relatively clear water to survive but were rare in the project area. Given these background conditions, small increases in turbidity would be unlikely to have a significant impact on aquatic ecology; however significant increases in turbidity could adversely impact the health, feeding and breeding ecology of some species of both macroinvertebrates and fishes, and macrophyte growth downstream of the development.

Decreased Habitat for Aquatic Fauna

Vegetation clearing and earthworks near and within the waterways of the project area may decrease the amount of habitat for aquatic fauna. Aquatic fauna use a variety of in-stream and off-stream structures for habitat including large and small woody debris, bed and banks, detritus, tree roots, boulders, undercut banks, and in-stream, overhanging and trailing bank vegetation, which were all found in the study area.

In-stream habitat is an important habitat component and territory marker for many fish and macroinvertebrates. Many species live on or around in-stream habitat as it provides shelter from temperature, current and predators; contributes organic matter to the system; and is important for successful reproduction. Australian fish species typically spawn either on in-stream vegetation or on hard surfaces like cobbles, boulders, and woody debris.

The deposition of fine sediments can decrease in-stream bed roughness and habitat diversity and may result in existing pools being filled in. This would be unlikely to have a significant impact in the project area, as freshwater streams only carry stormwater flows and they do not generally hold water. A decrease in habitat available for aquatic fauna could lead to a decline in the abundance and diversity of both macroinvertebrate and fish communities in the creeks, and potentially also on dependant predators (such as birds, reptiles and small mammals).

The risk associated with the removal of habitat for aquatic fauna is considered manageable given the depauperate nature of the communities, general lack of habitat in the project area, and the ephemeral nature of the waterways.

Creek Crossings

Creek crossings will be constructed within the transport and service corridor, including over Putney and Leeke’s creeks.

Increased Turbidity and Subsequent Sedimentation

Construction of new permanent and temporary crossings may disturb sediments, leading to increases in localised turbidity and sediment deposition. When construction is carried out during the dry season, these impacts will be minimal or absent, although a highly localised loss of emergent macrophytes and aestivating crustaceans may be expected within the construction footprint.

The impacts of disturbance to habitat will be highly localised and are considered acceptable in both a local and regional context, given the existing disturbed nature of creek crossing locations. However, after installation of crossings, the newly formed bed and banks may continually erode, given the high flows that occur in the region in the wet season. This may result in an increase in channel width and a loss in channel definition, which could in turn lead to a decrease in downstream flow.

Currently, most creek crossings in the project area are dirt fords or culverts. The existing dirt fords have a high potential for erosion, which can increase sediment run-off into creeks and elevate turbidity.

Impacts to Aquatic Fauna Passage

When construction of creek crossings is carried out in the wet season, there will be an impact to fish passage during construction activities, and potentially also to water quality. If the waterway holds water, isolation of the work area may leave fish stranded. These fish will perish unless they are relocated.

Where water storages are located off-stream they will have a negligible impact on fish passage.

Stream crossings can create waterway barriers that prevent or impede movements of aquatic fauna such as fish. Many of the fish native to ephemeral systems in Queensland migrate up- and downstream and between different habitats at particular stages of their lifecycle. Fish passage is already restricted in creeks by constructed fords and culverts, and poorly-designed crossings have the potential to further impact on fish movement within the study area. Given the depauperate freshwater fish community in the project area, the impact of the development on fish passage is considered manageable.

Litter and Waste

Litter and waste associated with vehicle maintenance and mining operations also has the potential to contribute to the degradation of water quality. As appropriate controls will be in place, the risk to water and sediment quality from litter and spilt waste is likely to be manageable during construction and operation.

Input of Nutrients or Other Contaminants

Aquatic biota could also be impacted by nutrients or other contaminants washed into the waterways by run-off and / or with sediment, e.g. nutrients from fertilisers used on the golf course. Nutrient inputs can lead to algal or macrophyte blooms. During the day, as the algae photosynthesises, these blooms can produce high levels of dissolved oxygen (DO). However, at night, there is a net consumption of oxygen as the algae continue to respire. This can cause DO to be reduced to very low levels during the night and early morning, that are harmful to fish and biota.

Input of nutrients or other contaminants into the waterways would impact on aquatic flora and fauna. Where the spill is acute communities may be impacted but would be expected to recover over time (and most likely fully following the next wet season). Chronic inputs of nutrients or contaminants to the waterways would be expected to have longer-term impacts on floral and faunal communities. Golf course design and operational protocols will seek to prevent nutrients entering freshwater environments, and fertiliser application levels will be designed to avoid nutrient leachate through the sand to the groundwater ((T Burt [Opus International Consultants] pers. comm., 27 July 2011; Opus International Consultants (Australia) Pty Ltd 2011b; a). Therefore the risk of eutrophication in association with the golf course is considered low and readily manageable.

Loss of Catchment Area

Construction of the development will result in the loss of a number of small ephemeral drainage lines and gullies, the most substantial being the loss of upper Putney Creek due to the proposed extension of the airstrip. This is unlikely to have a significant impact, as the upper reaches of Putney Creek appear to have not been connected to the lower reaches for some time (due to the existing resort). Furthermore, most of the drainage lines and gullies discharge in a disperse manner via localised flow paths, i.e. are not defined waterways and therefore do not support stable ecosystems (Opus International Consultants (Australia) Pty Ltd 2011a).

It is unlikely that these drainage lines and gullies hold water for any substantial period of time. Given the low stream order of the drainage lines and gullies and the small area of catchment to be impacted, the loss of these ephemeral drainages and construction of water storage dams and retention basins to capture flow is unlikely to have any significant impacts on the environmental values of the downstream receiving environment. The loss of catchment area is insignificant at a regional scale.

Changes to Flow Regimes

Changes to the flood regime, and the timing and magnitude of flows in watercourses, have the potential to impact on water and sediment quality, with flow-on effects to flora, fauna and ecosystem functioning. Extended periods of low flow can lead to increased nutrient concentrations, elevated electrical conductivity, and reduced dissolved oxygen, while more frequent high flow events can result in high turbidity and total suspended solids through erosion (ANZECC & ARMCANZ 2000).

The loss of catchment area and increase in hard surfaces will alter water flow in the project area. The proposed development is predicted to increase stormwater run-off due an increased area of hard (impermeable) surfaces and decreased area of permeable surface. Stormwater will be captured in detention and bio-detention (wetland vegetation) basins to control the quantity and quality of run-off into surface and ground water. Bio-retention swales and infiltration areas will also be used. Modelling by Opus International Consultants predicts no impact to receiving water quality (Opus International Consultants (Australia) Pty Ltd 2011a).

The potential impact associated with altered flow regimes is considered minor as waterways are ephemeral (i.e. dry for much of the year) and large parts of the catchment area will not be affected by the golf course development (i.e. will continue to provide seasonal environmental flows in downstream environments). The impact will be negligible where environmental flows are maintained, i.e. treated water is released form the water storage facilities in similar quantities and with similar timing to natural flows.

Water Quality Issues within Water Features

Blue-green Algae

There is potential for blue-green algae (cyanobacteria) blooms to occur in the water features during operation. However, as the water features will be exposed to wind-induced mixing and are likely to receive relatively large inflows during rainstorm events, the risk of blooms is considered to be low.

4.3 Airstrip

Airstrip construction activities have the potential to result in a similar suite of potential impacts as the golf course, including:

- spills of hydrocarbons and other potential contaminants
- vegetation clearing and earthworks
- loss of catchment area
- changes to flow regimes
- litter and waste, and
- associated ecosystem functioning.

Airstrip construction has the potential for the same suite of impacts to freshwater systems as golf course construction.

4.4 Transport and Service Corridor

Construction of the transport and service corridor has the potential to result in a similar suite of potential impacts as the golf course and airstrip, including:

- spills of hydrocarbons and other potential contaminants
- vegetation clearing and earthworks
- increase suspended sediment levels and sediment deposition due to vegetation clearing and earthworks
- altered passage of aquatic fauna
- litter and waste, and
- associated ecosystem functioing.

Operation of the transport and service corridor has the potential to result in:

- spills of hydrocarbons and other potential contaminants

- increase suspended sediment levels and sediment deposition due to vegetation clearing and earthworks
- altered passage of aquatic fauna
- litter and waste, and
- associated ecosystem functioning.

Construction of the service corridor has the potential for the same suite of impacts to freshwater systems as discussed above for golf course construction.

5 Cumulative Impacts

5.1 Nearby Tourism Developments

Nearby tourism developments identified by GBRMPA for assessment include:

- Rosslyn Bay Inn (as known as the Rosslyn Bay Resort), Rosslyn Bay, approximately 15 km to the west
- Seaspray Resort and Spa, Zilzie (near Emu Park), approximately 18 km to the south west
- Zilzie Bay, Zilzie, approximately 20 km to the south west, and
- Mercure Capricorn Resort, Yeppoon, approximately 24 km to the north west.

Rosslyn Bay Inn

The Rosslyn Bay Inn is a relatively large (29 studio and suite rooms, 6 ocean view balcony apartments and 12 private spa bungalows) inn located between Keppel Bay Marina (Rosslyn Bay Harbour) and Kemp Beach. The inn may contribute to the degradation of freshwater ecosystems through:

- litter and waste
- loss of catchment area, and
- changes to flow regimes and stormwater run-off.

Seaspray Resort and Spa

The Seaspray Resort and Spa is a relatively small resort (17 two and three bedroom fully self contained apartments) located adjacent Cocoanut Point National Park; this resort is not beachside. Activities offered by the resort (relevant to aquatic ecology) include nature hikes within the Cocoanut Point National Park and Wetlands Reserve. The resort may contribute to the degradation of freshwater ecosystems through:

- litter and waste
- loss of catchment area, and
- changes to flow regimes and stormwater run-off.

Zilzie Bay

Zilzie Bay is an urban development (accommodation) with the first synthetic golf course alongside the Great Barrier Reef. The development may contribute to the degradation of freshwater ecosystems through:

- spills of hydrocarbons and other potential contaminants associated with operation of the golf course
- altered passage of aquatic fauna
- litter and waste
- loss of catchment area
- changes to flow regimes and stormwater run-off, and
- water quality issues within water features (e.g. blue-green algal blooms).

Mercure Capricorn Resort

The Mecure Capricorn Resort is a large (281 rooms) beachside resort at Yeppoon. The resort's facilities (relevant to freshwater ecology) include two international golf courses and wetland canoe eco-tours. The development may contribute to the degradation of freshwater ecosystems through:

- spills of hydrocarbons and other potential contaminants (particularly nutrients from fertilisers) associated with operation of the golf course
- altered passage of aquatic fauna
- litter and waste
- loss of catchment area
- changes to flow regimes and stormwater run-off, and
- water quality issues within water features.

Potential Impacts Associated with the Resort Developments

The extent of potential impact in association with the operation of the Great Keppel Island development is likely to be minimal where appropriate mitigation measures are developed and adhered to. The cumulative impact of the operation of the Great Keppel Island development and nearby resorts is therefore likely to be minor or negligible. For example:

- potential impacts associated with spills of hydrocarbons and other potential contaminants are considered minor where managed through respective EMPs (noting that most golf carts are electric and use of vehicles fuelled with hydrocarbons will be minimal on golf courses)
- potential impacts associated with nutrient-laden run-off from the golf courses are considered negligible where all run-off is captured for treatment (noting there will be no impact to the downstream ecosystems of Leeke's Creek on Great Keppel Island, and there will be no impact in association with Zilzie Bay given the synthetic golf course does not require fertilisers or watering)
- potential impacts associated with litter and waste are considered minor where managed through the respective EMPs (and national park regulations); impacts to freshwater environments at each of the resorts are unlikely to have a cumulative impact given the minor nature of the potential impacts, the ephemeral nature of all waterways of Great Keppel Island, and the lack of freshwater connectivity between each of the respective resorts
- potential impacts to altered passage of aquatic fauna are considered negligible where barriers are constructed in accordance with best practice on Great Keppel Island (noting the apparent lack of major waterway barriers at each of the other developments)
- potential impacts associated with litter and waste are considered minor where managed through respective EMPs
- potential impacts associated with loss of catchment area and changes to flow regimes (e.g. increased stormwater run-off) are considered negligible at other resorts given their beachfront location and / or small development footprint (i.e. most of the drainage lines and gullies discharge in a disperse manner via localised flow paths and are not defined waterways supporting stable freshwater ecosystems); the impact associated with the Great Keppel Island development is considered manageable given that the upper reaches of Putney Creek appear to have not been connected to the lower reaches for some time (due to the existing resort), most of the drainage lines and gullies discharge in a disperse manner via localised flow paths, and stormwater will be captured in basins, and

- potential impacts associated with water quality issues within water features are considered minor given the coastal location of all golf course developments, and consequential exposure to wind-induced mixing and relatively large inflows during rainstorm events (thereby reducing the risk of blue-green algal blooms).

5.2 Climate Change

Climate change is associated with an enhanced 'greenhouse effect', i.e. increased levels of greenhouse gases (mostly carbon dioxide) trap more heat and warm the Earth. There is now consensus that emissions from human activities are largely responsible for increased greenhouse gas concentrations and the associated global warming. Changes in freshwater ecosystems, consistent with climate change, have been reported across Australia, with impacts on many freshwater environments and species (e.g. Salen-Picard et al. 2002; Vass et al. 2009; Hobday & Lough 2011).

Climate models are currently limited with regard to predicting impacts for freshwater ecosystems, particularly for impact and adaptation assessments (Hobday & Lough 2011). What is known, is that global warming could:

- alter rainfall and consequentially water flow and flooding
- increase the geographic range in invasive species
- bring about encroachment of estuarine ecosystems
- reduce the extent of dry season (drought) refuges for flora and fauna, and
- cause perennial streams to become ephemeral (Land & Water Australia 2008; DERM 2010a).

Climate change projections for the central Queensland region include a decline in rainfall, with increasing temperature and evaporation, in conjunction with more extreme weather events and sea-level rise (DERM 2010a; 2012).

Air Temperature

Average annual air temperature in central Queensland has increased by 0.5 °C over the last decade. Projections indicate an increase of up to 4.5 °C by 2070. By 2070, Rockhampton may have four times the number of days over 35 °C (increasing from an average of 16 per year to an average of 64 per year) (DERM 2012).

Rainfall

Average annual rainfall over the last 10 years decreased by approximately 14% compared with the previous 30 years. This is generally consistent with the natural variability evident over the previous 110 years, therefore it is difficult to detect any influence of climate change (DERM 2012).

Reduced rainfall, together with increased air temperatures, would result in reduced run-off, flows and water storage (Hobday & Lough 2011). Projections indicate annual potential evaporation could increase by 7 to 15% by 2070, further impacting flows and water storage. The central Queensland region has significant areas of land under irrigation and therefore a high rural water demand; furthermore, coastal developments and the expansion in mining and industry all add to the current pressure on the water resources. Further reductions in water storage and availability will place great pressure on consumptive uses and threaten environmental water uses (DERM 2010a; 2012).

Extreme Weather Events

Predicted sea level rise and more extreme weather events, such as flooding and storms, have the potential to increase salinity levels in freshwater (GBRMPA 2009 and references cited within). The 1-in-100-year storm tide event is projected to increase by 51 cm in Gladstone and 32 cm at Cape Clinton, under certain conditions (i.e. a 30 cm sea-level rise, 10% increase in cyclone intensity and frequency, and a 130 km shift southwards in cyclone tracks) (DERM 2012).

Potential Impacts Associated with the Development and Climate Change

Given the uncertainty around predicting impacts to freshwater ecosystems it is very difficult to assess the cumulative impacts of climate change and the proposed development.

There is the potential for impacts to flow associated with the development (in association with loss of catchment area and flow regimes due to the golf course) to be exasperated by climate change. However potential impacts associated with the development are considered minor as waterways are ephemeral (i.e. dry for much of the year) and large parts of the catchment area will not be affected by the golf course development (i.e. will continue to provide seasonal environmental flows in downstream environments); potential impact will be negligible where environmental flows are maintained (i.e. treated water is released form the golf course water storage facilities in similar quantities and with similar timing to natural flows).

Given the manageable nature of impacts to freshwater ecosystems in association with the proposed development, there are unlikely to be any major cumulative impacts associated with climate change.

The potential impacts on freshwater ecosystems of artificially opening the mouth of Putney Creek, combined with predicted sea level rise and landward encroachment of estuarine wetlands are discussed in Appendix A (Water Quality).

5.3 Ecosystem Functioning

Major impacts to freshwater ecosystem functioning are not predicted in association with the proposed development.

6 Measures to Avoid, Minimise and Mitigate Impacts

6.1 Risk Assessment

A risk assessment of potential impacts has been undertaken in accordance with a standard risk assessment matrix (Table 6.1), as presented in Table 6.2.

Table 6.1 Risk assessment matrix.

Probability	Consequence Catastrophic Irreversible Permanent (5)	Major Long Term (4)	Moderate Medium Term (3)	Minor Short Term Manageable (2)	Insignificant Manageable (1)
Almost Certain (5)	(25) Extreme	(20) Extreme	(15) High	(10) Medium	(5) Medium
Likely (4)	(20) Extreme	(16) High	(10) Medium	(8) Medium	(4) Low
Possible (3)	(15) High	(12) High	(9) Medium	(6) Medium	(3) Low
Unlikely (2)	(10) Medium	(8) Medium	(6) Medium	(4) Low	(2) Low
Rare (1)	(5) Medium	(4) Low	(3) Low	(2) Low	(1) Low

Table 6.2 Summary of potential impacts on freshwater ecosystems.

Design	Construction	Operation	Potential Impact	Mitigation Measure	Monitoring	Significance of Impact (Unmitigated)	Significance of Residual (Mitigated Impact)
	●	●	Hydrocarbon contamination	• fuel, oil and chemical storage and handling are undertaken in accordance with AS1940 • any fuel, oil or chemical spills are contained and cleaned up immediately • a Spill Management Plan prepared in accordance with State Planning Policy requirements and to the satisfaction of DERM • all refuelling is by licensed fuel suppliers in accordance with their Standard Operating Procedures • refuelling takes place in designated areas, in accordance with industry standards • the stored volume of fuel, oil or chemical in minimised, with storage in a secure area • any visible (or suspected) fuel, oil or chemical loss will be treated as an 'incident' • operators regularly check equipment for evidence of leaks and condition of hydraulic hoses and seals, and conduct maintenance or repairs as necessary to prevent drips, leaks or likely equipment failures • spill kit are provided and include bilge socks, heavy duty absorbent polypropylene pads, floating booms and blowback refuelling collars • a register of Materials Safety Data Sheets (MSDS) relating to all hazardous substances on board is maintained	• monthly water and sediment quality monitoring during construction and operation • annual (post-wet) aquatic ecology monitoring	WQ (10) Medium Flora (9) Medium Invertebrates (10) Medium Vertebrates (6) Medium	WQ (6) Medium Flora (6) Medium Invertebrates (6) Medium Vertebrates (3) Low

Design	Construction	Operation	Potential Impact	Mitigation Measure	Monitoring	Significance of Impact (Unmitigated)	Significance of Residual (Mitigated Impact)
●	●	●	Increased turbidity and sediment deposition	• an erosion and sediment control management plan is developed (as a part of the EMP) and implemented • water features are constructed prior to vegetation clearing and earthworks • vegetation clearing and earthworks are staged • clearing and earthworks for construction of creek crossings is undertaken in the dry season where possible	• monitoring and the use of 'trigger levels' during construction • monthly water and sediment quality monitoring during construction and operation • annual (post-wet) aquatic ecology monitoring	WQ (8) Medium Flora (8) Medium Invertebrates (8) Medium Vertebrates (4) Low	WQ (6) Medium Flora (6) Medium Invertebrates (6) Medium Vertebrates (2) Low
●	●		Vegetation clearing and earthworks – decreased habitat for aquatic fauna	• vegetation clearing and earthworks are staged • clearing and earthworks are undertaken in the dry season where possible • habitat (e.g. woody debris, riparian flora and boulders) is salvaged for use in other waterways / water features	• annual (post-wet) aquatic ecology monitoring	WQ (4) Low Flora (4) Low Invertebrates (4) Low Vertebrates (4) Low	WQ (2) Low Flora (2) Low Invertebrates (2) Low Vertebrates (2) Low
●	●	●	Creek crossings - aquatic fauna passage	• construction of creek crossings is undertaken in the dry season where possible • if waterway hold water, fish are salvaged if present	• annual (post-wet) aquatic ecology monitoring	WQ (6) Medium Flora (2) Low Invertebrates (4) Low Vertebrates (6) Medium	WQ (2) Low Flora (1) Low Invertebrates (2) Low Vertebrates (2) Low

Design	Construction	Operation	Potential Impact	Mitigation Measure	Monitoring	Significance of Impact (Unmitigated)	Significance of Residual (Mitigated Impact)
	●	●	Litter and waste	• waste materials contained within the designated maintenance area to prevent contamination of surrounding watercourses and vegetation • used oils, greases, rags, hoses and filters from maintenance activities will be collected and disposed of in the designated bins located at the workshop areas • on vessels, areas are allocated for solid and liquid waste storage, and waste should not be stored outside these areas • any waste fuels, oils or other chemicals are collected in separate drums and transported to an approved facility for disposal • all waste is disposed of lawfully and wastes listed as 'trackable wastes' are handled or transferred, documentation in accordance with Environmental Protection Policy (Waste) (refer EPP Waste) • a record / manifest is maintained for general and regulated waste disposal • waste is removed from vessels and disposed of at an approved facility • housekeeping procedures, including spillage control, are implemented to minimise the generation of waste, and • all waste awaiting disposal is stored appropriately	• observations during monthly water and sediment quality monitoring during operation • annual (post-wet) aquatic ecology monitoring	WQ (8) Medium Flora (6) Medium Invertebrates (6) Medium Vertebrates (6) Medium	WQ (4) Low Flora (4) Low Invertebrates (4) Low Vertebrates (4) Low

Design	Construction	Operation	Potential Impact	Mitigation Measure	Monitoring	Significance of Impact (Unmitigated)	Significance of Residual (Mitigated Impact)
●	●	●	Nutrient enrichment	• golf course design and operation (particularly retention of stormwater for treatment and appropriate fertiliser application) • stormwater retention and treatment as required • erosion control during earthworks (as nutrients can be introduced with sediment)	• monthly water and sediment quality monitoring during operation • annual (post-wet) aquatic ecology monitoring	WQ (9) Medium Flora (9) Medium Invertebrates (9) Medium Vertebrates (6) Medium	WQ (4) Low Flora (4) Low Invertebrates (4) Low Vertebrates (4) Low
●		●	Loss of catchment area	• maintenance of drainage lines and gullies where possible	• NA	WQ (4) Low Flora (2) Low Invertebrates (4) Low Vertebrates (4) Low	WQ (3) Low Flora (2) Low Invertebrates (3) Low Vertebrates (3) Low
●	●	●	Changes to flow regime	• best practice erosion and sediment control techniques during construction • stormwater will be retained, for treatment as required, in detention and bio-detention basins to control the quantity and quality of run-off into surface and ground water; bio-retention swales and infiltration areas will also be used	• monthly water and sediment quality monitoring during operation • annual (post-wet) aquatic ecology monitoring	WQ (8) Medium Flora (4) Low Invertebrates (6) Low Vertebrates (6) Low	WQ (4) Low Flora (2) Low Invertebrates (4) Low Vertebrates (4) Low

Design	Construction	Operation	Potential Impact	Mitigation Measure	Monitoring	Significance of Impact (Unmitigated)	Significance of Residual (Mitigated Impact)
●		●	Water quality Issues within water features (blue green algae and stratification)	• designed to maximum wind action and stormwater inflow • aerated if prone to stratification and / or low DO concentration • algal blooms or abundant flora removed	• monthly water and sediment quality monitoring during operation • annual (post-wet) aquatic ecology monitoring	WQ (6) Medium Flora (4) Low Invertebrates (8) Medium Vertebrates (8) Medium	WQ (4) Low Flora (3) Low Invertebrates (6) Low Vertebrates (6) Low

6.2 Mitigation Measures

Current 'best practice' assessment and engineering practices offer significant opportunities to minimise the impacts associated with both construction and operation of the proposed development.

6.3 Hydrocarbon Contamination

The risk of impact associated with spills of hydrocarbons and other contaminants is considered manageable, where:

- fuel, oil and chemical storage and handling are undertaken in accordance with AS1940 (Storage and Handling of Flammable and Combustible Liquids – encompassing spill containment and response protocols),
- any fuel, oil or chemical spills are contained and cleaned up immediately
- a Spill Management Plan is prepared in accordance with State Planning Policy requirements and to the satisfaction of DERM
- all refuelling is by licensed fuel suppliers in accordance with their Standard Operating Procedures
- refuelling takes place in designated areas in accordance with industry standards
- the stored volume of fuel, oil or chemical in minimised, with storage in a secure area
- any visible (or suspected) fuel, oil or chemical loss will be treated as an 'incident'
- operators and crew regularly check equipment for evidence of leaks and condition of hydraulic hoses and seals, and conduct maintenance or repairs as necessary to prevent drips, leaks or likely equipment failures
- spill kit are provided and include bilge socks, heavy duty absorbent polypropylene pads, floating booms and blowback refuelling collars, and
- a register of Materials Safety Data Sheets relating to all hazardous substances on board is maintained.

6.4 Vegetation Clearing and Earthworks

The risk of sediment-laden run-off to nearby waterways will be reduced where:

- an erosion and sediment control management plan is developed (as a part of the Environmental Management Plan (EMP)) and implemented
- water features are constructed prior to vegetation clearing and earthworks
- vegetation clearing and earthworks are staged, and
- clearing and earthworks for construction of creek crossings is undertaken in the dry season where possible.

During and after construction, water quality and freshwater ecosystems may be protected by:

- erosion control (such as jute matting, rock mulching, or similar), placed in ditches and drainage lines running from all cleared areas, especially on slopes and levee banks
- contour banks, ditches or similar formed across cleared slopes to direct run-off towards surrounding vegetation and away from creeks
- water features are constructed during each stage of construction to protect natural waterways from sediment-laden run-off
- monitoring water quality of creeks downstream of clearing / exposed soil, during periods of rainfall, and
- rehabilitation of the landscape, focusing on the:
  - salvaging of clumps of native grass, shrubs and trees prior to clearing
  - use of native vegetation of local provenance for replanting where possible, and
  - replanting along the margins of creeks following construction of the creek crossings (the width of the replanted riparian vegetation should be equal or greater than the width of existing riparian vegetation at the crossing location; planted trees in the riparian zone should provide canopy cover and have root systems that can stabilise the banks and disturbed area).

6.5 Aquatic Fauna Passage

Impacts associated with the construction of permanent creek crossings by the transport and infrastructure corridor will be minimised if:

- construction is undertaken during the dry season (minimising the likelihood of rainfall and run-off carrying sediment and other pollutants into the creeks), and
- stormwater and erosion control measures are implemented.

Where construction is undertaken during the wet season, impacts associated with the construction of road and pipeline crossings will be minimised if (AE 2001; APIA 2009):

- the workspace is isolated, irrespective of if there is an isolated pool or flowing water. The isolation should be designed such that:
  - it is completed within one work-day, to minimise the impact on aquatic fauna
  - upstream and downstream dams are installed on the edge of the temporary workspace, to maximise the area of the workspace. These dams should:
    - be constructed of an appropriate material for each creek (e.g. steel plates, flumes, sand bags or aquadam)
    - be made impermeable by using polyethylene liner and sand bags
  - if there is flowing water is present, 100% of this flow is maintained downstream by using appropriately sized pumps
  - pump intakes are screened, with openings no larger than 2.54 mm, to ensure that no fish are trapped
  - fish are salvaged from the isolated workspace and translocated to appropriate waterways
  - the upstream dam is slowly removed, to allow water to flush the sediment from the workspace area
  - sediment-laden water should be pumped into sumps or onto vegetation, and
  - operation of the clean-water pump to sustain flow below the downstream dams must be continued until the downstream dam is removed.

Waterway barrier works approvals are likely to be required under the Queensland *Fisheries Act 1994* (Fisheries Act) for the construction of temporary and permanent crossings where construction requires the use of coffer dams, etc. (as will potentially be required if construction is done in the wet season).

Depending on the nature of the works required at each crossing, the works may be either assessable or self-assessable development under the Integrated Development Approvals System (IDAS). This will be determined for each crossing prior to construction in accordance with the following Codes for Self-assessable Development:

- Minor waterway barrier works on low order inland waterways (Code WWBW01), and
- Temporary waterway barrier works (Code WWBW02).

Applications will be made for development approvals where required.

Obstruction of Fish Passage

Where culverts are used, their design and installation can significantly influence fish passage. It is recommended that the Department of Environment and Resource Management (DERM) be consulted during stream crossing design and the development of maintenance regimes, and that they are designed in accordance with DERM's Fish Habitat Guideline FHG 001 (Fish passage in streams, fisheries guidelines for design of stream crossings) (Cotterell 1998), which states that culverts should be designed such that they are:

- located at least 100 m from any other waterway barrier on the creek (e.g. road crossing, dam etc.) in order to minimise the cumulative effects of fish barriers
- as short (along the length of the stream) and wide (across the stream channel) as possible; whilst being designed to allow the passage of anticipated flood volumes and associated debris, and to allow enough water depth within the culvert to facilitate fish movement (estimated to be >0.3 m depth during flow periods for the fish species likely to be present)
- open-bottomed if possible, to retain the natural morphological features of the stream. If this is not possible, culverts should be countersunk below the stream bed and natural materials such as rocks secured to the base of the culvert to increase roughness and reduce water velocity (velocities of >1 m/s will likely impede all fish passage)
- constructed without a 'drop off' at the culvert outlet, as this impedes fish migration upstream
- constructed with minimum disturbance to the outer banks on stream bends, as these are usually the most unstable and prone to erosion, and

- surrounded by riparian vegetation (that is planted after construction if necessary) to stabilise banks, provide food and habitat for fauna and prevent predation of aquatic fauna by birds.

Impacts to in-stream habitat and aquatic fauna and flora will be minimised where culverts are:

- installed at the driest time of year (preferably in the dry creek bed, avoiding pools). During the wet season, impacts may be minimised where isolation methods are adopted in accordance with above guidelines, and
- maintained, and there is regular removal of debris or plant growth, which can impede fish passage (Cotterell 1998).

If required, translocation should be in accordance with QPIF fish salvage guidelines, as outlined below:

- fauna should be captured by suitably-qualified aquatic ecologists
- the timing of construction should be in the cooler months if possible, to minimise stress to the fauna (aquatic fauna are less active in the cooler months)
- salvaged fauna should be translocated to suitable waterholes in the Battle Creek catchment (to prevent the transfer of exotic fish or aquatic disease)
- fish and macrocrustaceans should be captured from using gear appropriate to the waterways and species present (at the site, this is likely to include electrofishing, cast nets, seine nets and set traps), and
- aquatic fauna should be handled, transported and released so as to minimise damage to the fish (e.g. handle with wet hands, hold correctly etc.).

Various apparatus used to capture / translocate fish will require a General Fisheries Permit, issued by the DEEDI, and should be operated by appropriately experienced professionals.

6.6 Litter and Waste

Where waste materials are contained within the designated maintenance area to prevent contamination of surrounding watercourses and vegetation, and used oils, greases, rags, hoses and filters from maintenance activities will be collected and disposed of in the designated bins located at the workshop areas, the impacts are considered manageable.

The risk associated with waste management is considered manageable where:

- areas are allocated for solid and liquid waste storage, and waste should not be stored outside these areas
- any waste fuels, oils or other chemicals are collected in separate drums and transported to an approved facility for disposal
- all waste is disposed of lawfully and wastes listed as 'trackable wastes' are handled or transferred, documentation in accordance with Environmental Protection Policy (Waste) (refer EPP Waste)
- a record / manifest is maintained for general and regulated waste disposal
- waste is removed from vessels and disposed of at an approved facility
- housekeeping procedures, including spillage control, are implemented to minimise the generation of waste, and
- all waste awaiting disposal is stored appropriately.

6.7 Water Features

Water features should be aerated if predictions indicate they are likely to be prone to stratification and / or low DO concentration. Algal blooms or over-abundant macrophytes should also be removed as they have the potential to critically decrease DO concentrations over night.

Water features will provide less diverse physical habitat than natural waterways. This can be mitigated through placement of habitat such as large woody debris in the shallow areas of the dam (<5 m deep) where practical.

6.8 Monitoring Requirements

Undertaking an ecological monitoring program will provide the opportunity to assess the accuracy of predicted impacts and inform management (and construction and operation EMPs), of potential issues and the need for responsive action. Regular monitoring will provide increased opportunity to identify the source of impacts and as required, both distinguish them from the *perceived* source of impact and inform enhancements to the EMP.

The monitoring program should be designed to detect changes to both the physical environment and floral and faunal communities of the waterways. It should focus on aquatic habitat, macroinvertebrates and fish as key indicators as outlined below, and compliment marine ecosystem monitoring (refer to Appendix C and E) where practical.

Water quality and aquatic habitat should be assessed in accordance with AUSRIVAS protocols. The percent coverage of each macrophyte species present should also be assessed at each site. This information may also be used in multivariate analyses of macroinvertebrate and fish communities. Quantitative replicate macroinvertebrate samples should be collected from each habitat present at each site. To determine differences among macroinvertebrate assemblages at different sites, community data should also be analysed using multivariate techniques. Fish communities should be surveyed during the post-wet season.

Turbidity Monitoring During Construction of Creek Crossings

Monitoring of turbidity levels in the creeks is recommended daily when constructing permanent or temporary creek crossings during the wet season.

It is recommended that turbidity be measured with a hand held probe:

- immediately upstream of the crossing site immediately prior to construction, to determine background conditions
- daily during construction, at locations both upstream and downstream of the crossing, and
- daily after construction until water quality returns to background conditions, as established by the initial background monitoring prior to crossing construction.

Where turbidity levels downstream of the crossing site are >10% above background turbidity levels, it is recommended that construction cease and that stormwater and erosion and sediment control measures be revised prior to re-commencement of construction.

Water Features

Water quality in the water supply dam should be monitored regularly (notionally monthly from the commissioning of the dam) to:

- confirm the suitability of the water for irrigation (including monitoring of blue green algae), and
- to confirm water quality in the event of release to the receiving environment.

The timing of monitoring may need to vary depending on the results and the season. For example, water quality will likely vary more during the wet season than the dry season. As such, monitoring frequencies may need to be higher in the wet season than in the dry season.

7 Summary and Conclusion

7.1 Existing Environment

Aquatic Habitat

Most sites had a moderate habitat bioassessment score; sites D1 (Large Dam), LFC (Leeke's Creek) and P2 (downstream Putney Creek) had a good score. Scores were relatively at sites D2 (Homestead Dam), D3 (Resort Dam) and RP (Resort Creek) due to limited in-stream habitat and lack of water flow as the dams were located off-stream. Dense algal cover reduced habitat diversity at sites RP (Resort Creek) and D3 (Resort Dam). Site LFC (Leeke's Creek) had the highest score due to low embeddedness, limited channel alteration and relatively high water flow.

Water Quality

The pH was within the QWQG trigger value range at most sites; it was below the range at sites D2 (Homestead Dam) and LFC (Leeke's Creek). The reason for this is not clear; it may be related to local geology.

Electrical conductivity was above the QWQG upper trigger value at most sites; the dams (D1 to D3) were below the trigger value. This is likely to be related to evaporation at most sites and the groundwater waters source at site RP (Resort Creek).

The total suspended solid concentration was highest at sites P2 (downstream Putney Creek), P3 (mid Putney Creek) and LFC (Leeke's Creek) and relatively low at sites D3 (Resort Dam) and site RP (Resort Creek).

The concentration of total nitrogen was above the QWQG lower trigger value at all sites. The concentration of total phosphorous was above the QWQG lower trigger value at all sites, except site D3 (Resort Dam). This is likely to be related to seepage from septic systems and possibly landfill.

Concentrations of total arsenic, cadmium, mercury and nickel were below laboratory detection limits and / or the relevant ANZECC & ARMCANZ trigger values at all sites. Total chromium, copper, lead and zinc concentrations were above laboratory detection limits and / or trigger values at some sites, which is likely to be related to seepage from landfill, historical livestock grazing activities and / or local geology. The concentration of total chromium was above the trigger value at site P1 (upstream Putney Creek). The concentration of total copper was above the trigger value at sites D1 (Large Dam), D2 (Homestead Dam) and in Putney Creek (P1 to P3). The concentration of total lead was above the trigger value at sites D3 (Resort Dam) and LCF (Leeke's Creek). The concentration of total zinc was above the trigger values at most sites; it was below the trigger value at sites D2 (Homestead Dam), D3 (Resort Dam) and LFC (Leeke's Creek).

The concentration of the total petroleum hydrocarbon C15 to C28 fraction was relatively high at site D1 (Large Dam); this site may have been exposed to diesel. The total concentration of the C29 to C36 fraction was relatively high at sites D1 (Large Dam), D2 (Homestead Dam) and P2 (downstream Putney Creek); these sites may have been exposed to mineral-based oils and lubricants.

Sediment Quality

The concentration of total nitrogen was highest at sites P2 (downstream Putney Creek), P3 (mid Putney Creek) and RP (Resort Creek). The concentration of total phosphorus was highest at sites P3 (mid Putney Creek) and RP (Resort Creek). This is likely to be due to seepage from septic tanks and possibly landfill.

The concentration of arsenic, cadmium, chromium, copper, lead, mercury, nickel and zinc was below the ISQG-low trigger value at all sites. Concentrations were relatively high at some sites, which is likely to be related to seepage from landfill, livestock grazing activities and / or local geology.

Aquatic Flora

Taxonomic richness was highest at site LFC (Leeke's Creek) and lowest at sites D3 (Resort Dam) and P3 (mid Putney Creek). Cover was greatest at site RP (Resort Creek), but also relatively high at sites D1 (large Dam), LFC (Leeke's Creek) and P3 (mid Putney Creek), and lowest at site D2 (Homestead Dam). The low cover at site D2 (Homestead Dam) is likely to be related to clearing for livestock grazing.

No single species was widespread; communities were characterised by a range of species with low cover. Three naturalised species were recorded and one potentially exotic species was recorded. These species were uncommon and sparse, with each species covering <5% of one site.

No macrophytes listed under the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999* or Queensland *Nature Conservation Act 1992* were recorded during the survey, or are likely to occur in the project area.

Aquatic Macroinvertebrate Communities

Diving beetles (family Dytiscidae), midge larvae (subfamilies Chironomidae and Tanypodinae), water boatmen (family Corixidae), backswimmers (family Notonectidae), damselflies (family Coenagrionidae), dragonflies (family Libellulidae) and mayflies (family Baetidae) were the most common and abundant taxa sampled. Typically, these families are tolerant of a wide range of environmental conditions and are often found in moderately disturbed ecosystems.

Total taxonomic richness in the AUSRIVAS samples was below the QWQG value at most sites; it was above the guideline value at sites P1 (upstream Putney Creek), RP (Resort Creek) in bed habitat and DERM site 120009 in both habitats. Taxonomic richness was relatively low at site LFC (Leeke's Creek) and relatively high at sites P1 (upstream Putney Creek) and RP (Resort Creek). Abundance was lowest at sites LFC (Leeke's Creek), P2 (downstream Putney Creek) and P3 (mid Putney Creek) and relatively high at sites P1 (upstream Putney Creek) and RP (Resort Creek).

PET richness in the AUSRIVAS samples was below the QWQG value at most sites; it was equal to or above the guideline at site D3 (Resort Dam) in edge habitat, site P2 (downstream Putney Creek) in bed habitat and DERM site 120009 in both habitats. Low abundance of PET taxa may indicate poor water and / or habitat quality, however, several sites were ephemeral and PET taxa are rare in these environments.

Most communities were within Quadrant 4, which is indicative of urban, industrial or agricultural pollution. Bed habitat at sites P1 (upstream Putney Creek) and RP (resort Creek) and both habitats at DERM site 120009 were within Quadrat 2, which is indicative of better water quality than Quadrant 4.

Freshwater Fish Communities

One freshwater fish, Midgley's carp gudgeon (*Hypseleotris* sp.) was caught at site P2 (downstream Putney Creek). This is likely to be because the majority of sites are off-stream dams or ephemeral streams that are dry for most of the year. Although only one fish was captured, the waterways of the project area are likely to support a depauperate community of freshwater fishes common to the region.

Freshwater Turtles Communities

Freshwater turtles were not observed during the surveys, however it is possible that turtles common to the region may occur in the project area.

7.2 Potential Impacts

Hydrocarbon Contamination

Various vehicles and equipment will be used in the construction and operation phases. During operation the major of vehicles will be electric or solar powered and therefore the risk of hydrocarbon spills is very low. Vehicles may use substances such as hydraulic fluid and lubricating fluids, which each pose a potential threat to water and sediment quality if spilt. Spilt hydrocarbons are most likely to enter the creeks via an accidental spill on tracks near creek crossings; or when there are construction activities adjacent to waterways. A significant fuel spill to a watercourse (in the order of tens or hundreds of litres) is likely to have a locally significant impact on water quality, with the quantity spilt and the volume of water in the creeks being the most significant factors influencing the length of stream impacted.

Implementation of best practice fuel management will effectively address this risk. Additionally, the risk to aquatic flora and fauna in the project area and downstream waters is reduced as the creeks are dry or isolated pools for much of the year, and therefore many spills could be effectively cleaned up before they can disperse downstream. There is evidence of current hydrocarbon contamination in the project area.

Vegetation Clearing and Earthworks

Vegetation clearing and earthworks will be required in association with construction of several components of the development. There is a high potential for soil erosion and sedimentation following vegetation clearing and earthworks due to the intense seasonal rainfall and soil characteristics present on-site. This could lead to impacts on water and sediment quality via increased turbidity and nutrient and contaminant levels in these waterways.

It is expected that un-contained and un-treated run-off from vegetation clearing and earthworks pose a moderate risk to water quality through increases in suspended fine sediment loads and associated nutrients and contaminants during rainfall events.

However, where the run-off from disturbed areas is effectively managed by the use of retention basins, and construction takes place during the dry season, the impact is likely to be negligible.

Creek Crossings

Creek crossings will be constructed within the transport and service corridor, including over Putney and Leeke's creeks.

Increased Turbidity and Subsequent Sedimentation

Construction of new permanent and temporary crossings may disturb sediments, leading to increases in localised turbidity and sediment deposition. When construction is carried out during the dry season, these impacts will be minimal or absent, although a highly localised loss of emergent macrophytes and aestivating crustaceans may be expected within the construction footprint.

The impacts of disturbance to habitat will be highly localised and are considered acceptable in both a local and regional context, given the existing disturbed nature of creek crossing locations. However, after installation of crossings, the newly formed bed and banks may continually erode, given the high flows that occur in the region in the wet season. This may result in an increase in channel width and a loss in channel definition, which could in turn lead to a decrease in downstream flow.

Currently, most creek crossings in the project area are dirt fords or culverts. The existing dirt fords have a high potential for erosion, which can increase sediment run-off into creeks and elevate turbidity.

Impacts to Aquatic Fauna Passage

When construction of creek crossings is carried out in the wet season, there will be an impact to fish passage during construction activities, and potentially also to water quality. If the waterway holds water, isolation of the work area may leave fish stranded. These fish will perish unless they are relocated.

Stream crossings can create waterway barriers that prevent or impede movements of aquatic fauna such as fish. Many of the fish native to ephemeral systems in Queensland migrate up- and downstream and between different habitats at particular stages of their lifecycle. Fish passage is already restricted in creeks by constructed fords and culverts, and poorly-designed crossings have the potential to further impact on fish movement within the study area. Given the depauperate freshwater fish community in the project area, the impact of the development on fish passage is considered manageable.

Litter and Waste

Litter and waste associated with vehicle maintenance and mining operations also has the potential to contribute to the degradation of water quality. As appropriate controls will be in place, the risk to water and sediment quality from litter and spilt waste is likely to be manageable during construction and operation.

Water Quality Issues within Water Features

Blue-green Algae

There is potential for blue-green algae (cyanobacteria) booms to occur in the water features during operation. However, as the water features will be exposed to wind-induced mixing and are likely to receive relatively large inflows during rainstorm events, the risk of blooms is considered to be low.

7.3 Mitigation Measures

Current 'best practice' assessment and engineering practices offer significant opportunities to minimise the impacts associated with both construction and operation of the proposed development. Table 6.2 provides a summary of mitigation measures and the associated residual risk.

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Appendix H Commercial and Recreational Fisheries

Contents

Tables

Figures

1 Methodology

The recreational and commercial fisheries of the broader study area were described through literature review, to provide a regional and ecological context of the condition and productivity of the project area. Available literature and fisheries data was sourced from researchers, government agencies (primarily the Department of Employment, Economic Development and Innovation, DEEDI), marine operators, community-based groups and consultancies to provide a description of fish and fisheries in the vicinity of the proposed project and of the region.

2 Existing Environment

2.1 Commercial Fisheries

There are several important commercial fisheries operating in the marine and estuarine waters within and adjacent to the proposed project area. There are several freshwater dams and waterways in the project area however none are associated with commercial fishing.

Fish, Crustaceans and Molluscs Fisheries

Queensland's annual commercial catch exceeds $300 million landed value (Bishop 1993; Roy Morgan Research 1999). In 2005, commercial fishing in the Great Barrier Reef (GBR) region produced a total of 10 119 tonnes of seafood, worth over $100 million (Queensland Government 2011).

Line, net, pot and trawl fisheries operate near the proposed development. Table 2.1 shows the type of catch for each of these commercial fisheries.

Table 2.1 Catch type of fisheries operating near the proposed development[1].

Catch type	Line	Net	Pot	Beam Trawl	Otter Trawl
banana prawn				✓	✓
barramundi		✓			
bay prawn					✓
blue swimmer crab			✓		✓
bream		✓			
bugs					
cod		✓			
coral prawn				✓	✓
coral trout	✓				
emperor fish	✓				
endeavour prawn					✓
flathead		✓			
garfish		✓			
greasy prawn				✓	

Catch type	Line	Net	Pot	Beam Trawl	Otter Trawl
grey mackerel		✓			
grunter		✓			
jewfish		✓			✓
king prawn					✓
mud crab			✓		
mullet		✓			
queenfish		✓			
scallop					✓
school mackerel		✓			
sea perch		✓			
shark	✓	✓			✓
shovelnose ray		✓			✓
spanish mackerel	✓				
squid					✓
steelback		✓			
stingray		✓			
blue threadfish		✓			
tiger prawn					✓
trevally		✓			
triple tail		✓			
whiting		✓			

[1] Data source: Queensland Government 2011

The project area is in catch grid 29 (Figure 2.1). Table 2.1 shows the annual volume and value of the commercial catch in 2005[1] for this grid. In 2005, 69 boats operated in this grid and caught 181 tonnes of fish worth $1.2 million. Net fisheries had the highest catch and value. Beam trawl, otter trawl and pot fisheries had a moderate catch and value, and line fisheries had the lowest catch and value (Queensland Government 2011).

[1] Data post-2005 is not publically available.

Table 2.2 Catch and value of production of commercial fisheries in Catch Grid R29 in 2005.

Fishery	Catch (tonnes)	Boats	Days	Gross Value of Production (GVP; AU$)
Line	2.7	5	58	16 400
Otter Trawl	21.9	16	569	197 100
Beam Trawl	23.5	18	147	214 900
Pot	23.4	27	1125	239 200
Net	109.3	41	963	566 600
All	**180.9**	**69**	**2669**	**1 234 200**

Figure 2.2 and Figure 2.3 show commercial seafood catch trends between 1988 and 2005 (Queensland Government 2011). Annual catch ranged from less than 10 tonnes by line fisheries during most years, to at least 120 tonnes by net fisheries in 1995, 2003 and 2004 and otter trawl fisheries in 1991. Catch by otter trawl, beam trawl and pot fisheries has generally increased since 2000. The annual value of commercial fisheries was lowest for line fisheries (less than approximately $50 000) and highest for otter trawl fisheries (typically around $700 000). The annual value of the fishery generally increased with increased catch

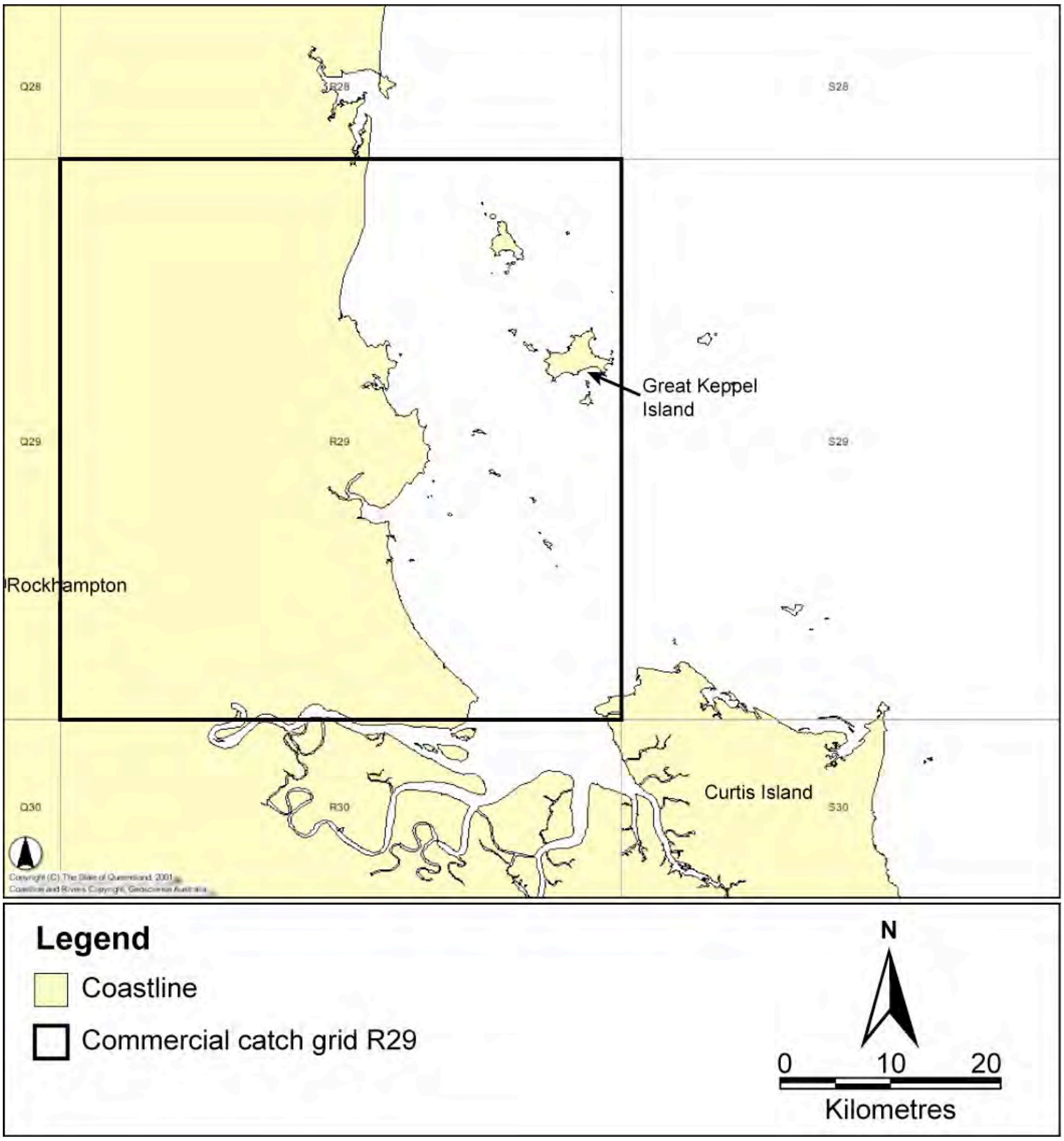

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	Figure 2.1 The location of commercial catch grid R29.	
	Queensland Government 2011	March 2011

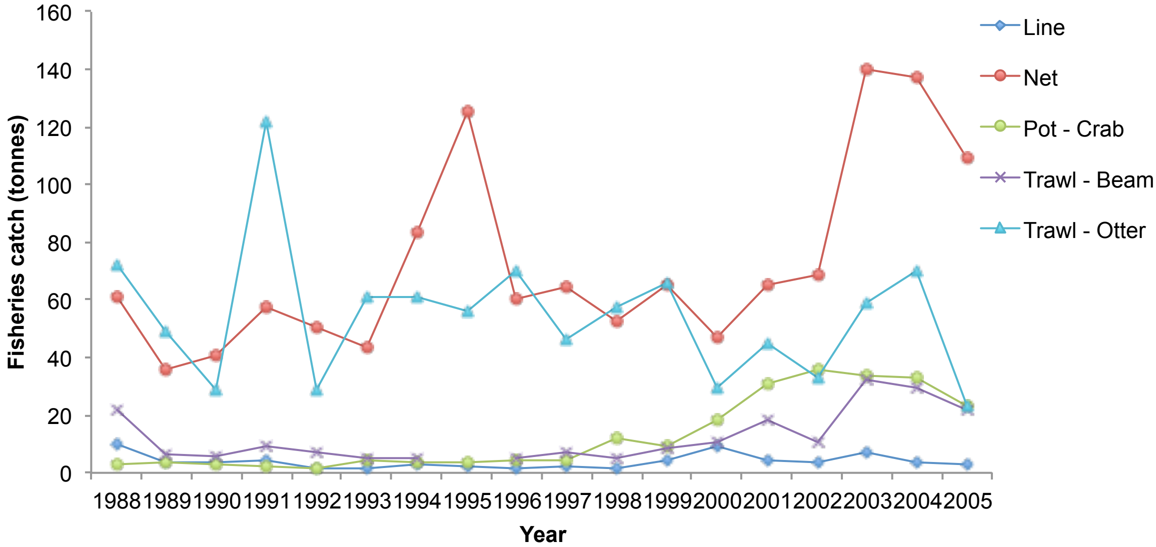

Figure 2.2 Commercial fisheries catch in catch grid R29 from 1988 to 2005.

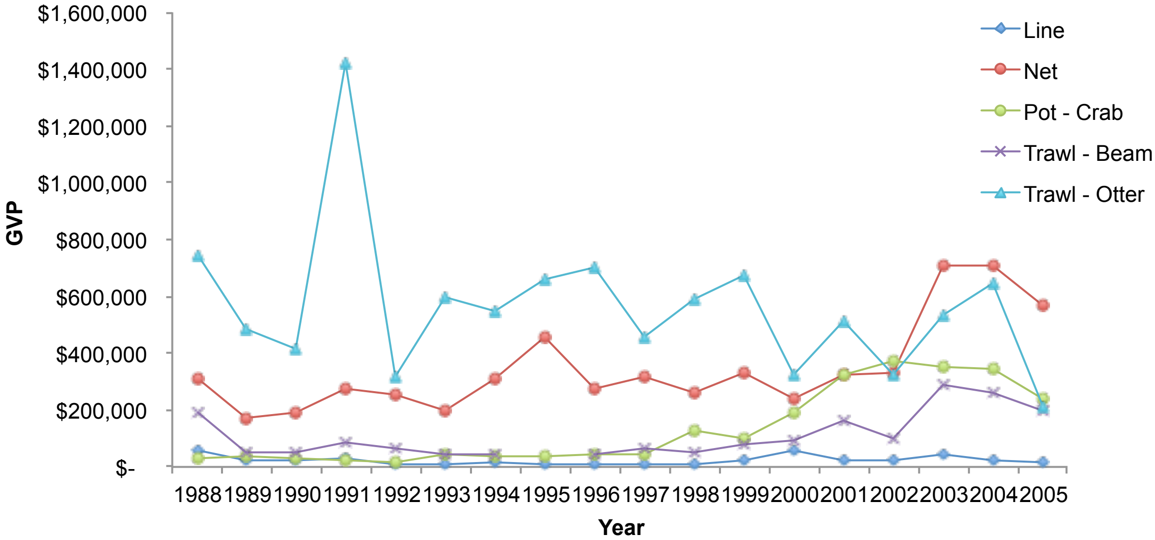

Figure 2.3 Value of commercial fisheries in catch grid R29 from 1988 to 2005.

Coral Fisheries

The Keppel Islands are within a spatially defined high use Coral Collection Area (CCA) The Queensland Coral Fishery (QCF) collects coral and associated material, including:

- live corals (i.e. anemones, and soft and hard corals)
- ornamental (non-living) corals
- living rock (i.e. dead coral skeletons inhabited by algae and other organisms)
- coral rubble (i.e. coarsely broken-up coral fragments), and
- coral sand (i.e. finely ground-up particles of coral skeleton).

In Queensland, the aquarium trade has a total allowable harvest of 200 tonnes of coral and associated material, and 59 authorities to collect (DEEDI 2009). This is a small-scale, quota-managed and hand-harvested (non-mechanical) fishery. The quota allows 30% of live coral and 60% of live rock, coral rubble and ornamental coral (combined). Great Keppel Island is located in commercial catch grid R29 (Figure 2.1). Coral collection data for this grid are shown in Table 2.3.

Table 2.3 Collection of coral, sand star and shell grit within catch grid R29[1].

Year	Licences	No. of Harvest Days	Weight (t)
2004	7	177	8.327
2005	NA	NA	NA
2006	6	104	15.216
2007	NA	NA	NA
2008	6	66	8.493
2009	NA	NA	NA
2010	6	30	2.652

NA data not available

[1] Data provided by the Department of Employment, Economic Development and Innovation (DEEDI) 2011.

Marine Aquarium Fish Fishery

The Keppel Islands are within a Special Management Area (SMA) for the Marine Aquarium Fish Fishery (MAFF) (Ryan & Clarke 2005). Active users of the MAFF include commercial and recreational fishers that collect marine aquarium fish species for display in either private or public aquariums (Ryan & Clarke 2005). Data on the harvest of aquarium fish within catch grid R29 grid is shown in Table 2.4.

Table 2.4 Harvest of aquarium fish within catch grid R29[1].

Year	Licences	No. of Harvest Days	Number
2004	5	123	4 678
2005	NA	NA	NA
2006	5	69	4 220
2007	6	73	3 257
2008	5	42	2 260
2009	8	80	5 317
2010	5	79	5 346

NA data not available

1 Data provided by the Department of Employment, Economic Development and Innovation (DEEDI) 2011.

The peak Queensland marine aquarium fishing industry body (Pro-Vision) instigated a voluntary moratorium on the commercial take of certain anemonefish and anemone species, following the 2006 bleaching event. This is a pro-active measure to increase the resilience of reef ecosystems and aid recovery (GBRMPA 2011).

Aquaculture and Wild Harvest Fisheries

The closest approved aquaculture site to the proposed development is a barramundi and clam farm on an estuary on the mainland, over 14 km from Great Keppel Island.

There are several licences for commercial wild harvest of the milky oyster (*Saccostrea amasa*) near the proposed development[2] (Figure 2.4). The licence for the Putney Point area adjacent to the proposed marina development was surrendered (Figure 2.4). Licence holders must take oysters by hand only (using non-mechanical implements) and

2 Harvest data for these licences is currently not available.

destroy any exotic Pacific oysters (*Crassostrea gigas*), as this species dominates endemic stocks (Queensland Government 2011).

Between 2004 and 2009, approximately 70% of Queensland-approved oyster leases recorded no harvest. In 2005 to 2006, the total harvest of oysters in Queensland was 161 500 dozen, valued at approximately $600 000. Oysters are generally sold to local seafood retailers and the hospitality industry (Queensland Government 2011).

No information has been made available on the harvest from leases near to the proposed development.

Commercial Fishing Zoning

Commercial fishing is the largest extractive activity in the Great Barrier Reef Marine Park (GBRMP), harvesting about 15 000 tonnes of seafood annually. Commercial fishing is legislated by zoning plans under the Commonwealth *Great Barrier Reef Marine Park Act 1975* (Figure 2.5).

Under Queensland fisheries legislation there are limits on the types of gear that may be used, quota limits, possession limits and size limits on fish species. Queensland DPI&F manage entry, effort restrictions, spatial and seasonal closures, gear restrictions and restrictions on retained species.

Commercial trawlers are restricted to the ‘general use’ zones.

Netting by commercial fisheries is allowed in ‘general use’, ‘habitat protection’, and ‘conservation park’ zones (bait netting only).

Line fishing[3] is allowed in ‘general use’, ‘habitat protection’, and ‘conservation park’ zones (limited line fishing only).

No more than one dory (line fishing vessel) is to be detached from its primary commercial fishing vessel in ‘conservation park’ or ‘buffer’[4] zones. No dory is to be detached from its primary commercial fishing vessel in ‘marine national park’ zones.

Trolling[5] is allowed in ‘general use’, ‘habitat protection’, ‘conservation park’ and ‘buffer’ (for pelagic species only) zones.

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[3] Fishing using not more than three hand-held rods or handlines per person with a combined number of not more than six hooks attached to the line(s).

[4] No buffer zones occur in the proposed development.

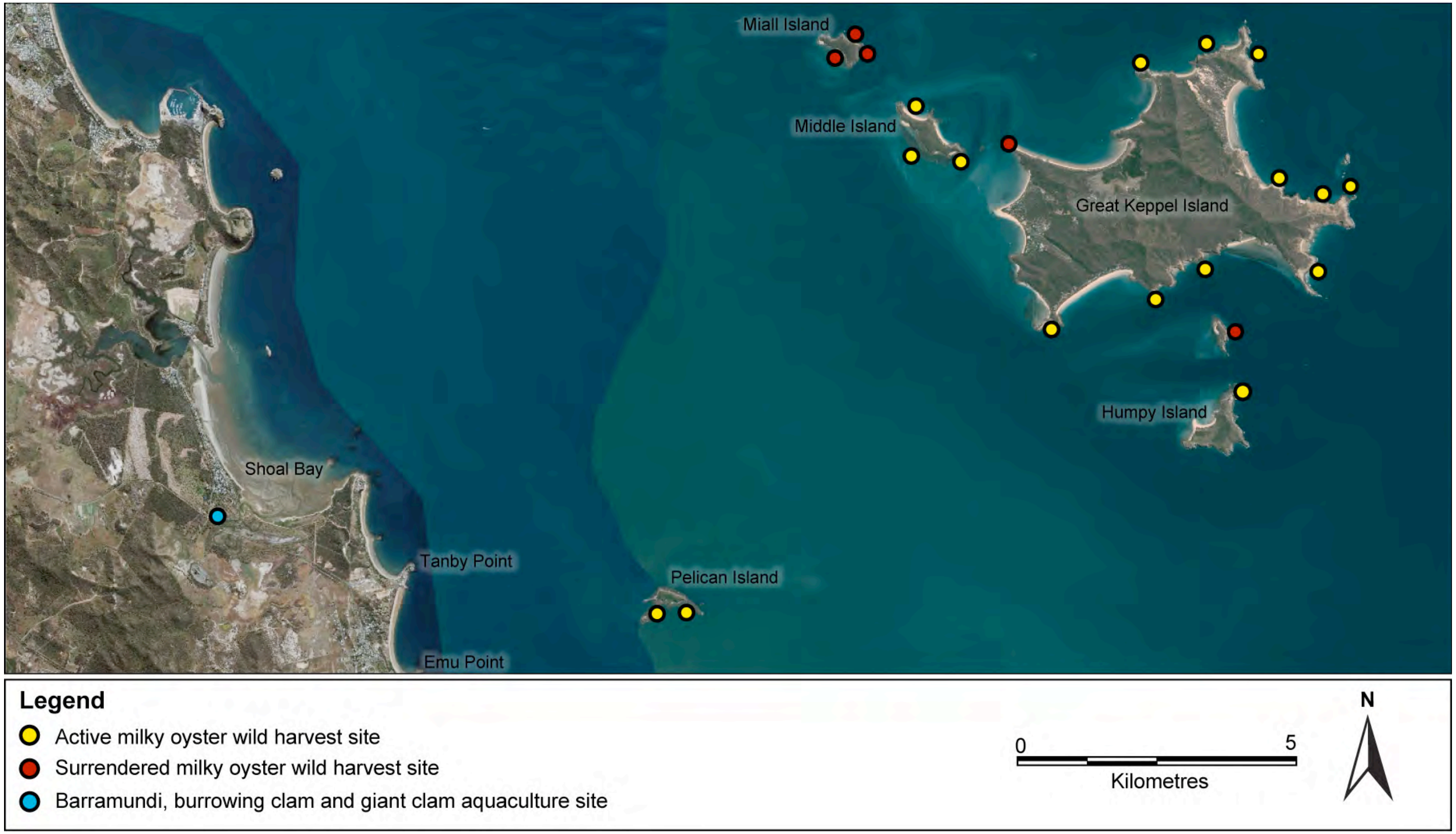

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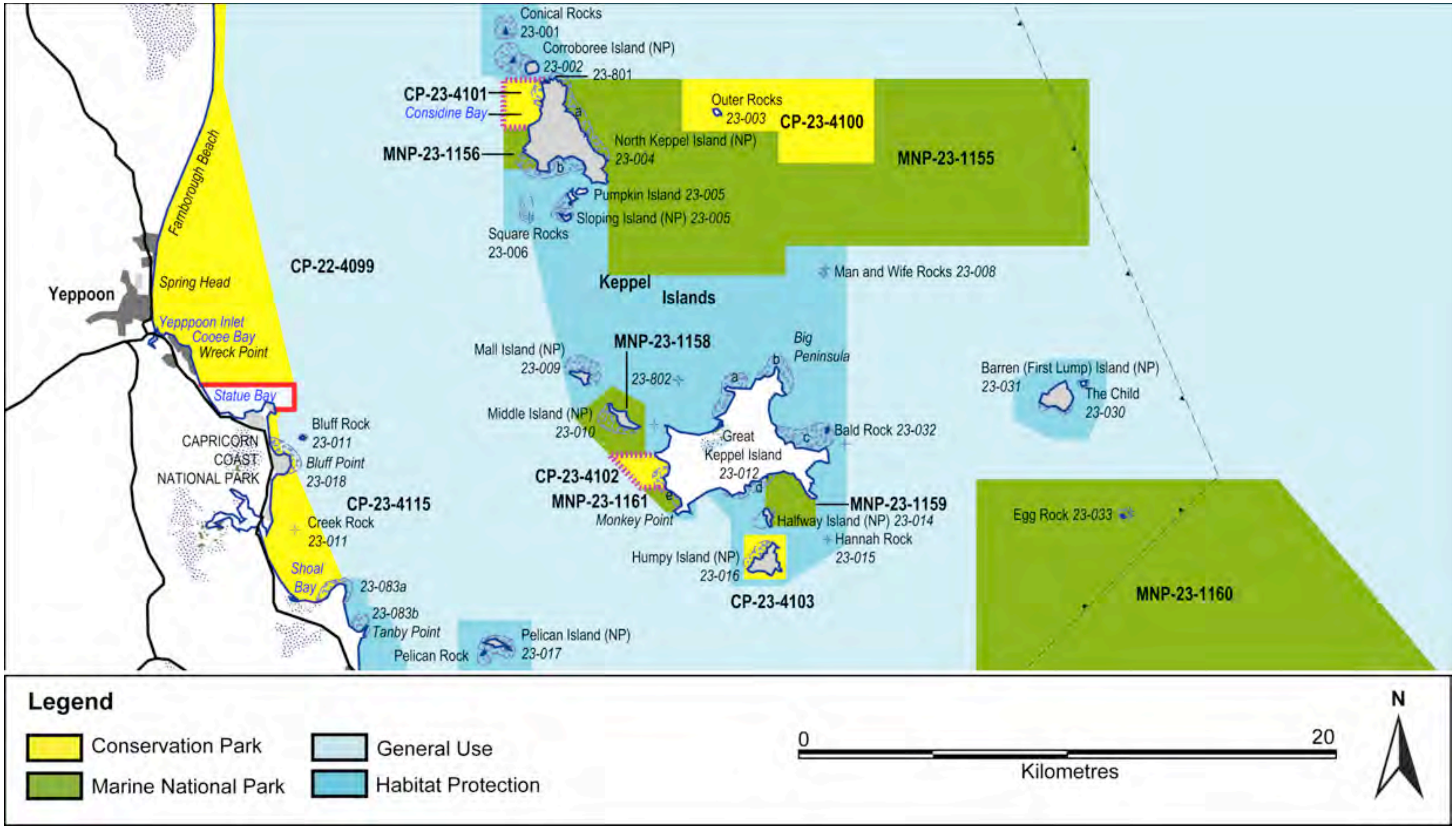
	Figure 2.4 Aquaculture and wild harvest sites in the vicinity of the project.
	Queensland Government 2011 — March 2011

Pot fishers are only allowed to collect crabs only in the GBRMP. Pot fishing (e.g. crab pots and dillies) is allowed 'as of right'[6] in 'general use', 'habitat protection', and 'conservation park' (restricted to four apparatus per person) zones.

Under the Great Barrier Reef Marine Park Zoning Plan 2003, dive-based harvest fisheries require a permit for the collection of aquarium fish, coral, tropical rock lobster, trochus and sea cucumber.

Great Keppel Island is within a 'habitat protection' zone, which prohibits commercial trawling in the waters directly around the island. A 'conservation park' and two 'marine national park' zones exist within the vicinity of the proposed development. The 'conservation zone' extends along Fishermans Beach, allowing for limited line fishing and trolling for pelagic species (though only one dory may be detached from the primary commercial fishing vessel). No netting (other than bait netting) is permitted off Fishermans Beach. 'Marine national park' zones exist around Middle Island and from Clam Bay to the eastern portion of Halfway Island. No commercial fishing is permitted in these areas.

[6] No permit is required, but users must comply with any legislative requirements in force.



Great Keppel Island Revitalisation EIS	
Figure 2.5 Great Barrier Reef Marine Park zoning in the vicinity of the project.	
GBRMPA Zoning Plan 2003 MPZ17	March 2011

2.2 Recreational Fisheries

Recreational fishing is a popular pastime for locals and to a lesser extent tourists in the region. In 2007, there were an estimated 14 340 fishing trips in the Capricorn Coast region (from Shoalwater Bay in the north to Keppel Sands in the south). Recreational fishers:

- caught between 1 and 257 fish per trip (average 18.7 fish per trip)
- had trips that lasted between 1 and 20 days (average of 1.5 days), and
- lived near the departure boat ramp (55% within 10 km; 90% within 50 km).

The annual consumer surplus (economic value) of recreational fishing on the Capricorn Coast was estimated to be over $5.5 million in 2007 (Prayaga et al. 2009).

Table 2.5 provides the 2005[7] estimated recreational catch data for the Fitzroy Statistical Division (from Shoalwater Bay in the north to Hummock Hill Island in the south). Common species caught (excluding bait species) included saltwater yabbies, bream, mud crab, tropical snapper, whiting, sweetlip, mullet, trevally, school mackerel, flathead and dart (Queensland Government 2011).

[7] Data post-2005 is not publically available.

Table 2.5 Recreational fisheries catch data for the Fitzroy Statistical Division in 2005[1].

Common name	Caught (individuals)	Harvested[2] (individuals)	Released (individuals)
bait	755 225	645 830	109 395
saltwater yabbies	363 612	286 950	76 662
bream	333 781	95 080	238 701
mud crab	293 481	79 760	213 722
tropical snappers	211 564	80 576	130 988
whiting (unspecified)	154 762	67 162	87 600
sweetlip	154 248	82 642	71 607
Mullet	141 810	114 501	27 309
trevally	105 483	49 939	55 545
school mackerel	79 899	32 710	47 189
summer whiting	77 044	42 061	34 984
flathead	72 185	23 795	48 390
dart	61 609	36 576	25 032
sweetlip (unspecified)	58 002	34 971	23 031
red throat emperor	41 778	20 409	21 369
stripey	41 156	23 728	17 428
nannygai	38 277	8 426	29 851
hussar	36 916	14 818	22 098
garfish	34 742	31 251	3 491
parrotfish	33 323	13 390	19 933
crab (unspecified)	33 180	6 626	26 554
grassy sweetlip	31 195	14 338	16 856
winter whiting	30 665	13 848	16 817
red emperor	27 126	3 169	23 958
sand crab	22 713	9 909	12 803
coral trout	21 661	15 826	5 834
sweetlip (unspecified)	19 965	9 109	10 856
moses perch	19 285	3 613	15 673

Common name	Caught (individuals)	Harvested[2] (individuals)	Released (individuals)
fingermark	14 395	5 840	8 556
rays	13 309	717	12 592
spanish mackerel	12 736	9 276	3 460
prawn	11 925	11 321	605
shark	10 662	1 509	9 153
mangrove jack	10 067	3 950	6 117
tailor	9 562	6 900	2 662
queenfish	8 796	879	7 916
spangled emperor	8 699	5 916	2 783
spotted mackerel	6 773	6 430	343
tunas	4 760	4 076	683
squire snapper	2 710	1 174	1 536
mackerel (unspecified)	2 115	1 382	733
grey mackerel	2 110	1 270	840
cobia	1 213	552	660
squid	936	936	0
pearl perch	249	124	124
kingfish	172	0	172
other	152 862	51 928	100 933

[1] Data source: Queensland Government 2011.

[2] Not released.

Around inshore islands of the GBRMP, line fisheries mainly target coral trout (*Plectropomus leopardus* and *Plectropomus maculatus*) and stripey (*Lutjanus carponotatus*) (Evans and Russ 2004). Live rock and coral may be recreationally harvested outside of State Marine Parks and the GBRMP (DEEDI 2009).

Recreational Fishing Zoning

Recreational fisheries are zoned under the Commonwealth *Great Barrier Reef Marine Park Act 1975* (Figure 2.5).

Recreational line fishing is allowed in 'general use' and 'habitat protection' zones, and limited[8] line fishing is allowed in 'conservation park' zones. Line fishing is prohibited in the 'marine national park' zone. Trolling is allowed in the 'general use', 'habitat protection' and 'conservation park' zones.

Bait netting is allowed in the 'general use', 'habitat protection' and 'conservation park' zones.

Recreational spearfishing with a spear or spear gun is allowed in the 'general use', 'habitat protection' and 'conservation park' zones. Spearfishers are prohibited from using:

- a power head spear gun
- a firearm
- a light, or
- underwater breathing apparatus (other than a snorkel).

Spearfishing is prohibited in two areas of Great Keppel Island: along the western coastline, and along the southern coastline within the 'marine national park' zone of Clam Bay (Figure 2.6). These areas extend 400 m from the shore at low tide and are protected under the Queensland Fisheries Regulation 2008.

Recreational fishing occurs regularly from Fishermans Beach and Leeke's Beach by local residents, day visitors and overnight visitors to Great Keppel Island. A 'conservation park' zone exists off Fishermans Beach, which allows for limited line fishing and restricts netting to bait netting only. No fishing is permitted within the 'marine national park' zones off Shelving Beach, Monkey Beach and eastern Clam Bay.

[8] Limit of one hand-held rod or hand line allowed per fisher, with one hook attached to each line.

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	Figure 2.6 Spearfishing closure areas around Great Keppel Island.
	DEEDI 2011 · April 2011

2.3 Habitats Important to Fish and Fisheries

Individual species of finfish, crustacean and mollusc have particular habitat requirements, which may change through their life cycle. Many economically important species (targeted by recreational and commercial fishers) depend on estuarine habitat at some stage of their life cycle (most commonly as post-larvae and juveniles). Examples of habitat associations for representative species likely to occur near the proposed development are in Figure 2.7 to Figure 2.9 (SKM & FRC Environmental 2001).

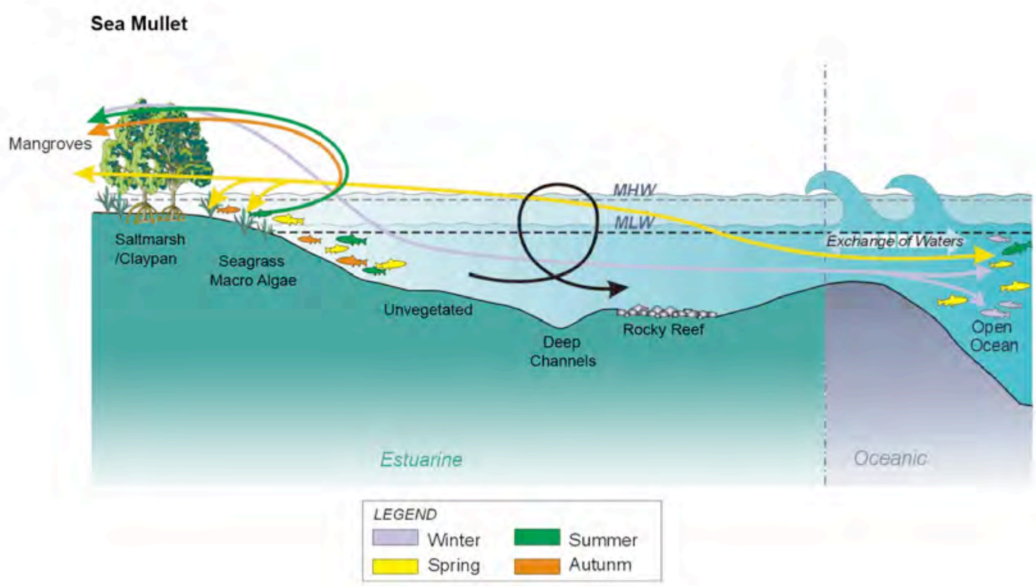

Figure 2.7 Habitat associations for the sea mullet.

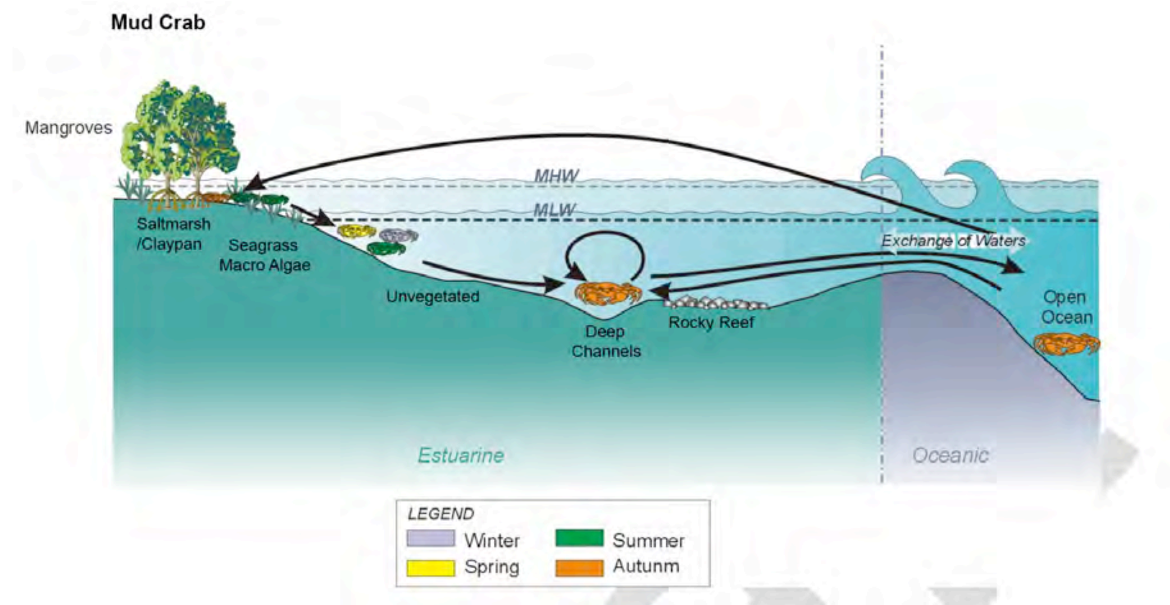

Figure 2.8 Habitat associations for mud crab.

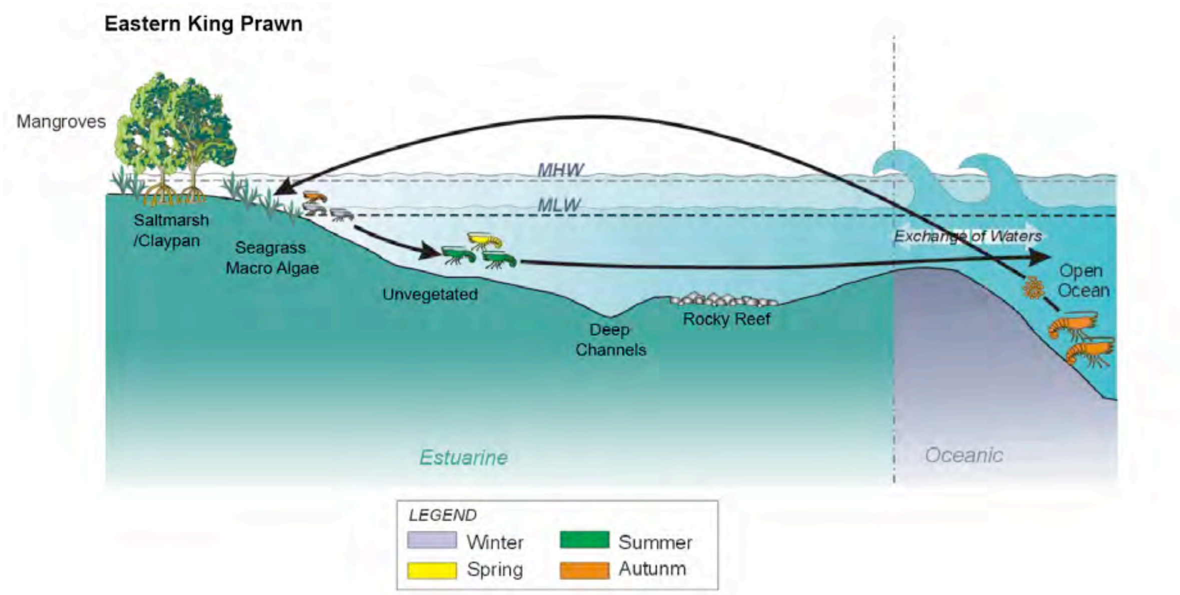

Figure 2.9 Habitat associations for eastern king prawn.

Near the proposed development there are a number of different habitats including seagrasses, mangroves, saltmarshes, unvegetated sand, mudflats, and rocky or coral reefs. These habitats provide a range of ecological values and are important for the maintenance of fisheries resource, biodiversity and ecosystem services, and often support a high abundance and diversity of fish and invertebrates (Beck 2001). In addition to sustaining adult populations, many habitats are recognised for their role as nurseries for juvenile fish, crabs and prawns, and are recognised for their contribution to the productivity of offshore fisheries (Coles & Lee-Long 1985; Connolly 1994; Halliday 1995; Laegdsgaard & Johnson 1995; West & King 1996; Blaber 1997; Butler et al. 1999; Beck 2001). For example, adult mud crabs spawn offshore, move into coastal waters as post-larvae to settle in seagrass meadows and associated sand bars, and typically move into narrow, mangrove-lined tidal waterways as juveniles and into larger channels and open estuaries as adults (Hill et al. 1982).

Mangrove and Saltmarsh Communities

Mangrove forests are important nursery grounds for many species of juvenile fishes, including commercially important species (Robertson & Blaber 1992; Halliday 1995; Laegdsgaard & Johnson 1995; Blaber 1997). Mangrove-lined creeks support a variety of fish species that have habitat-specific distributions due to species-specific requirements for food and shelter (Zeller 1998).

Mangrove forests can act as carbon sources for estuarine, inshore, and offshore waters, through the export of leaf and fruit material (Lee 1995). Decomposing mangrove material provides both soluble nutrients and detrital fragments that are eaten by crustaceans (e.g. prawns and crabs) and some fish. Decaying plant and animal matter are consumed by juvenile and adult greasy back prawns, and juvenile banana prawns, both of which are obligate residents of mud banks adjacent to mangroves (Staples et al. 1985). Adult banana prawns eat both small benthic invertebrates feeding on detritus in channels draining mangroves, and benthic algae on adjacent mud flats (Newell et al. 1995).

Mangroves trap, accumulate and release nutrients (and in some cases pollutants) and particulate matter (silt) from surrounding land, and act as a buffer to the direct effects of runoff. They protect the shoreline from water erosion (e.g. waves and boat wash) or the land erosion (e.g. run-off). Mangroves contribute to the establishment of islands and the extension of shorelines (Blamey 1992).

Saltmarsh areas provide permanent habitat for a number of animals, including crabs, mosquitoes and other insects. Crabs play a major role in saltmarsh ecosystems. Large clutches of crab larvae are produced in saltmarsh areas during the spring tides when the marsh is inundated; the highest concentrations of zooplankton in estuaries are found in spring tides in saltmarshes (Saintilan 2004). This concentrated release of plankton into the water column is an important food source for other organisms such as fish, including some commercially important species (Saintilan 2004) (Mazumder et al. 2006). As well as providing prey for wader birds and other animals, crabs perform bioturbation and nutrient cycling functions vital for the ongoing health of saltmarsh communities.

Saltmarsh communities and their role in intertidal habitats are poorly understood, especially in Australia. Saltmarsh communities may export carbon, act as fish habitats during inundation, stabilise bare mud flats and reduce erosion in the upper intertidal zone (van Erdt 1985, cited in Adam 1990). Saltmarshes are involved in re-mineralisation of terrestrial and marine debris, contribute to the nutrient cycling of estuaries, and may buffer water bodies from excess nutrients from the land (Adam 1990).

Our understanding of the direct use of saltmarshes by finfish and free-swimming crustaceans is comparatively poor (Connolly 1999). While some studies indicate that commercial and recreational fish species rarely use upper littoral saltmarsh habitat (Morton et al. 1987; Connolly et al. 1997), others found widespread use of saltmarshes by a range of common and commercially important fish species (Thomas & Connolly 2001).

Seagrass and Macroalgal Communities

Seagrasses are significant primary producers (Hillman et al. 1989), and are recognised for playing a critical role in coastal marine ecosystems (Pollard 1984; Poiner & Roberts 1986; Hyland et al. 1989). They provide shelter and refuge for resident and transient adult and juvenile finfish, crustaceans and cephalopods. Many of these species are of commercial and recreational importance, and others are the preferred foods of these species (Dredge et al. 1977; Hutchings 1982; McNeill et al. 1992; Coles et al. 1993; Edgar & Shaw 1995; Gray et al. 1996; Connolly 1997). Seagrasses have a number of other ecological functions including providing large amounts of substrate for encrusting animals and plants (Harlin 1975; Klumpp et al. 1989); and trapping detritus and dissolved organic matter, which increases local nutrient cycling (Moriarty et al. 1984).

While juvenile abundance of many fish and crustacean species is commonly higher in seagrass habitats than over bare sand or mud, there are significant differences in abundance between seagrass beds (e.g. Gray et al. 1996). Some sites have consistently higher recruitment (McNeill et al. 1992), while other sites may only periodically or temporarily have higher abundances (Gray et al. 1996; Connolly et al. 1999). This may be due to the structural complexity of the seagrass beds; location of the seagrass beds with respect to currents and the dispersal of larvae; and natural fluctuations (patchiness) in population sizes (Gray et al. 1996; Connolly et al. 1999). To date, the importance or fisheries value of seagrass has largely been measured by the absolute abundance of fauna found in it. However, seagrass habitat may also provide important linkages and refuges between different habitat types (e.g. mangroves and seagrass), and between upstream and downstream communities. So, while a seagrass bed may not support high abundances of fish or crustaceans at any one time, over a period of time many individuals may use it as they pass through to other areas.

Macroalgae are a commonly overlooked component of the marine environment. Macroalgae may significantly contribute to an area's ability to support marine life, in particular fish and crustacea. The macroalgal component of floral communities may consist of several elements: loose-lying or drift algae, rhizophytic or benthic macroalgae, and epiphytic algae on seagrass or on other algae (den Hartog 1979). Macroalgal communities can play a role similar to other macrobenthic plants, providing oxygen, food and habitat for small fauna.

Macroalgae are likely to provide shelter and refuge for resident and transient adult and juvenile animals, many of which are of commercial and recreational importance. Macroalgae stabilise and hold bottom sediments, supply and fix biogenic calcium carbonate, produce and trap detritus and provide food for many species. Macroalgae are major primary producers within coastal waters, with 10% (kelp communities) and 60% to 97% (algal turf communities) of algal production entering grazing food chains (Carpenter 1986; Klumpp and McKinnon 1989 - each cited in Phillips 1998). Even in seagrass meadows, herbivores consume 20% to 62% of algal epiphytes on seagrass leaves compared to a maximum of 10% of seagrass (Klumpp et al. 1992; Orth 1995 - both cited in Phillips 1998).

Bare Substrate

Unvegetated sandy and muddy sediment, while commonly considered to be not as productive as areas supporting seagrass, are also important to the ecosystem. Bare substrate is rarely bare. Where sediment is stable, microalgae communities become established within both the intertidal and shallow subtidal sediment. Microalgae support an associated community of small benthic invertebrates (e.g. polychaete and nematode worms, cumaceans, copepods and soldier crabs), which are an important source of food for fishes (e.g. bream and whiting) (Weng 1983).

Laegdsgaard and Johnson (1995) suggest mudflat habitats may be transitional zones between juvenile and adult habitats. Bare substrates in shallow waters may provide camouflage and shelter from larger predators. Whiting, flathead and flounder are examples of species positively associated with bare substrate habitat. Intertidal and shallow subtidal sand flats support a variety of fish species. Fish such as whiting and flathead feed in sandy areas, and bream and mullet prefer the fauna in muddy areas. Shallow surf bars are also the spawning grounds for whiting, flathead, luderick, tailor and mullet.

Bream and other important species, including juvenile sand whiting, feed over and along the edges of sand banks (Morton et al. 1987). Female sand crabs are associated with sand banks, while males are likely to be found in adjacent gutters (Smith & Sumpton 1987). Bait species important to both commercial and recreational fishers inhabit intertidal and shallow subtidal banks of sheltered bays (e.g. worms) and estuaries (e.g. yabbies) (Zeller 1998).

Fauna associated with soft sediment habitats is determined by the character of the sediment (its grain size and stability); and with the presence or absence (Poiner 1980; Humphries et al. 1992), or proximity of seagrass (Ferrell & Bell 1991). Grain size influences the ability of organisms to burrow, and influences the stability of permanent burrows.

Unstable sediment supports less diverse benthic communities than stable sediment. Bare sediments within 10 m of seagrass meadows support a similar total abundance of fishes (but a reduced diversity of species) when compared with nearby *Zostera* meadows; whereas bare substrate 100 m distant from the seagrass meadows support significantly fewer individuals and species (Ferrell & Bell 1991). In partial contrast, bare substrate and nearby *Ruppia* meadows had higher finfish diversity than bare substrate, but abundance and biomass was highest in seagrass meadows (Humphries et al. 1992).

Shallow water, bare sediment communities are characterised by widely fluctuating abundances, species richness and diversity. These fluctuations are correlated with severe abiotic disturbances (such as wind and wave activity). During calmer months, shallow bare sand developed similar communities to deep-water bare sand habitats (Poiner 1980).

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Appendix I Mosquito and Biting Midge

Contents

Tables

Figures

1 Background

This report considers how the proposed project will alter the distribution of mosquitoes and biting midges at the development site and on adjoining land. It also assesses the risk that mosquitoes and biting midges may pose to workers and visitors to the proposed project, and to residents in surrounding areas. In this report we provide guides to refine the design, construction and operation of the proposed project, so that any identified risks are reduced to acceptable levels. Specific strategies to minimise mosquito breeding on-site are presented.

This report has been prepared following discussion with vector control officers of Rockhampton Regional Council (RRC), Queensland Health, and a review of the current literature. Mosquito and biting midge survey data is not readily available for Great Keppel island and this report therefore extrapolates on data available for the adjacent mainland.

Our assessment of the likely impacts and risks has been developed after considering:

- the nature of the undeveloped site
- the proposed development of the site
- the ecology of the dominant species of mosquito and biting midges in the Rockhampton region, and
- the currently accepted 'best practice' design and construction principles aimed at reducing the incidence of mosquitoes and biting midges.

2 Existing Environment

2.1 Development Site and Adjoining Lands

The site for the proposed project is on Great Keppel Island, approximately 12 km off the coast of Yeppoon, in the Capricorn Region of Queensland. Mosquitoes and biting midges are highly likely to breed and roost (rest) on Great Keppel Island and are unlikely to travel to Great Keppel Island from other islands or the mainland, except perhaps during strong westerly winds.

2.2 Potential Breeding Habitats on Great Keppel Island

There is a large estuarine wetland associated with Leekes Creek, along the north western shore of the island (Figure 2.1). There is a small estuarine wetland associated with Putney Creek, on the western shore, which is in poor health with sparse mangrove trees and several dead trees. Both wetlands include areas of mangrove (predominantly *Rhizophora stylosa* and *Avicennia marina*), saltmarsh (predominantly *Sporobolus* sp. and *Salicornia* sp.), claypan and sedges / rushes (e.g. *Juncus* sp. and *Eleocharis* sp.). Casuarina trees also grow at the Putney Creek wetland, several of which are dead. These habitats offer potential breeding habitats for mosquito and biting midge. Refer to Appendix E for a discussion of marine flora.

There are also several watercourses (e.g. Putney, Blackall and Wreck catchments) that are likely to provide breeding habitat for mosquitoes and biting midges[1]. Refer to Appendix G for a discussion fo freshwater communities.

The proposed project will develop several water bodies that could provide breeding grounds for mosquitoes and biting midges. This includes the rainwater tanks and pools, stormwater and wastewater collection and drainage systems, and pools and wet areas associated with irrigation of gardens and the golf course. Open areas of the proposed development, with low or no vegetation (e.g. the golf course), may be effective barriers that prevent the movement of mosquitoes and biting midges (refer to Section 0).

[1] The Department of Environment and Resource Management (DERM) have mapped a palustrine wetland adjacent to Putney Creek. Discussions are currently underway between DERM and the project team regarding the correct classification of this vegetation / regional ecosystem as it is not representative of the assigned RE throughout.

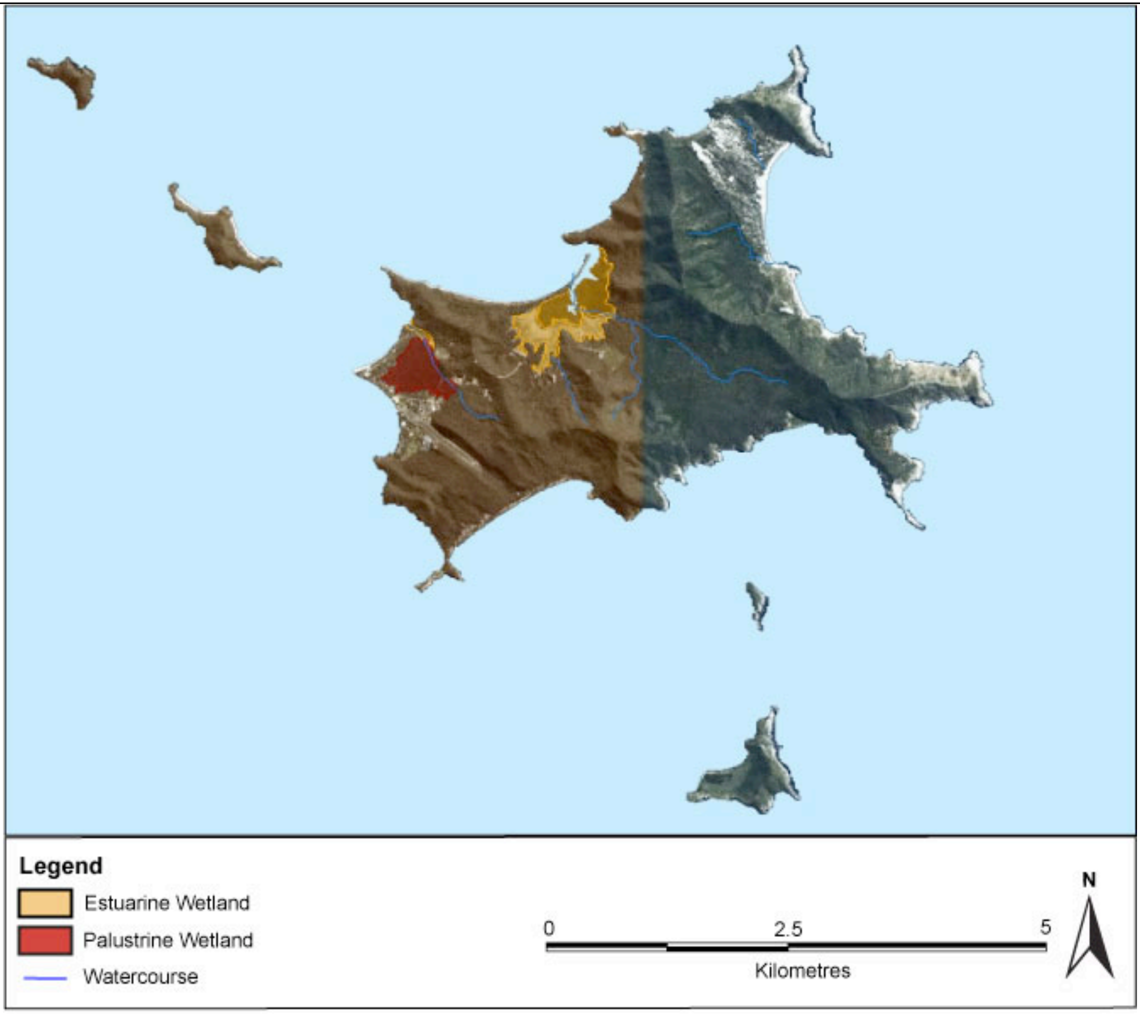

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	Figure 2.1 Coastal wetland communities of Great Keppel Island mapped by DERM.	
	Source: DERM 2010 & Google Earth 2010	March 2011

That is, the current site and the surrounding vegetation, and also the proposed project provide potential breeding and roosting habitat for mosquito and midge species. Most of the existing mosquito and midge habitat is in the north west of the island, upwind of the proposed project for much of the year when easterly and south easterly winds prevail (BOM 2010; HRPPC 2010) .

2.3 Mosquitoes and Biting Midges in the Rockhampton Region

There are a variety of species of mosquito and biting midge associated with the estuarine and freshwaters of the Rockhampton region. Estuarine species have been the primary focus of research and control efforts as they have higher incidences of 'nuisance' complaints and arbovirus infections. The RRC uses chemical, biological and engineering control for saltmarsh mosquitoes and biting midges.

Each species of mosquito and biting midge has specific breeding habitat requirements, dispersal capabilities and patterns of activity.

Mosquitoes

Characteristics of mosquito species that potentially occur on Great Keppel Island are summarised in Table 2.1. There are more than 20 common species of mosquito in the Rockhampton region, including the saltmarsh (*Ochlerotatus vigilax)* and freshwater (*Culex annulirostris)* mosquito both of which are vectors of Ross River virus (RRv) (epidemic polyarthritis) and Barmah Forest virus (BFv), and other species such as *Aedes aegypti, Aedes vigilax, Anopheles amictus, Anopheles annulipe, Culex annulirostris, Culex quinquefasciatus, Culex sitiens, Mansonia uniformis and Verrallina funerea* that are known vectors of human disease.

Female mosquitoes lay eggs in mud or on vegetation associated with pooled water; many species of mosquito share breeding habitat. The eggs hatch when water levels rise (with the incidence of tidal inundation or heavy rainfall). Mid-summer, the larval and pupal stages require a total of approximately six days to develop (longer during cooler weather). The adults rest among dense foliage, and bite (man, mammals and birds) during the day and night. *Aedes vigilax* bite predominantly at dusk and dawn, while *C. sitiens* and *C. annulirostris* bite predominantly at night. In south east Queensland, more than 10,000 biting females per night have been collected in traps set within 1 km of breeding sites (Rust & PPK. Pty Ltd 1995).

Major pest species such as *A. aegypti* (a carrier of dengue fever) commonly breed in artificial and natural containers associated with developed senvironments, including pot plants, saucers, tyres, bromeliads, tree axils and discarded palm fronds. The RRC regularly inspects properties to identify *A. aegypti,* and they run public awareness campaigns on how to control this species. Dengue fever is not common in the region (RRC 2010).

Table 2.1 Characteristics of mosquito species potentially on Great Keppel Island (Marks & Reye 1982; Queensland Health 2002b).

Mosquito Species	Habitat	Disease Carried	Travel
Aedes aegypti	Artificial containers & tree holes close to human settlement	Dengue fever and dog heartworm	–
Aedes alboannulatus	Temporary ground pools & artificial containers	None known	–
Aedes notoscriptus	Tree & rock holes; fallen palm fronds & artificial containers	Myxomatosis to rabbits, and possibly RRv	–
Aedes Tremulus	Holes in trees & stumps; car tyres; tanks & drums	Potential RRv vector	Adults enter houses at dawn & evening
Aedes vittiger	Temporary sunlit ground pools with marginal vegetation & emergent grasses	None known	May travel several kms from breeding site, depends on wind strength
Aedes vigilax	Breeds prolifically within pooled saltwater of intertidal lands	RRv, and possibly BFv, Murray Valley encephalitis and dog heartworm	–
Anopheles amictus	Fresh water; sunlit ground pools & swamp margins	Malaria & filariasis & potentially RRv	–
Anopheles annulipes	Fresh water; ground & rock pools; swamps; streams; large artificial containers; polluted & slightly brackish pools	Myxomatosis to rabbits; malaria & filariasis to humans	–
Coquillettidia linealis / *Coquillettidia xanthogaster*	Permanent & semi-permanent swamps & water holes	Potentially RRv	–
Culex australicus	Open fresh water rock & ground pools; slightly polluted or brackish drains	Myxomatosis to rabbits	Range close to human settlement
Culex annulirostris	Freshwater swamps; pools; streams; usually within vegetation but also in low lying grassy areas following heavy rain	RRv, BFv, Australian encephalitis, Japanese encephalitis & dog heartworm	Range of about 5 km
Culex molestus	Heavily polluted sites such as septic tanks & rubbish dumps	None known	–

Mosquito Species	Habitat	Disease Carried	Travel
Culex quinquefasciatus	Fresh & polluted water including drains & sewers; in artificial containers containing water	Australian encephalitis, dog heartworm & bird malaria	Range of about 1 km
Culex sitiens	Temporary brackish pools & marshes filled by spring tides: irrigation areas containing salt	RRv	Range of about 3 km; up to 35 km from breeding site in favourable conditions
Mansonia uniformis	Permanent & semi-permanent swamps and water holes with plants	RRv and Australian encephalitis (in laboratory studies)	Range of about 2 km
Ochlerotatus vigilax	Temporary brackish pools & marshes flooded by highest tides, often associated with *Sporobolus* sp. and *Salicornia* sp.	RRv, BFv & dog heartworm	Range of about 5 km; up to 50 km from breeding site in favourable conditions
Verrallina funerea	Brackish ponds under mangroves, Melaleuca and emergent vegetation.	RRv, potential BFv	Range of about 2 km; do not usually disperse far from breeding site

Biting Midges

There are at least seven species of biting midge that potentially inhabit Great Keppel Island (Table 2.2). No species of Australian biting midge are vectors of human disease, although some have been linked to the transmission of veterinary arboviruses (e.g. bluetongue and akabane). However, an abundance of adult biting midges can cause intense itching, skin reactions, blisters and weeping serum in people with sensitive skin (Queensland Health 2002b).

Midges of the genus *Culicoides,* depending on the species, typically lay their eggs in well-aerated wet areas, in the upper half of either fresh or saline intertidal zones. Breeding is commonly dependent on monthly tidal inundation; so adult emergence and the incidence of biting activity are synchronous with phases of the moon. Apart from around the breeding site itself, *Culicoides* spp. bite vertebrates (including man) around dusk and dawn. Infestations are usually the result of a number of species rather than an individual species (Marks & Reye 1982) . A range of *Culicoides* species are typically associated with intertidal muddy substrates such as the saltmarsh and mangrove forests on Great Keppel Island.

Table 2.2 Characteristics of biting midge potentially encountered on Great Keppel Island (FRC Coastal Resource & Environmental 1997; Queensland Health 2002b).

Biting Midge Species	Breeding Habitat	Distance Travelled
Culicoides immaculatus	Boulder covered foreshores where boulders lie on a mud, sand and shell substrate, moderate wave action, near high tide level	Range of about 400 m.
Culicoide ornatus	Within a narrow band surrounding Mean High Water Springs MHWS; no strong wave or current action	Range of about 16 km
Culicoide marmoratus	Algal covered mud in saltmarshes or below mangroves; breeding area must remain moist	Peak emergence is up to 10 days prior to spring tides; range of about 15 km
Culicoide molestus	Relatively clean sand along open beaches or inlets (light mangrove cover tolerated); sandy canal developments; between MHWS & Mean Tide Level	Range of about 1.5 km
Culicoide subimmaculatus	Estuarine sand to sandy mud between MHWS & Mean High Water Neaps; sheltered from wave action with sparse vegetation or open forest	Range of about 500 m
Lasiohelia townsvillensis	Decaying vegetation & moist conditions of rainforests; well-watered & mulched tropical gardens	
Styloconops australiensis	Clean sandy shores with moderate wave action.	Range of about 50 m.

Culicoides ornatus is a widespread species, which causes major pest problems along Queensland's east coast (Shivas & Whelan 2001, cited in Warchot 2004). *Culicoides molestus* may inhabit the sandy shores around the island.

Lasiohelia townsvillensis breeds prolifically in leaf litter and well-watered urban gardens of the tropics and sub-tropics. It may be also be present (or become established post-development) on the development site, following rain or excessive watering. This species is known to bite at any time of the day.

Styloconops australiensis are typically found in sandy substrates with moderate wave action, such as bays and estuaries. This species bites during the day. They may inhabit sandy shores on the island, particularly where there is limited wave action.

2.4 Incidence of Arboviruses in the Rockhampton Region

Over the past five years, there have been no reported cases of mosquito-borne diseases for Great Keppel Island. However, diseases acquired on Great Keppel Island may have been reported (and treated) elsewhere such as Rockhampton (Queensland Health 2010).

RRv is the most common human disease transmitted by mosquitoes in Queensland (Rust & PPK. Pty Ltd 1995). Symptoms of the disease include polyarthritis, muscle tenderness, lethargy and fatigue. The disease is not fatal, but has no cure. RRv may also infect fruit bats, horses, sheep and dogs, although only humans and horses show clinical signs of infection (Queensland Health 2001). The onset of symptoms occurs between three days and three weeks post-infection. The length of incapacity varies from one to 24 weeks, and symptoms may persist for up to 40 weeks (Rust & PPK. Pty Ltd 1995).

The disease usually occurs in seasonal outbreaks, due to increased mosquito breeding during periods of high rainfall or high tides (Queensland Health 2001). The number of RRv notifications[2] in RRC peaks during summer months, with two large peaks recorded in 2008 and 2009. In 2010, between five and 15 notifications per month were reported (Figure 2.3; Queensland Health 2010).

BFv may have similar symptoms to RRv , although symptoms are believed to be of shorter duration (Queensland Health 2002a). The incidence of BFv increased across the state during the 1990s (FRC Coastal Resource & Environmental 1997), however reported notifications of BFv in the RRC area are still lower than those of RRv (Figure 2.4; Queensland Health 2010).

Reported cases of RRv in RRC constitute 2.8 to 6.5% of the total number of cases reported in Queensland each year; reported cases of BFv constitute 2.9 to 5.3% of the total (Table 2.3; Queensland Health 2010). The reported cases of both RRv and BFv are likely to significantly under-estimate actual infection rates, as not all infected people show symptoms (Queensland Health 2001; 2002a).

[2] Data from Notifiable Conditions System (NOCS) database. NOCS is a laboratory based notification system, which records data of notifiable conditions in Queensland. Electronic transfer of data from other laboratories has increased the timeliness and accuracy of the data. The number of cases recorded on NOCS may not accurately reflect the incidence of the disease in a community, as medical advice may not be sought, tests may not be completed or the disease may not be reported.

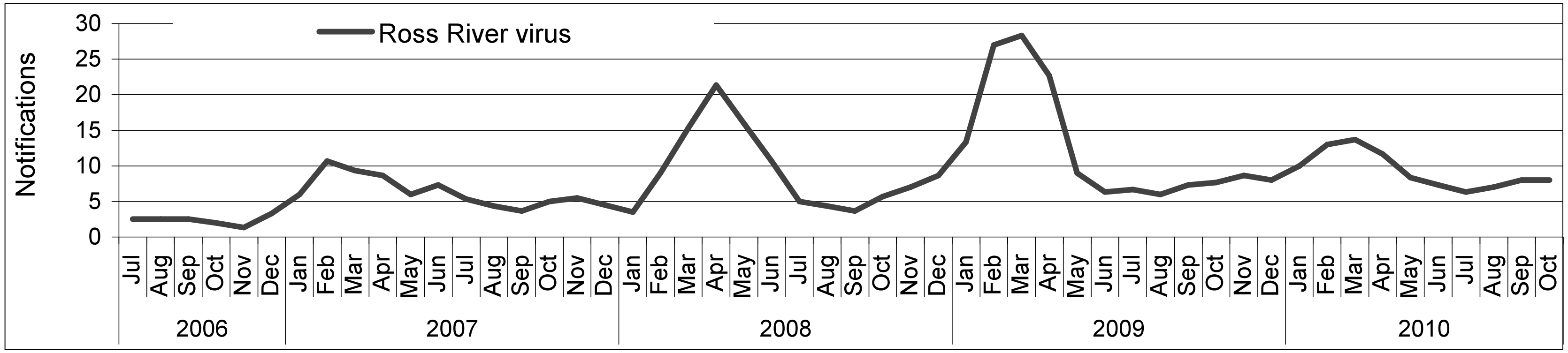


Figure 2.2 Three-month moving average of Ross River virus notifications in the Rockhampton Regional Council between July 2006 and October 2010 (Queensland Health 2010).

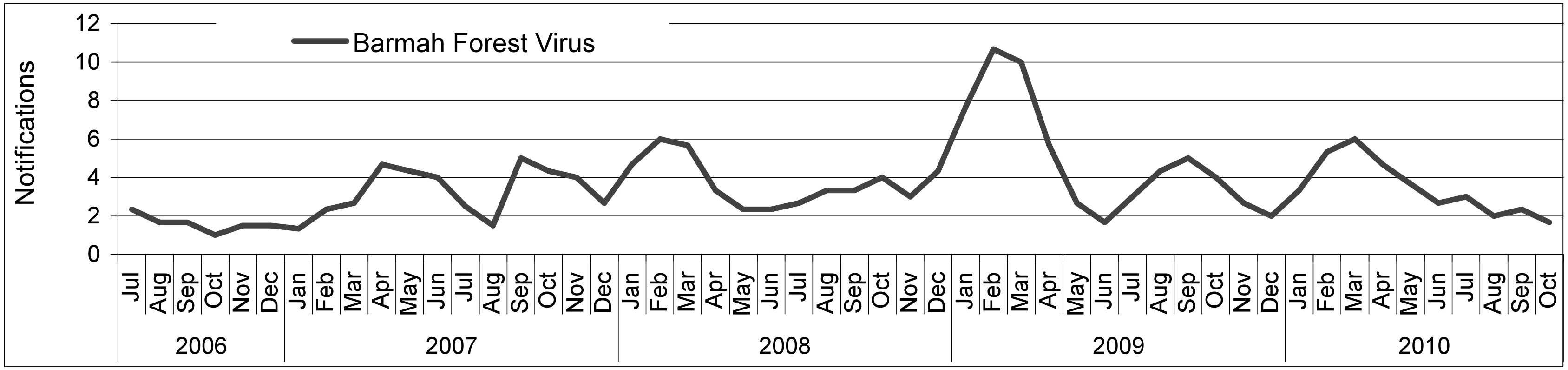


Figure 2.3 Three-month moving average of Barmah Forest virus notifications in the Rockhampton Regional Council between July 2006 and October 2010 (Queensland Health 2010).

Table 2.3 Annual notifications of Ross River virus and Barmah Forest virus in Rockhampton Regional Council and Queensland from 2005 to 2010 (Queensland Health 2010).[1]

	2005		2006		2007		2008		2009		2010*	
	RRC	QLD	RRC	QLD	RRC	QLD	RRC	QLD	RRC	QLD	RRC	QLD
Ross River virus	72	1180	74	2610	109	2136	152	2845	105	2152	146	2243
Barmah Forest virus	20	679	35	951	44	823	61	1244	37	797	37	797

RCC = Rockhamton Regional Council

QLD = Queensland

* data for 2010 includes up to 22 November 2010

3 Impacts and Mitigation

3.1 Potential Impacts of the Proposed Project on Mosquitoes and Biting Midges

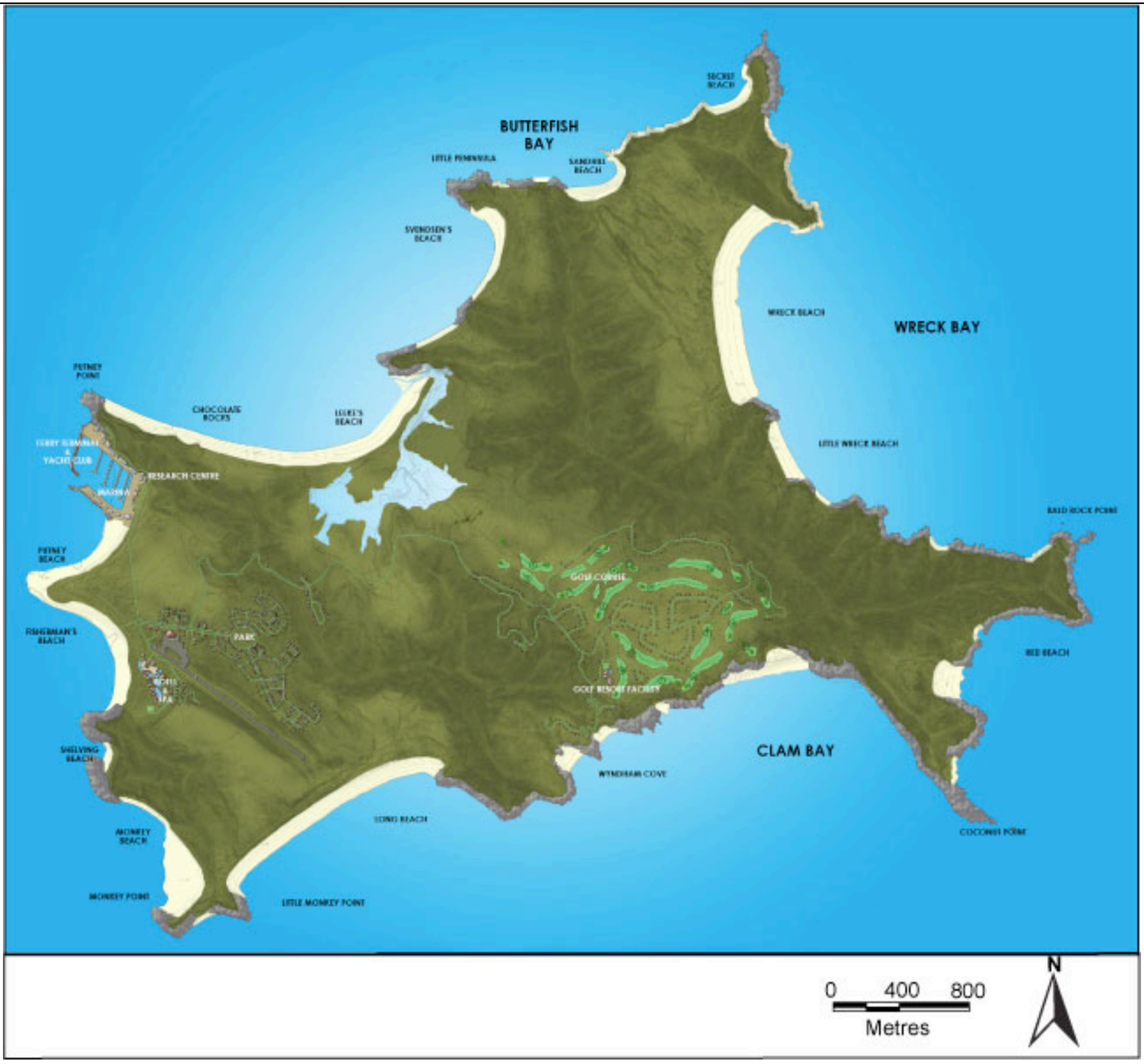
Scope of Project

The Great Keppel Island Revitalisation Plan proposes to upgrade the existing resort and airstrip and to create a low-rise, ecotourism resort on Great Keppel Island (Figure 3.1). Much of the proposed project will be surrounded by native vegetation, as the project aims to restore and preserve native vegetation with a significant area (545 hectares) preserved as an Environmental Protection Area.

The new proposed marina facility will be built at the northern end of Putney Beach. The 250-berth marina will be open to the public. A mix of cafés, restaurants, small shops, ecotourism apartments and the Great Keppel Island Research and Conservation Centre will surround the boardwalk of the marina.

The current hotel facilities at Fishermans Beach will be demolished and replaced by a new 250-suite, low-rise hotel with swimming pools, beach activities, family entertainment and day-tripper facilities. On the northern side of the extended airstrip here will be low-rise ecotourism villas and apartments and a public sports oval.

The proposed development includes a Golf Resort Facility between Leeke's Homestead and Clam Bay. The will include an 18-hole golf course, shops, café, restaurant, swimming pool, day spa, tennis courts and gymnasium facility. Low-rise ecotourism villas will surround the golf course, and will be set below the tree canopies, within the natural topography of the island. This area is designed to ensure a vegetation buffer for the Leekes Creek wetlands and to ensure no adverse runoff to Leeke's Creek, streams, underground water or drainage paths. The buffer zones and the grass species used will ensure minimal water and fertilizer requirements however, the area will still be irrigated with drip irrigation and smart irrigation controls (e.g. rain sensors), where practical. Constructed wetlands within and adjacent to the golf course will capture and filter stormwater runoff for reuse.



frc environmental AQUATIC ECOLOGISTS deep thinking. science.	Great Keppel Island Revitalisation EIS
	Figure 3.1 Great Keppel Island Revitalisation Plan Project Area.
	Source: HRPPC 2010 — November 2010

Potential Breeding Sites within the Proposed Development

Mosquitoes and biting midges are unable to breed in deep, flowing, chlorinated water; therefore, the pool and spa facilities will not provide mosquito and biting midge breeding habitat. Potential mosquito breeding habitat may be created in features and infrastructure such as rainwater tanks, stormwater drains and retention basins, landscaped gardens, the golf course and its waterways, wastewater treatment plants and other infrastructure such as roof guttering and rainwater collected in man-made containers.

The following key potential breeding sites have been identified from the Great Keppel Island Resort Revitalisation Plan – Initial Advice Statement (HRPPC 2010). Appropriate design and maintenance of water bodies associated with the development may reduce pest impacts of mosquito and biting midge as detailed in section 0.

Rainwater Tanks

The proposed project will maximise harvested rainwater by installing rainwater tanks to all ecotourism villas and apartments and throughout the resort (HRPPC 2010). Rainwater tanks can provide a breeding site for mosquitoes and have been recognised by the World Health Organisation (WHO) as a potential breeding site for vectors of dengue virus. However, with correct design and control measures, problems associated with mosquitoes breeding in rainwater can be avoided (refer to Section 0).

The dominant biting midge species of the region are not likely to breed in rainwater tanks.

Stormwater Drains, Basins and the Gold Course

Using best practice engineering principles, stormwater treatment systems will be designed to capture and / or treat stormwater from disturbed areas, for reuse. There is no intention to interfere with any watercourses or disturb flow into wetlands. Stormwater retention basins (e.g. artificial wetlands and lakes on the golf course) are likely to provide breeding habitat for freshwater mosquitoes (*Culex annulirostris)*. Mosquitoes prefer to breed in shallow vegetated water hence breeding will most likely be limited to the margins of lakes and and shallow sections of wetlands. Mosquitoes breeding in these water bodies may have a notable impact on visitors because freshwater mosquitoes have a flight range of approximately 5 km. Poorly planned development may exacerbate the problems, for example seepage, surface runoff, and silt inputs from stormwater can all enhance or create mosquito breeding habitat (Rust & PPK. Pty Ltd 1995).

The dominant biting midge species of the region are not likely to breed in these water bodies.

Open spaces such as the golf course and tall open vegetation may be effective buffers preventing movement of mosquitoes, as they prefer heavily shaded or dense vegetation.

Landscaping

Over summer, the biting midge *Lasiohelia townsvillensis,* which breed prolifically in leaf litter and well-watered urban gardens of the tropics and sub-tropics, is likely to establish populations within some landscaped gardens. The use of sub-surface watering and drip lines in the gardens and golf course (as opposed to using mists and sprinklers) is likely to reduce the presence of biting midges in these areas by reducing pooling water. Water features can also provide habitat for mosquito and biting midge.

Wastewater Management

Wastewater will be generated from the accommodation facilities, restaurants, bars, spa, pools, marina, and airport. A wastewater treatment and recycling plant is proposed for construction, to treat site-generated wastewater. Depending on the design (e.g. size, water depth and vegeation coverage) these areas may create suitable breeding areas for mosquitoes and biting midges.

Other Infrastructure

Other development infrastructure may create breeding habitat suitable for both mosquitoes and biting midges. In particular, roof guttering and rainwater collected in man-made containers may provide breeding sites for a number of species of mosquito, notably *Aedes aegypti*.

3.2 Interactions of Mosquitoes and Biting Midges with Residents and Visitors

Tropical and sub-tropical resorts often bring humans into contact with mosquitoes and biting midges. Visitors are likely to be more susceptible to bites because they generally wear fewer clothes to protect themselves from bites.

Mosquitoes

A variety of species of mosquitoes may breed in a range of habitats within the project area (refer to Section 0). Mosquitoes may also be carried to the site by prevailing winds from nearby wetland breeding grounds on ocassion, although strong easterly and south easterly winds will prevent this migration during much of the year (refer to Section 2.1 for more information).

Guidelines prepared by the Queensland Department of Heath (Queensland Health 2002a) provide a quantitative (though imprecise) assessment of likely mosquito impacts:

- two to 10 km from breeding sites. Pest impact from mosquitoes, particularly *Aedes vigilax, Verrallina funereus* and *Culex sitiens* will be noticeable, with the intensity and frequency of attacks increasing as distance from the breeding site decreases. Regular monitoring and control measures will be required.
- 10 to 15 km from breeding sites. *Aedes vigilax* is likely to be the only species encountered in moderate number, causing some discomfort. Monitoring should be undertaken, and control measures may be required.
- 15 to 20 km from breeding sites. This distance is greater than the flight range of most species of mosquito, *A. vigilax* is a notable exception. Pest problems will be sporadic and not severe.

The wetlands on the island are generally within approximately 1 km of the proposed development and consequently mosquitoes from these breeding areas may reach the proposed project. However, for much of the year, these breeding areas are upwind of the project (BOM 2010; HRPPC 2010), which will reduce the likelihood of these mosquitoes reaching the proposed project area and causing a pest impact.

Biting Midges

The site's close proximity to the coast and tidally influenced wetlands is likely to result in the presence of a number of species of biting midges on the proposed development site. Under the right conditions, *Culcoides* spp. may travel to the site from estuarine breeding areas (Queensland Health 2002a). The biting midge *Lasiohelea townsvillensis* breeds in freshwater environments, and may breed in well-watered landscaped areas within the site.

3.3 Minimising the Abundance of Mosquitoes and Biting Midges

Through appropriate site planning, engineering design and building design, the impact of mosquitoe and biting midge breeding, both on the development site and adjacent land, can be minimised.

Current Monitoring in the Rockhampton Region[3]

Rockhampton Regional Council monitors the presence of mosquitoes in urban and rural freshwater and saltmarsh areas through water sampling (for larvae) and light trapping (for adults).

Current Control Measures in the Rockhampton Region

Mosquitoes

Mosquito control treatment is undertaken when sampling indicates that larval or adult abundances are unacceptably high. The community may be informed if large numbers of mosquitoes are expected (RRC 2010).

Larvicides / adulticides used in the mosquito control program in the RCC area include:

- s-methoprene – a growth regulator that prevents larvae from developing into adults
- *Bacillus thuringiensis israelensis* (BTI) – a biological control agent that kills mosquito larvae between the first and third larval instar (moult), and
- synthetic pyrethoid (misting) – a chemical compound similar to natural chemicals produced by flowers that is widely used to kill adult insects (non-discriminatory).

Rural saltmarsh areas are treated with the aerial application of BTI or the ground-based application of either s-methoprene or BTI. Treatments are usually undertaken after tidal inundation or after sufficient rainfall. Urban saltmarsh and freshwater areas are treated manually with s-methoprene. Owners of land adjacent to urban saltmarsh and freshwater areas may request misting; treatment is usually undertaken manually, from the back of a vehicle, at dusk or dawn (RRC 2010).

[3] Further information regarding midge monitoring in the region has been requested from Rockhampton Regional Council.

Biting Midges

Biting midges are not affected by mosquito larvicides. Due to the toxicity of midge adulticides (e.g. Bifenthrin) to marine organisms, biting midges are not treated by chemical means. For chemical control to be effective, biting midge habitat must be identified and then Bistar (a midge adulticide containing Bifenthrin) can be applied to barriers such as foliage or fences, to isolate midges from people.

Other Potential Control Measures

Natural Control Using Native Fish

Native larvivorous fish stocked in freshwater bodies can contribute to mosquito control. The Queensland Department of Primary Industries and Fisheries (DPI&F) list a number of species that are native to the central Queensland coast[4] and likely to assist with mosquito control (Table 3.1). Of the species recommended by DPI&F (DPI&F 2006)[5], the empire gudgeon (*Hypseleotris compressa*), fly-specked hardyhead (*Craterocephalus stercusmuscarum*) and Pacific blue eye (*Pseudomugil signifer*) are likely to be the most effective at controlling mosquito populations in freshwater lakes (Hurst et al. 2004).

Native fish can be obtained from registered fish hatcheries (DEEDI 2010). Native fish from commercial suppliers typically cost between $200 and $400 per 100 fish (frc environmental 2002). Previous studies suggest that fish densities of around 1 / m^2 of potential breeding habitat should be sufficient to control mosquito populations (frc environmental 2002).

For stocked fishes to effectively control mosquito breeding, the fish must develop sufficiently abundant populations, and must be able to access mosquito breeding habitats. This requires permanent and relatively stable water quality, and sufficiently deep water.

[4] there is no information readily available regarding the native freshwater fish communities of Great Keppel Island and the listed species may not be native to the island (indigenous); there may be adverse ecological impacts of introducing non-indigenous fish species to a waterway

[5] not all of the species in were tested by Hurst et al. (2004)

Table 3.1 Native freshwater fish species recommended for mosquito control along the central Queensland coast (DPI&F 2006).

Family *Species*	Common Name	Key Characteristics
Chandidae		
Ambassi agassizi	olive perchlet	reaches 60 mm in length; inhabits flowing and still water bodies; primarily eats microcrustaceans and insects (larvae and adult)
Denariusa bandata	pennyfish	reaches 45 mm in length, but typically less than 35 mm, inhabits floodplain lagoons and muddy lowland lagoons; primarily eats chironomid (non-biting midge) larvae and other aquatic insects, with cladocera and other microcrustaceans also important prey
Melanotaeniidae		
Melanotaenia maccullochi	McCulloch's rainbowfish	reaches 60 mm in length, but typically less than 50 mm, inhabits low velocity areas less than 80 cm deep; primarily eats algae, with aquatic insects also important prey
Melanotaenia splendida splendida	eastern rainbowfish	reaches 200 mm in length, but typically 60-80 mm, inhabits streams, wetlands and floodplain lagoons; primarily eats algae, with chironomid larvae, ephemeropteran nymphs, trichopteran larvae and other aquatic insects also important prey
Eleotridae		
Hypseleotris compressa	empire gudgeon	reaches 100 mm in length; inhabits lower reaches of rivers; primarily eats cladocerans and insect larvae, algae and detritus
Mogurnda adspersa	purple-spotted gudgeon	reaches 100 mm in length, inhabits clear and turbid environments; primarily eats aquatic insects and crustaceans
Atherinidae		
Craterocephalus stercusmuscarum	fly-specked hardyhead	reaches 100 mm in length; inhabits still or slow flowing water; primarily eats mosquito larvae, aquatic insects and crustaceans
Pseudomugilidae		
Pseudomugil gertrudae	spotted blue-eye	reaches 60 mm in length, but typically less than 25 mm, most common in lowland, low elevation habitats typically in floodplains; primarily eats algae, with aquatic insects and microcrustaceans also important prey
Pseudomugil signifer	Pacific blue eye	reaches 62 – 88 mm in length; inhabits fresh and brackish coastal waters; primarily eats mosquito larvae and other insects

Project Design

Careful attention to elements of conceptual and detailed design can significantly reduce the potential for mosquitoes and biting midges to breed on site.

Rainwater Tanks

To minimise mosquito problems associated with rainwater tanks, WHO recommends that all tanks have screens or other devices to prevent adult mosquitoes from emerging (WHO 1997). All inlets, overflows and other openings should be covered with closely fitted, removable, mosquito-proof mesh to prevent access by adult mosquitoes, and if larvae are present, to prevent the escape of adult mosquitoes. Queensland Regulations (1996) specify that screens should be brass, copper, aluminium or stainless steel gauze with apertures not coarser than 1 mm. Rainwater should not be allowed to pond in containers or on surfaces below tank outlets or taps, as this can also provide a breeding site.

Rainwater tanks should be inspected for larvae at least once every six months. Detection of larvae indicates the female mosquito has accessed the tank to lay eggs, or eggs have been laid in ponded water and then entered the tank. The point of entry should be located and sealed. As a last resort, tanks can be treated with a small amount of kerosene or medicinal paraffin however these treatments are not ideal. Paraffin can lead to coagulation and deposits forming on the sides of some tanks. Kerosene is not suitable for tanks coated with aquaplate steel or lined with plastic and can be a human health risk if used in excess quantities. Kerosene added to the surface water of the tank will not mix with the water therefore it will evaporate or be washed out by overflow. Kerosene should not be added to a tank when water levels are low, and if kerosene can be tasted in the water, the tank should be drained and cleaned. The recommended dose of kerosene is 5 mL for a 1 kL tank and up to 15 mL for a 10 kL tank. When using paraffin the dose is doubled (Enhealth Council 2004).

Stormwater, Wastewater and Water Features

Mosquito breeding within constructed wetlands / lakes, stormwater drains and basins, and water features can be minimised by reducing the 'soft' edges and ensuring that the edges are steep and free of dense emergent vegetation (which supports mosquito breeding) (Queensland Health 2002b). Increased bed depth (>3 m) and 1:3 batters effectively restrict the distribution of most emergent reeds and rushes around margins, thereby minimising mosquito breeding habitat. Using concrete and rock revetments and preventing water from stagnating by ensuring adequate circulation and the use of fountains can also reduce the suitability of breeding grounds. Native larvivorous fish can be stocked in freshwater bodies (e.g. constructed wetlands and lakes) to contribute to mosquito control (refer to Section 0). Regular clearing of vegetation and debris from any 'soft' egdes should be undertaken to reduce mosquito and midge breeding habitat and allow predatory fish access to the larvae should allow the effective control of emerging mosquitoes.

Fluctuation of Water Levels

Fluctuating water levels may directly and / or indirectly influence mosquito and midge breeding. Depending on timing and frequency, fluctuating water levels may either create or destroy favourable breeding habitat. For example, falling water levels may expose suitable moist substrate and leave shallow waters free from predators. Rising water levels may inundate drying substrate which triggers hatching and provides habitat suitable for larval development. Fluctuating water levels commonly encourage the expansion of fringing aquatic vegetation, indirectly providing increased habitat suitable for mosquito breeding. Concrete and rock revetments would largely mitigate the effects of fluctuating water levels.

Lake water levels should also be monitored if mosquito and midge are abundant. Time-series data analysis may reveal a correlation between fluctuations in water level and pest abundance that can be used to predict the need for treatment.

Landscaping

Landscaping and drainage that minimises ponding can reduce suitable breeding habitat. This is particularly applicable to open grassed areas, such as gardens and the golf course. During construction, incidental depressions and holes that may hold standing water should be filled as a matter of standard practice. All site drainage should be designed and installed so that sediment cannot accumulate and water cannot pond (Queensland Health 2002b). Where possible, drains should discharge into a flowing waterway with healthy ecological processes that may assist to control mosquito numbers (Queensland Health 2002b). Discharge of stormwater to a constructed wetland / lake is considered appropriate, though open reaches of shallow depth should be minimised.

Landscaping of public open space, gardens and the golf course, that involves irrigation, may encourage the breeding of the biting midge *Lasiohelea townsvillensis.* Current landscaping design, such as drip irrigation, smart irrigation and the selection of vegetation to ensure minimal water and fertiliser use, will reduce mosquito and midge pest problems on the site.

Dense plantings of trees in close proximity to accommodation may encourage the retention of mosquitoes and midge on site. The use of native groundcovers, low shrubs and small trees may trap mosquitoes and biting midges, and act as a conduit onto the site. However, prevailing easterly / south easterly breezes will provide effective flushing of open areas.

Building Design

To reduce opportunities for biting insects to enter the preferred leeward side of the buildings, more open window area on the windward side can be used to passively 'pressurise' the building. Buildings should be fully screened to prevent insect entry. Ceiling fans and similar circulation devices can be incorporated to increase airflow, which will inhibit entry of mosquitoes and biting midges. Roof guttering should be cleared regularly to prevent the build-up of debris and trapping of water, which would provide mosquito and midge breeding habitat.

Buffer Zones

Dense vegetation corridors between mosquito / biting midge breeding sites and development provides a dispersal conduit for the insects (Queensland Health 2002b). Dense vegetation adjoining known breeding sites and public open space can provide roosting habitat for mosquitoes and biting midges. The incidence of mosquitoes and biting midges within developed areas can be minimised by providing sparsely vegetated buffer zones (such as the golf course, sporting oval, and other public open space and recreational areas) between known breeding sites and public areas. Choosing trees and shrubs with light foliage will reduce the conduit effect of vegetation corridors (Queensland Health 2002b). The duration of nuisance infestations will be lessened by conditions that cause the pest population to disperse widely; breezeways across known breeding sites and around public areas should be incorporated into the site layout where practical. The existing design will provide some buffer zones such as the golf course and sporting oval.

Barrier treatments (such as solid fences) can be effective at preventing mosquitoes and midges moving between breeding areas and neighbouring areas. Timber fences over 1.8 m high have contributed to reducing the immigration of biting insects by as much as 90%. However, the effectiveness of barriers appears to be site-specific, and subject to a variety of environmental factors, which as yet, are not well understood. Regular treatment of fences with Bistar midge adulticide will further improve the effectiveness of such fences (Fanning 2005). This design element is unlikely to suit the more open areas of the project, however it may be of some benefit to higher-density areas such as the hotel precinct.

Site Planning and Engineering Design

There are a number of engineering principles that can be applied to the design and construction of the site that may reduce the potential breeding habitat for mosquitoes and biting midges.

- During construction, incidental depressions and holes that may hold standing water should be filled as a matter of 'standard practice'. Grade irrigated areas to prevent the pooling of water.
- Irrigation, sewage and stormwater channels and drains should be designed to minimise standing water. Channels should be kept clear of vegetation and silt.
- Drains should be constructed to follow natural drainage patterns.
- Where possible, discharge of stormwater should be to flowing waterways with healthy ecological processes that may assist to control mosquito numbers (Queensland Health 2002b); in this case discharge to the proposed retention basin is considered acceptable.
- Roadway embankments should be designed to prevent standing water, and prevent the redirection of waters into potential mosquito breeding habitat.
- Landfill for elevated development should not impede the natural drainage of surrounding lands.

The provision of elevated access and management easements, of approximately 20 m width, around identified breeding sites (e.g. wetlands or retention basins) will contribute to the ease and effectiveness of breeding control. Locate lower activity areas (e.g. natural parkland) and other daytime recreation areas closest to breeding sites, so they provide a buffer for residential and night-time activity areas. Well-lit, sealed areas can also be used as buffers for activity areas, especially adjacent to biting midge breeding sites.

Breaks in vegetation corridors may be provided between breeding sites and high activity areas. Minimising vegetation density near public and evening activity areas will also reduce roosting of mosquitoes and midges near populated areas. Avoiding the use of heavy foliage plants and those that require frequent watering will discourage mosquito and midge roosting and midge breeding. Trees with high canopies may provide good air circulation at ground level.

4 Conclusion

The proposed project area is adjacent to (generally within 1 km of) mosquito and biting midge breeding habitat. The proposed project has the potential to create new breeding habitat in the form of rainwater tanks, stormwater drains and retention basins, landscaped gardens, the golf course and its constructed water bodies (wetlands / lakes), wastewater treatment plants and other infrastructure such as roof guttering and rainwater collected in man-made containers.

The incidence of mosquito breeding in constructed waterways and stormwater retention basins can be minimised by:

- reducing the extent of shallow water and aquatic vegetation in water bodies
- providing conditions conducive to the development of an abundant community of larvivorous fishes, and
- ensuring those fishes have access to mosquito breeding habitat.

The limited extent of water level fluctuation will assist in minimising the extent of emergent macrophytes. Sympathetic landscaping that reduces ponding of water and does not use heavy mulching can also effectively eliminate breeding opportunities for biting midges. Rainwater tanks should be fitted with mosquito-proof screens and buildings should have more open window area on the windward side of buildings, be fully screened, and have a ceiling fan or other air circulation device.

The breeding activities of freshwater species may require monitoring and controlling, to effectively minimise the abundance of biting adults over the project area. Rainwater tanks should be monitored at least every six months. Monitoring and control measures should be triggered by complaints by visitors or staff.

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Appendix J Sediment Sampling and Analysis Plan

Contents

Tables

Figures

1 Background

1.1 Objectives

The objective of this Sampling and Analysis Plan (SAP) is to enable the collection of sufficient data to characterise the sediment to be dredged and otherwise disturbed at Putney Beach, Great Keppel Island within Keppel Bay. This SAP has been developed for submission to the Department of Sustainability, Environment, Water, Populations and Communities (SEWPAC), the Great Barrier Reef Marine Park Authority (GBRMPA) and the Department of Environment and Resource Management (DERM) to meet their requirements for the appropriate screening of dredged sediment. The SAP has been designed in accordance with the *National Assessment Guidelines for Dredging* (NAGD) (DEWHA 2009), the *Guidelines for Sampling and Analysis Procedure for Lowland Acid Sulfate Soils (ASS) in Queensland 1998* (the ASS guidelines) (Ahern et al. 1998) and the *State Planning Policy 2/02 Guideline: Acid Sulfate Soils*.

1.2 Description of Proposed Dredging

The proposed dredging at Putney Beach is to allow for the construction of a 250-berth marina. The following work is proposed as part of the project:

- dredging of the marina entrance channel to a depth of -5.9 m Australian Height Datum (AHD) (-3.5 m chart datum), and
- dredging of the marina basin to a depth of -4.9 m AHD (-2.5 m chart datum).

It is estimated that this dredging will generate a maximum total dredge volume of 300 000 m^3.

1.3 Sediment Characteristics of Dredge Spoil

Physical Characteristics

Keppel Bay is a mixed wave- and tide-dominated system; sediment transport is highly dynamic and variable. Sediment around the western side of Great Keppel Island is dominated by moderately well sorted sand; 89.03% – 99.87% sand, 0.01% – 7.87% mud and 0.00% – 3.37% gravel, with a sorting coefficient of 5.5 – 7.0. The sediment is composed of 4.99% – 9.22% calcium carbonate material, and 12.10% – 15.05% feldspar sands (Ryan et al. 2007).

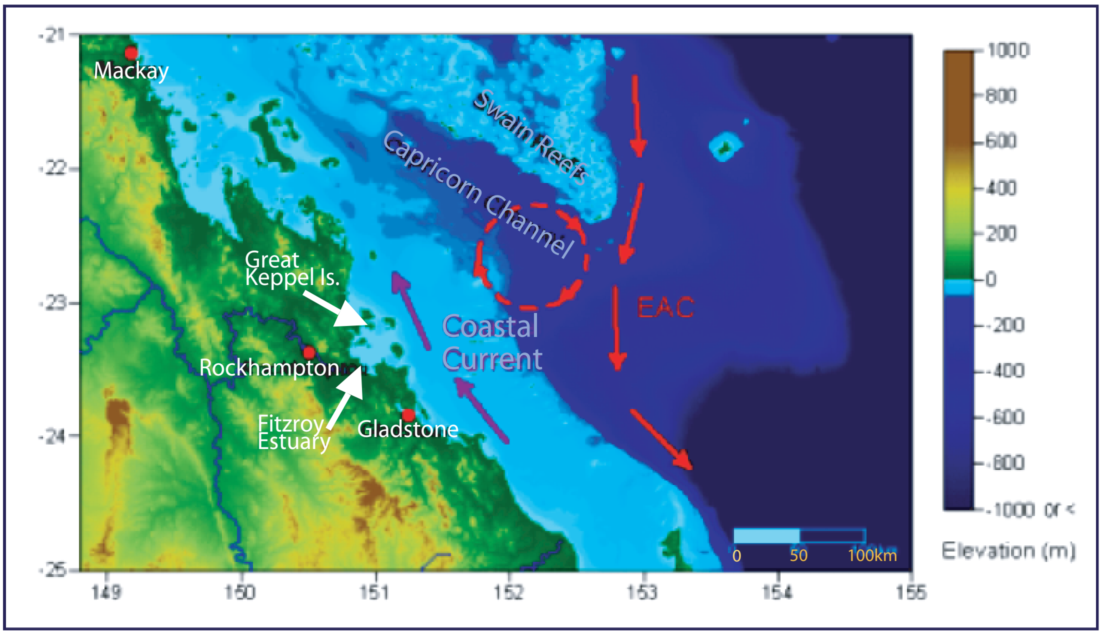
Based on previous sampling by Ryan et al. (2007) in the Great Keppel Island region, and sediment profiling at Putney Beach undertaken by Water Technology in 2011, the sediment to be dredged at Putney Beach is expected to be primarily sand.

Nutrients and Contaminants

Contaminants of concern may accumulate from a variety of sources including the discharge from mainland rivers, local catchments and marine activity.

Discharge from the Fitzroy River to the south affects the water quality of Keppel Bay and coastal areas to the north (Schaffelke et al. 2005; Webster et al. 2006). Therefore, inputs of contaminants from land-uses upstream in the Fitzroy catchment, dominated by agriculture, may impact Great Keppel Island sediment quality. Contaminants known to occur in the Fitzroy River system and Keppel Bay include herbicides, pesticides, polynuclear aromatic hydrocarbons (PAHs) and nickel (Webster et al. 2006; frc environmental 2008). The Fitzroy River is also a major source of nutrients and fine suspended sediments to nearby coastal waters (Schaffelke et al. 2005). However, due to the northerly direction of the coastal current in Keppel Bay region (Figure 1.1), sediment plumes from the Fitzroy River rarely reach Great Keppel Island (Figure 1.2). As such, contaminant levels within the Putney Beach area are expected to be low.

Surface sediment samples (i.e. < 20 cm depth) within the marina footprint at Putney Beach were collected by frc environmental in November 2010 and March 2011. Nutrients and metals and metalloids were detected in the sediments (although concentrations of metals and metalloids were below the NAGD screening levels). The concentrations of organochlorine pesticides and polynuclear aromatic hydrocarbons (PAHs) were below the laboratory limits of reporting (LOR) for all samples. As such, it is not expected that agricultural or industrial contaminants from the Fitzroy River are present



frc environmental AQUATIC ECOLOGISTS deep thinking.science.	Great Keppel Island Revitalisation EIS	
	Figure 1.1 Currents in the Capricornia region of the Great Barrier Reef.	
	Source: Webster et al. 2006	April 2011

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	Figure 1.2 Turbid plume resulting from the 1989 flood event.	
	Source: modified from Webster et al. 2006	April 2011

Acid Sulfate Soils

The sediment to be dredged at Putney Beach is expected to be primarily sand. Based on work completed by Douglas Partners, acid sulfate soils have not been detected on Great Keppel Island. It is therefore considered unlikely that acid sulfate soils will be present in the proposed marina footprint.

Disposal of Dredge Spoil

It is intended that dredge spoil will be used to fill geotextile bags, which will be used in the construction of the marina. It is anticipated that material dredged during maintenance dredging will be used as beach nourishment. No ocean disposal is anticipated during capital or maintenance dredging.

2 Proposed Sampling and Analysis Plan

Marine sediments will be assessed in accordance with the *National Assessment Guidelines for Dredging 2009* (NAGD) (DEWHA 2009) and the *Sampling and Analysis Procedure for Lowland Acid Sulfate Soils in Queensland* (ASS guidelines) (Ahern et al. 1998), except where varied below.

2.1 Timing

Samples will be collected and analysed as an element of the project's Environmental Impact Statement (EIS).

2.2 Number of Cores

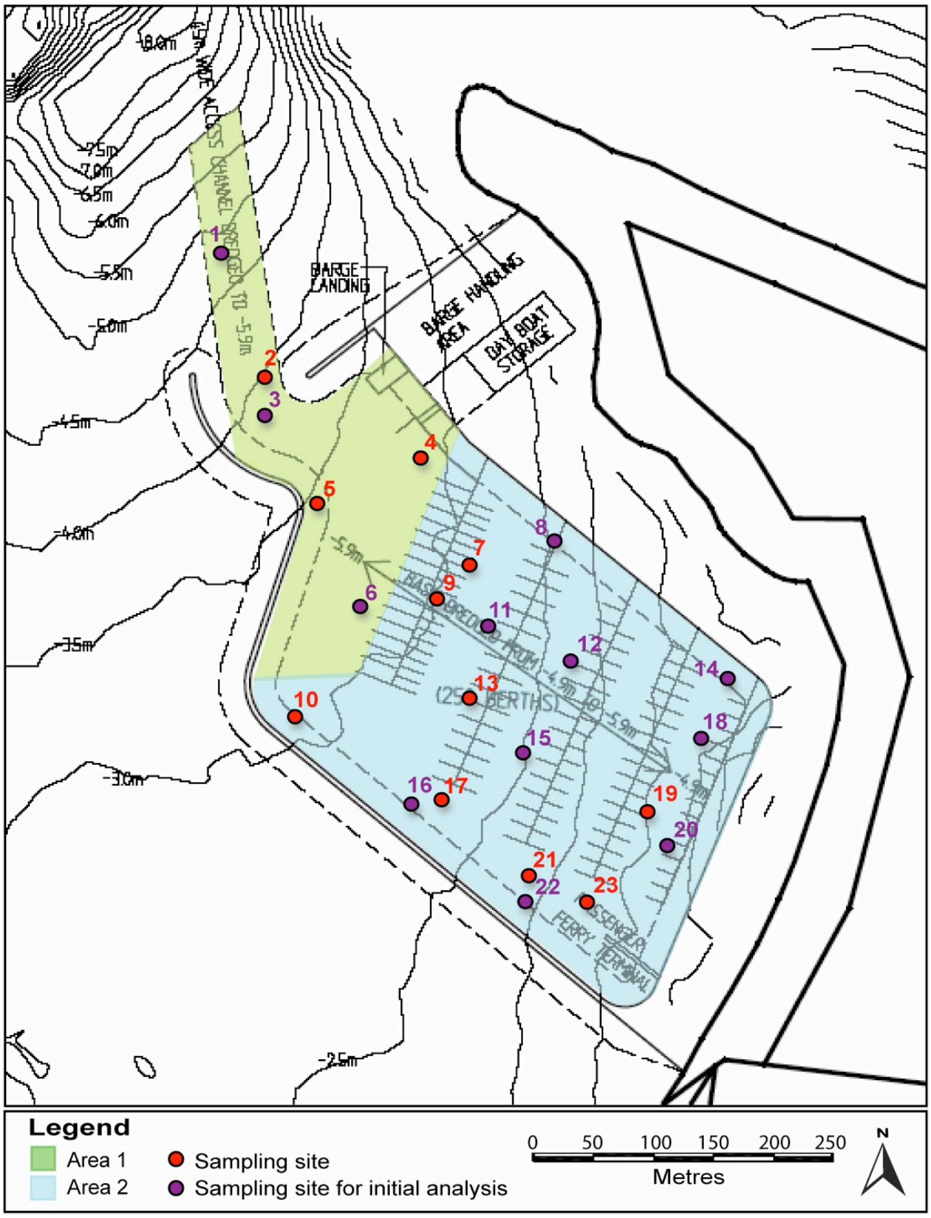
The proposed dredging is classified as a medium project (50 000 – 500 000 m^3 of dredge spoil) under Appendix A of the NAGD. The NAGD recommends that 23 sites be sampled where 264 000 – 305 000 m^3 of dredge spoil is to be removed. Sampling sites will be distributed across the:

- channel access area – Area 1, and
- basin area – Area 2 (Figure 2.1).

The selection of sample sites was done randomly over a grid, in accordance with the methods outlined in Appendix D of the NAGD. However, as outlined in the NAGD, when sampling sediments that are considered to be 'probably clean', the number of sites can be halved. Preliminary (surface) sediment sampling and analysis from the marina and channel footprint indicates that the sediments are 'probably clean'. As such, it is proposed to analyse only 50% of the 23 cores in the first instance (i.e. 12 cores). Where this sampling indicates that sediments are clean, no further analyses will be completed. Where the results indicate that sediments are potentially contaminated (exceeding trigger levels), the remaining cores will be analysed.

The 12 cores to be initially analysed represent the spatial extent of the dredge area and the range of sediment depths to be dredged (Table 2.1).

Cores will be taken as close as practical to the sites in Figure 2.1. The positions of each sampling site will be recorded using a GPS, and the coordinates and a map of the actual sampling sites will be included in the final report.



Great Keppel Island Revitalisation EIS	
Figure 2.1	Proposed sediment sampling sites, Putney Beach.
Source: International Marina Consultants	May 2011

Table 2.1 Required core length at each location.

Location	Approximate Depth of Seabed at Site (m below AHD)	Dredge Depth (m below AHD)	Required Core Length (m)
Area 1			
1*	–4.8	–5.9	1.6
2	–4.0	–5.9	2.4
3*	–3.9	–5.9	2.5
4	–3.3	–5.9	3.1
5	–3.4	–5.9	3.0
6*	–3.2	–5.9	3.2
Area 2			
7	–2.9	–4.9	2.5
8*	–2.5	–4.9	2.9
9	–3.0	–4.9	2.4
10	–3.2	–4.9	2.2
11*	–2.7	–4.9	2.7
12*	–2.3	–4.9	3.1
13	–2.7	–4.9	2.7
14*	–1.2	–4.9	4.2
15*	–2.5	–4.9	2.9
16*	–2.7	–4.9	2.7
17	–2.7	–4.9	2.7
18*	–1.1	–4.9	4.3
19	–1.5	–4.9	3.9
20*	–1.2	–4.9	4.2
21	–2.2	–4.9	3.2
22*	–2.1	–4.9	3.3
23	–1.7	–4.9	3.7

* Samples from these sites to be analysed in the first instance

Site Observations

At each site we will record the:

- position of the sampling site using a GPS (Garmin GPSMap 60CSx, accurate to 3 m)
- time and date of sampling
- name of the sample collector
- weather conditions at the time of sampling
- sea state at the time of sampling
- general comments (e.g. wind speed and level of shipping traffic)
- presence of biota or litter in the cores
- water depth at core location
- height of the top and bottom of each core, relative to lowest astronomical tide LAT
- length of the core, and
- type of corer used.

2.3 Sampling Method

Coring Equipment

Cores will be collected using an appropriate barge-mounted vibracorer (likely to be operated by Abyss Commercial Diving ex. Brisbane). This is a recommended sampling method for coarse or firm sediment, as outlined in Appendix D of the NAGD.

Core Length

Where possible, all cores will be taken to at least 0.5 m below the proposed dredge depth. The required length of each core has been calculated based on the proposed dredge depth and the current surveyed seabed depth at each site (Table 2.1). Prevailing conditions on the day (e.g. waves and surges) may affect our calculation of depths and required core lengths.

If the proposed dredge depth cannot be achieved when collecting a core, a new core will be taken nearby and the old core discarded.

Number of Subsamples

As outlined in Appendix D of the NAGD, contaminated sediment typically occurs in the top 0.5 to 1 m of sediment. Therefore, the upper 1.0 m of each sediment core will be subsampled (0 to 0.5 m Subsample A, 0.5 m to 1.0 m Subsample B). As there is no reason to suspect contamination in the remainder of the core, the remainder will be taken as a single subsample (Subsample C). Each section of the core will be mixed and a single composite subsample taken from each section. If the sediment shows distinct and thick strata, these strata will be sub-sampled separately.

In accordance with the ASS guidelines, subsamples will be collected every 0.5 m for analysis of acid sulfate soils.

2.4 Acid Sulfate Soil Field Sampling

Acid sulfate soil field sampling will be completed in accordance with the ASS guidelines. Briefly, every 0.25 m or before and after any discontinuities, we will record the:

- distance from the top of the core
- colour
- approximate particle size
- field texture
- mottles
- plasticity
- odour
- presence of shell or carbonate material, along with a measure or estimate of their abundance and size distribution, and
- field pH and field pH after oxidation with 30% peroxide.

2.5 Quality Control / Quality Assurance (QA/QC)

The sampling equipment will be cleaned of all traces of sediment and rinsed with ambient seawater between cores. Collected cores will be drawn off into poly-sleeves, eliminating the chance of cross-contamination post-coring.

Samples will be preserved under appropriate storage conditions (based on the parameters analysed and their appropriate holding times) and forwarded to the analytical laboratory within 72 hours of collection.

To comply with QA / QC procedures in Appendix F of the NAGD, triplicate cores will be collected from two sites to assess field variation (although only one of the triplicates will be analysed in the first instance); and one subsample will be split into three to assess variation associated with subsample handling and laboratory analysis. One of the three split samples will be sent to a different analytical laboratory.

All sampling work will be carried out under a total quality management system, which includes sampling and preservation, sample registration, methodology, date records, calculations and reporting of results.

3 Proposed Laboratory Analyses

Given the distance from the mainland, and the historical use of the area, the sediments at Putney Beach are not likely to be contaminated, however there are insufficient data available to wholly support this. There, a comprehensive suite of analyses is proposed for each sample, except where varied below.

3.1 Physical Characteristics

Subsamples will be analysed for the physical parameters outlined in Table 1 of Appendix A in the NAGD, as presented in Table 3.1 below.

Table 3.1 Physical parameters that will be analysed for each sample.

Parameter	Practical Quantitation Limit (PQL)
Moisture content	0.1%
Total organic carbon	0.1%
Particle size distribution	NA (use of sieve + hydrometer method)
Settling rate	NA

3.2 Nutrients

Nutrient concentrations in the subsamples will be analysed, as outlined in Table 3.2.

Table 3.2 Nutrient parameters that will be analysed for each sample.

Parameter	Practical Quantitation Limit (PQL)
Total nitrogen	0.4 (mg/kg)[A]
Total phosphorus	0.1 (mg/kg)
Ammonia	0.1 (mg/kg)

A Does not meet the PQL indicated in Table 1 of Appendix A in the NAGD. However, there are no guideline values for nutrients, and a result of <0.04 mg/kg total nitrogen would be considered low, based on our experience of nitrogen concentrations in sediments along the Queensland coast.

3.3 Contaminants

The concentration of potential contaminants of concern will be analysed in the subsamples, as outlined in Table 3.3.

Table 3.3 Contaminants that will be analysed for each subsample.

Parameter	Practical Quantitation Limit (PQL)
Total petroleum hydrocarbons (TPH)	100 (mg/kg)
Phenols (speciated) [1]	1 (mg/kg)
Volatile chlorinated hydrocarbons (VCHs)	0.05 – 5 (mg/kg)
Chlorobenzenes[1]	50 (µg/kg)
Organochlorines including:	1 (µg/kg)
Total chlordane, oxychlordane, dieldrin, heptachlor, heptachlor epoxide, methoxychlor, endrin, DDD, DDE, DDT, alpha and beta BHC, endosulfan (total alpha, beta and sulphate), hexachlorobenzene, lindane, aldrin[1]	(each individual species)
Total Polychlorinated Biphenyls (PCBs) [1]	5 (µg/kg)
Polynuclear Aromatic Hydrocarbons (PAHs) including: Naphthalene, 2-methylnaphthalene, acenaphthalene (each individual species), acenaphthene, fluorene, phenanthene, benzo[b]fluoranthene, fluoranthene, indeno[1,2,3-cd]pyrene, benzo[k]fluoranthene, chrysene, coronene, dibenz[a,h]anthracene, benzo[e]pyrene, benzo[a]pyrene, perylene, pyrene[1]	5 (µg/kg) (each individual species)
Total PAHs[1]	100 (µg/kg)
Benzene, toluene, ethylbenzene, xylene (BTEX)	200 (µg/kg)
Dioxins[2]	0.02 (µg/kg)
Non-organochlorine pesticides, including: Organophosphates, carbamates, pyrethroids, and herbicides[1]	10 – 100 (µg/kg) (each individual species)
Organotin compounds (monobutyltin, dibutyltin, tributyltin)[1]	1 (µgSn/kg)
Metals and metalloids (mg/kg)	
copper	1
lead	1
zinc	1

Parameter	Practical Quantitation Limit (PQL)
chromium	1
nickel	1
cadmium	0.1
mercury	0.01
arsenic	1
silver	0.1
manganese	10
aluminium	200
cobalt	0.5
iron	100
vanadium	2
selenium	0.1
antimony	0.5
Total cyanide	0.25 (mg/kg)

[1] As these contaminants are not expected to be found in levels above the screening level, they will be analysed at five sites only in the first instance to confirm this assessment (i.e. 20% of the sampling sites for a pilot study, as per the NAGD). The QAQC laboratory and field replicates will also be analysed for these contaminants.

[1] Note that as dioxins are not expected to be present at harmful levels, and as there is no screening level for dioxins in the NAGD, it is proposed to analyse dioxins in Subsample A samples from 20% of the sampling sites in the first instance.

3.4 Acid Sulfate Soils

As the sediments are not expected to be acid sulfate soils (ASS), samples from approximately 20% of the collected cores (i.e. 5 cores) will be analysed for acid sulfate soils (using either the reduced Chromium Suite of tests or SPOCAS analysis; the appropriate test will be decided based on sediment characteristics), as detailed in the *Acid Sulfate Soils Laboratory Methods Guidelines 2004* (Ahern et al. 2004). The cores to be analysed will be based on the results of the field tests (i.e. those cores that represent the highest risk with respect to ASS will be analysed). The remaining subsamples will be stored frozen. Where the results indicate that potential acid sulfate soils are present, the remaining subsamples will be analysed. This staged approach to analysis of samples is considered acceptable under the ASS guidelines.

3.5 Quality Assurance / Quality Control

Samples will be forwarded to Advanced Analytical Australia Pty Ltd, and analysed by National Association of Testing Authorities (NATA) accredited laboratories. One of the QA / QC samples will be sent to a second NATA-accredited laboratory to assess inter-laboratory variation. Laboratory quality control procedures are in accordance with the requirements outlined in Appendix F of the guidelines and ISO/IEC 17025:1999 standard, and will be documented in the laboratory analysis certificates.

Approximately 1 kg of each sediment sample will be retained under suitable conditions for a minimum of four weeks after delivery of the final analysis results.

4 Reporting

4.1 Data Analyses

The assessment of sediment quality will follow the approach outlined in Appendix A of the NAGD. Any results less than the PQL will be entered as half of the PQL, for statistical and analytical purposes (DEWHA 2009). The concentration of organic compounds (if detected) will be normalised to total organic carbon (TOC) content, as outlined in Appendix A of the NAGD.

The upper 95% confidence limit of the arithmetic mean for the Subsample A samples, Subsample B samples, Subsample C samples, and all of the samples collected from the dredge area, will then be compared to the screening levels outlined in Table 2 in Appendix A of the NAGD.

Where the confidence limit is below the screening level, it is unlikely that sediment contaminants will have any adverse effect on organisms living in or on that sediment, and that sediment will be considered not contaminated. Where this result is obtained, no further analyses will be undertaken. Where results exceed guidelines levels at any of the sites, the remaining samples will be analysed.

If all 23 sites are sampled and analysed and the confidence limit exceeds the screening level or the maximum level, we will discuss the suitability of the dredge spoil for the intended uses, in accordance with the framework presented in Chapter 4 of the NAGD. This may include further sampling to determine elutriate and bioavailability of contaminants in sediments (Phase III) and toxicity and bioaccumulation of sediments (Phase IV). Since sediments are expected to be clean marine sands, methods for these components have not been presented in this SAP.

4.2 Quality Assurance / Quality Control

4.2.1 Field

The relative percent difference (RPD) or relative standard deviation (RSD) will be calculated for each parameter, from the field replicates collected. As outlined in Appendix A of the NAGD, an RPD or RSD of ± 50% is acceptable for field replicates, although this may not always be achievable where sediments are not homogenous, or differ substantially in grain size. If the RPD or RSD for field replicates is great than 50%, we will discuss possible reasons for this, and ensure the interpretation of results incorporates this variability.

Laboratory

The RPD for laboratory duplicates will be calculated. As outlined in Appendix A of the NAGD, an RPD of ± 35% is acceptable for laboratory duplicates. If the RPD for laboratory duplicates is not below 35%, the values for that parameter will be flagged as an estimate and will be more closely investigated with respect to the guideline screening and maximum levels.

4.3 Final Report

The final sediment sampling and analysis report will include at least the following:

- an executive summary
- a description of the study
- detail of the quantities of biota or litter found within the proposed dredge area
- details of the sampling methodology
- drawings showing precise locations of the sampling points
- a core log with descriptions of each core (based on all parameters measured)
- a description of any observations or anomalies during sampling and / or analysis
- a summary table of results with the actual field sample numbers used, indicating exceedence of relevant guideline levels
- an interpretation of results
- an appendix containing laboratory analysis certificates (and identification numbers), which outline QA / QC procedures (e.g. blanks, laboratory duplicates, spikes, statistical research methods and quality control data) and the PQLs achieved, and
- reporting of PASS in accordance with the relevant sections of the DERM guidelines *General Information Required to Assist Assessment of Development Proposals involving Acid Sulfate Soils 2004*.

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